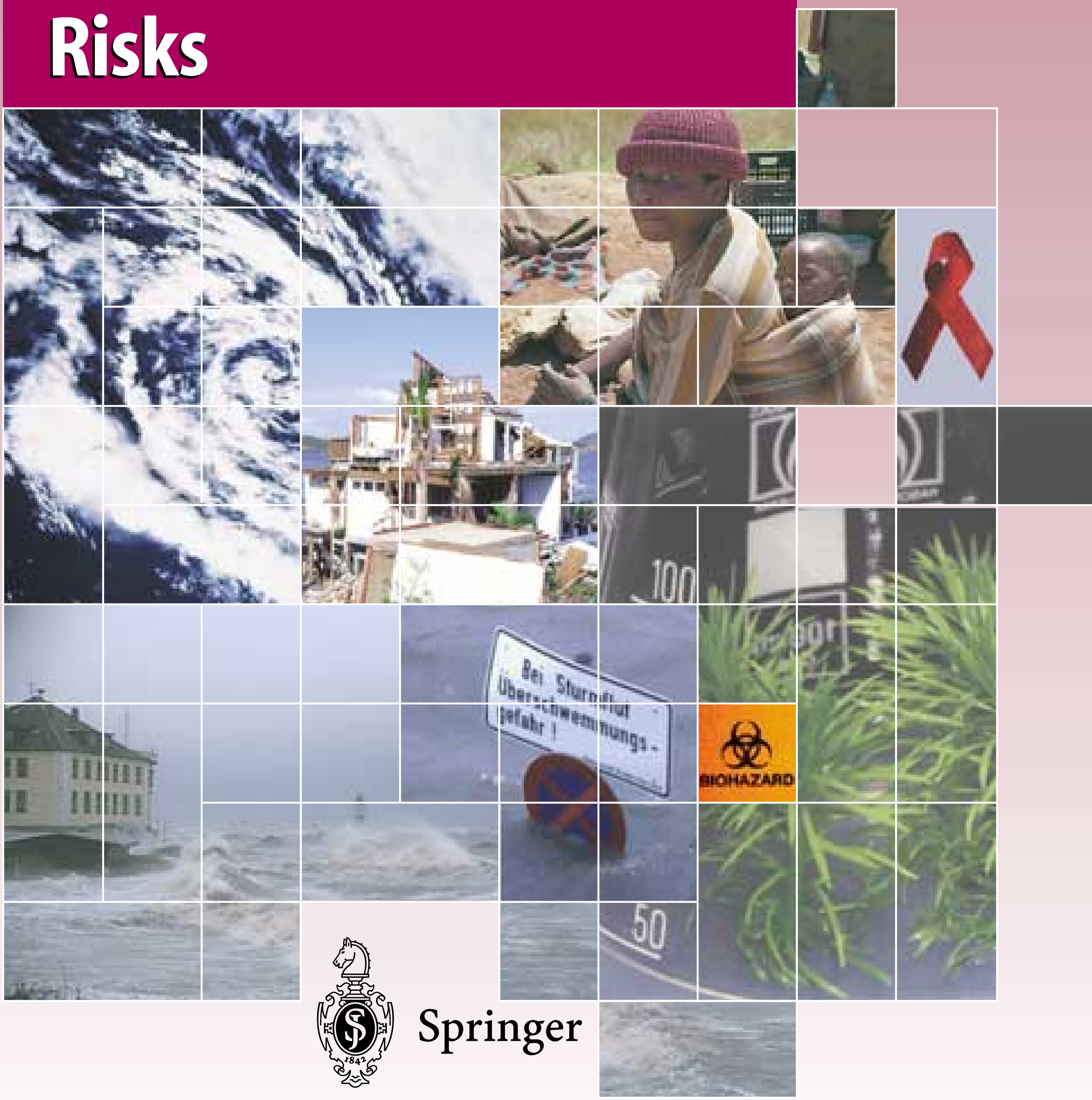
German Advisory Council
on Global Change

World in Transition

Strategies for Managing Global Environmental Risks

Annual Report
1998



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World in Transition:
Strategies for Managing Global Environmental Risks

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Springer

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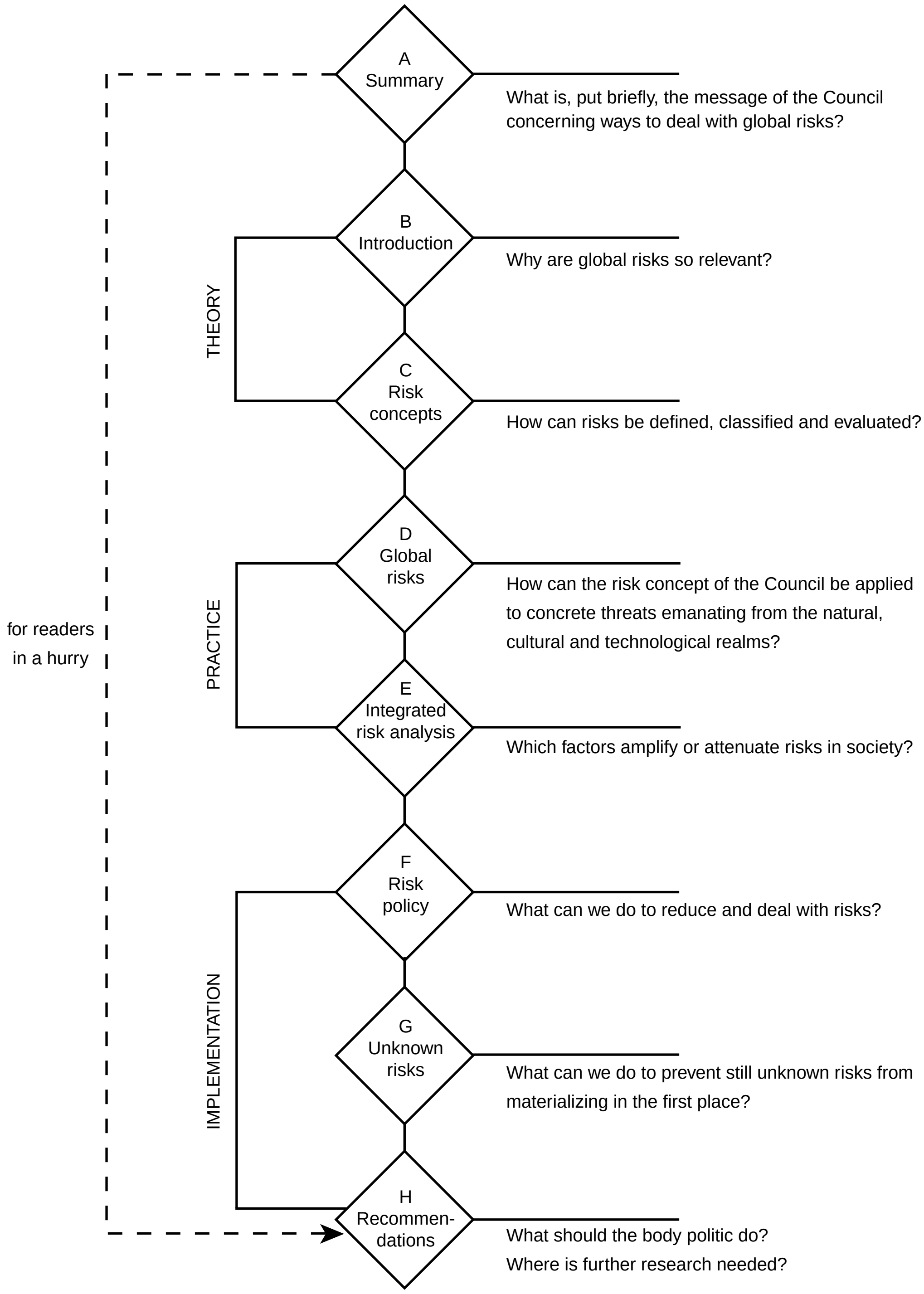
Acronyms and abbreviations

AIA	Advance Informed Agreement (under the draft Biosafety Protocol to the CBD)
AIDS	Acquired Immune Deficiency Syndrome
ALARA	As Low As Reasonably Achievable (emissions)
APEOs	Alkylphenolethoxylates
ASP	Amnesic Shellfish Poisoning
BACT	Best Available Control Technology
BCC	Basal Cell Carcinoma (of the skin)
BGB	Bürgerliches Gesetzbuch (German Civil Code)
BImSchG	Bundesimmissionsschutzgesetz (German Emission Control Act)
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BMG	Bundesministerium für Gesundheit (German Federal Ministry of Health)
BMI	Bundesministerium des Innern (German Federal Ministry of the Interior)
BMJ	Bundesministerium der Justiz (German Federal Ministry of Justice)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry for Economic Cooperation and Development)
BSE	Bovine Spongiform Encephalopathy
BSWG	Open-ended Ad Hoc Working Group on Biosafety (CBD)
B. t.	*Bacillus thuringiensis*
BverwG	Bundesverwaltungsgesetz (German Administrative Code)
CAC	Command and Control Approach (regulatory controls)
CBD	Convention on Biological Diversity
CDC	Centers for Disease Control and Prevention (USA)
CDM	Clean Development Mechanism (FCCC)
CFC	Chlorofluorocarbon
CHC	Chlorinated hydrocarbon
ChemG	Chemikaliengesetz (German Chemicals Act)
CJD	Creutzfeldt-Jakob disease
CLC	Civil Liability Convention (1969 International Convention on Civil Liability for Oil Pollution Damage)
DDT	Dichlorodiphenyltrichloroethane
DEHP	Di-(2-ethylhexyl)phthalate
DES	Diethylstilbestrol
DIVERSITAS	International Program of Biodiversity Science (IUBS, SCOPE, UNESCO, ICSU, IGBP-GCTE, IUMS)
DNA	Desoxyribonucleic acid
ECHAM	Climate model based on the ECMWF model
ECMWF	European Centre for Medium Range Weather Forecasting
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms program (USA)
EEZ	Exclusive Economic Zone (under the law of the sea)
EIA	Environmental Impact Assessment
EMAS	Eco-Management and Audit Scheme (EU)
EMF	Electromagnetic Field
EMS	Environmental Management System

ENSO	El Niño/Southern Oscillation
FAO	Food and Agriculture Organization (UN)
FCCC	Framework Convention on Climate Change (UN)
FEWS	Famine Early Warning System (USAID)
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GDCh	Gesellschaft deutscher Chemiker (German association of chemical engineers)
GDP	Gross Domestic Product
GenTG	Gentechnikgesetz (German Genetic Engineering Act)
GenTVfV	Gentechnikverfahrensordnung (German procedural code for genetic engineering)
GISP	Global Invasive Species Programme (DIVERSITAS)
GNP	Gross National Product
GPA	Global Programme on AIDS (WHO)
GPPIS	Global Plant Protection Information System (FAO)
HCB	Hexachlorobenzene
HDI	Human Development Index (UN)
HIV	Human Immune Deficiency Virus
HNS	Hazardous and Noxious Substances
HSFK	Hessische Stiftung Friedens- und Konfliktforschung (Peace Research Institute Frankfurt, Germany)
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
ICSU	International Council of Scientific Unions
IDNDR	International Decade for Natural Disaster Reduction
IFCS	Intergovernmental Forum on Chemical Safety
IGBP	International Geosphere-Biosphere Programme (ICSU)
ILO	International Labour Organization
IMAGE 2	Global Integrated Assessment Model
IMF	International Monetary Fund
IMO	International Maritime Organization
INF	Intermediate-range Nuclear Forces
IPCC	Intergovernmental Panel on Climate Change (WMO, UNEP)
IPPC	Integrated Pollution Prevention and Control
IRPTC	International Register of Potentially Toxic Chemicals (UNEP)
ISO	International Organization for Standardization
IUBS	International Union of Biological Sciences
IUMS	International Union of Microbiological Societies
KOSIMO	Konflikt-Simulations-Modell (conflict simulation model)
LMOs	Living Modified Organisms
MARPOL	International Convention for the Prevention of Pollution from Ships
MCA	Maximum Credible Accident
MEHP	Mono-(2-ethyl-hexyl)phthalate
MOGUN-TIA	Global Atmospheric Transport Model
NBC	Nuclear, Biological and Chemical Weapons
NGO	Non-governmental Organization
NPP	Net Primary Production (of ecosystems)
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
nv-CJD	New Variant of Creutzfeldt-Jakob disease
OECD	Organisation for Economic Co-operation and Development
OSPAR	(Oslo-Paris) Convention for the Protection of the Marine Environment of the North-East Atlantic
PCB	Polychlorinated biphenyl
PCDD	Polychlorinated di-benzo-p-dioxins
PCDF	Polychlorinated di-benzo-p-furans
PIC	Prior Informed Consent

POP	Persistent Organic Pollutant
PPP	Purchasing Power Parity
ProdHG	Produkthaftungsgesetz (German Product Liability Act)
RAINS	Regional Integrated Assessment Model
RNA	Ribonucleic acid
SBO	Specified Bovine Offals
SCC	Squamous Cell Carcinoma (of the skin)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SRU	Rat von Sachverständigen für Umweltfragen (German Council of Environmental Advisors)
SSM	Superficial Spreading Melanoma
START	Strategic Arms Reduction Talks
STC	Scientific and Technical Committee (IDNDR)
STD	Sexually Transmitted Diseases
StFV	Störfallverordnung (Swiss Major Accident Ordinance)
STOA	Scientific and Technological Options Assessment Unit (European Parliament)
TBT	Tributyl tin
TCE	Trichloroethylene
THC	Thermohaline Circulation (in the oceans)
TLV	Threshold Limit Value (for workplace exposure)
TNT	Trinitrotoluene
TOGA	Tropical Ocean Global Atmosphere Programme (WCRP)
TOVALOP	Tanker Owners Voluntary Agreement Concerning Liability for Oil Pollution
UBA	Umweltbundesamt (German Federal Environmental Agency)
UGB-KomE	Umweltgesetzbuch Kommissionsentwurf (draft German Environmental Code)
UmweltHG	Umwelthaftungsgesetz (German Environmental Liability Act)
UNAIDS	Joint United Nations Programme on HIV/AIDS
UNCED	United Nations Conference on Environment and Development (the 1992 Rio 'Earth Summit')
UNDP	United Nations Development Programme
UN-ECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFPA	United Nations Population Fund
UNICEF	United Nations Children Fund
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
USAID	United States Agency for International Development
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)
WCRP	World Climate Research Programme (WMO)
WFP	World Food Progamme (UN)
WHG	Wasserhaushaltsgesetz (German Water Resources Management Act)
WHO	World Health Organization (UN)
WMO	World Meteorological Organization (UN)
WTO	World Trade Organization (UN)
ZPO	Zivilprozessordnung (German Code of Civil Procedure)

World in Transition: Strategies for Managing Global Environmental Risks
A guide for the reader



Executive summary: Strategies for Managing Global Environmental Risks

A

Global change: A fresh approach to new risks

A 1

Global risk potentials and their interplay with economic, social and ecological processes of change have emerged as a novel challenge to the international community. Never before has human intervention in nature assumed global dimensions. This has been driven on the one hand by a growing global population, particularly in developing countries, and on the other hand by rising human aspirations in conjunction with specific patterns of production and consumption (throughput growth), above all in industrialized countries. By presenting this report, the Council hopes to contribute constructively to an effective, efficient and objective management of the risks of global change. The approach taken by the Council is to:

- Identify a *taxonomy of globally relevant risks* and highlight the particularly relevant classes of risk;
- Link both established and innovative risk assessment strategies and corresponding risk management tools to these classes, in order to define *management priorities*.

The approach taken to generate and apply knowledge relating to the identification and management of risks is a decisive element in the quest for ways to deal with global risks. It is plain enough that it is essential to depart from the principle of 'trial and error' that has until now dominated in empirical science. An error with global consequences can lead to unacceptable damage. In a globally intermeshed world, in which disasters can assume global proportions more rapidly than ever before, letting events run their course and mitigating any damage that may arise is not an ethically acceptable principle. In the past, environmental risks were generally restricted to the regional level. For instance, while the deforestation of ancient Greece has significantly impaired the utilization potentials of the soil there through erosion and karstification, these environmental impairments have remained locally contained. By contrast, many of today's environmental risks are global by nature. If the Gulf Stream ceases, sea levels rise or a new Spanish Influenza pandemic afflicts the world, then the consequences for the whole of humanity will be so incisive and conceivably also irreversible that – even if the probability of these events occurring is low – timely counterstrategies are essential. The more far-reaching the possible effects and the fewer avenues for compensation there are, the more important a risk policy centered on precautionary measures becomes, in order to prevent global disasters as far as possible.

At the same time, however, it is impossible to safeguard against all global risks, particularly as opportunities will always entail risks. The American sociologist Aaron Wildavsky has fittingly characterized this dilemma: "No risk is the highest risk at all". This is why a further hope of the Council in the present report is that it may contribute to an approach in which the expedient combination of licensing procedures, state regulation, liability rules and the application of state-enforced precautionary principles may enhance confidence in the management capacities of modern societies and may thus help to make the international risk debate more rational and objective. By 'rational' we do not mean blaming the potential victims for their understandable aversion to tolerate risks. Still less do we wish to play down the severity of global risks. By an objective approach the Council rather means the urgent necessity to face real hazards – with all the associated uncertainties and ambiguities – in a manner that is targeted, rational and efficient, while at the same time exploiting the opportunities associated with taking risks. Without a willingness to venture upon risks, there will be no innovation. Without innovations, in turn, the economic and ecological problems of the world will remain unsolved. We need to steer a prudent middle course between boldness and caution.

Charting this middle course is hampered by the circumstance that empirically oriented research is not in a position to prove experimentally – not to mention predict – the consequences of global environmental risks. Although partial aspects of global risks can indeed be analyzed in model experiments, opportunities to carry out empirical experiments on global effects are limited for obvious reasons. For example, no one would want to experiment to see whether an event in a nuclear power plant that slightly exceeds a credible accident scenario really leads to the predicted impacts upon human health and the environment. Geophysical risks place even greater constraints upon empirical testing.

For the first time in human history, anthropogenic emissions account for a substantial proportion of geochemical cycles in nature. Measurements can reflect the dynamics and distribution of concentrations, but tell us little about long-term consequences. Attempts to model these consequences in the laboratory at a smaller, scaled-down level soon meet the limits of transferability. Here science is largely dependent upon analogies (for instance in the sphere of medical risks) or computer simulation (for instance in the sphere of climate risks). As yet, however, non-linear processes and complex cause-effect patterns in nature can only be captured to a limited extent by modeling, simulation or other analytical tools. If we further consider that ecology is a field particularly characterized by these non-linear and complex cause-effect chains, then scientific forecasts are inescapably subject to large uncertainties and ambiguities. Even where the greatest efforts are applied, these uncertainties and ambiguities can only be reduced to a certain extent (Section E). Risk policy is thus inescapably bound to seek an objectively appropriate and ethically acceptable pathway in a cloud of uncertainty, gaps in knowledge, ambiguity and indeterminacy (Section G).

Against this backdrop, the Council hopes that its annual report may promote, through its painstaking analysis and assessment of the risks of global change, an objective debate on the acceptability of risks. In its previous reports, each focusing on a specific domain of global change, the Council has identified *'guard rails'* for these domains that cannot be crossed without incurring excessive damage to humanity and the environment. The present report identifies such guard rails for the domain of global risks. Where activities constitute a risk, the guard rails are extended to form a boundary zone – a *critical zone*. If a risk falls in the boundary zone, then particular care and special precautions need to be taken.

In the opinion of the Council, the risks inherent in global change can only be estimated with sufficient accuracy and managed effectively through applying a systemic approach. The impact areas characteristic of the human-environment relationship overlap in many ways, forming a complex structure of triggers, modulators and effects. For instance, the risks of climate change, biodiversity loss, soil degradation and food insecurity interlock with typical manifestations of global change such as urbanization, population growth, migration or impoverishment. Political factors (e.g. human rights, type of governance, institutional stability and credibility) also play a crucial role here.

As a matter of principle, the risks of global change should be tackled as closely as possible to the individual generators of risk, i.e. where possible at the local or regional level. In this respect, the Council endorses a management philosophy that initially largely relies on the liability principle. However, this requires appropriate structural conditions in the individual countries. Where these are not given, they would need to be created. Particularly where the severity of their effects is largely uncertain, many global risks further require a supraregional and state or international regulation (Section H 2).

It is not only the inherent characteristics of global problems that call for global policies provisioning against risks. It is also the asymmetries among individual countries in their capacity to manage such risks effectively and efficiently that point to the necessity of international efforts to put in place a supranational system of cooperation and coordination in risk prevention and emergency planning. The Council sees such disparities particularly in the capacities to identify and assess global risks, in corresponding management competency and in vulnerability to the risks of global change. For instance, the governments of some developing countries are inadequately able to assess new risks and to take effective countermeasures, or are only able to do so after some delay. This is compounded by the circumstance that many countries have not established strong institutional provisions for risk management and emergency planning. Structural deficits and problems of implementation also need to be noted here. This is why the Council accords particular importance to financial and technical development cooperation in global policy. Furthermore, risks of global change that affect internationally highly valued assets or that can be expected to develop global impacts call for management at the global level. This is exemplified by the prospect of a global food security crisis (Section E 3.2), global climate change (Section D 6) or the spread of 'old' and new pandemics (Sections D 3 and E 3.1).

Given the great number of risks and possible threats on the one hand and the undisputed necessity to promote innovation and technological development on the other, the Council hopes to have developed an approach that is appropriate to the phenomenon of risk, while also being practicable and making a contribution to structuring global change in a way that limits risks and extends opportunities. This approach combines the 'guard rail' philosophy, emphasis on the liability principle and a management oriented classification of classes of risk. Core elements of this concept include measures to improve the use of existing knowledge or methods of generateing new knowledge, and strategies aimed at 'containing' risks. For each class of risk, graduated responses and appropriate tools for containment are elaborated (Section H 2).

The decision-making support provided by the following strategies for action thus pursues the guiding objective of ensuring that, while the capacity for action and innovative vigor of the international community does not slacken or even retract into unproductive wariness, the hazard potentials of global risks are not ignored but rather taken to heart and tackled in a precautionary fashion. These recommendations build upon the taxonomy of risk that the Council has developed for this report. These classes of risk are characterized in detail in Section C and are used in Section H to substantiate class-specific strategies. These classes are further discussed in the proposals for handling deficits in knowledge (Section G 4) and for managing global risks (Section F 6).

A 2 Localizing risks in normal, transitional and prohibited areas

The risks to which humanity is exposed are almost beyond number. Some of these risks are associated with natural processes and events, while others have been created or intensified by human activities. The fundamental dilemma is that all human activities can be associated with unintended side effects, while at the same time human needs cannot be met without such activities. Taking risks is thus a necessary element of human behavior and indeed a precondition to economic and social development. At the same time, an accumulation of risk threatens the continued viability of a society. As set out above, a middle course needs to be charted between taking opportunities and containing risks.

The Council is convinced that there is no simple recipe for assessing risks. In view of divergent preferences and states of development worldwide, risks must be viewed as heterogeneous phenomena that preclude standardized assessment and handling. At the same time, however, risk policy would be overburdened if it were to develop and employ a special strategy for the assessment of the risk of each individual activity. The Council views a categorization of the various risks in risk classes to be expedient, in a manner similar to that already commonly applied today in the assessment of toxicological risks. Categorization in these risk classes is guided above all by the basic concern to develop class-specific procedures and management rules that permit handling of risks in a way appropriate to the individual risk and commensurate to the need for risk containment.

The procedure for handling risks recommended by the Council can be represented as a simple *decision tree* (Fig. A 2-1). If an operator, a regulatory authority or any other group interested in an activity or technology that constitutes a risk needs to assess this risk, then the questions should be answered in the order that is posed in the decision tree. At the top of the tree we ask whether the risks of a new activity or technology are sufficiently known for there to be reasonable grounds to assume a causal link between the risk cause and possible adverse effects, and, further, whether the potential severity of effects can at least be identified and the probabilities of these effects occurring roughly estimated. If the risks are entirely or largely unknown, then the classic precautionary strategies are called for, consisting of three parts:

- First, a prudent further development of risk-generating activities that is informed by risk containment or limitation;
- Second, strengthening the resilience of affected systems; and
- Third, intensifying research efforts in order to permit future unequivocal categorization according to the various classes of risk and in order to identify possible side effects early on.

Finally, an early warning system for the perception and researching of risks needs to be established (Section G 4).

If the first question leads to the conclusion that there are reasonable grounds to assume a causal link between a specific cause and effect, that the magnitude of potential damage is largely identifiable and that probabilities can be roughly estimated, then the second question arises as to whether the risk is situated in the 'normal area', 'transitional area' or 'prohibited area'. The distinction between these three areas is set out in detail in Section C, and graphically illustrated in Fig. A 2-2. Risks in the *normal area* have the following characteristics:

- Low uncertainties regarding the probability distribution of damage,
- In total, a small catastrophic potential,
- Low to medium uncertainty about both the probability of occurrence and the associated magnitude of damage,
- Low statistical confidence intervals with respect to probability and magnitude of damage,
- Low levels of persistency and ubiquity (scope in time and space),
- High reversibility of potential damage, and
- Low potential for social conflict and mobilization (above all, no distinct inequities resulting from discrepancies in the assessments made by the group that is exposed to the risk and the group to which opportunities and benefits accrue).

In this 'normal' case a simple link of probability and severity through multiplication, with due considera-

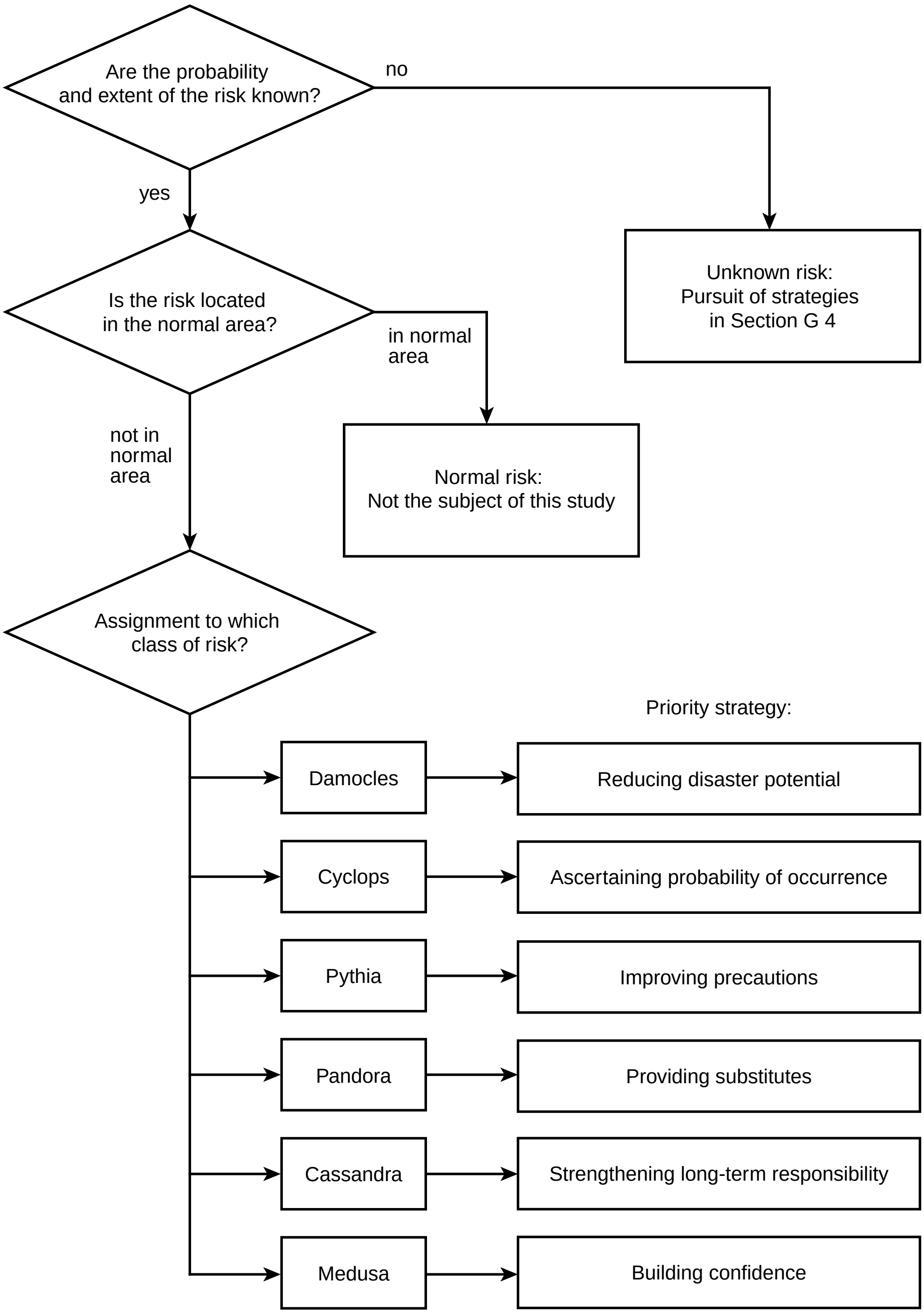


Figure A 2-1
Decision tree for classifying the risks of global change.
Source: WBGU

tion to respective variances, is expedient and appropriate, as practiced for many years in technical risk analysis and in the insurance industry. If the two factors – probability and severity – are relatively small, then the product of the two falls in the normal area. For politicians, risks situated in this area indicate the 'routine case', for which, at least in Europe and in many other countries, the existing laws and regulations generally suffice. Indeed, further deregulation could even be considered here. At the international

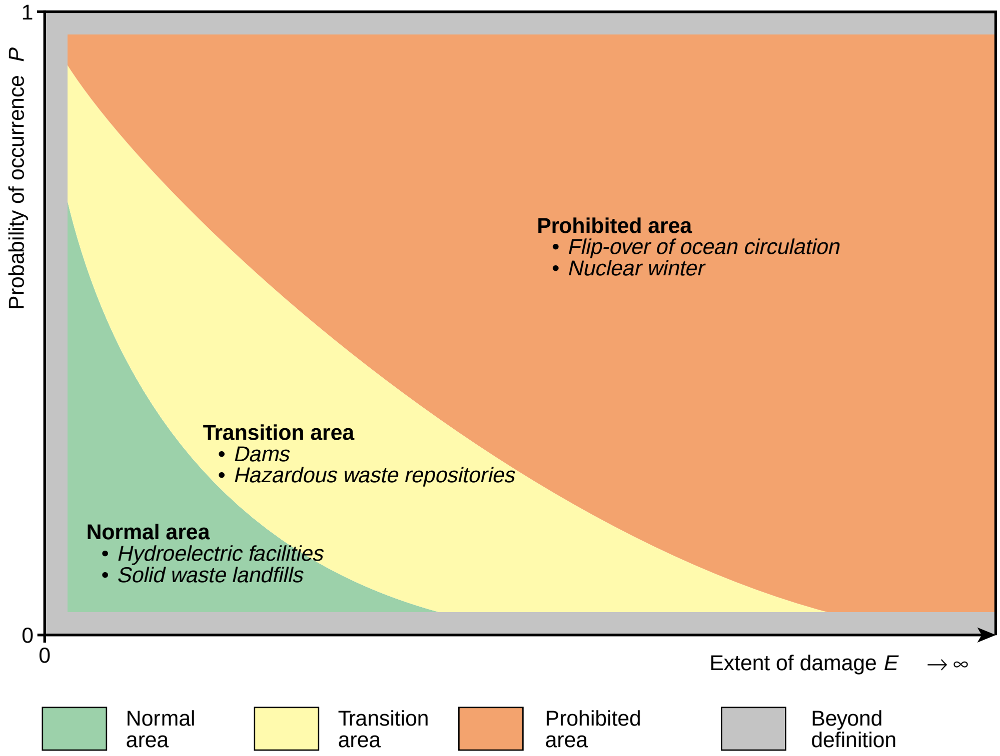


Figure A 2-2
Normal, transition and prohibited areas.
Source: WBGU

level, too, the Council sees no immediate need for action on normal risks other than making sure that proper management procedures are in place.

Most risks will already have been sieved out after the second question. The definition of a normal area thus allows effective and innovation-promoting policies that permit opportunities to be taken. Under such policies, opportunities and risks can be compared and weighed systematically.

The situation becomes more problematic when risks touch areas that significantly transcend everyday levels. The *transitional area* is reached if one or more of the following conditions are met:

- The damage potential is high,
- The probability of occurrence is high, approaching 1 (where none of the other conditions is given, this case is not so relevant at the global level),
- The uncertainty of the probability distribution of adverse effects is high,
- The confidence intervals of probability and magnitude of damage are large,
- Persistency, ubiquity and irreversibility are particularly high, whereby there must be reasonable grounds to assume a causal link between trigger and effects, and
- For reasons of perceived distributional injustice or other social and psychological factors, a major potential for conflict or mobilization is to be expected (migration, refusal, protest, resistance).

If one of these conditions is given, then the product of probability and severity will usually be in the transitional area. If the high level of risk is further joined by a low benefit or a low expectation of opportunity, or if the product of the two components of risk assumes extreme levels, then the risk is situated in the *prohibited area*. This area is also easy to handle. In the prohibited area, the consequences to be expected from taking a risk are so severe that risk reduction is unconditional. In extreme cases, the proper response here is an immediate ban or moratorium.

Handling risks in the transitional area is more problematic. Here either relatively high factor products or high uncertainties are to be expected, or one of the exacerbating assessment dimensions is clearly violated (Section C 3). These include the criteria of *irreversibility* (damage cannot be remedied), *persistency* (contaminants accumulate over long periods), *ubiquity* (contaminants spread worldwide) and *mobilization* (risks lead to severe conflicts and dread among the general public). A special case is to be

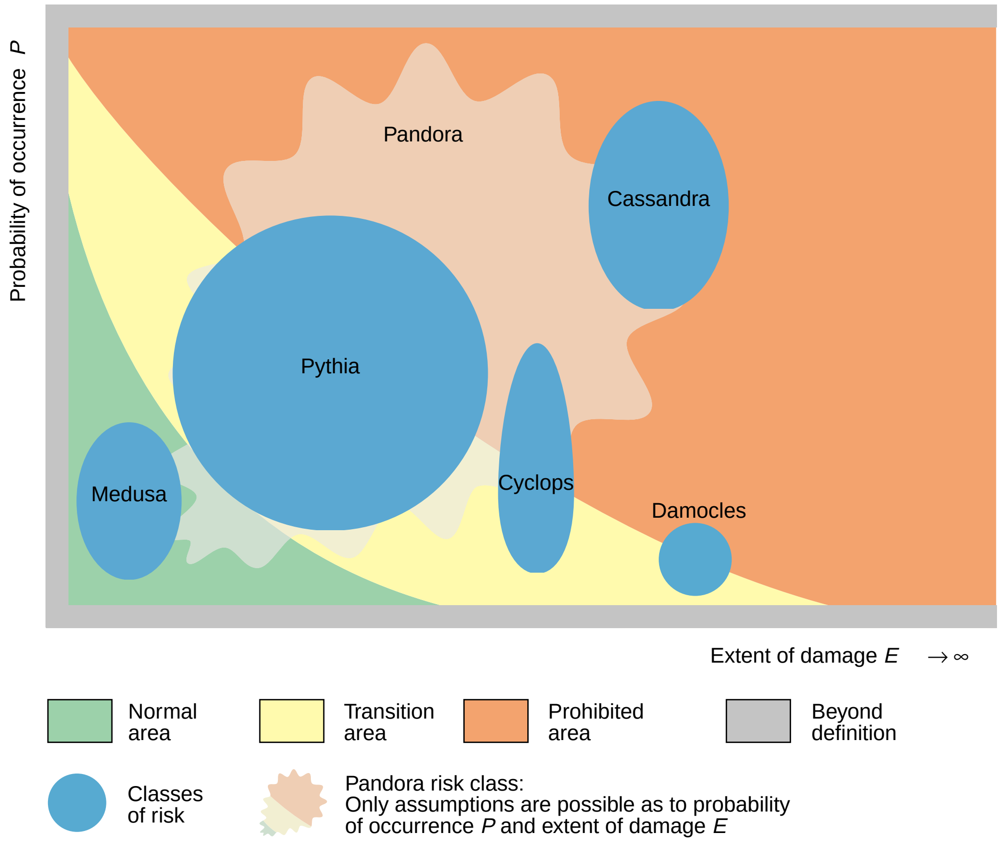


Figure A 2-3
Classes of risk and their location in the normal, transition and prohibited areas.
Source: WBGU

seen in risks that combine high severity with high probability. Normally, such risks will not be permitted at all and are situated in the prohibited area without much further discussion. However, if a sufficiently lengthy period (delay effect) lies between the triggering event and the occurrence of damage, then decision-makers are often not aware of or easily dismiss the problems associated with such a risk. Such risks are effectively unacceptable, but are frequently not perceived as such, neither politically nor socially. If thus the answer to the second question in the decision tree places a risk in the transitional area, risk policy must proceed with particular caution. In this case we need to move on to the next question in the decision tree and to assign the risks to certain risk classes, as specific strategies need to be chosen for each class. The locations of the risk classes developed by the Council are shown in Fig. A 2-3.

A 3 Categorization according to risk classes

The task of the decision-maker at this node in the decision tree is thus to categorize risks located in the transitional area according to specific classes. How are these classes of risk defined? The characteristics of the six classes identified by the Council are described in detail in Section C and are summarized here in Table A 3-1.

Damocles

Greek mythology reports that Damocles was once invited by his king to a banquet. However, he was obliged to take his meal under a razor-sharp sword hanging above him on a fine thread. For Damocles, opportunity and danger were closely linked, and the 'Sword of Damocles' has become a byword for a happy situation overshadowed by danger.

However, the thread seems to have been quite strong, for the fable tells us nothing of its having torn with deadly consequences. The threat was expressed as the possibility that, at any point in time, if albeit with low probability, an event deadly to Damocles could occur. This class of risk accordingly comprises sources of risk that have a very high catastrophic potential but where the probability that this potential manifests itself as damage is considered to be conceivably low. Nuclear power plants, large-scale chemical facilities and dams are examples. In addition to large-scale industrial risks, various types of natural disaster also fall within this class. In a fashion similar to the large-scale technology risks, natural disasters with known damage-probability functions entail major damage potentials in conjunction with usually low probabilities of occurrence, as is for instance the case for meteorite impacts. However, in contrast to large-scale technology risks, the potential for political mobilization and the pressure to implement precautionary risk management is weak for natural risks. In societal discourse, natural disasters tend rather to be attenuated, while technological risks tend rather to be amplified (Kasperson et al., 1988).

Cyclops

Ancient Greek mythology tells of mighty giants who, for all their strength, were limited by having only one single, round eye, which was why they were called 'round eyes' or Cyclopes. With only one eye, only one side of reality can be perceived. In the Cyclops class, the probability of occurrence is largely uncertain, while the maximum damage is well defined. A number of natural events such as floods, earthquakes and El Niño fall in this class, as does the occurrence of AIDS, wherever there is no or only contradictory information about the probability of occurrence.

Pythia

When in doubt, the ancient Greeks consulted one of their oracles, among which the most famous was the Delphic Oracle with its blind seeress Pythia. However, Pythia's answers always remained unclear: Pythia's prophecies illustrated that a major danger might be impending, but not how large its probability of occurrence, its severity or its distribution might be. Thus Pythia prophesied to King Croesus that if he were to attack Persia he would destroy a great empire. Belligerent Croesus failed to realize that this meant his own empire. The Pythia class thus involves, for definable damage, a high degree of uncertainty as to possible adverse effects and as to the probability of the risk's occurrence. The potential for damage can be stated, but the scale of damage is still unknown. This class includes risks associated with the possibility of sudden non-linear climatic changes, such as the risk of self-reinforcing global warming or the instability of the West Antarctic ice sheet, with far more disastrous consequences than gradual climate change. It further includes far-reaching technological innovations such as certain applications of genetic engineering, for which neither the precise level of risk nor the probability of certain damaging events occurring can be estimated at the present point in time.

Pandora

This class of risk includes such risks that have persistent, ubiquitous and irreversible effects. Persistent organic pollutants (POPs), which remain stable over long periods in the environment, are a typical example of this. Often the effects of these risks are still un-

Table A 3-1
Overview of risk classes: characterization and substantive examples. *P* signifies the probability of occurrence and *E* the extent of damage.
Source: WBGU

Risk class	Characterization	Examples
Damocles	*P* is low (approaching 0) Reliability of estimation of *P* is high *E* is high (approaching infinity) Reliability of estimation of *E* is high	• Nuclear energy • Large-scale chemical facilities • Dams • Floods • Meteorite impacts
Cyclops	*P* is unknown Reliability of estimation of *P* is unknown *E* is high Reliability of estimation of *E* tends to be high	• Earthquakes • Volcanic eruptions • AIDS infection • Mass development of anthropogenically influenced species • Nuclear early warning systems and NBC-weapons systems • Collapse of thermohaline circulation
Pythia	*P* is unknown Reliability of estimation of *P* is unknown *E* is unknown (potentially high) Reliability of estimation of *E* is unknown	• Self-reinforcing global warming • Release and putting into circulation of transgenic plants • BSE/nv-CJD infection • Certain genetic engineering applications • Instability of the West Antarctic ice sheets
Pandora	*P* is unknown Reliability of estimation of *P* is unknown *E* is unknown (only assumptions) Reliability of estimation of *E* is unknown Persistence is high (several generations)	• Persistent organic pollutants (POPs) • Endocrine disruptors
Cassandra	*P* tends to be high Reliability of estimation of *P* tends to be low *E* tends to be high Reliability of estimation of *E* tends to be high Long delay of consequences	• Gradual human-induced climate change • Destabilization of terrestrial ecosystems
Medusa	*P* tends to be low Reliability of estimation of *P* tends to be low *E* tends to be low (exposure high) Reliability of estimation of *E* tends to be high Mobilization potential is high	• Electromagnetic fields

known, or there are at most reasonable grounds to assume their adverse effect. The Council has named these risks after Pandora. The ancient Greeks explained many ills of their times with the myth of 'Pandora's Box', a box brought down to the Earth by the beautiful Pandora created by Zeus, but which only contained evils. As long as the evils remained in the box, no damage was to be feared. If, however, the box was opened, all of the evils contained in it were released, then to plague the Earth irreversibly, persistently and ubiquitously.

Cassandra

Many types of damage occur with high probability, but in such a remote future that for the time being no one is willing to perceive the threat. This was the problem of Cassandra, a seeress of the Trojans, who correctly predicted the danger of a victory of the Greeks, but was not taken seriously by her countrymen. The Cassandra class of risk thus harbors a paradox: both the probability of occurrence and the damage potential are known, but because the damage will only occur after a long period there is little concern in the present. Risks of the Cassandra class are only then of interest if the damage potential and the probability of occurrence are both relatively high. This class is accordingly located in the prohibited area. If the time interval were shorter, the regulatory authorities would most probably intervene. The distant time horizon between trigger and consequence easily creates the fallacious impression of security. A typical example of such an effect is gradual anthropogenic climate change, which can trigger severe damage in vulnerable areas such as coastal and mountain zones.

Medusa

In classical mythology, Medusa was one of three cruel Gorgon sisters whose sight alone made people turn into stone. Some novel phenomena have an effect on modern people in a way similar to that in which the Gorgons, as purely imaginary figures of fable, aroused fear and terror. Some innovations are rejected even if scientists scarcely view them as dangerous. Such phenomena have a high potential for public mobilization, as did once the fear of the actually nonexistent Gorgon sisters. According to the best knowledge of the risk experts, risks of this type are located within the normal area, but, due to certain characteristics of the risk source, are a particular source of dread that leads to massive rejection (a criterion for mobilization). A good example of such mobilization is given by the concern over the carcinogenic effect of electromagnetic radiation in low concentrations.

The risks in the Damocles or Cyclops classes are more characterized by sudden occurrence, while the risks in the Medusa, Cassandra and Pandora classes tend rather to involve gradual dangers that also arise in 'normal operations'. The Pythia class includes both accidents and accumulative effects through continuous emissions.

Class-specific strategies and tools for action A 4

These six classes of risk call for specific strategies. The associated tools (Section H 2.1) are presented here in summary and listed in the following tables (Tables 4-1 to 4-6). The Council makes important recommendations for the classic fields of action of risk policy elsewhere in this report (Section H 2.2). The goal of the specific strategies for the risk classes identified here is to shift these from the prohibited or transitional area into the normal area (Section 4). The aim is thus not to reduce risks down to zero, but to a level that permits routine management. Both the strategies and the tools or measures are listed in receding order of priority. Naturally, more than one strategy and more than one tool will be necessary in most cases. If, however, a limited selection must be made, the items at the top of the list should be considered first.

Strategies for the Damocles risk class

For Damocles-type risks, the Council recommends three prime strategies: firstly, reducing disaster potential through research and technological measures, secondly, strengthening resilience, i.e. the robustness of a system against surprise, and finally, ensuring effective disaster management (Table A 4-1).

The first strategy – reducing damage potential and preventing the occurrence of damage – is concerned with improving technological measures to reduce the disaster potential and with researching and implementing measures to contain the spread of damage. In nuclear energy, for instance, the main strategy implemented in the past has been to further minimize the probability of occurrence of core meltdown by means of technological barriers. This has not been adequate to move this risk from the transitional area into the normal area. Design changes aimed at reducing the disaster potential would have been more expedient (and this is indeed the avenue now pursued). The Council further recommends introducing or strengthening liability rules, which can provide an incentive to improve knowledge and to reduce residual risks. It is further necessary to research and develop alternatives to technologies with unavoidably high disaster potential, and to substitute them with others whose disaster potential is significantly lower. Under certain conditions, this can require subsidization in the introductory and trial phase.

The second strategy is aimed at enhancing resilience to risk potentials. This necessitates strengthening the overarching institutional and organizational structures that impact upon licensing procedures, monitoring, training etc. At the same time, liability law can promote a careful approach to these risks. In addition, technological methods for enhancing resilience need to be introduced or improved. This can be done through, for instance, redundant design measures for technologies and safety-relevant organizational units, through introducing leeway, buffers and elasticity (error-friendly systems) and through diversification, i.e. thinly spreading risk potentials or sources. Organizational forms and proven licensing procedures that are viewed as resilient should be made available to other states, as a template or model, through the transfer of technology and knowledge. Furthermore, international control and monitoring needs to be strengthened, and an international safety standards authority established.

Disaster management is the third and last priority among the strategies for action in this risk class. While not unimportant, this should nonetheless be subordinated to risk-reducing strategies as a back-end strategy aimed at limiting damage. Here, as before, human resources and institutional capacities need to be further strengthened by developing and promoting national emergency planning, preparedness and response programs. Through technology and knowledge transfer, the emergency planning measures and techniques that have proven themselves in many industrialized countries can be passed on to local risk managers in the form of education, training and empowerment. Finally, international, precautionary disaster relief, such as is aimed at under the aegis of the International Decade for Natural Disaster Reduction (IDNDR) initiated by the UN, is also requisite to counter human-induced disasters.

Table A 4-1
Strategies and tools for the Damocles risk class. The main problem in this class is the high disaster potential.
Source: WBGU

Strategies	Tools
1. Reducing disaster potentials	• Research aimed at developing substitutes and reducing the disaster potential • Technological measures for reducing the disaster potential • Stringent liability regimes • International safety standards authority • Subsidization of alternatives that have equal utility • Containment (minimizing the spread of damage) • International coordination (e.g. to mitigate meteorite hazards)
2. Strengthening resilience	• Human-resource and institutional capacity building (licensing procedures, monitoring, training etc.) • International liability commitments • Expansion of technological procedures by which to improve resilience (redundancy, diversity etc.) • Blueprint for resilient organizations • Model role: licensing procedures • International controls (IAEA)
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Education, training, empowerment • Technological protective measures, including containment strategies • International emergency groups (e.g. fire services, radiation protection etc.)

Strategies for the Cyclops risk class

Among the measures and tools for the Cyclops class, determining the probability of occurrence has supreme priority. This calls for promotion of the necessary research (Table A 4-2). Furthermore, international monitoring needs to be ensured through national and international risk centers. Here, the Council relies above all upon the establishment of a UN Risk Assessment Panel, whose task would be to network the national risk centers and to collate and evaluate the knowledge gained about global risks. The tasks, structure and functions of this Panel are explained in detail in Sections F 6.3.1 and H 2.2.

The second strategy for action is aimed at preventing undesirable surprises and safeguarding society against these. One option for doing this is to introduce a strict liability regime. Under certain preconditions, mandatory insurance (or possibly a fund model) should be considered. The tools for strengthening human-resource and institutional capacities and the technological measures correspond largely to those set out for the Damocles class above.

The third strategy, disaster management, applies the same tools as in the Damocles class.

Strategies for the Pythia risk class

In the Pythia class, which is characterized by particularly high uncertainties concerning both components of risk – probability and severity – it is similarly necessary to improve knowledge, particularly in basic research (Table A 4-3). However, compared with the Cyclops class, an even stronger focus needs to be placed on precautionary strategies, as the liability principle can possibly only be enforced to a limited extent and the severity of effects can assume global proportions. Regulatory impositions and containment measures are generally indispensable in this area.

Concerning precautions, the Council recommends pursuing a strategy that employs tools such as the ALARA (As Low As Reasonably Achievable) principle or the 'best available scientific knowledge and technology test', under which the sum of the costs of not implementing risk reduction policies plus the costs of risk reduction policies implemented is to be kept as low as possible. Limiting the sphere of action and impacts in which the risk is permitted is also an important precautionary tool. The severity of an unpredictable disaster can thus be contained expediently. Instruments of liability law are in principle recommendable here, too, but are possibly not always enforceable. This is why the use of fund models should also be considered. Global Pythia-type risks call for international institutions in order to carry out controls and monitoring and to put in place safety precautions. Tools aimed at containing the spread of damage, strengthening human resources and institutional capacities and improving resilience have already been discussed for the previous two classes of risk.

The second strategy is to improve knowledge in order that future risk analyses can deliver more reliable appraisals. This necessitates research to identify probabilities and possible severities. An internation-

Table A 4-2
Strategies and tools for the Cyclops risk class. The main problem in this class is the uncertainty of occurrence.
Source: WBGU

Strategies	Tools
1. Ascertaining the probability of occurrence *P*	• Research to ascertain numerical probability *P* • International monitoring through – National risk centers – Institutional networking – International Risk Assessment Panel • Technological measures aimed at estimating probabilities
2. Preventing surprises	• Strict liability • Compulsory insurance for risk generators (e.g. floods, settlements) • Capacity building (licensing procedures, monitoring, training etc.) • Technological measures • International monitoring
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Education, training, empowerment • Technological protective measures, including containment strategies • International emergency groups (e.g. fire services, radiation protection etc.)

al early warning system is further necessary here, as in the Cyclops class.

The specific tools of damage management are very similar to those of the previous risk classes. The distinguishing feature here is the limitation of damage severity through local restrictions upon risk-generating activities.

Strategies for the Pandora risk class

The Pandora class of risks is characterized by uncertainty as to both probability and severity (only assumptions) and by high degrees of persistency and ubiquity (Table A 4-4). As the negative effects of these risk sources are still unknown, but can, in the worst case, assume global proportions with irreversible consequences, there is an urgent need for research efforts to develop substitute substances, and for regulatory measures aimed at containing or reducing these sources of risk. Implementation needs to cover the international context, too.

In the Pandora class, the provision of substitute substances or processes has priority over all other

Table A 4-3
Strategies and tools for the Pythia risk class. The main problem in this class is the low certainty of assessment, in conjunction with plausible scenarios suggesting high damage potentials. *P* signifies the probability of occurrence and *E* the extent of damage.
Source: WBGU

Strategies	Tools
1. Improving precautions and mitigating effects	• Institutionalized, precautionary technical standards such as ALARA, BACT, state-of-the-art etc. • Fund solutions • Mitigation (minimizing the spread of damage) • International agreements on control, monitoring and safety measures • Human-resource and institutional capacity building (licensing procedures, monitoring, training etc.) • Technological measures aimed at enhancing resilience (redundancy, diversity etc.)
2. Improving knowledge	• Research to ascertain *P* and *E* • International early warning structure through: – National risk centers – Institutional networking – International Risk Assessment Panel • State-sponsored (basic) research
3. Emergency management	• Containment strategies • Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Education, training, empowerment • Technological protective measures • International, rapidly deployable task forces (e.g. for decontamination)

Strategies	Tools
1. Developing substitutes	• Research aimed at developing substitutes • Technological measures aimed at disseminating and enforcing substitutes • Promotion of basic research • Subsidization of alternatives that have equal utility
2. Enforcing restrictions upon substance quantities and dispersal, through to outright bans	• Regulatory limitation of quantities, through – environmental standards or – incentive schemes (certificates) • Strict liability, where appropriate • Improving and extending retention/containment technologies • Command-and-control limit values and bans • Capacity building (technological know-how, technology transfer, training) • Joint Implementation
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Technological protective measures, including containment strategies • Education, training, empowerment

Table A 4-4
Strategies and tools for the Pandora risk class. The main problem in this class is the uncertainty of both the probability and extent of damage, in conjunction with high degrees of persistency and ubiquity.
Source: WBGU

strategies. As concerns researching and developing substitutes, the same applies in principle as in the Damocles class. Beyond this, the Pandora class requires wide-ranging basic research that needs to be promoted accordingly.

In a second step, the risk potentials should be reduced by minimizing, locally containing or even completely prohibiting certain sources of risk. Here, both command and control approaches are suitable, for instance through quantitative restrictions by means of environmental standards, and economic incentive systems using certificates. In some cases, the implementation of a strict liability regime is also appropriate. Technological approaches to risk reduction and strengthening human resources and institutional capacities apply as in the previous classes of risk.

Strategies for the Cassandra risk class

With Cassandra-type risks, there is scarcely any uncertainty, but people dismiss these risks in view of their gradual form or the time lag between triggering event and occurrence of damage (Table A 4-5). Frequently, the short-term legitimization of politicians brought about by short periods of office leads to a

Strategies	Tools
1. Strengthening long-term responsibility	• Voluntary commitments, codes of conduct of global actors • Coupling participation, empowerment and the institutional bolstering of long-term strategies • Remedying state failure • Fund models • International coordination
2. Steady reduction through substitutes and quantitative restrictions, through to outright bans	• Incentive schemes (certificates and levies) • Strict liability, where appropriate • Quantitative restrictions through environmental standards (also international) • Improving and extending retention/containment technologies • Human-resource and institutional capacity building (technological know-how, technology transfer, training) • Joint Implementation
3. Contingency management	• Human-resource and institutional capacity building (ecosystem restoration, emergency prevention, preparedness and response) • Technological protective measures, including containment strategies • Education, training, empowerment

Table A 4-5
Strategies and tools for the Cassandra risk class. The main problem in this class is the delay between triggering event and damage (high latency, insidious risks).
Source: WBGU

Table A 4-6
Strategies and tools for the Medusa risk class. The main problem in this class is the high mobilization potential, while the probability and extent of damage tend rather to be low.
Source: WBGU

Strategies	Tools
1. Building confidence	• Establishing independent institutions for information and public education • Improving opportunities for individuals to participate in decisions affecting their own life worlds, with an obligation to choose among conflicting options • Promotion of social science research on mobilization potentials • Model function: licensing procedures with participation rights of parties affected • International controls (IAEA) • International liability commitments
2. Improving knowledge	• Research aimed at improving the certainty of risk assessments • State-sponsored (basic) research
3. Communicating risks	• Clear presentation of the cause-effect relationships between triggers and consequences • Intensified environmental education in schools and in adult education • Direct feedback of measured data to the public

lack of motivation to tackle such long-term threats. Here, the Council takes the view that long-term responsibility needs to be strengthened worldwide, by means of collective self-commitments (such as codes of behavior of multinational corporations), by means of global institutions with a long-term perspective (UN Risk Assessment Panel) and by means of international conventions. To minimize the risks themselves, restricting the emissions of substances is a suitable tool.

Where there is a substantial time lag between triggering event and damaging effect, appropriate instruments need to be used to strengthen long-term responsibility to future generations. Here, the Council relies primarily upon voluntary commitments of states and important actors (such as multinational corporations or reinsurers). Fund models may also be useful here. At the more individual level, people potentially affected can gain more capacity for action through a combination of participation and empowerment, thus receiving impulses for long-term responsibility vis-à-vis their own life world.

The second priority is to continuously reduce risk potentials by developing alternatives in the form of substitute substances and processes, and containing unsubstitutable risk potentials through quantitative limits or at least limits upon the scope of application. The requisite tools have already been discussed for the other risk classes.

Strategies for the Medusa risk class

The Medusa class of risks requires measures aimed at building confidence and improving knowledge in order to reduce the remaining uncertainties (Table A 4-6). Public education alone does not suffice here. The affected people must rather have a part in the structuring of their own life worlds, and must constructively integrate in their own decisions the uncertainties and contradictions that remain intrinsic to these risks.

In this class of risk, the severity of effects and the probability of their occurrence are low, but the potential for mobilization is particularly high. In order to be able to educate the public about the actual severities and probabilities, confidence needs to be built first of all. Independent institutions providing open information about the findings of scientific research but also about the purely hypothetical character of many fears can play a role here. Furthermore, affected persons should have an opportunity to participate actively in structuring their life world. This confronts them with decisions that frequently involve making a choice between options that constitute different levels of risk. When weighing these risks, they must then decide themselves to what extent they accord more weight to the often poorly founded fears in the public than to the proven damage potentials of alternative options. Affected parties should also be able to participate in licensing procedures in order to weigh for themselves the value conflicts and to select from the range of options that which is most acceptable. To deal with the problem of Medusa-type risks in society, social science research that studies mobilization potentials and the social handling of risk conflicts needs to be promoted.

For this class, too, the knowledge of presumed risk potentials should be improved. There is a need for research to improve the certainty of assessments and for basic research. In addition, effective and credible risk communication measures need to be instituted.

A 4.1
A dynamic perspective

The ultimate goal of all measures taken for class-specific risk reduction is to commute risks from the transitional area to the normal area. In stating this aim, the Council proceeds from the fundamental understanding that it cannot be the concern of risk policy to reduce risks down to zero, but rather to transmute risks such that they reach a scale at which the common methods of risk-benefit assessment can be applied by market participants and by state regulators. The Council further wishes to stress that the management of global risks located in the normal area need not necessarily require international efforts. Nonetheless, here the industrialized countries can provide assistance in establishing effectively operating regulatory authorities, functioning insurance markets and effective contingency measures. If, however, by applying the decision tree explained in Section 2 a global risk is identified as belonging to one of the risk classes localized in the transitional area, then international measures are indeed called for in order to move the risk from the transitional area to the normal area.

This commutation will generally need to follow a process passing through several stages. Regardless of the success of individual measures, a risk can move from one class to another without directly entering the normal area. Fig. A 4.1-1 illustrates this movement from class to class.

In general, we may distinguish between two types of measure: those aimed at improving knowledge (through research and via liability), and regulatory measures impinging upon critical, class-specific quantities (probability, severity, irreversibility, persistency, time lag and mobilization). As Fig. A 4.1-1 indicates, improved knowledge generally leads to a movement from one class of risk to another (for instance, from Pandora to Pythia, from Pythia to Cyclops and from there to Damocles or Medusa). Measures acting upon a specific critical quantity can similarly trigger a cascade movement, or can bring about a direct movement to the normal area.

In the following, this movement from one class of risk to another is explained for a fictitious example. Imagine a substance that is used globally, is highly persistent and for which there are reasonable grounds to assume that it causes irreversible effects. This risk belongs in the Pandora class. It is located in the upper third of the transitional area, whereby the uncertainty bars (confidence intervals) extend into the unacceptable range. A risk of this type suggests two primary strategies: expanding knowledge and limiting the risk potential. Let us first examine the outcome of expanding knowledge. The knowledge pertaining to the risk can be further quantified, in the process of which the assumption of irreversible consequences or of high persistency may be substantiated. If this is the case, a substitution of the substance or even a ban is urgently called for. The risk is thereby unequivocally moved into the prohibited area. We are dealing with a special case if a large period of time will elapse between the triggering event (human or environmental exposure) and its consequence, so that there is little political prospect of taking direct influence through a ban or restriction. We then have a typical Cassandra-type risk. To handle this, long-term responsibility needs to be strengthened and principal actors need to be mobilized in order that the necessary strategy of substitution or at least of containment is effectively implemented.

Let us assume in our illustrative example that the spatial distribution of this substance can indeed be limited such that ubiquitous dispersal is prevented. In this case, the risk is moved to the Pythia class, as the probability of occurrence and the severity of effects are still both subject to major uncertainties. The next step in this case is thus to determine the severity more clearly. Let us then assume that there are grounds to assume substantial damage and that this damage seems large enough to preclude locating the risk in the normal area. Under these conditions, movement continues in the direction of the Cyclops class. Cyclops forms a pivotal node in Fig. A 4.1-1, as risks can undergo transmutation from there to a variety of other classes. If, for instance, we can succeed in determining the probability of occurrence and this is relatively low, then the risk can be categorized as belonging to the Damocles class, characterized by high severity and low probability. If, however, probability is found to be high and there is a time lag, the risk again moves towards the Cassandra category. Without this time lag, a ban or a rapid substitution can be expected (movement to the prohibited area). If technological or other measures can be applied to reduce the severity to a 'normal' level, nothing now stands in the way of commutation to the normal area.

If the disaster potential remains very high despite reduction efforts, the risk lands in the Damocles class. From here, too, it can be moved to the normal area through a two-pronged strategy of improving knowledge and reducing disaster potential. If all reduction tools fail, then a fundamental decision is due as to whether the benefit associated with this risk is considered to be so substantial that the high potential for damage is tolerated, its probability of occurrence being low. If the outcome of this decision is negative, the risk moves into the prohibited area.

For all types of risk, the desired commutation to the normal area can be via the Medusa class. Thus, in

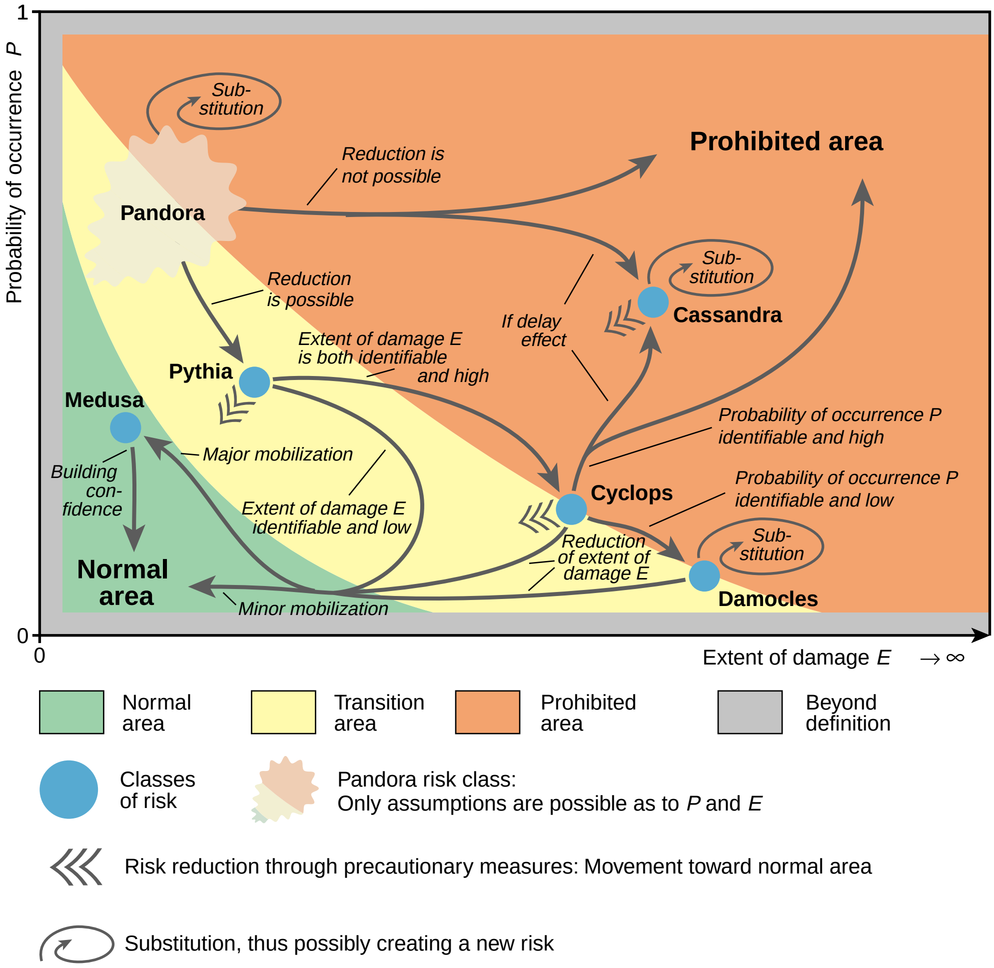


Figure A 4.1-1
Risk dynamics in the normal, transition and prohibited areas.
Source: WBGU

our fictitious example, the public may have little confidence in the purported reduction of damage potential. By way of illustration, we only need to recall the uproar caused in Germany by the 'Castor' nuclear waste transports. Even if the health risk from radiation is assessed as low in terms of both probability and severity – which appears justified considering the isolated cases of radiation dose limits being exceeded – the loss in terms of credibility and reliability is large enough to generate a major political and psychological mobilization effect. Acting on a long history of suffering in public risk debates and their political ramifications, many risk regulators may prefer to opt for a ban, even though both probability and severity indicate a normal risk. In such a case, measures aimed at building confidence and further improving knowledge are necessary in order to convince the public of the 'normality' of the risk and at the same time to commit technology operators to handle the risk as required by law. In addition, a need always remains to critically review whether the measures instituted really have led to the intended risk reduction.

After passing through all these stations, the normal area will finally be reached. The Council realizes that this cascade movement presupposes intensively tackling the risks to be assessed, and continuously monitoring and evaluating the risk reduction measures to be taken. This requires time, institutional provisions and resources. Nonetheless, the Council is convinced that, given the extent of global threats, investments in global risk management are worthwhile. The analytical framework of risk classes put forward here and the associated dynamic conception of measures offer a logically consistent and politically practicable concept. This concept can help the German government and the international community at large to concentrate on those risks that have the potential to emerge as global threats, while risks in the normal area are adequately addressed by national regulatory structures. Concentrating on essentials is in fact an important message to the public, which, beset by widespread confusion as to the disaster potential of risks, expects the policy-makers and the scientific community to deliver orientation and certainty in action. At the same time, the categorization in risk classes and the implementation of class-specific measures can help society to deal with risks effectively and in a targeted way, and can instruct risk managers in industry and policy on how to handle risks rationally.

Prime recommendations for action

A 5.1
Extending strict liability

We find that there is an array of global trends which may compromise the sustainability of society (for instance, growing world population, economic development, socio-economic interpenetration of nations and economies). Reactions to this can take two forms. One approach is to attempt to use expert stipulations, technology assessment and consensual debate in society to define a development path that proves to be sustainable. At the global level, limits are imposed upon such an approach by the diversity of preferences and interests, disparities in the risk acceptance of individual societies and gaps in available knowledge. There are, however, global environmental risks for which a global consensus is emerging concerning the developments that are viewed as undesirable and unsustainable. Thus for climatic risks, for instance, (variable) 'guard rails' or 'development corridors' can be stated which should not be overstepped or left.

This approach has its limits. Limited knowledge of the consequences of today's actions for the future and the associated assessment problems, in conjunction with limited capacity to control complex economic and social systems, hamper a stringent formulation of 'guard rails' and targeted direction of systems. Sustainability is thus not so much a definable target than rather a charge upon the people living today to develop rules and regulations that point the production of knowledge in a direction guided by long-term perspectives. Furthermore, through timely revelation of the negative implications of today's activities, these rules and regulations should make it possible to trigger rapid societal adaptation reactions in terms of risk reduction. Sustainable societies must thus be continuously innovating and learning systems equipped with incentive arrangements for risk reduction.

The Council therefore accords great importance not only to creating new knowledge, but also to mobilizing the potentials of problem-solving competence which are available decentrally within society but unknown to any central agency. This is above all a matter of revealing previously unidentified risks and promoting the innovation of new, less risky lines of technological development. Because an assessment of risk consequences is not possible, or only to a limited extent, appropriate incentives should be provided for the production and mobilization of knowledge. In addition to promoting basic research, this further entails guaranteeing room for manoeuver, and thus also assigning clearly defined property and utilization rights. The door can thus be opened to diverse searching processes, taking place on the market under competitive conditions, which are able to reveal errors and avoid mistakes in time. An important element in such processes is the enforcement of the liability principle, which, due to its preventive effect, can contribute to precluding damage. As the Council has repeatedly stressed, the preventive side of liability is the main aspect. This preventive effect is enhanced if the risks in question are insurable. The insurance companies will then set up expert groups to assess these risks and will arrive at premiums reflecting their assessments. This will in turn lead to the acceleration of risk-reducing knowledge production – for insurer and insured alike will conduct risk research in their own best interests in order to avoid faulty assessments and in order to limit losses and reduce the probability of these losses occurring.

Where risks are found to be uninsurable, this might well have the effect that the risk-generating activity is discontinued. If that is not in the interest of the state, liability must be limited.

A 5.2
Precautionary knowledge production

Knowledge of the causes, mechanisms and adverse effects of possible, undesired events forms the basis for managing global environmental risks. The production of new knowledge, however, which is generally by processes of technological innovation, can itself generate new risks with previously unknown characteristics. In a highly dynamic society, policy-makers are under a particular obligation to ensure that the 'ignorance coefficient' – the ratio between the totality of risks and the relevant prevention and management knowledge – at least does not deteriorate.

The ignorance coefficient can be positively influenced by issue-focused risk research tackling such hazards that are known or that can at least be surmised. It follows that it is essential to maintain or indeed even raise the high standards that research has reached in Germany in this field (from technology assessment to global systems research). This cannot be delivered for free, but the requisite expenditure is politically reasonable.

Managing still unknown or not systematically identifiable risks that may perhaps be far in the future is a much more problematic situation. Here, clearly defined, objectives-oriented knowledge production with short-term safety yields is impossible. The Council has discussed this situation repeatedly and in detail elsewhere.

Proactive risk management does not turn on ad-hoc knowledge production, but on a store of knowledge produced in advance. This can only be delivered by broad, 'value- and purpose-free' basic research. Only a continuously replenished and extended stock of knowledge not subject to direct exploitation requirements will make it possible to discover complex risk constellations coincidentally, in passing or playfully, and to find management strategies in a similar manner. This is why the Council advocates an undiminished *basic funding for the environmental sciences* in the broadest sense, whereby the long-term objective must be to significantly improve our understanding of the interconnections in the Earth System. Such research will uncover real risks which are presently not visible in the slightest, but will presumably be amenable to management by appropriate measures.

The Council notes in this connection that research thrives on diversity and competition: it would be a dangerous fallacy to assume that basic research can be made 'leaner' through rigidly avoiding duplication and parallel efforts – such as by commissioning *one* institute worldwide and researching *one* specific compartment of the ecosphere. On the contrary, a spectrum of opinions, approaches and methods is necessary in order to subject the space of possible risk constellations to a sufficiently tightly meshed scan. This applies particularly to simulation models for the climate, ocean circulation, vegetation dynamics and so forth, where it is precisely a broad spread of different research designs and realization that will permit the coincidental identification of critical – i.e. *not* evident – hazard aspects. Knowledge is venture capital, and this capital needs diversification!

A 5.3
International mechanism for risk detection and assessment

Knowledge thus holds the key to risk management – but the key must also be used. Worldwide, this use has in the past been completely inadequate. Various factors have been responsible for this inadequacy: insufficient integration of specialist knowledge, asymmetrical access to knowledge, ineffective structures of knowledge transfer and so forth. We do not mean here the implementation of insights in concrete actions for dealing with risk, but a preliminary stage where knowledge provides an indication of the need to act. Particularly in terms of global environmental threats, there can as yet be no talk of any such processing of the already available insights. Here action-relevant risk knowledge would need to make global hazard potentials visible in a geographically explicit manner. Concerning, for instance, the perspectives of global food security, we presently have nothing more than an array of speculations, built on shaky ground, that do not even begin to make use of the knowledge already available today (e.g. on the impacts of expected climate change or continuing soil degradation processes).

The Council therefore recommends that a (UN) Risk Assessment Panel be established. The essential functions of this Panel should be similar to those of the Intergovernmental Panel on Climate Change (IPCC), but the task of the (UN) Risk Assessment Panel would be less to analyze already detected risks, and more the timely and integrated detection of novel risks of global importance that are only just beginning to become visible.

The (UN) Risk Assessment Panel should not conduct research of its own, but should underpin and stimulate existing relevant research structures, condense their findings and – after a comprehensive international scientific assessment process – present these to policy-makers in a purposeful form. The main aim would be to establish a network node in which various national risk identification and assessment processes come together, are collated and coordinated. Thus, under the aegis of this Panel, certain tasks or functions set out in Section F 6 could partially be delegated to already existing international organizations or institutions. Such a Panel would not involve founding a new international organization, but would make use of the capacities and competencies of existing bodies.

In particular, the Panel should assume five focal tasks:

- *Early warning system*. For an international networking of early detection and early warning, as much scientific data and findings of early detection research as possible should be collected, systematized and synthesized worldwide. This can ensure reliable forecasting of impending threats. A precondition would presumably be to support certain countries in the creation of national early detection systems or risk centers, particularly in vulnerable areas.
- *Evaluation of monitoring*. The Panel should evaluate the findings of monitoring systems in a timely and action-focused manner. The task would be to monitor, control and regulate risk potentials. In order to ensure effective monitoring, states would need to commit themselves to certain technical and organizational standards. The review of and compliance with these standards could be the remit of an international safety standards authority (Section H 2.2.4), which could be modeled on institutions such as the International Atomic Energy Agency (IAEA). International monitoring can only be effective if national monitoring structures are effectively coordinated through institutional linkages.
- *Knowledge production and dissemination*. A (UN) Risk Assessment Panel can function as a multiplier of 'risk knowledge' by making available to all interested actors the scientifically substantiated findings of risk analysis and risk assessment (Section C). In addition, the Panel should stimulate, support and coordinate basic risk research in order to close the gaps in knowledge relating to the analysis and assessment of certain risk potentials (in the transitional area, see Section C).
- *International risk evaluation methodology*. The proposed (UN) Risk Assessment Panel could also contribute to ensuring that a uniform method of risk analysis and assessment attains collective validity. Risk assessments would then become easier to compare and to operationalize. The Council proposes basing such a methodology on differentiation according to normal, transitional and prohibited areas set out in Section C. Global risk potentials would need to be treated in accordance with this risk classification. This means that a collectively recognized risk assessment procedure would evaluate those risk potentials that are located in the prohibited area as being unacceptable, and would ban them. Risk potentials located in the transitional area would need to be handled by regulatory policies, whereby considerable importance would attach to continuous knowledge production.
- *Focusing on essential issues and determining the 'safety margin'*. The (UN) Risk Assessment Panel should identify the essential policy domains (perhaps four or five), concentrate its work on these and determine for these the respective 'safety margins', i.e. the just acceptable boundary zones to intolerable conditions.

The function of the Panel would thus be to condense, in an interdisciplinary fashion, the scientific research on the risks of global change (policy-oriented weighing of all individual findings). In this, it should make all efforts to be:

- Independent of the direct interests of individual states,
- Independent of the direct exploitation interests of private industry,
- Independent of the direct influence of non-state political associations and lobby groups.

The (UN) Risk Assessment Panel should moreover serve as a – scientifically substantiated – interface between non-state actors (environmental and development organizations, industry federations) and the body politic, by permitting submissions of non-governmental organizations and scientifically examining and assessing these. A further important task of the Panel would be to inform both state and non-state actors (at all levels) about the state of knowledge of all environmental risks of international relevance.

A 5.4
Building effective capacities for dealing with risk

The above recommendations are geared to ensuring that environmental risks cannot arise in the first place, or are detected early on and assessed properly. However, these political measures will not lead by themselves to a complete prevention of global hazard potentials, nor to a total suppression of regionally damaging events. It remains essential to transpose knowledge into action and contingency measures. There is a lack of the necessary institutional and technical capacities. This already applies to many industrialized countries, and all the more to most developing countries. At the international level, we can only find first rudiments. The Council makes the following recommendations in this area:

- *Enhancing national and international civil protection*. Almost all of the risks of global change call for investment in emergency prevention, preparedness and response capacities. Where existing mechanisms are not fully operative, the establishment of new structures should be considered in order to resolve acute problems. At the national level, each government will have to make its own provisions, whereby the financially constrained developing countries should be offered financial and technical assistance by the international community. At the international level, the establishment of supra-state 'stand-by' emergency response units should be considered. The emergency relief units of the Red Cross or the international task force for decontamination at the IAEA are examples of such units. These could be expanded to form 'rapid deployment forces' and, with due regard to considerations of national sovereignty, could be specially trained to deal with environmental disasters. The control center for these units should be integrated in an international organization in the United Nations system, and closely linked to the (UN) Risk Assessment Panel proposed above. It also needs to be examined in this context whether the implementation of a voluntary international environmental inspection system could enhance risk regulation and remediation.

- *Strengthening non-state actors, in particular NGOs.* Strengthening non-state environmental associations could form a crucial element in the long-term management of global environmental risks. In intrastate politics, it needs to be considered to what extent environmental associations might be allowed to use collective litigation (or individuals might be allowed to bring environmental citizen suits) to champion the interests of the environment and of future generations more effectively than has been the case in the past. However, there are concerns that an unconsidered widening of avenues of litigation, or indeed the introduction of public-interest popular action in environmental law, may create opportunities for abuse, and may further lead to international competitive distortions. Nonetheless, a careful broadening of access to justice would correspond to the general tendency of European Community law. A precondition to this would be to promote a culture of open communication, in firms, in municipalities and within states – a culture open to different value judgments and different notions of what constitutes environmental quality and the quality of life. In international politics, environment and development groups have attained ever growing importance. In some arenas, non-governmental organizations (NGOs) are already granted the right to be heard at diplomatic conferences and within the United Nations system, and have access to many documents. It should be examined to what extent NGOs could be integrated even more effectively in the international negotiation and implementation processes. With a view to a global strategy for dealing with risk, the Council recommends an extensive right of NGOs (including industry federations) to initiate proceedings in the proposed (UN) Risk Assessment Panel. Here, the problem of a possible lack of legitimization of non-state actors needs to be taken into consideration.
- *Promoting self-help potentials in developing countries.* In its previous reports, the Council has repeatedly noted that the risks of global change are distributed very unevenly among the countries and populations of the world. People in developing countries are particularly at risk. Strengthening capacities to cope with these risks in the developing countries, particularly among the poor, who are those most at risk, is therefore an important element of effective global risk policy. A further reason why combating poverty through self-help is such an important part of global risk prevention and attenuation policy is that it not only aims at broad impact, but at the same time stimulates structural reform in state and society. In some cases, the basic essentials for an effective handling of the risks of global change first need to be created, namely the basic structures of an issue-focused state administration. Here, too, the international community is called upon to exercise solidarity. In sum, further technical and financial development cooperation can be brought to bear in such a way that the potential extent of damage of risks is significantly reduced. Through its three focuses – 'poverty alleviation', 'environmental protection and the conservation of natural resources' and 'education and training' – German development cooperation already makes an important contribution to handling the risks of global change. Nonetheless, the available funding does not suffice. The Council has therefore repeatedly called for a significant boost in government funding for development cooperation. The capacity of a society to deal with the risks of global change, its knowledge of causation and cause-effect linkages and its ability to communicate about risks depend directly upon the level of education and the available scientific competence. But the education sector is an area where the North-South gradient has become particularly steep in recent years. The production of risk knowledge in the innovation process is gaining particular importance for those countries whose industrialization is only just beginning, and where crucial decisions are due to be taken in the future in key sectors of the economy. Knowledge transfer in all purposeful forms between industrialized and developing countries is thus an indispensable instrument of global risk management. Here, the (UN) Risk Assessment Panel proposed above could play a pivotal role.

A 5.5
Ecological criteria in development cooperation

Even best-intentioned solidarity with the countries and groups that are particularly vulnerable to global change is doomed to fail if the recipients of solidarity inputs do not themselves observe a number of basic rules concerning the protection of our common environment. The Council therefore recommends giving greater consideration to ecological criteria in development cooperation.

Environmental protection was already included by the German government in 1975 in its catalog of development policy objectives, and was declared in 1986 to be one of the five thematic foci of development cooperation. Since the Rio Earth Summit, this trend has gathered momentum. More than a quarter of all bilateral development cooperation commitments now relate to the field of environmental protection. In recent years this has amounted to more than DM 1 billion.

The Council views these activities as a very important contribution to reducing global environmental risks. It welcomes the circumstance that environmental acceptability has now been integrated as an element in the project promotion procedures of the German Federal Ministry for Economic Cooperation and Development (BMZ). Environmental standards should gain a higher priority in the future as a basis of development cooperation. In this connection, the ongoing efforts of the OECD Development Assistance Committee to harmonize the protection and monitoring measures of the various donor countries deserve support. Not least, it should be examined at the European Community level whether the protection of the global environment should be enshrined as a Community-wide objective of development cooperation through insertion in Article 130u para 2 of the EC Treaty (or, after entry into force of the Amsterdam Treaty, Article 177 para 2).

A 5.6
Promoting risk awareness

If indispensable socio-economic opportunities are to be seized, then there is no risk-free path for a dynamically developing global community. In fact, a policy of risk aversion can be all the more hazardous over the long term, as avoiding known hazards can mean foregoing opportunities for later handling currently unknown risks. However, global change harbors risks with novel characteristics (e.g. the danger that ocean circulation patterns are changed) which concern practically everyone on the planet, albeit in most cases with a highly asymmetrical distribution of consequences, and whose potential effects can extend far into the future of humankind. This special quality of risk demands a new quality of risk responsibility such as can only be assumed by the 'risk-aware citizen'.

The risk-aware citizen

- Should be adequately informed about the current state of knowledge of global environmental risks,
- Should be involved to the greatest possible extent in really critical decisions on the acceptability of certain environmental risks, and
- Should continue to stand by the decisions taken with his or her involvement, even if these subsequently prove wrong.

The Council recommends that the German Federal Government examines whether the existing tools for promoting these three principal elements of risk-awareness have in the past really been exploited, and whether these tools should be further developed. The not exactly confidence-inspiring events surrounding BSE and shipments of radioactive material give ample reason to presume that distinct improvements are indeed possible here.

This endeavor needs to address two fundamental challenges: firstly, when dealing with global hazards – i.e. in particular hazards that transcend national boundaries and human generations – competent, fair and efficient forms of political representation and participation need to be developed. It is around this challenge that the debate on the perspectives of 'global governance' currently revolves. The process of forging and implementing the UN Framework Convention on Climate Change (FCCC) may offer a paradigm for what could correspond in the global context to local consensus-building processes (including 'round tables').

Secondly, risk-awareness is not an objective whose realization devolves entirely to politicians or public authorities. Opportunities for information, discourse, co-determination and joint responsibility must be made use of by the 'global citizen'. Insofar, this summary ends with a call to all those who feel themselves or their descendants put at risk by global environmental changes to engage in a risk partnership. Even relative safety is not an asset that can be made freely fungible – not by any collectivity, no matter what kind.

Introduction

B

What is it that makes the world-famous mountaineer Reinhold Messner scale the highest mountains on foot without oxygen mask; what induces people to hazard their entire worldly possessions in games of chance? Why were remnants of animal carcasses fed to cows in England without regard to the associated risks? Why is humanity finding it so difficult to reduce greenhouse gas emissions at the risk of climate change that can trigger global catastrophe? Why are most people more afraid of flying than of driving a car, although the accident risk in a car is far higher? Why are fewer and fewer people having themselves vaccinated although the danger of epidemics is waxing rather than waning? There are no simple answers to these questions. For it is not only the level of risk – understood as the combination of the probability and magnitude of adverse effects – which leads individuals and whole peoples to perceive certain activities and technologies as tolerable or even desirable. It is also and above all social, political and cultural contexts and individual and cultural value judgments that determine people's responses to the risks around them (Shrader-Frechette, 1991; Luhmann, 1991; Krücken, 1997).

The Council has tackled the contentious and all-embracing topic of 'risk' in its present report because many of the dangers facing humanity will not occur with certainty, but only with a more or less ascertainable probability. It can neither be confirmed nor excluded, for instance, whether the Gulf Stream that is vital to Europe may cease due to human-induced climate change, whether genetic material urgently required in the future may be destroyed through clearing rainforests, or whether high social density and high mobility may inflict new, disastrous pandemics upon the world. We could continue this list of global risks indefinitely. How should a nation, how should the international community deal with such a hazard potential? On the one side, societal change is impossible without deliberately taking risks. On the other side, humanity is already intervening so fundamentally in natural cycles that the associated risks no longer have only regional but now also global consequences (Zürn and Take, 1996).

In this interdependent world, environmental risks play a particularly important role. As most ecological connections can only be explained scientifically by means of complex, non-linear models, uncertainties and ambiguities necessarily remain (Renn, 1996). In many cases, these uncertainties are used by the political realm as an excuse for inaction. Conversely, however, even the smallest uncertainties are often used as a pretext for exaggerated precautions. This is why the Council has made it its task in the present report to classify the global risks associated with environmental change. Using this typology, we then describe the hazard potential of each class of risk, analyze the psychological, social, economic and cultural factors influencing risks, and develop, on this basis, management strategies appropriate to each specific class of global risk. It is the Council's hope that the recommendations concerning risk identification, evaluation and management given in this report may help to deal politically with objective hazards in a more targeted and efficient manner. The Council restricts itself in this report solely to risks whose chain of effects embraces environmental consequences and whose scope extends beyond national borders.

The high risk potential presented by human activities is not the only reason why the Council has turned to this topic. Risks are currently at the forefront of public debate. Not a day passes without press reports of accidents, impending disasters and insidious health hazards. Although hazards to human health and the environment have prevailed at all times, risk has only recently become an issue of public debate. The high degree of topicality enjoyed by 'risk' is due above all to four factors:

1. *From stroke of fate to calculated risk*. At all times, people have made provision for hazards. However, in the past, lack of anticipatory knowledge led people to view negative events less as an outcome of their own behavior than as 'divine retribution' or strokes of fate (Wiedemann, 1993). Be it plagues, failed harvests or ruptured dams, any disaster in which, by a modern understanding, there is at least some element of human causation was largely interpreted as vicissitude or retribution directed by an external agency. In the modern era, according to the sociologist Niklas Luhmann, hazards perceived by people as external and to which they previously felt themselves passively exposed have become transformed into risks controllable by society (Luhmann, 1991, 1993). Risk management, the modern formula for reducing and controlling undesirable side-effects of human activities, bears ample testimony to the transformation of hazards originally perceived as external into societally addressable, socially influenceable and regulated activities aimed at mitigating undesirable consequences of human action. Today, even natural disasters, while not thought of as being caused by human action, are nonetheless viewed as hazards whose consequences can be amplified or attenuated by human behavior. At the same time, the inclusion of risk within the sphere of human actions is raising demands upon risk management institutions to take effective precautions against risks in order to prevent or mitigate negative events (O'Riordan, 1983; Evers and Nowotny, 1987; Kleinwellfonder, 1996).

2. *Transition from natural to human-made hazards.* In parallel with the attainments of technology, medicine and hygiene, the relative proportion of natural hazards (e.g. infectious diseases) has dropped and the proportion of human-made risks (e.g. through technology, diet or recreational activities) has risen (Fritzsche, 1986). One hundred years ago, fatalities at an early age were mainly due to infectious diseases that had to be accepted as strokes of fate in the same way as natural disasters (Harriss et al., 1979; Hohenemser et al., 1983). Accidents or environmentally mediated damage, to the extent that they were perceived at all as being connected to human activities, were considered far less relevant. Today, in contrast, road accidents, cancers caused by smoking, unhealthy lifestyles and exposure to environmental stress are perceived as dominant individual risk factors in modern industrialized societies.
3. *Rising disaster potential in conjunction with falling individual risk*. In many spheres, technological development is characterized by a tendency towards raising disaster potentials while at the same time reducing the probability of occurrence (Lübbe, 1993). The prospect of major disasters, as small as their probability may be, is consciously accepted in order to hold at a low level the probability of suffering individual damage and in order to reap gains through economies of scale (lower costs through mass production; Perrow, 1984). Traveling by rail instead of by private car is more favorable from an economic perspective in terms of cost-effective resource utilization and is safer in terms of the individual probability of suffering an accident (Akademie der Wissenschaften zu Berlin, 1992). However, in the event that a railway accident happens, the number of victims is usually higher than in a road accident. When dealing with nuclear energy or major chemical installations, this connection is even more dramatic. Raising the disaster potential while at the same time reducing the individual risk of damage demands collective decision-making processes (as opposed to the personal decision to take a risk). It thus also calls for a particular consideration of the distribution of risks and benefits (MacLean, 1987).
4. *Growing impacts of ecological risks upon individual well-being.* In times of economic prosperity and consumption diversity, the individual marginal utility derived from economic welfare in the narrower material sense has dropped vis-à-vis the marginal utility of general health, a clean environment and psychological well-being (Klages, 1984; Renn and Zwick, 1997). It thus becomes all the more difficult to justify risks whose utility is largely economic in nature. While environmental concerns are no longer as much at the forefront of public discourse as they were a few years ago, the great majority of the German population continues to be in favor of improved environmental protection (BMU, 1996). Environmental risks remain important topics in public perception and politics.

All four factors have contributed to risk having become perceived as a societal problem and having gained political clout at both the national and international level. In step with improved forecasting capacities and the growing moral commitment of modern society to reduce risks, citizens are placing growing demands upon political and economic decision-makers to actively structure the future and to proactively tackle possible hazards engendered in the natural environment and the technosphere. Safety from future hazards and proactive risk management have thus become central concerns of almost all segments of the population (BMU, 1996).

However, there is a danger that the enhanced awareness of risk and the understandable desire to minimize risks as far as possible may stifle, for fear of possible damage, the technical and social innovations necessary to cope with global processes of change. This is why the Council proposes in the present report an approach in which appropriate risk management strategies are linked with a prudent combination of permitting procedures, regulatory controls and liability rules – and the application of state-enforced precautionary principles or institutional provisions for risks with a high level of uncertainty. It is hoped that such an approach may enhance confidence in the management capacities of modern societies and may thus help to make the international risk debate more rational and objective. By 'rational' we do not mean blaming the potential victims for their understandable aversion to tolerating risks. Still less do we wish to play down the severity of global risks. By an objective approach the Council rather means the urgent necessity to face real hazards – with all the associated uncertainties and ambiguities – in a manner that is targeted, rational and efficient, while at the same time seizing the opportunities associated with taking risks.

This endeavor urgently requires substantive knowledge in order to ascertain the risk itself on the one hand and orientative knowledge in order to ascertain the acceptability of risks on the other (Renn, 1997a). The pluralization of substantive knowledge in conjunction with a constructivist perspective is particularly popular in the risk arena but is counterproductive for effective risk management. The reality is that people die and suffer because of erroneous knowledge. Precisely because knowledge of the consequences associated with risk decisions entails uncertainties and thus spans a large range of legitimate claims to truth, it is essential to separate methodologically reliable knowledge from mere assumptions or speculations. If the boundaries between scientifically supported knowledge and mere assumptions or anecdotal knowledge become blurred, even the most absurd fear of risk will find a 'knowledge-based' justification. The science realm itself should ascertain the range of methodologically underpinned knowledge, as it is only in this realm that the methodological rigor and semantic tools are available by which to expediently do justice to or resolve competing claims to truth. This is why risk research efforts are so essential and indispensable (Section H 1).

The Council has made every effort to analyze the risks described in this report as objectively as possible and to set out the damage potentials and the related uncertainties associated with the risks as accurately as possible. Nonetheless, this is not a report on genetic engineering, nuclear energy or volcanic eruptions. No single report would be able to cover such a range. Rather, these risks are used as illustrations by which to point out possible hazards and their modes of effect from which to derive and to flesh out the taxonomy of risk developed by the Council. The Council is confident that this taxonomy makes it possible to group a great number of different risks in one class and thereby to characterize them with sufficient accuracy. This classification promotes an understanding of risks, and furthermore supports decision-makers in designing special procedural and substantive rules for each class without drowning in a sea of individual measures specific to each risk.

In addition to substantive knowledge, knowledge for normative orientation is also crucial to dealing with risks. The question of the acceptability of residual risks, the decision on how to handle ambiguities and uncertainties, the problems of a fair distribution of risks and benefits – all of these require normative stipulations. Nobody can derive the acceptability or unacceptability of nuclear engineering, genetic engineering applications or waste incineration plants in a logically unequivocal fashion – neither factually nor normatively. Risk decisions are always characterized by both the knowledge of outcomes and the moral assessment of expected impacts. The Council has developed procedural proposals that facilitate a factually required and morally acceptable risk policy. These procedural proposals include on the one hand risk management strategies tailored to the above-mentioned classes of risk, and on the other hand pivotal recommendations for action and research that flow from the special responsibility of the Council to address and assess global environmental change (Sections H 1 and H 2).

Concepts of risk and their applications C

Risk: Concepts and implications C 1

C 1.1
Analytical approach

The concept of risk is based on the distinction between reality and possibility (Markowitz, 1990). Only if the future is perceived as being at least partially modifiable by human agency, is it possible to avoid potential hazards or to mitigate their impacts (Ewald, 1993). This may appear trivial to the modern citizen. However, by far the greater part of human history has been characterized by a fatalistic attitude to the future (Covello and Mumpower, 1985). Thinking in categories of risk (and also opportunity) presupposes a minimum of ability to modify the future and thus to avoid undesirable events by taking precautions. To predict possible hazards, it is necessary to identify causal relationships between sources and consequences. These cause-effect relationships can be scientific, anecdotal, religious or magic (Douglas, 1966; Wiedemann, 1993). As the effects are undesired, the concept of risk always also implies a normative aspect. Society is called upon to prevent, reduce or at least control risks. In step with growing technological hazard potentials and the cultural incorporation of external hazards by means of calculable risk estimations, the need for risk science and management is growing (Beck, 1986).

Risks thus refer to possible consequences of actions or events that are considered by the great majority of people to be undesirable. In the various disciplines, risk concepts differ according to the manner in which these consequences of human actions or events are identified and evaluated. Here four core issues emerge (Renn, 1992, 1997b):

1. *What are desirable and what are undesirable outcomes?* In more concrete terms: how can possible categories of damage be defined and according to which criteria can positive (i.e. desirable) and negative (i.e. undesirable) consequences of actions or events be distinguished? Does it suffice if this distinction is made by individuals of their own accord, or are collective decision-making processes required? On this, the Council submits proposals in Section C 2.
2. *How can potential outcomes of actions or events be predicted, or at least estimated in a manner that is intersubjectively valid?* Which methodological tools are available to cope with uncertainty and to assess the probability and magnitude of possible damage (conceptualized in question 1)? The question of the amenability of risks to scientific assessment is largely treated in Section C 1.
3. *What possibilities are there of classifying risks in certain risk classes?* Which further characteristics of risk play an important role in risk assessment in addition to probability of occurrence and extent of damage? Are there typical classes of risk that might permit us to rank risks according to priorities (Sections C 3 and C 4)?
4. *Which combination and which distribution of desirable and undesirable outcomes legitimates the rejection or approval of a risk-causing action?* On which criteria can risk assessments be based, and how can risks and benefits be offset against each other? This issue is taken up in Section C 3 and is discussed in depth in Sections F and G, leading to recommendations for action in Section H.

The first question concerns the social definition of desirable and undesirable outcomes. Who determines what is desirable for a society and what is not? Does the category of undesirable outcomes include only physical consequences such as death, injury or ecological damage, or does it also include the impairment of social relations and cultural values? If we prefer a broad definition of damage categories, the question of priorities among the various categories immediately arises (Berg et al., 1994). Should psychological impairments be ranked lower than chronic diseases and are these in turn less important than invalidity?

The Council had to define its field of study here. As it is primarily concerned with environmental impacts, it addresses in the present report only those damage categories which clearly include environmental impacts in the course of their chain of effects. Purely civilizational risks which proceed from people and also affect people are thus not the subject of this report (Section C 2). Furthermore, this report only addresses such hazards that, firstly, are of a global nature (Section C 2.4) and, secondly, have outcomes associated with uncertainty from the perspective of the observer. Environmental effects that can be expected with certainty are not treated further here even if these effects are particularly severe. For instance, the environmental damage caused every year by the routine dumping of oil residues from ships at sea is not a subject of this report.

The second question concerns the *predictability of outcomes*. Which tools are available for calculating the probability of outcomes? As the future is indeterminate as a matter of principle, agreement between prediction and real consequences cannot be measured in a strict empirical sense, but can at best be ascertained *ex post*, i.e. after expiry of the source of risk in question. This uncertainty does not imply an incapacity to act, but rather a necessity to orient action to uncertain but by no means arbitrary assessments of the outcomes of action (Birnbacher, 1994; Bonß, 1996). Here the Council proceeds from the assumption that, despite remaining uncertainties and gaps in knowledge, there are better and worse predictions, i.e. there are quality criteria by which to evaluate risk assessments. The goal of every risk analysis must therefore be to predict as accurately as possible the probability and magnitude of effects of activities or events, taking into consideration other risk-related factors, too (Sections C 1 and C 3). Beyond this, it is necessary to develop strategies for forward-looking risk avoidance and above all reduction, in order to be also able to contain the scope of effects of unpredictable risks (Section G).

The third question points to the *special characteristics of risks* that call for particular attention on the part of society in addition to the conventional criteria 'probability' and 'extent of damage'. The Council proposes to consider criteria such as persistency of damaging effects over time, spatial distribution (ubiquity), irreversibility and others (Jungermann, 1986; California Environmental Protection Agency, 1994; Margolis, 1996). In situations where little is yet known about the causal relationships between emission, exposure and effect, such correlates of risk gain particular importance (Section C 3).

Finally, the fourth question addresses the *normative component of risk acceptance*. In particular, the following questions arise:

- Which undesirable outcomes are still tolerable to a society and which are not?
- How much uncertainty is acceptable if the outcomes can have catastrophic consequences?
- Do the affected individuals perceive the positive and negative outcomes as being equitably distributed (at the global level, too)?

When evaluating the acceptability of risks, all three aspects need to be taken into consideration – whether negative and positive outcomes can be offset against each other, the choice of a strategy to cope with uncertainty and the distribution of anticipated outcomes across different groups (Rowe, 1979; Fischhoff et al., 1981; NRC, 1983; Clarke, 1989; Hood et al., 1992; Vlek, 1996).

In order to be able to carry out such evaluations in a systematic manner, the Council proposes a typological classification of risk that concentrates certain types of risk in classes and determines strategies for dealing rationally with each class. The classes are explained and elaborated in Section C 4. The consequent proposals for action are set out in Sections F and G. Such evaluations are not purely scientific, knowledge-based decisions, but rather presuppose the explicit or at least implicit inclusion of social and cultural values and preferences of the individuals and groups concerned in a society (Shrader-Frechette, 1991).

C 1.2
Clarifying the concepts: Risk and uncertainty

Extent of damage

The two central categories of risk are the extent (magnitude) of damage and the probability of occurrence (Knight, 1921; NRC, 1983; Fischhoff et al., 1984; Fritzsche, 1986; Short, 1984; Bechmann, 1990; EC, 1993; Kolluru and Brooks, 1995; Hood and Jones, 1996; Banse, 1996; Rosa, 1997). By damage we shall mean here an effect of a human activity (such as accidents through car driving, cancer through smoking, forest dieback through pollution) or of an event (such as a volcanic eruption, earthquake, explosion) that is evaluated negatively in the general understanding of the public (i.e. intuitively by the great majority of people). The dimension that is viewed as being violated by a damage is termed the protected interest. Section C 2 presents in detail the protected interests of relevance in the context of global environmental risks. The *damage* or *hazard potential* is the sum total of possible adverse effects that can be caused by an activity or an event. In purely formal terms, the sum of conceivable adverse effects is always infinite, as for every event with a specific estimated number of adverse effects an alternative damage scenario can be conceived with an even greater number of adverse effects. In actual practice it becomes apparent, however, that it is indeed possible to state ceilings of the maximum possible extent of damage (Morgan, 1990). The damage potential of a car accident must evidently be rated lower than the potential that could be released in the event of the explosion of a chloric gas storage facility.

Probability of occurrence

The question of the probability of occurrence entails greater terminological problems. As opposed to the measurement of physical damage, there is no clear-cut method for determining probabilities of occurrence (Tittes, 1986; Hauptmanns et al., 1987; Kaplan and Garrik, 1993). If an event occurs periodically (such as high and low tide or the rotation of the seasons), then we do not speak of a risk but of a periodic event, even if this event lies in the future. In this case the probability of occurrence is 1; i.e. the event will certainly occur. Such events are not treated in this report. The term 'risk' is rather used for damaging events on which there is information or only speculation concerning the relative frequency of this event over time, but the precise point in time of the event or the extent of cyclic events remain uncertain.

In medicine the term 'risk' is also used to characterize possible damage in cases where the timing of the harmful event is known, but the number and identity of those harmed is not (Lave, 1987; Graham et al., 1988). In carcinogenesis, identical exposures of individuals can lead to tumor formation in one case while in another no tumor is formed (Hoberg, 1994). Thus one smoker may develop lung cancer due to consuming ten cigarettes per day, while another smoker with the same habit remains unaffected. It is thus impossible as a matter of principle to use risk assessments to make concrete predictions of individual harm on the basis of observed or estimated frequencies of events over time or over a group of individuals (Rowe, 1983). Risk statements always refer to probabilities. The fact that an event is to be expected on average once every 1,000 years consequently says nothing about the point in time at which the event will actually occur: this can be tomorrow, in 10,000 years or even later.

A variety of terms are used in the literature to refer to the quality of *uncertainty* associated with the assessment of the probability of damage forecasts (Fritzsche, 1986; Häfele et al., 1990; Bonß, 1991; Beroggi and Kröger, 1993; Bechmann, 1994; Rosa, 1997). We find terms such as ambiguity, uncertainty, ignorance, indeterminacy or fuzziness. To avoid misinterpretations as far as possible, the Council uses the following definitions for the characterization of uncertainty in risk assessment in the present report:

Ignorance means the absence of knowledge of both the possible consequences and their probability of occurrence. Thus for instance in the 1950s, society was oblivious of the impacts of CFCs upon stratospheric ozone, as it was at the end of the 1970s with respect to AIDS. In the stage of ignorance, we can recommend general strategies of prudent implementation, of further research and of the precautionary measures set out in detail in Section G.

An *indeterminate risk* characterizes a situation in which the extent of damage is largely known, but no reliable statements can be made as to the probability of occurrence or *vice versa* (such as the case of the computer breakdown risk in the year 2000). If indications are available by which to ascertain both the probability of occurrence and the magnitude (the probability-magnitude function) of a risk, then the degree of reliability of this determination of the two risk components is termed *certainty of assessment*. If the distribution function of probabilities of occurrence and corresponding extents of damage is known, then the certainty of assessment is high. If, however, this function is only vaguely recognizable and subject to considerable error corridors, then the certainty of assessment is low. If the certainty of assessment can be quantified by means of statistical techniques (for instance a 95% confidence interval), then we speak of *statistical uncertainty*.

Statistical uncertainty is normally determined using the methods of classical statistics. However, if insufficient historical data is available or if the variance of distribution is very high, then the safety sciences also use subjective estimates as an approximation to the 'objective' distribution of relative frequencies (Hauptmanns et al., 1987; Edwards, 1968). The general circumstance that all risk assessments remain uncertain is circumscribed here by using the term *incertitude* (Krücken, 1997). Incertitude is a fundamental property of risk, while the certainty of assessment may be anywhere between extremely high and extremely low values.

The fact that it is impossible to make objective predictions of individual damaging events on the basis of risk assessments should by no means be taken to mean that the assessment is arbitrary (Rosa, 1997). If there are two options for action for which the same undesirable event will occur with differing probabilities, then the conclusion for a decision under uncertainty is clear: every rationally thinking person will choose the option with the lower probability of occurrence (Renn, 1996). If, for instance, in Russian roulette there were a choice between a revolver with one bullet and one with two bullets, then the game with one bullet is plainly less risky. Nonetheless, it is by no means out of the question that when playing with one bullet one will lose one's life at the first shot or that when playing with two bullets one will survive several shots.

In mathematical terms, risk events are combinations of systematic causal relationships (or cyclic processes) and chance events. Chance is expressed in two dimensions: in the probabilities for a certain event (first order uncertainty) and in the variance of damaging events for given probabilities (second order uncertainty: certainty of assessment).

Hazard and risk

The difficulty in defining an objective concept of risk is a consequence of these chance variations (Evers and Novotny, 1987; Bradbury, 1989; Shrader-Frechette, 1991; Krohn and Krücken, 1993; Banse, 1996). The circumstance of an objective threat posed by a future damaging event is generally termed a *hazard* (Scherzberg, 1993). People are continuously exposed to hazards while being oblivious or only partially aware of them. When hazards have been recognized and characterized, Luhmann (1993) speaks of risks. These serve as mental constructs by which to characterize hazards more precisely and to organize or even quantify them according to the degree of threat that they pose, that is according to the severity and frequency of damage. Due to the uncertainty of future events, risk assessments must always remain approximations of the objective hazard. The latter can only be known with certainty after the damaging event has occurred. For there is no way of unequivocally revealing a risk assessment as being false at the point in time of the forecast (Rowe, 1984). Even if, for instance, two nuclear power plants should experience a maximum credible accident (MCA) within the next 10 years, this by no means implies that the findings of conventional risk assessments for power plants (an MCA every 100,000 years on average) are false. Just as little must a roulette table be rigged if a person selects the right number three times in succession. The probability of occurrence only tells us that when examining a very long period of time under constant boundary conditions, an event is to be expected with a certain relative frequency.

Narrowing down the concept of risk to the relative frequency of undesirable events is an attempt to make limited forecasts of future events upon the basis of historical experience and modeling of the future. This attempt relies mainly upon the two risk components of probability of occurrence and extent of damage, while other risk-relevant aspects are left out of the analysis. This is why many risk analysis theorists avoid using the terms 'true' or 'objective' risk, as risk is, as a matter of principle, a mental construct used to image complex cause-effect chains with chance events. This contract has no direct counterpart in reality (Shrader-Frechette, 1991; Rayner, 1993; Rohrmann, 1995a; Kunreuther and Slovic, 1996).

Where the Council does use the term *objective risk*, this refers to an idealized concept whose substantive materialization can only be ascertained *ex post*, i.e. after the expiry of a source of risk or, for natural events, only at the end of natural history. It is ascertained as a pattern of distribution of damaging events over a set of individuals or over time. Objective risk is thus an ideal quantity that can be defined as a relative frequency of recognizable patterns of distribution of damaging events when looking back over the entire period of time during which the event can occur at all. The fit between the assessed risk and the objective risk will be all the closer

- The more accurately the system under consideration is understood in its causal relationships or tendencies,
- The more is known about the relative frequencies, and
- The smaller system change is, i.e. the less one expects changes of causal relationships in the future.

Risk analysis

On the basis of the above considerations, we can now move on to further terminological clarifications. *Risk analysis* is the attempt to determine qualitatively and, as far as possible, quantitatively by means of scientific methods and as accurately as possible the probabilities of occurrence of concrete damage or the probability function of the magnitude of damage. This is done on the basis of observation, modeling and scenario formation (NRC, 1982; Krewski and Birkwood, 1987; EC, 1993; IAEA, 1995; Kolluru, 1995). Using risk analyses, the attempt is made to determine as objectively as possible the expected value (EV) of a risk, i.e. the expected extent of damage averaged over time or over risk objects (such as individual persons). In the conceivably simplest case, the relative frequency of the past can be extrapolated to the future as long as the risk agent does not change over time (such as through a changed biological half-life) and so long as no relevant societal intervention takes place (Häfele et al., 1990). If in the previous year there were X fatalities due to road accidents, then under almost equal conditions the number of fatalities will be roughly the same in the coming year. If we are dealing with more complex phenomena or if we lack historical experience, then probabilities must be modeled or synthesized. The technical-scientific risk perspective thus assesses hazard-triggering elements and their environmental and health consequences by modeling potential impacts and effects.

The findings of a risk analysis are not falsifiable in a narrower sense, or at least not conclusively (Marcus, 1988). However, if the risk assessment refers to foreseeable periods and comprises quantitative confidence intervals, events that lie repeatedly outside of these confidence intervals can indeed serve to signify an inadequate or erroneous analysis. Such events can also be simulated by the computer so that the damaging events need not occur in reality. However, it will never be possible to predict individual events on the basis of a risk analysis, nor can the quality of an assessment be appraised on the basis of an individual event. The intrinsic uncertainties attaching to risk statements and the difficulties attaching to an objective appraisal of their predictive power are a part of the reason why in modern knowledge-based societies risks give rise to such considerable controversy in technology and environmental policy. This is all the more so as the possibilities of modern technology have led to a depth of human intervention in natural processes and in the structure of the anthroposphere that is a source of grave concern to many (von Gleich, 1997; Japp, 1992; Krücken, 1997).

C 1.3
Intuitive perceptions of risk

Risk perception must be distinguished from risk analysis. In view of the hypothetical character of probability statements, some authors even go so far as to say that every risk statement is nothing more than a more or less systematically structured intuition of future events (Rayner, 1984; Wynne, 1992). However, the Council does not consider it useful to blur the distinction between scientific risk assessment and intuitive risk perceptions, as fluid as the boundary between risk analysis and societal risk perception may be. Given the great propensity of risks to jeopardize the well-being of entire societies, it is the task of the academic community and of other producers of knowledge to conduct risk assessments as accurately as possible. In the meantime, an array of methodologies and techniques have been developed to model the connections among cause-effect patterns and chance influences. These methods have greatly improved the predictive accuracy of relative frequencies of possible damage. Scientists remain charged with the task of continuously developing and improving methodologies and techniques tailored to the events to be forecast, in order to permit an increasingly accurate assessment of risks.

Risk perception, by contrast, does not need to orient itself to the stringent criteria of methodologically founded risk analysis. Risk perception is based largely on personal experience, mediated information (such as through the press) and intuitive estimations that have emerged in the course of biological and later cultural evolution (Section E 2.2). As studies of intuitive risk perception have shown, people associate with risks not only physical damage, but also violations of social and cultural values (Fischhoff et al., 1978; Covello, 1983; Slovic, 1987; Brehmer, 1987; Gould et al., 1988; Renn, 1989; Drottz-Sjöberg, 1991; Pidgeon et al., 1992; Jungermann and Slovic, 1993b; Rohrmann, 1995b). The technical-scientific risk perspective has largely excluded this dimension of risk, restricting itself essentially to damage to property, health and the environment. It was only psychological and sociological risk research that then created a basis for sufficiently characterizing and largely explaining societal risk experience. Beside underscoring non-physical risk dimensions, perception research has also shown that people base their evaluations of risks on a series of contextual risk properties in addition to the probability and severity of damage. For instance, it is on the basis of the knowledge of non-physical dimensions and contextual risk properties that we can understand why the public reacted to a potential oil pollution of a few thousand liters (through the planned sinking of the Brent Spar oil platform) by boycotting Shell, while no similar reaction occurs to the careless discharge of oil from ships to the oceans, which pollutes the seas with some 10 million tonnes oil every year (Löfstedt and Renn, 1997). What a society defines or professes to perceive as risk is thus not necessarily in any direct relation to the magnitude of risk as defined by the two components of probability of occurrence and extent of damage.

It is very important for several reasons that a proactive and rationally structured risk policy addresses the issue of risk perception. For one thing, the behavior of people is guided by their perceptions and not by scientific risk models. The perception of risk is not independent of the 'objective' risk. Over the long run, only those risk perceptions will prevail that tally with the experience of real damage. However, in rare cases, imagined risks can generate precisely those symptoms that are in principle caused by the damage potentials of the risk sources in question. Psychosomatic reactions are frequently the consequences of risk perceptions (Aurand and Hazard, 1992).

Secondly, in addition to severity and probability people also act on other risk properties that not only reflect their personal preferences but should also be integrated in a rational risk policy on the basis of normative considerations (Renn, 1998). Whether a potential damage is irreversible or not, or whether it may impact upon other people or upon future generations, are dimensions that are usually excluded from classic risk assessments (Section C 3).

Thirdly, most people are not indifferent to distributional patterns of damage over time and space. The risk assessment process is based by definition on relative frequencies, necessarily meaning that averages are formed over space and time. However, in the perception of most people it is by no means the same thing whether a source of risk damages 1,000 people at one blow or continuously damages 1,000 people over a certain period (Jungermann and Slovic, 1993b). From a normative perspective, too, it may also be appropriate to integrate distributional patterns as an evaluation criterion in their own right in the analysis, as sporadic damage frequently requires a greater compensation effort than continuous damage. Moreover, people also link concepts of social equity and justice to distributional patterns . In most cultures, an asymmetrical distribution of benefits and risks requires a particular social justification. Whether a risk is viewed as fair or acceptable depends less upon the magnitude of the risk than upon an individual or cultural standard of equity. Classic risk assessments do not inform us on this point.

C 1.4 Elements of risk evaluation

Risk evaluation means judging whether an existing risk is acceptable and tolerable to society as a whole or to groups in society. Here the Council considers it necessary to use both scientific assessments and risk perceptions registered by empirical studies as a joint basis of information for rational weighing of risks and benefits (Fiorino, 1989). Both types of information are essential elements of *risk evaluation*. In particular, the risk evaluation process should observe the following principles (Shubik, 1991; Banse, 1996; Fischhoff, 1996):

- Technical-scientific risk analyses are helpful and necessary tools of rational risk policy. It is only by using these tools that relative risks can be compared with each other and options selected with the lowest expected value of damage. However, they must not serve as the sole guide for evaluating and dealing with risks. The price paid for the universality of risk assessments is contextual abstraction and the exclusion of perceptual risk properties that are indeed expedient from a rational perspective. Contextual and situational circumstances need to be taken into consideration in every risk analysis.
- Risk properties are essential characteristics of risk perception. These perceptual patterns are not arbitrarily manipulatable notions cobbled together irrationally, but are concepts that have emerged in the process of human evolution and have proven themselves in day-to-day life. Such patterns can be reconfigured but not extirpated. Their universal character permits a common orientation towards risks and creates a basis for communication. The wealth underlying these perceptual processes can and must be utilized in risk evaluation.
- It is certainly desirable from a rational perspective to systematically identify the various dimensions of intuitive perceptions of risk and to measure the empirical manifestations of these dimensions. Research tools are in principle available by which to measure these dimensions. They include the extent to which different technical options distribute risks asymmetrically among segments of the population, the extent to which avenues of institutional control are available, and the extent to which risks are accepted by voluntary agreement. What is important above all is that these factors are taken into consideration in the political evaluation of risks. The Council takes the view that the dimensions of intuitive risk perception must be legitimate elements of rational evaluation, but that the assessment of different sources of risk in each dimension must be conducted according to scientific criteria of validity and reliability.
- As important as risk perception is, it cannot be a substitute for dealing with risks rationally. Just as technical-scientific risk analyses must not be made the sole basis of decisions, neither should the factual evaluation of risks be made the sole political standard of their acceptability. If it is known that certain risks, such as passive smoking, can lead to severe disease, then this risk is not acceptable, even if there is a lack of awareness of the problem among the general public. Many risks are repressed because one does not wish to face them. This applies above all to risks whose adverse effects can occur only in the distant future. Letting oneself be guided by suppressed or plainly false notions can scarcely form a justifiable basis for dealing with risk. However, knowledge of these perceptual patterns can be used expediently to design and implement risk communication and education programs. Many people find it difficult to comprehend probability statements (Kahneman and Tversky, 1974) or to perceive the degree of risk posed by sources of risk with which they have been acquainted for a long time (Ross, 1977). Here targeted education and information programs can be applied (Jungermann, 1991). The Council therefore advocates risk communication programs that integrate technical-scientific risk analysis and intuitive risk perception.
- Even if one had collected the best scientific knowledge of all dimensions considered by people to be relevant (which is scarcely possible in reality), the decision on which technical option to choose is by no means preprogrammed. The process of balancing options always presupposes a normative weighting of the different value dimensions (Derby and Keeney, 1981). Such balancing processes depend on the context and upon the selection of dimensions. When selecting dimensions, perception research can provide us with important indications. In the balancing process and the rela-

tive weighting of dimensions, the criterion of fair distribution of risks and benefits plays an important role (MacLean, 1986). It is no longer the task of science to carry out such balancing processes. Rather, it should provide the information and partially also the techniques by which to place the politically legitimated decision-makers or the persons affected in a position to arrive at a judgment appropriate to their preferences and to the matter in hand (Shrader-Frechette, 1991; Krücken, 1997). Of course the experts can and should actively cooperate in this process of judgment formation.

While there are clear rules for measuring and treating stochastic phenomena, it lies in the nature of probability statements that these can result in highly disparate and even diametrically opposed instructions for action. From all these considerations the Council comes to the conclusion that a clear-cut scientific prescription of how to deal with risks is not possible.

C 1.5
Criteria for rational risk evaluation

As set out above, the question of the acceptability of risk cannot be resolved in a clear-cut manner. This ambivalence harbors major political volatility, for decision theory cannot prescribe any rationally unequivocal solution as to how one should choose between a diverse array of options for action that entail differing risks (Fischhoff et al., 1985): the decision will vary depending upon risk preferences.

The ways in which people express aversion to tolerate risks varies (Erdmann and Wiedemann, 1995). The gambler concentrates upon the outcomes that promise the greatest benefit for him even if the probability of these occurring is low. More timid characters will stare as if hypnotized at the outcomes that may entail particularly large losses, even if their occurrence is extremely improbable. Cool reckoners will multiply the probabilities by the respective loss and benefit figures and will select the option that promises the largest expected utility (EU). All three characters can state good reasons for their behavior and no one can dispute their right to have differing risk preferences.

Based simply on the fact that people have differing strategies by which to deal with risks, we may draw the fundamental conclusion that a rational risk policy should leave individual actors the freedom to assume the management of risks that they take themselves and whose consequences they must bear themselves (Sopolski, 1990). Whoever likes to engage in risky sports or damages himself through excessive consumption of alcohol or nicotine should assume responsibility for the consequences of this behavior and should be free to deal with these risks according to his own preferences. The precondition to this is that the damage to society (such as the costs for rescue services or health care) incurred by this behavior is covered by an insurance or other liability scheme. Such a regulation according to market principles would transfer the choice of the proper form of risk management to whoever must then also bear the consequential costs of the choice of risk. Our society only then departs from this 'elegant' solution of the problem of decision under uncertainty where individuals lack the maturity to freely choose management options or would appear to lack this according to common consensus (drug addiction, legal protection of minors etc.). Situations in which individual risk behavior of one person entails risks for other people (external effects) or risks for collective goods are more problematic and less elegantly resolvable. In this case the state must either enforce certain rules for dealing with the risk (such as environmental standards or licensing procedures) or must enact liability rules by which to pass the consequential costs to those who, by their behavior, have passed risks to others. Both cases call for a decision to be taken as to the direction of the collective resolution of the dilemma of decision under uncertainty (in the case of command and control law to directly institute risk-reducing measures, in the case of liability law to indirectly stipulate the necessary compensation payments). Where collective risks are concerned, how should a society decide the fundamental procedure to adopt when outcomes are uncertain? Which strategy should a society adopt if the outcomes of risky actions affect many people with differing preferences?

Risk evaluation strategies

Philosophers and decision theorists have rightly arrived at divergent conclusions at this point (Shrader-Frechette, 1991; Leist and Schaber, 1995). The philosopher Hans Jonas was clearly in the camp of the cautious. His minimax principle reads: "minimize the maximum expectable damage". The problem with this solution is that, with a little imagination, as soon as the technology has gained any appreciable market share there is for each source of risk a possible if albeit in the individual case not very probable disaster scenario (Jonas, 1979, 1990). Society would thus be damned to immobility and to the surrender of all opportunities. John Rawls (1971, 1974) is less apodictic. His solution to the problem is oriented to the subjective expectations of different groups: "choose that variant to which those in a society who are most disadvantaged by the decision can also agree". Rawls consciously also integrates the possibility of providing compensation to those disadvantaged in his formula, so that the economic rationality of the Pareto criterion, according to which each individual must be in at least as good a position after a decision as before the decision, is satisfied. Rawls concentrates, as does Jonas, on the conceivable negative impacts, but views them through the eyes of those affected.

In contrast, most decision theorists are in the camp of the cool reckoners. Ward Edwards, the developer of multiattribute decision analysis, argues with the middle ground taken by this camp (Edwards, 1954). According to Edwards, if there are evidently risk-averse and risk-seeking people in society, then society should take a neutral stance and use the respective expected values as orientative markers. This would do justice to both sides, the risk-seeking and the risk-averse. The Arrow-Hurwicz rule (1971) promises a golden mean: "choose that option for action which offers the optimum values in the combination of best possible and worst possible outcomes". Others take the view that society has a duty to evaluate more negatively than the intermediate cases adverse outcomes that will occur with a very high probability and disasters that will occur with a very low probability (Derby and Keeney, 1981). This formula might be termed 'beware the extremes'.

The controversy over the ethically required resolution of uncertainty shows that even with identical value orientations – i.e. a consensus concerning degrees of desirability – the solution for collective coping with uncertainty cannot be determined unequivocally. Thinking in terms of risk forces people to live with a legitimate diversity of solutions. Neither the one nor the other is right. There is no sufficient, intersubjectively compelling reason to opt for a risk-averse or a risk-neutral decision logic. Both options are possible and can be substantiated with good reason. This ambivalence is thus based on normative determinations as to how an individual or a group wishes to deal with a risk and which preferences (risk-seeking, -averse or -neutral) prevail (Renn, 1996).

This ambivalence, which is an outcome of decision logic, is plainly all the sharper when we consider that the assumption of identical value orientations and interests is completely unrealistic in a pluralistic society. Different groups will naturally evaluate outcomes differently, depending upon how severely they are affected and which consequences they perceive as being more or less severe. Environmentalists will place a particular weight on the environment, entrepreneurs on competitiveness. Although these two objectives are connected, no one can claim *ex cathedra* that one has more right to his weighting than the other.

As in the question of objective risk identification, the process of risk evaluation and the resulting choice of instruments by which to control risks is by no means arbitrary, despite the necessity of subjective weighting. Depending upon the preferences and objectives given, the acceptability of risks can be consistently derived. Among the general public, the debate on the ambivalence of risk evaluation has frequently left an impression of inadequate competence on the part of risk experts and thus an impression of a risk policy that operates according to superficial interests (Brown and Goble, 1990). This impression of political arbitrariness has partially poisoned the public climate and has contributed to a loss of credibility of the scientific and political communities. The Council wishes to stress firmly here that, despite all uncertainty and ambivalence, the risks assessed by scientific tools and the evaluation made according to decision analysis principles do have a function in guiding actions – a function that cannot be substituted by intuition, nor by factual acceptance, nor by political instinct or partisan evaluation. The Council therefore recommends basing the choice of appropriate regulatory instruments upon the scientifically substantiated assessment of the risk in question, and, building upon this, to perform a stringent and consistent evaluation.

Normal, transitional and prohibited areas of risk

In order to support practicable risk evaluations and to guide rationally arguable risk management, the Council distinguishes three categories of risks: the 'normal area', the 'transitional area' and the 'prohibited area'. Risks in the *normal area* have the following characteristics:

- Low uncertainty about both the probability of occurrence and the associated magnitude of damage,
- In total, a small catastrophic potential,
- In total, a low to medium probability of occurrence,
- Low levels of persistency and ubiquity of risk sources or consequences,
- High reversibility of risk consequences should the damage occur,
- Low statistical confidence intervals with respect to probability and magnitude of damage,
- No distinct distortions between the group that is exposed to the risk and the group to which opportunities and benefits accrue (distributional equity).

In this case the objective magnitude of risk is almost identical to that ascertained by scientific risk assessment. For risks situated in the normal area, the Council follows the recommendation of the majority of decision theorists, namely to proceed from a neutral

Box C 1.5-1

The Swiss risk assessment experience

In connection with a project carried out by the Stuttgart Center of Technology Assessment on rational risk assessment techniques, approaches to assessing risks implemented abroad were collated (Petringa, 1997; Löfstedt, 1997; Hattis and Minkowitz, 1997; Beroggi et al., 1997; Hauptmanns, 1997; Poumadère and Mays, 1997). This included a study on the situation in Switzerland (von Piechowski, 1994). Since 1 April 1991, the Swiss Industrial Accident Ordinance (Störfallverordnung, StFV) stipulates how technological risks are to be dealt with in Switzerland. The Ordinance defines risk as the combination of the probability and magnitude of damage. In order to clarify the Ordinance, handbooks have been prepared that concretize the risk identification process and propose techniques for risk assessment. Here risk assessment proceeds in four steps. First indicators must be identified that can then be used to predict and measure the extent of damage associated with an accident scenario. In the second step, probabilities of occurrence are identified for the various accident scenarios. Using a probability-magnitude diagram, the section under consideration is defined in the next step (Fig. C 1.5-1). The boundary in the lower area is formed by the transition to small or insignificant accidents that are regulated by the Swiss Labor Act (Arbeitsgesetz). The upper boundary of the unacceptable area signifies catastrophic accidents. In the fourth and final step, the political decision-making process determines those risk acceptance areas in which risks are either still viewed as tolerable or are considered unacceptable.

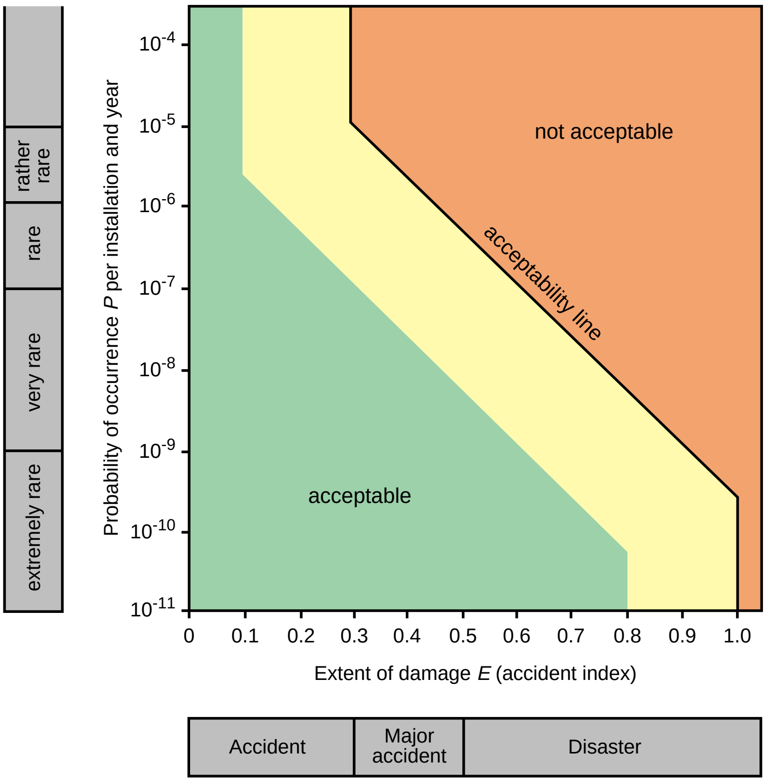


Figure C 1.5-1
Areas of risk acceptance according to Appendix G of Handbook I pursuant to the Swiss Industrial Accident Ordinance (Störfallverordnung)
Source: von Piechowski, 1994

risk attitude for collectively binding decisions. In this case a weighting by simple multiplication of the probability and magnitude of possible damage with inclusion of respective variances is purposeful and appropriate. This approach also permits an effective and innovation-promoting policy aimed at seizing opportunities, as both risks and opportunities can be calculated using the same algorithm (expected value; Section F). Events that are certain, too, regardless of whether positive or negative, can be unproblematically included in such a balancing process with a weighting of 1. This approach is termed the maximization of expected utility (probability multiplied by consequences weighted according to utility) and fits seamlessly with classical cost-benefit analysis or utility analysis (Merkhofer, 1984).

The situation becomes more problematic when risks touch areas that significantly transcend everyday levels (Fig. C 1.5-2). In such a case either the 'transitional' or the 'prohibited area' is reached. It is characteristic for both areas that the certainty of assessment is low, the potential damage can assume alarming proportions, or the systematic knowledge of consequences and chance fluctuations are scarcely

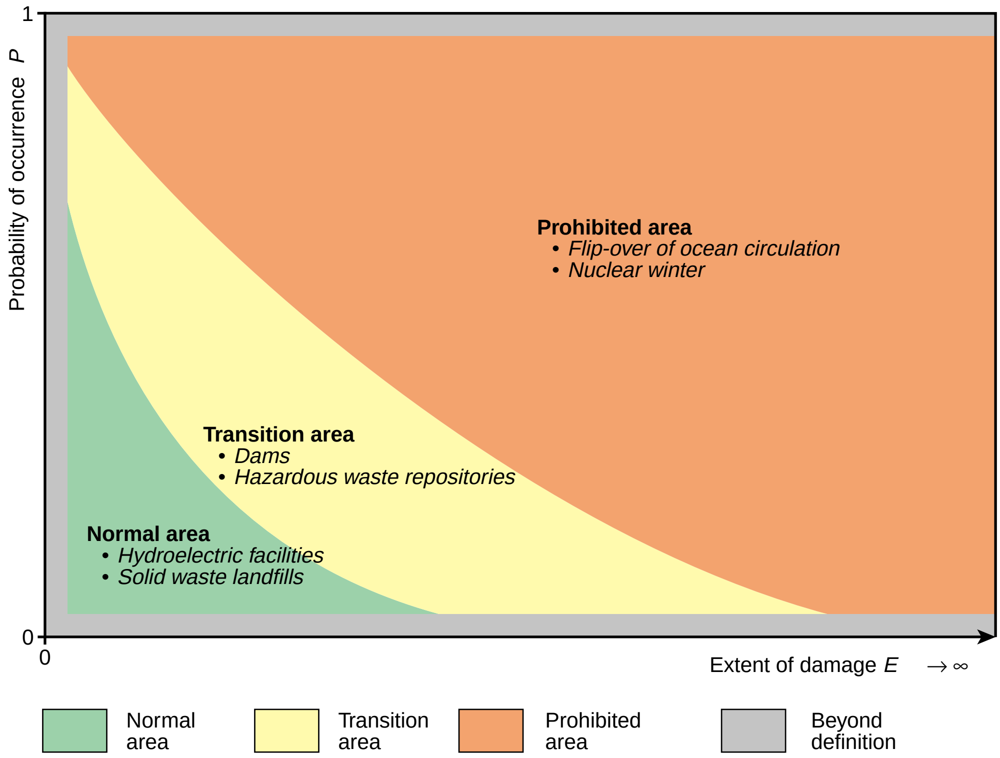


Figure C 1.5-2
Normal, transition and prohibited areas.
Source: WBGU

known or are not determinable. The situation is also critical if risks cause global, irreversible damage, accumulate over lengthy periods or tend to particularly mobilize or cause dread among the public. Risks in the transitional or prohibited areas have at least one of the following characteristics:

- Uncertainty is high for all risk parameters,
- The damage potential is high,
- The probability of occurrence is high, approaching 1 (where none of the other conditions is given, this case is not so relevant at the global level),
- The certainty of assessment is low, but there are reasonable grounds to assume that major damage is possible,
- Persistency, ubiquity and irreversibility are particularly high, whereby here too there must be reasonable grounds to assume that damage is possible,
- For reasons of perceived distributional injustice or other social and psychological factors, a major potential for mobilization is to be expected (refusal, protest, resistance).

As is already practiced in many countries (e.g. Great Britain, Denmark, the Netherlands and Switzerland, Box C 1.5-1), it makes sense to break down the critical area into a transitional and a prohibited area when facing one of the conditions mentioned above. The transitional area calls for risk-reducing measures whose implementation promises a transmutation into the normal area. In the prohibited area the risks are so severe that generally a ban should be imposed, unless there is a consensus in society that these risks are to be accepted because of the associated opportunities.

In both the transitional and prohibited areas, it is rarely possible to make a clear-cut statement of the validity of scientific risk assessment processes. In the transitional area, risk-averse behavior is certainly appropriate, as here the limits of the human faculty of cognition are often reached. It is then no longer primarily a matter of a balancing risk decision, but frequently more one of limiting the possibilities of wide-ranging negative surprises. Precautionary strategies of risk control, strict liability arrangements, general rules of prudence and aspects of risk avoidance then have priority over impact-focused optimization rules. The choice of tools will accordingly differ depending upon which area is touched. At the same time, the Council wishes to stress that risks are often associated with opportunities, so that the aim cannot be to minimize or even prevent risks in each and every case. Only in the transitional and prohibited areas is particular caution called for, through to an outright ban.

Having localized a risk in one of the three areas, specific risk management follows. By *risk management*, the Council understands the sum of measures instituted by persons or organizations to reduce, control and regulate risks (Lowrance, 1976; Covello et al., 1984; Lave, 1985; Clarke, 1989; Morgan, 1990; Kolluru, 1995). This term also covers the tools of risk control, from politically stipulated limit values over economic incentives, liability regimes and planning techniques through to educational measures (Section H). Insofar as risks are situated in the normal area, there thus being no particularly problematic conditions or circumstances, the Council recommends that the legitimated decision-makers, be these individuals, companies or the state, make a balancing decision according to their risk and opportunity preferences. However, it must be kept in mind that the sum of many discrete risks that do not touch the transitional area alone can, when cumulated, enter the hazardous transitional area. In the prohibited area it is indispensable to reduce probability, magnitude or other risk parameters. In the transitional area, management packages specific to each class of risk need to be implemented. The present report is concerned exclusively with risks which, whether discrete or cumulative, fall in one of the risk classes situated in the transitional or prohibited area as set out in Section C 4. In the opinion of the Council, the available control mechanisms suffice to assess and manage normal risks.

The risk concept of the Council

In summary, the Council distinguishes between five elements in its risk concept:

1. An idealized understanding of risk that reflects the objective degree of hazard.
2. A technical-scientific risk assessment based on observation and modeling that aims at acquiring an as accurate as possible knowledge of the relative frequencies of damaging events averaged over time and space.
3. A general risk perception based on intuitive risk identification and its individual or societal evaluation.
4. An intersubjective risk evaluation based on processes of rational judgment formation in terms of a risk's acceptability or tolerability for society as a whole or for certain groups and individuals.
5. A balanced risk management that integrates, for each specific class of risk, the suitable and appropriate measures and tools by which to reduce, control and regulate risks.

C 2 Categories of damage and criteria for selecting globally relevant environmental risks

C 2.1
Damage as an evaluation category

In a simple sense, 'damage' is understood to mean the tangible destruction of or damage to a concrete thing. However, terms such as 'bodily harm', 'mental harm', 'moral harm', 'civilizational harm' and 'cultural harm' illustrate that this simple concept of damage may be extended beyond what human faculties can perceive, to embrace impairments to the function or performance of body and soul or of ethical and cultural values. If we combine the common characteristics of the more abstract concepts of damage, we arrive at a general concept of damage that may be defined as follows: "destruction, diminution and impairment of concrete or abstract values in both the tangible and intangible spheres" (Berg et al., 1994).

To perceive a damage as such, there must be an evaluating subject. The concept of damage is thus inherently anthropocentric. Damaged objects, by contrast, can also be outside of the anthroposphere, such as animals, the environment or artifacts.

The natural sciences generally define damage as a physically measurable change for which there is general societal consensus that it is not desirable (Renn, 1992). Here, too, people are the evaluators of damage, but the categories of damage are limited to areas in which there are physical equivalents of the evaluation dimensions (such as health or environmental damage) and where at the same time there is a high level of agreement that these changes are to be evaluated negatively. In this perspective, the magnitude of damage depends directly upon the extent and quality of physical change.

In economics, the wider social sciences and philosophy, a much broader range of meanings attaches to the concept of damage. Here the economic or social evaluations of physical changes are taken into consideration, as are physically not measurable, symbolic or immaterial losses of what is considered by society to be desirable. While economics recurs to the subjective concept of utility as a common denominator of all categories of damage, the other social sciences stress, in addition to utility, the violation of values or beliefs (Dake, 1991). The distribution of these violations among different groups in society is also an important subject of the social sciences.

In psychology, damage is generally defined as consequences of an action or event that are subjectively perceived and weighted with the own values and interests of the individual (Berg et al., 1995). The substance of the damage depends upon the subject and thus embraces both material (physical) and immaterial (symbolic) changes of the environment. Moreover, it is the subject who evaluates these changes; the evaluation depends upon

- The values considered by the individual to be of relevance to his/her own person (such as maintaining his/her own health),
- The values considered relevant by society (such as maintaining the security of supply of energy systems),
- Own interests (such as material benefits),
- Attitudes towards those who cause and those who are affected by the damage, and
- The judgments of reference groups and the media.

The individual evaluation of damage is joined by the perceptions and evaluations of groups or organizations. Here the level of the evaluating subject is moved from the individual to a collective subject, and also quite different categories of damage come into play. The evaluated magnitude of perceived overall damage is important, as are the differing ways in which damage affects groups in society. The issue of the symmetry of the distribution of damage and benefit among various social groups is often more volatile, both socially and politically, than the aggregated or average magnitude of damage. The distributional problem is joined by symbolic categories of damage such as the loss of credibility of institutions, the effects of events upon political mobilization or apathy (e.g. political disinterest) and upon the capacity to politically master the conflicts associated with a damage.

Which categories of damage are now of relevance to global environmental risks? The Council has essentially concentrated on those risks that have both global impacts and whose damage chain includes environmentally relevant effects (Section C 5). The next subsection makes an appropriate selection from the great number of possible global damage categories.

C 2.2
Relevant categories of damage

When examining a certain risk one needs to ask what form the possible damage can take, how this is perceived by people and how it is evaluated. The following categorization can be useful in ascertaining the type of possible damage:

1. *Effective or real damage.* Loss of real life values. This refers to tangible or (physically or psychologically) experienced impairments of material wealth or of bodily-mental status. This includes damage to property and bodily or mental harm – i.e. impairment of an object of legal protection, a right or a legally protected interest of a person or society by another person or society.
2. *Contingent damage.* Loss of a real or expected opportunity; non-attainment of possible utility. Personal injuries (bodily or mental harm) generally lead to a loss or reduction in capacity to work and thus cause a loss of income for the individual affected, and a potential loss of goods and services for society as a whole.
3. *Compensation damage.* Effort required to offset damage that has occurred. This comprises the effort required to replace or restore what has been destroyed or damaged. Compensation damage only arises in the event of damage to property.

These three categories of damage are not mutually exclusive, but rather highlight the same factual circumstances from differing perspectives. They offer different evaluation patterns for identifying and qualifying damage. In addition to the above categories, it is expedient to differentiate between material and non-material damage.

But how should we evaluate damage potentials that cannot be clearly expressed in terms of monetary loss? A loss of confidence in the integrity of political decision-makers, for instance, cannot be expressed in monetary terms, but is rather expressed by the circumstance that voter turnout drops or that governments are reshuffled at short intervals. For this and similar forms of non-material damage, standards need to be formulated that permit the creation of evaluation classes as in the case of property losses. This illustrates that, depending upon the risk under consideration, quite specific constellations of indicators need to be applied that can frequently only be formulated with corresponding expert knowledge. Care needs to be taken in practice that the damage potential can be measured by means of a limited number of indicators such that an allocation to classes of relevance is possible.

A final important point is whether the possible damage is irreversible, or can be remedied or compensated. For instance, contamination can irreversibly destroy a local ecosystem. However, this need not appreciably impair the natural bases of human existence if the ecological functions can be compensated by means of substitution or productivity enhancement in another ecosystem. Irreversible modifications of the Earth System are thus always then of particular relevance if they cannot be compensated.

Criteria for ascertaining the damage potential

1. Are we dealing with real, contingent or compensation damage?
2. Is there material damage? How high is this?
3. Is there non-material damage (e.g. to cultural heritage)? How can this be measured and how high is it?
4. How many people are affected by the damage and how high is the average damage potential?
5. Is the damage irreversible or uncompensatable?

If we apply these criteria, then it is apparent that the damage potential can assume very different forms. This is illustrated by the example of earthquake risks: here it is not primarily a matter of how strong the earthquake must be in order to cause a certain damage, but rather above all a question of which physical and social potentials may be damaged by the earthquake. Regardless of the circumstance that among different regions of the Earth vulnerability to such natural risks varies, the damage potential refers to both the natural physical-geographical and the civilizational inventory. For earthquakes this means that many people are at risk from the event, the material damage is generally high, cultural goods suffer and damage can thus also be irreversible.

In contrast to the above example, it is very much harder to ascertain the damage potential for the risk from BSE. It can be assumed that civilizational protected interests are not affected by this risk. However, the prospect of harm to the natural physical-geographical potential is presently not ascertainable, as the available knowledge on the risk from BSE is still too scant to make reliable statements. Nonetheless, attempts to assess this risk have indicated that in many countries both the real and the contingent and compensation damage can assume considerable macroeconomic importance.

C 2.3
Problems of aggregating damage categories to one damage index

One of the greatest challenges in damage assessment is to aggregate the different categories of damage to one *overall damage index* (Baram, 1980). In principle, all risk assessors proceed from the assumption that decisions under uncertainty require a balancing of benefit and damage. In economics, this is conducted on the basis of risk-benefit analyses, in psychology according to the common patterns of subjective expected utility and in sociology according to the collective expected utility of groups or institutions.

The equitable, comprehensive and reproducible identification and evaluation of damage potentials is already extremely difficult for individual damage categories. Particular consideration needs to be given to the following conceptual and instrumental problems (Renn, 1995):

- Many individuals and groups view a number of damage categories as being not fungible, even though the risk of experiencing such a damage may be offset against other risks. Generally, the point at which a bearer of risk is no longer prepared to accept monetary compensation for the risk to be accepted can be expressed by an exchange function with the probability of occurrence on the abscissa and the benefit-equivalent compensation sum on the ordinate. As individuals have differing risk preferences and the threshold values of the function will thus also vary, there is a need for collective processes of standard setting in order to ascertain a limit of compensatability acceptable to all individuals. Such an agreement naturally only applies to such risks that cannot be completely individualized.
- Balancing cannot be stipulated in an intersubjectively binding manner by formal procedures. This is because each group weights the various categories of damage differently. Conversion into monetary units or some other accounting unit would presuppose that there is a theoretically satisfactory and practically acceptable procedure by which to aggregate individual preferences. Unfortunately, this is not in sight.
- In addition to the magnitude of damage, the distribution of damage also plays an important role when offsetting forms of damage against each other. Balancing processes that only optimize allocation (such as aggregated cost-benefit analyses) frequently lead to an asymmetrical distribution of burdens. The same can also be said of pure majority decisions. It is thus essential that distributional questions are also taken into consideration in the balancing process. This can be done by involving all bearers of risk or their representatives in the decision-making process, so that these can themselves participate in determining the risk-benefit distribution they consider acceptable.

Because of the difficulty encountered in stipulating universally binding criteria for balancing damage ex ante, it is frequently demanded that such accounting procedures be determined in a discursive process among the interest groups. However, such a shift of 'substantive legitimation' to 'legitimation by process' does not change the fact that participants of a discourse also need to argue according to substantive rules of accounting. The advantage of such a discursive solution is, however, that disparate systems of equity and balancing rules can compete with each other in an exchange of arguments. Section G discusses the procedures for determining aggregate risk.

C 2.4
Criteria for screening globally relevant environmental risks

C 2.4.1
Choosing screening criteria

The categorization of risks in risk classes does not yet suffice to screen from the great number of possible risks those environmental risks that have global relevance. Thus, for instance, murder or suicide are certainly among the prime risks in our society, and can indeed be positioned within our typology of risk, but are not of interest to the Council because no environmental changes are concerned. Moreover, there are many local, regional and also national risks that require particular attention at their respective political level but do not develop global impacts. This is why it is necessary to introduce two further 'filters' in addition to the restriction of the present report to risks in the transitional or prohibited areas:

1. The *global filter* screens risks according to their transnational character. The scope of the risk extends beyond the boundaries of a country or can only be mastered by means of global risk management.
2. The *environmental filter* ensures that only such risks are examined for which significant environmental damage is to be expected in the risk's chain of effects.

These two screening filters are described in detail in the following. All risks analyzed in the further course of this report must meet both criteria.

C 2.4.2
Global filter

As the environmental risks that we wish to screen are closely tied to the people-environment interface, the global filter can be causally connected to the *core problems of global change* that have already been identified by the Council (WBGU, 1997a). These core problems characterize critical constellations in people-environment interactions that can be the source of global environmental risks. As they have global relevance *per definitionem*, it should be possible to derive from them a globally relevant probability of hazard. The global filter thus first screens the relation of risks to the core problems of global change. Here it is asked whether an environmental risk is caused directly or is amplified significantly by the core problems. In addition to an effect upon the incidence of hazardous constellations, an increase in vulnerability plays a particularly important role here (Section E 2). It can be equated in this context with the damage potential.

Climate change, soil degradation, the loss of biodiversity, scarcity of freshwater resources, overexploitation of the oceans, increasing incidence of (human-induced) natural disasters, population growth, increasing mass migration (environmental refugees), urbanization dynamics, threats to global food security and to human health and the growing wealth gradient between industrialized and developing countries are the prime negative manifestations of global change (Box C 2.4-1). They are modifying worldwide the vulnerability to consequences of disaster and thus also the evaluation of environmental risks with regard to their global relevance.

A further consequence of this nexus is that adequate environmental management of those global environmental risks that are connected, in the manner set out above, to the core problems of global change requires supranational cooperation (Section F).

Core problems of global change thus have two central attributes: they are transnational in character and can only be resolved through supranational efforts. Environmental risks directly connected to the core problems of global change will therefore always have global relevance.

The global filter must further take into consideration types of risk that have no direct connection to the core problems of global change. This is the case, for instance, for certain genetic engineering applications which, while having no such connection, do have the potential to pose a global risk. The global filter therefore needs to be extended to include further screening criteria that refer, inter alia, to the threat or management potential associated with a risk. Proceeding from the above considerations, three questions are formulated as filter criteria.

Criteria of the global filter
1. Is there a connection between the risk and the core problems of global change?
2. Does the potential threat presented by the risk have global or at least international relevance?
3. Is management at the global level required to master the risk?

C 2.4.3
Environmental filter

The purpose of the environmental filter is to ensure that only such risks are included in the analysis whose pathway can be expected to include significant environmental damage. This filter screens out all risks that do not relate to a people-environment or environment-environment interaction. In accordance with the mandate of the Council, people-people interactions such as ethnic conflicts (although indubitably of global relevance) are excluded from examination.

Here we must also consider complex interrelations among various sorts of damage. Damage, be it isolated or widespread, can trigger a chain of further damage that may well develop a considerably wider scope of effects than the initial damage. The environmental filter must assess these consequential effects and integrate them in the evaluation.

The simplest constellations may be termed ‘two-link chains’. These include:

- *Environment-environment interactions.*
  El Niño leads to the flooding of valuable natural areas.
- *Environment-people interactions.*
  Earthquakes lead to considerable material damage.
- *People-environment interactions.*
  Sulfur and nitrogen oxide emissions lead to globally relevant forest damage.

The following ‘three-link chains’ are also still relatively distinct:

- *Environment-environment-people interactions:*
  El Niño leads to flooding, this then hampering the supply of the population.
- *Environment-people-environment interactions:*
  Earthquakes lead to the destruction of human settlements, resettlement then appropriates natural areas.
- *People-environment-environment interactions:*
  Dams cause changes in river flow regimes, this leading to the loss of mangrove forests in distant

Box C 2.4-1

Core Problems of Global Change

Ecosphere

- *Climate change*. By enriching the atmosphere with long-lived greenhouse gases, humankind is inducing a significant level of climate change that can already be distinguished from natural climate variability 'noise'. There is growing anxiety that anthropogenic global warming is having feedbacks on oceanic circulation and the dynamics of the polar ice caps. Extensive uncertainty still prevails as to the precise impacts that the predicted shift of the climate belts (and thus vegetation cover and cultivation zones), rising sea level and increasingly frequent weather extremes will have on human societies and nature, both regional and globally.
- *Soil degradation*. In many countries today the soils of the Earth display degradation ranging from medium to extreme severity, and the situation is worsening from year to year. Such degradation is caused by rapid growth of the world population and its economic activities, resulting in overexploitation and transformation of plant cover, compaction and surface sealing of soils, as well as contamination by organic and inorganic compounds. Severe soil degradation means destruction of humanity's life-support systems and can therefore trigger famine, migration and military conflicts.
- *Loss of biodiversity*. Land-use changes spanning large areas of the globe (such as clearing of forests, conversion of pasture land to cultivated land, etc.) bring about a reduction in the reservoir of potentially useful species and the natural products they provide, an impairment of the regulatory function of ecosystems and a decline in culturally and esthetically valuable biotopes. Loss of plant varieties and domestic animal breeds leads to greater susceptibility to pests and diseases, thus endangering the very food sources on which humanity is vitally dependent.
- *Scarcity and pollution of freshwater resources*. Freshwater resources are being overexploited on a local and regional scale through irrigation farming, industrialization and urban growth. Many parts of the world face mounting scarcity and pollution of water supplies. The consequence is a rise in economic, social and political conflicts over declining water resources, which in turn may have global impacts.
- *Overexploitation and pollution of the world ocean*. The oceans perform important ecological (especially climatic) functions, are a major source of food and act as a sink for anthropogenic wastes. Coastal regions and marginal seas, in particular, are further polluted with contaminants through immissions and direct discharges via rivers. Global impacts ensue, beyond the threats to fishing regions, due to the importance of fisheries for global food security.
- *Increasing incidence of human-induced natural disasters*. There are many indications that natural disasters are increasing in frequency as a result of human interference with natural systems. Forest clearing in the Himalayas, for example, gives rise to floods in foothill regions, thus posing an existential threat to the population there. Among other things, this induces migration pressure (environmental refugees) and the concomitant impacts on large sections of the international community.

Anthroposphere

- *Population growth and distribution*. The world population continues to grow, primarily in the developing and newly industrializing countries. One of the root causes is inadequate education, which is bound up with high birth rates, weak social security systems and social marginalization of large parts of the population in these countries. Other trends are rural-urban migration and intra- and international migration flows. The latter produce rapid urban growth, particularly in coastal regions; the urban infrastructure (energy, water, transport, social services, etc.) of many cities is unable to keep pace with this growth. The environmental degradation and poverty which then result, and the potential for social unrest this entails, are having global impacts.
- *Environmental threats to global food security*. Large sections of humanity suffer from malnutrition and undernourishment. Feeding these people is rendered increasingly difficult by soil degradation, water scarcity and population growth. This trend is frequently reinforced by misdirected economic and development policies.
- *Environmental threats to health*. Factors such as population growth, famine, war, contamination of drinking water and inadequate waste water treatment lead to an increasing incidence of infectious diseases and epidemics in many countries of the world. As global mobility grows, so, too, does the risk of rapidly spreading epidemics. In industrialized countries, air pollution causes increased incidence and severity of certain illnesses among the population.
- *Global disparities in development*. The structural imbalances between industrialized and developing countries have not declined in recent decades – on the contrary. The driving forces behind this development are economic, technical and social changes, above all the globalization of the world economy and the intensifying international division of labor. This process has helped some countries to achieve the desired economic development, though often at the expense of the natural environment. Nevertheless, most developing countries (particularly in Africa) have remained very poor, and it is there that the loss of social security and related migration processes are creating enormous problems. This 'development dilemma' is characteristic of global change and represents a growing risk.

coastal regions.

- *People-environment-people interactions*. Inappropriate feeding practices lead to BSE in cattle, the consumption of beef then damages human health.

As the syndromes of global change identified by the Council illustrate, complex people-environment interactions can have far more than three links in the chain (WBGU, 1995a, 1998a). The chain can close in on itself. This creates feedback loops ('vicious circles') of global change. If the chain does not close, or if there are indications of several sub-chains for a risk, then the question arises of the still tolerable number of secondary risks. In some cases the number of links in the chain can be ascertained exactly, in other spheres of risk there is inadequate knowledge to identify all secondary risks. Section E discusses in depth the systemic interrelations among chains of damage.

The Council derives the following criterion for the environmental filter: the chain of effects of a risk must include at least an environment-environment, people-environment or environment-people interaction (within its complex chain).

C 3 Risk characterization

C 3.1
Certainty of assessment

Risks are classically defined by two factors: the probability and the magnitude of damage (Hauptmanns et al., 1987). The assessment of these two factors depends upon the quantity and quality of respective data permitting a valid prediction of relative frequencies. This is where the concept of 'certainty of assessment' comes into play. Ideally, certainty of assessment can be expressed by statistical ranges of the probability and magnitude of damage.

By the term 'certainty of assessment', the Council understands the degree of reliability with which a statement can be made as to the probability of damaging events. Risk analyses normally place the two variables 'magnitude of damage' (e.g. 1–10,000 persons injured) and 'probability of occurrence' of each specific magnitude (from extremely low probabilities to almost one for an almost certain event) in relation to each other. We thereby receive a function from which we can read the probability of each magnitude of damage. However, there is usually a lack of clear and unambiguous information on the probabilities associated with specific magnitudes. If only limited data is available from observation of past events, then the tools of inductive statistics can be used to state a range of values within which – for instance with a 95% or 99% second order probability – the true value of the probability associated with a certain magnitude of damage must lie.

Often not even samples or observed data are available. In these situations, expert judgments must be used additionally as substitutes for empirical data records based on historical observation. Here two avenues can be pursued. The first method is to ask a large number of experts to estimate the range, and then to aggregate to one interval the various ranges stated by the individual experts. The second is to ask the experts to deliver a discrete estimate that is as precise as possible, and then, after statistical processing, to take the dispersion among the experts as the range. In both cases we receive a probability-magnitude function showing for each manifestation of damage a mean value (the point on the curve) and a range (error bar). It may also be purposeful to take as reference the probability and to organize the range around the magnitude of damage. The question then becomes: what is the range of magnitude associated with an x% probability of occurrence? The findings of the analysis of ranges can be visualized by superimposing the error bars (of either probability or magnitude of damage) over the probability-magnitude function. Fig. C 3.1-1 shows an ideal-type curve of such a function.

The smaller the error bar, the higher the certainty of assessment. In order to further standardize this criterion, it has become common practice to state certainty of assessment as a numerical value ranging between 1 (high certainty or no error bar) and 0 (low certainty or error bar from 0 to almost infinity). If the value is close to 1, it can be stated with certainty that a damaging event with a probability of x is to be expected. This value x is itself of course a limit value of frequency distribution (and thus not a forecast of a specific event), but all experts agree that it accurately reflects the real-world situation. If the value is close to 0, all experts are evidently in disagreement with each other or the observed data are so dispersed that, while it is possible to form a mean value, the dispersion around this mean is substantial. If values approach 0, the boundary to indeterminacy or ignorance is crossed, as the data or estimates then evidently vary so greatly that one cannot speak of any reliable assessment.

The concept of 'certainty of assessment' can be illustrated by the example of a lottery with black and white balls. If certainty of assessment is 1 (high certainty), then one knows exactly the number of black and white balls. The probability with which a black or a white ball will be drawn can therefore be stated exactly. If certainty of assessment is low (large error bar), then the number of black and white balls (or their ratio in the urn) is unknown. It must be deduced indirectly from a number of draws or from the estimates of a number of experts who have been able to glance into the urn. Using classic statistics (in the case

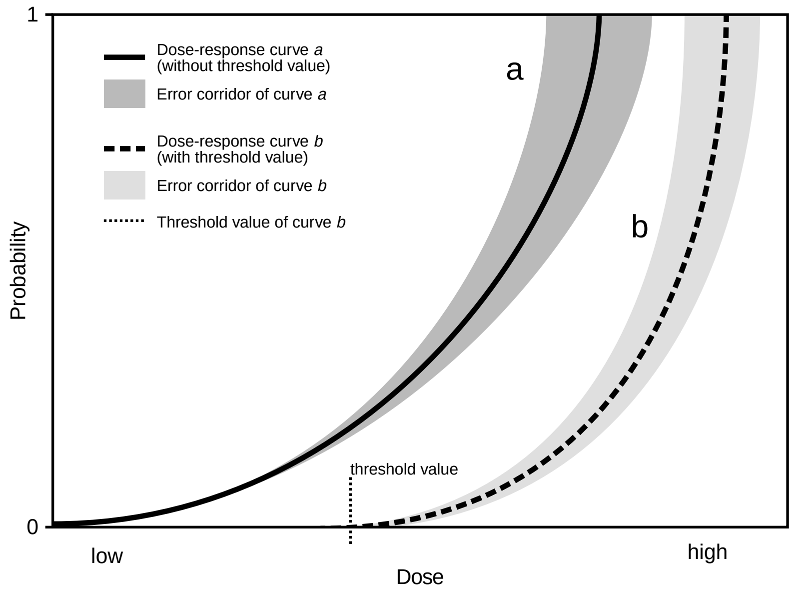


Figure C 3.1-1
Dose-response function with error corridors.
Source: WBGU

of a number of draws) or Bayesian statistics (in the case of expert judgments), an approximation of the ratio of black to white balls can be formulated, for which in turn a (second order) probability can be stated. It is then possible to predict for a long series of draws, with a probability of, for instance, 95% the maximum number of white balls without knowing the precise expected value for drawing a white ball.

When considering global risks, the certainty of assessment is crucial. For even if the statistical mean for global damage is relatively low, the error bar can be large, i.e. there can still be great uncertainty as to whether the probability of global damage is not considerably larger or smaller than the mean value suggests. Two events with the same mean value in the probability-magnitude function must therefore be viewed very differently depending upon the certainty of assessment. If it is high (close to 1), then limit values and technical standards will usually suffice to place the risk in the normal area. If, however, it is low (close to 0), then precautionary measures need to be taken in order to be reasonably prepared for the event that the upper margin of the error bar proves to have been realistic.

It can be assumed that the certainty of assessment is relatively high if large quantities of data with low levels of variance are available, if there have been long observation periods with short intervals between causes and effects and with a high constancy and if possible intervening variables are robust. In these cases the Council speaks of low uncertainty although singular events can still not be predicted. Gaps in knowledge concerning the probability and magnitude of damage associated with uncertain events are a result of either information deficits (which can essentially be remedied), a lack of experiential knowledge (due to singular events or extremely long cycles), difficulties in understanding the systematic causal chain (because of an impenetrable maze of intervening variables) or inadequate significance of the damage against the background noise of chance events. For indeterminate risks only the probability of occurrence or the extent of damage is unknown, but for ignorance both components are unknown. Such risks need to be tackled by means of anticipatory strategies of risk avoidance and social system strengthening (Collingridge, 1996). These two types of risk are discussed in detail in Section G. A low certainty of assessment is indicative of an inadequate data base or of events having a large component of chance.

It is expedient to distinguish between indeterminacy (probability or extent unknown) and ignorance (both components unknown). For instance, insurance companies can cope quite well with risks that have a low certainty of assessment on the probability side, as long as the certainty of assessment is high on the damage magnitude side (Kleindorfer and Kunreuther, 1987). If, however, the magnitude is also highly uncertain, it is almost impossible for insurance companies to assess a loss-covering premium. In such cases, private or public liability funds may step in (Section F 3).

The Council therefore notes that the choice of risk management tools depends not only upon the probability and magnitude of damage, but also upon the certainty of assessment of each of these components.

C 3.2
Further differentiation of evaluation criteria

In addition to the two classic components of risk – probability and magnitude – further evaluation elements should be included in risk characterization (Kates and Kasperson, 1983; California Environmental Protection Agency, 1994; Haller, 1990). These evaluation elements can be derived from risk perception research. They have already been proposed as criteria for risk evaluation procedures in a number of countries (such as Denmark, the Netherlands and Switzerland). The following are particularly important:

- *Ubiquity*. Spatial distribution of damage or of damage potential (intragenerational equity)
- *Persistency*. Temporal scope of damage or damage potential (intergenerational equity)
- *Irreversibility*. Non-restorability of the state that prevailed prior to occurrence of damage. In the environmental context, this is primarily a matter of the restorability of processes of dynamic change (such as reforestation or water treatment), not of the individual restoration of an original state (such as preserving an individual tree or extirpating non-native plant and animal species).
- *Delay effect*. The possibility that there is large latency between the cause and its consequential damage. Latency can be of physical (low reaction speed), chemical or biological nature (such as in many forms of cancer or mutagenic changes). It can also result from a long chain of variables (such as cessation of the Gulf Stream due to climatic changes).
- *Mobilization potential* (refusal of acceptance). The violation of individual, social or cultural interests and values that leads to a corresponding reaction on the part of those affected. Such reactions can include open protest, the withdrawal of trust in decision makers, covert acts of sabotage or other forms of resistance. Psychosomatic consequences can also be included in this category.

The criteria that have been identified by perceptual research are fully or sufficiently covered by the criteria chosen here. A review of the relevant studies of risk perception shows that most people connect to risks questions of (individual and institutional) controllability, voluntariness, habituation to the source of risk and an equitable risk-benefit distribution (Jungermann and Slovic, 1993b). The evaluation of controllability is covered in its physical aspect by the criteria of ubiquity and persistency, and in its social aspect by the criterion of mobilization. From a collective perspective, the criterion of voluntariness can scarcely be used as an evaluation criterion for societal risks because the risks which interest us here are those which affect many at the same time and have asymmetrical distribution patterns. The protest potential associated with imposed risks is contained in the criterion of mobilization. Habituation to a source of risk is not in itself a normatively purposeful evaluation criterion, as it is possible to become accustomed to large and possibly unacceptable risks (e.g. road accidents).

The desire to evaluate accustomed risks more positively than novel ones is however an expression of justified concern that the degree of uncertainty of a risk can not yet be estimated with sufficient accuracy and one should therefore proceed with caution. This aspect is covered in our catalog of criteria by 'certainty of assessment'.

Criteria relating to distributional equity are harder to address, as there is a lack of intersubjectively valid measures of equity and inequity. The question of whether the usufructuaries of an activity and the people who are affected by a risk are identical is unproblematic to answer.

If they are identical, an individual regulation of risk appears expedient as already set out above. If not, then collective regulation mechanisms need to be employed. These can be commitments under liability law (and thus renewed individualization), rights of risk-bearers to participate in decisions, or licensing regulations. However, to what extent asymmetries are felt to be inequitable and monetary or non-material compensation is viewed to be adequate depends upon the values prevailing in the cultural system concerned.

Usually it is necessary to examine effects on a case-by-case basis in order to substantiate intersubjectively a violation of the equity postulate. Ubiquity and persistency provide an indication of the possibility of an inequitable distribution of burdens. A risk with global effects generally affects intragenerational equity, while a persistent damage potential affects future generations. Where extreme values are found for these two indicators, there are grounds to suspect an inequitable distribution. But only the analysis of the specific case can definitely reveal whether certain equity postulates are met or violated.

The analytical and philosophical literature on risks also contains proposals for multi-dimensional evaluation (Hohenemser et al., 1983; Akademie der Wissenschaften zu Berlin, 1992; Shrader-Frechette, 1985; Gethmann 1993; Femers and Jungermann, 1991). These proposals partially suggest similar and partially slightly divergent evaluation criteria. Multi-dimensional evaluation procedures have until now been included explicitly in the national legislation of Denmark and the Netherlands. In other countries, above all the USA, advisory bodies conduct such

Table C 3.2-1
Bandbreadths of criteria.
Source: WBGU

Criterion	Bandbreadth
Probability of occurrence *P*	0 to approaching 1
Certainty of assessment of *P*	Low or high certainty of assessment of the probability of occurrence
Extent of damage *E*	0 to approaching infinity
Certainty of assessment of *E*	Low or high certainty of assessment of the extent of damage
Ubiquity	Local to global
Persistency	Short to very long removal period
Irreversibility	Damage not reversible to damage reversible
Delay effect	Short to very long time lag between triggering event and damage
Mobilization potential	No political relevance to high political relevance

multi-criteria evaluations as a part of the standard-setting process (Hattis and Minkowitz, 1997; Beroggi et al., 1997; Petringa, 1997; Löfstedt, 1997). The Council recommends such an approach for Germany, too, particularly where global risks are concerned.

The criteria recommended by the Council are summarized in Table C 3.2-1. This table serves in the further course of this report as a basis for characterizing the various individual risks and for formulating risk priorities. The criteria are further used to construct classes of risk (Section C 4).

C 3.3
Risk evaluation in the context of the Council's guard rail concept

What role do these criteria play in risk evaluation? In its previous reports the Council has developed a 'guard rail concept' (WBGU, 1996). This concept derives from the idea that certain prospects of damage entail such far-reaching losses of substance that they cannot be justified by the associated gains. When certain levels of damage are overstepped, then so many or such severe negative consequential effects are to be expected that even large former gains cannot compensate for these effects. The Council has taken this phenomenon into account by defining ecological and social 'guard rails'. Certain ecological functions must not be endangered and certain economic and social attainments must not be jeopardized in order to achieve short-term economic gain or to enforce certain environmental protection measures.

To evaluate risks, this guard rail concept needs to be extended. As damage can only occur with a certain probability, an unambiguous guard rail can no longer be defined. Apart from cases in which major damage can occur with sufficiently large probability, it is hardly possible to define a clear-cut guard rail that might permit a definite ban or abstention, thus relieving us of the necessity to balance costs and benefits. Instead, the Council proposes a 'guard rail corridor'. This serves to signify that particular care is required in controlling and regulating a particular risk. The concept indicates the necessity of institutional regulations in order to arrive at an adequate evaluation and regulation. Risks that fall in the guard rail corridor are located in the transitional area set out above, or may be in the prohibited area.

The eight evaluation criteria can now be used to differentiate more clearly between the normal and transitional areas, and to assign risks in an understandable manner to the one or other area. Risks reach the transitional area, i.e. the guard rail corridor, if the individual criteria of risk characterization have extreme values. If several extreme values are found for one and the same source of risk, then this risk will generally be in the prohibited area.

For instance, the probability of occurrence can approach 1, or the extent of damage can tend towards infinity. A guard rail corridor is also entered if the certainty of assessment is infinitely small or if the consequences are irreversible, non-compensable and simultaneously highly persistent and ubiquitous, even if one knows little yet about the magnitude of possible damage. The next section constructs prototypical classes of risks that reach one or several extreme values.

C 4 Constructing a typology of risk

Purely theoretically speaking, a completely unmanageable number of risk classes could be constructed out of the eight criteria. If only the two alternatives of the 'normal' and 'transitional' case are distinguished, eight variables lead to 2^8 combinations. Such a diversity of cases would run counter to the purpose of classification, namely to present a clear-cut matrix of risk classes. In reality, however, some of the criteria are closely coupled to each other, while other combinations, although theoretically conceivable, have little or no empirical grounding. Moreover, to apply the 'guard rail corridor' concept developed by the Council it suffices if the transitional case is reached for one criterion alone, regardless of whether the other criteria additionally fall into the extreme range. An allocation procedure was therefore applied under which individual risks were assigned to that class where they reach or overstep to a particularly striking degree one of the possible extreme values. As the first and third criteria each have two sub-categories, ten theoretically conceivable cases result in which the transitional range can be reached or crossed. These cases are listed in Table C 4-1.

The first case is not relevant to global risks, as a damaging event with a probability approaching 1 is either locally contained or, on the other hand, would certainly cross one of the guard rails established by the Council in previous reports (as it is certain that the consequences would occur). Major damage potentials with a probability that approaches 1 will scarcely be acceptable. Such risks are very rare. It is precisely a characteristic of most anthropogenic risks that the extent of damage correlates negatively with the probability of occurrence. Usually, the larger the damage the lower the probability. Case 1 can therefore be dismissed from further analysis unless it is associated with a major delay effect, in which event case 9 applies. Case 2 can similarly be dismissed from the analysis. A probability of occurrence approaching 0 gives no cause for concern as long as the associated magnitude of potential damage is not considerable. The special case of a small probability associated with a very large magnitude of potential damage is already covered by case 3. All other cases are requisite to characterize global risks.

The case 6 in Table C 4-1 refers to globality of effects. This case need not be further highlighted here, as the Council anyway only considers risks that have global effects or require global action (Section C 2.4-2). It may further be noted that ubiquity correlates closely with persistency (for chemicals, ubiquity is a function of persistency and mobility).

In the following, the classes of risk resulting from cases 3 to 10 are described using ideal type tables. These ideal type tables list, for each class, the relevant criteria and their properties. Each table includes probability of occurrence, extent of damage and the confidence intervals for these two criteria. Where requisite to characterize the risk class, one or several other criteria are included in the table. The confi-

Criterion	Extreme property	Case
Probability of occurrence *P*	High (approaching 1) Low (approaching 0)	1 2
Extent of damage *E*	Approaching infinity	3
Certainty of assessment	Of probability *P*: low Of extent *E*: low	4 5
Ubiquity	Global effect	6
Persistency	Very long removal period	7
Irreversibility	Damage not reversible	8
Delay effect	Very long time lag	9
Mobilization potential	High psychological and political relevance	10

Table C 4-1
Extreme cases of the evaluation criteria selected.
Source: WBGU

Box C 4-1

Terms used in the ideal type risk class tables

The tables contain information in five dimensions:

1) The two classic risk factors, *probability of occurrence P* and *extent of damage E*.
2) The *certainty of assessment* of these two factors. High certainty of assessment means that the statement of a specific probability that a particular damaging event occurs (or a certain magnitude of damage materializes) or the statement of a specific magnitude of damage for a particular probability can be made with great reliability. A low certainty of assessment means that statements of the probability of a particular event or, conversely, statements of magnitude for a particular probability are subject to considerable variance. If certainty of assessment is high, the error bars around a value on the magnitude-probability function are very small, if certainty of assessment is low the bars are very large.
3) The *quality of uncertainty* attaching to the various criteria. Uncertainty prevails if there is a lack of knowledge about either the probability (indeterminacy) or the potential magnitude (obliviousness) of damage. However, there must be at least reason to assume that damage is to be expected. Under uncertainty, the certainty of assessment is by definition extremely low (approaching 0). Uncertainty is indicated in the tables separately for each criterion.
4) The risk criteria of *ubiquity, persistency, irreversibility, delay effect* and *mobilization potential*. All of these criteria are treated separately in the tables.
5) The *range of the sources of risk* within a type of risk. Most of the tables for specific risk potentials in Section D are constructed for a type of risk (such as floods) or for a risk in a particular social context (such as BSE in England or Germany). The individual sources of risk within a type can have different properties for the various criteria. This range of sources within a type is indicated by grey to black shading in the horizontal bars of the tables. The lighter the shade, the less sources of risk are situated at this point in the continuum. Dark shading indicates the median of the risks within a type.

The properties of the criteria range from 'low' to 'high'. The various meanings of 'low' and 'high' are briefly explained in the following:

- *Unknown*
  Unknown means that available knowledge does not permit any specific rating in the spectrum from low to high, nor a meaningful statement of confidence intervals (e.g. lies with a probability of 90% between x and y).
- *Probability of occurrence P*
  'Low' means 'highly improbable' (approaching 0).
  'Tends to be low' means 'improbable'.
  'Tends to be high' means 'probable'.
  'High' means 'highly probable' (approaching 1).
- *Extent of damage E*
  Self-explanatory
- *Certainty of assessment of P or E*
  'Low' means 'poor' certainty of assessment.
  'Tends to be low' means 'still relatively poor' certainty of assessment.
  'Tends to be high' means 'relatively good' certainty of assessment.
  'High' means 'good' certainty of assessment.
- *Ubiquity*
  'Low' means 'local'.
  'Tends to be low' means 'regional'.
  'Tends to be high' means 'transboundary'.
  'High' means 'global'.
- *Persistency*
  'Low' means 'short-term' (<1 year).
  'Tends to be low' means 'medium-term' (1–15 years).
  'Tends to be high' means 'long-term' (15–30 years).
  'High' means 'several generations' (>30 years).
- *Irreversibility*
  'Low' means 'restorable'.
  'Tends to be low' means 'largely restorable'.
  'Tends to be high' means 'only partially restorable'.
  'High' means 'irretrievable'.
- *Delay effect*
  self-explanatory
- *Mobilization potential*
  'Low' means 'politically not relevant'.
  'Tends to be low' means 'tends not to be politically relevant'.
  'Tends to be high' means 'tends to be politically relevant'.
  'High' means 'politically highly relevant'.

dence intervals of probability of occurrence and extent of damage express the certainty of assessment in each instance.

C 4.1 Damocles

The third case in Table C 4-1 is of great relevance, both theoretically and empirically. Many sources of technological risk have a very high catastrophic potential, although the probability that this potential manifests itself as damage is extremely low. Nuclear power plants, large chemical facilities, dams and meteorite impacts are typical examples. This is why the Council has chosen this case as one of the classes of risk to be studied. A prime characteristic of this class of risk is its combination of low probability with high magnitude of damage. Theoretically the damage can occur at any time, but due to the safety measures implemented this is scarcely to be expected.

We call this type 'Damocles' (Renn, 1990). In Greek myth, Damocles was once invited by his king to a banquet. However, he was obliged to take his meal under a razor-sharp sword hanging on a fine thread. For Damocles, opportunity and danger were closely linked, and the 'Sword of Damocles' has become a byword for a happy situation overshadowed by danger. The damage potential of the risk taken by Damocles was the highest possible, namely the loss of his life. On the other hand, the probability of occurrence was extremely low, for according to the myth

Table C 4.1-1
Ideal type table for the Damocles risk class. Terms are explained in Box C 4-1.
Source: WBGU

Criterion	Property				
	Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					

the thread did not break. Modern society feels about many large-scale technologies as Damocles felt about the sword that could have fallen on him at any time while he was eating (although the thread was evidently so stable that this event never occurred). Accordingly, a major mobilization effect upon the population is associated with this class of risk.

The consequences of damage are generally direct, but also, in the case of contaminant emissions, may not become injurious until some future time. By contrast, both the probabilities and magnitudes of damage are sufficiently well known. Of course here, as in the other classes, uncertainties and possible unpredictable events remain. However, compared with other risks, the possibilities of damage occurring have largely been researched by scientific methods and their causal structures are understood (Table C 4.1-1).

C 4.2 Cyclops

The fourth case in Table C 4-1 refers to a constellation in which there is high indeterminacy in the assessment of the probability of occurrence, while the maximum damage is largely known. A number of natural events such as volcanic eruptions and floods belong in this category, as does the outbreak of pandemics wherever there is no information on their probability of occurrence or the information is contradictory. There is often too little knowledge about causal parameters, or too little observation time in which to identify cyclic regularities. This class of risk also includes such events or developments in which humankind modifies, through intervention in the ecosphere, the relative frequencies with which unpredictable natural processes occur, whereas the effects of these processes are largely known and their magnitude can be assessed. Changes in ocean circulation brought about by human-induced climate change are a typical example. Similarly, a number of chemical or biological risks, where the maximum extent of damage is known but the dose-response relation is still unclear or controversial, can be grouped in this class. We call this type of risk 'Cyclops'. Ancient Greek mythology tells of mighty giants who, for all their strength, were disabled by having only one single, round eye, which was why they were called 'round eyes' or Cyclopes. With only one eye, only one side of reality can be perceived and perspective is lost. When viewing risk, only one side can be ascertained while the other remains uncertain. Here it is often the case that risks are greatly underestimated whose magnitude can be grasped but whose probability of occurrence is uncertain or continuously

Table C 4.2-1
Ideal type table for the Cyclops risk class. Terms are explained in Box C 4-1.
Source: WBGU

Criterion	Property				
	Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					

Table C 4.3-1
Ideal type table for the Pythia risk class. Terms are explained in Box C 4-1.
Source: WBGU

	Property				
Criterion	Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					

changes. The greater the time lag the more likely this is to happen. The mobilization potential is low. Consequences can be considerable if ubiquity and persistency are high and the expected damage is irreversible (Table C 4.2-1).

C 4.3 Pythia

The fifth case in Table C 4-1 refers to a risk for which the potential magnitude of damage is unknown and the probability of occurrence also can not be ascertained with any accuracy. To that extent, we must assume for risks of this type that there is great uncertainty with regard to possible adverse effects and also with regard to the probability of ascertainable damage. We call this type of risk 'Pythia'. When in doubt, the ancient Greeks consulted one of their oracles, among which the most famous was the Delphic Oracle with its blind seeress Pythia. Pythia intoxicated herself with gases, in order to make predictions and give advice for the future in a state of trance. However, Pythia's prophecies were ambiguous. They revealed that a major danger might be impending, but not how high its probability or severity might be, nor the distribution or type of harm.

This class includes risks associated with the possibility of sudden non-linear climatic changes, such as the risk of self-reinforcing global warming or of the instability of the West Antarctic ice sheet, with far more disastrous consequences than those of gradual climate change. It further includes far-reaching technological innovations in certain applications of genetic engineering, for which neither the precise level of risk nor the probability of certain damaging events occurring can be estimated at the present point in time. Finally, the Pythia class includes chemical or biological substances for which certain effects are suspected, but neither their magnitude nor their probability can be ascertained with any accuracy. The BSE risk is the best example of this (Table C 4.3-1).

C 4.4 Pandora

A number of human interventions in the environment cause wide-ranging and persistent damage. These two criteria are exemplified by persistent organic pollutants (POPs) or by biosystem changes that remain stable over long periods. In a study prepared on behalf of the Council, the two criteria have been aggregated under the heading of 'scope' and expressed in quantitative terms (Müller-Herold, 1998).

Here particular attention needs to be given to risks characterized simultaneously by high ubiquity, persistency and irreversibility (cases 6, 7 and 8 in Table C 4-1). The presence of these criteria is also an indication that it will be scarcely possible to compensate for damage. There are some risks that are only persistent but by no means irreversible (for instance, with a high energy input it would be possible to transform radioactive waste into isotopes with short half-lives), but most of the risks grouped in this class are characterized by high levels of both persistency and irreversibility. It is not so important whether the consequences arise after a time lag or not. The Council has named these risks after Pandora. The ancient Greeks explained many ills of their times with the myth of 'Pandora's Box', a box that, although brought down to the Earth by the beautiful Pandora, created by Zeus, only contained evils. As long as the evils remained in the box, no damage was to be feared. If, however, the box was opened, all of the evils contained in it were released to plague the Earth irreversibly, persistently and ubiquitously. Once released, the evils pose a persistent hazard to humankind. The consequences of these risks are often still unknown or there are at best presumptions as to their possible adverse effects. The magnitude of damage does not approach the infinite, but is large enough to justify countering it with risk policies. This risk type is exemplified by persistent plant protectant residues and xenobiotics. It further includes many culturally conditioned risks insofar as they are taken

Table C 4.4-1
Ideal type table for the Pandora risk class. Terms are explained in Box C 4-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					■
Certainty of assessment of *P*					■
Extent of damage *E*					■
Certainty of assessment of *E*					■
Ubiquity				■	□
Persistency				■	□
Irreversibility				■	□

universally, such as putting all hopes upon a small number of cereal crop varieties, pursuing globally uniform dietary habits and lifestyles, among others (Table C 4.4-1).

C 4.5 Cassandra

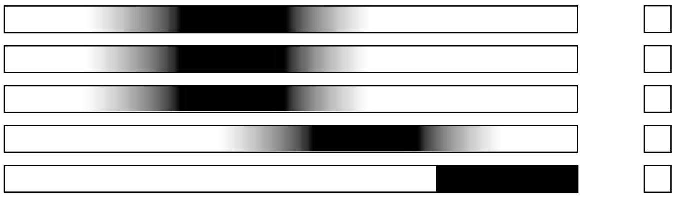
Case 9 in Table C 4-1 refers to a risk characterized by a relatively lengthy delay between the triggering event and the occurrence of damage. This case is naturally only of interest if both the probability and magnitude of damage are relatively high. If the time interval were shorter, the regulatory authorities would certainly intervene (the risk being in the prohibited range). The distance in time between trigger and consequence creates the fallacious impression of safety. Above all, the belief that a remedy will be found before the actual damage occurs can be taken as an excuse for inactivity. We can find examples in both the medical and the geophysical or climate arenas. A typical example is gradual human-induced climate change, which can trigger severe damage in vulnerable regions such as coastal and mountain areas. The Council has called this class of risk 'Cassandra', because those who warn of such risks are rarely given credence. Many types of damage occur with high probability, but in such a remote future that for the time being no one is willing to acknowledge the threat. This was the problem of Cassandra, a seeress of the Trojans, who correctly predicted the danger of a Greek victory but was not taken seriously by her countrymen. The Cassandra class of risk thus harbors a paradox: both the probability of occurrence and the damage potential are known, but because the damage will not occur for a long period of time, there is little concern in the present. Cassandra-type risks often also display relatively high levels of ubiquity and persistency. They also entail allotting an inequitable share of the risk to future generations, thus violating the principle of sustainability (Table C 4.5-1).

Table C 4.5-1
Ideal type table for the Cassandra risk class. Terms are explained in Box C 4-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*			■	■	□
Certainty of assessment of *P*		■			□
Extent of damage *E*			■	■	□
Certainty of assessment of *E*			■		□
Delay effect				■	□

Table C 4.6-1
Ideal type table for the Medusa risk class. Terms are explained in Box C 4-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					
Mobilization potential					



C 4.6
Medusa

Case 10 in Table C 4-1 refers to the potential for public mobilization. This criterion expresses the extent of individual aversion to risk and the political protest potential fueled by this aversion, both of which are triggered among the lay public when certain risks are taken. This type of risk is only of interest if there is a particularly large gap between lay risk perceptions and expert risk analysis findings. If the two assessments are congruent, then political and scientific priorities are set in parallel. If risks considered high by experts are rather underestimated by the lay public (as is the case for leisure-time accidents or for indulgence in substances such as tobacco or alcohol), then risk policies are necessary that call attention to these hazards by means of suitable communication and educational measures. This case, however, is already covered elsewhere in our typology, as risks considered particularly hazardous by experts will definitely meet one of the other criteria. It needs to be noted, though, that experts can also tend to rate both Pandora-type and Pythia-type risks as being lower than objective analysis would suggest. Studies have indicated that experts frequently overestimate the certainty of their statements and are not willing to admit gaps in their knowledge or to include uncertainties in their judgment. Insofar, the typological classification presented here may also serve as a checklist for both expert and lay risk evaluators, helping them to identify and evaluate risks in a manner commensurate with the actual threat posed. The above constellation – expert underestimation vis-à-vis correct lay intuition – is similarly covered elsewhere in our typology.

The reverse constellation, however, is not explicitly covered by any of the other cases in our typology. Many risks which, by all other criteria, have moderate-to-low values are often perceived by the lay public as being particularly threatening. This leads for one thing to psychosomatic reactions and thus to a real manifestation of harm, and for another thing to substantial pressure upon policy makers to focus resources on limiting these risks. The scientific literature often calls risks that are evaluated by the public as high 'phantom risks'. This phrase only partially describes the phenomenon. Most risks perceived as threatening involve situations where a large number of people are exposed and adverse effects are in principle possible but not statistically verifiable. If, moreover, no clear threshold values derived from toxicological experiments are available, as is indeed the rule for genotoxic substances, then a wide array of competing models that extrapolate large to small doses can be theoretically justified without it being possible to subject these models to unambiguous empirical review and verification. Where there is so much room for uncertainty, dread thrives, as unequivocal reference points are absent and the lay public is largely dependent upon information from experts who themselves are unable to make unequivocal statements.

This effect is exemplified by concern over the carcinogenic effect of electromagnetic radiation in low concentrations. The knowledge that cancer can be caused by ionizing radiation initially legitimates the intuition that every cancer in the vicinity of a nuclear power plant can be explained by radiation emitted from that plant. Anyone who contracts cancer or experiences the affliction by this disease of a member of the family or a friend will seek for a logical and above all meaningful explanation. Metaphysical explanations have lost validity in our secularized world. The best possible explanation according to the present state of knowledge, namely a largely random incidence of cancer, does little to satisfy the psychological need for a 'meaningful' explanation. How desolate to be the chance victim of a disease occurring at random. If, however, a concrete reason can be identified, such as radiation exposure, smoking, unsuitable diet etc., then the occurrence of the disease at least makes sense. If, moreover, one's own fault can be excluded and the faults of others can be found to be the cause of the disease, then the disease may even fulfill a social purpose, namely to alert future potential victims and to do battle against the source of the evil. Insofar, such risks function as a signal triggering social and political mobilization.

To do justice to this complex phenomenon, the Council has constructed the 'Medusa' risk class. In Greek mythology, the world was full of dangers that menaced common people, heroes and even the Olympic gods themselves. The imaginary Gorgons were particularly terrible. Medusa was one of the three cruel Gorgon sisters, the mere sight of whom turned people into stone ('petrified' them). Some novel phenomena affect people today with the same fear and dread the fabulous Gorgons aroused among the ancient Greeks. Innovations are then rejected even if scientists can scarcely view them as a hazard. Some of these phenomena even have a particularly high potential for public mobilization, as the dread of the mythical Gorgon sisters once did.

The same applies to many smaller hazards which public perception amplifies far beyond their true magnitude and which may even turn out to be harmless. The risks grouped in this class are frequently an expression of a general unease with technological development, with certain forms of modernization and globalization and with the perceived inability to determine one's own lifeworld. This situation calls for scapegoats to whom to transfer this discontent. Such scapegoats are by no means 'little lambs', but do indeed embody many of the properties responsible for

Table C 4.7-1
Overview of risk classes: characterization and substantive examples. *P* signifies the probability of occurrence and *E* the extent of damage.
Source: WBGU

Risk class	Characterization	Examples
Damocles	*P* is low (approaching 0) Certainty of assessment of *P* is high *E* is high (approaching infinity) Certainty of assessment of *E* is high	• Nuclear energy • Large-scale chemical facilities • Dams • Floods • Meteorite impacts
Cyclops	*P* is unknown Reliability of estimation of *P* is unknown *E* is high Certainty of assessment of *E* tends to be high	• Earthquakes • Volcanic eruptions • AIDS infection • Mass development of anthropogenically influenced species • Nuclear early warning systems and NBC-weapons systems • Collapse of thermohaline circulation
Pythia	*P* is unknown Certainty of assessment of *P* is unknown *E* is unknown (potentially high) Certainty of assessment of *E* is unknown	• Self-reinforcing global warming • Release and putting into circulation of transgenic plants • BSE/nv-CJD infection • Certain genetic engineering applications • Instability of the West Antarctic ice sheets
Pandora	*P* is unknown Certainty of assessment of *P* is unknown *E* is unknown (only assumptions) Certainty of assessment of *E* is unknown Persistence is high (several generations)	• Persistent organic pollutants (POPs) • Endocrine disruptors
Cassandra	*P* tends to be high Certainty of assessment of *P* tends to be low *E* tends to be high Certainty of assessment of *E* tends to be high Long delay of consequences	• Gradual human-induced climate change • Destabilization of terrestrial ecosystems
Medusa	*P* tends to be low Certainty of assessment of *P* tends to be low *E* tends to be low (exposure high) Certainty of assessment of *E* tends to be high Mobilization potential is high	• Electromagnetic fields

the general unease. However, they can be exchanged at any time as soon as other scapegoats are mentally available or concerns have been allayed to the point at which it seems essential to move on from the scapegoat formerly chosen (Table C 4.6-1).

The Council has very consciously chosen to tackle this difficult class of risk because many of the risks belonging to this group hold out considerable opportunities for the future. Effective risk policies could be pursued, while at the same time seizing opportunities, if these policies did justice to peoples' legitimate aspirations to limiting and successfully dealing with risks without having to invest considerable costs and time in regulating risks whose damage potential is low. If confidence in rational and precautionary risk policies could be enhanced among the public, then it would be much easier to implement technical and organizational innovations. This requires clear impositions upon spheres of risk that transcend the normal area, while at the same time exercising calm when dealing with risks that are plainly within the normal area. The Council hopes that its present report can contribute to this.

C 4.7
Summary

Table C 4.7-1 summarizes the six types of risk described in Section C 4 with their relevant criteria and properties. It further lists a number of illustrative examples, which, among others, are discussed in detail in Section D.

The six types allow us to classify the risks situated in the transitional area (Fig. C 4.7-1). The classification is not final: risks can evolve in the course of time from one class to another. Through further research and a longer period of experience, we may move a Pythia-type risk to the Cyclops class and from there onwards to the normal area. Risk management tools can also be brought to bear to shift risks from one class to another.

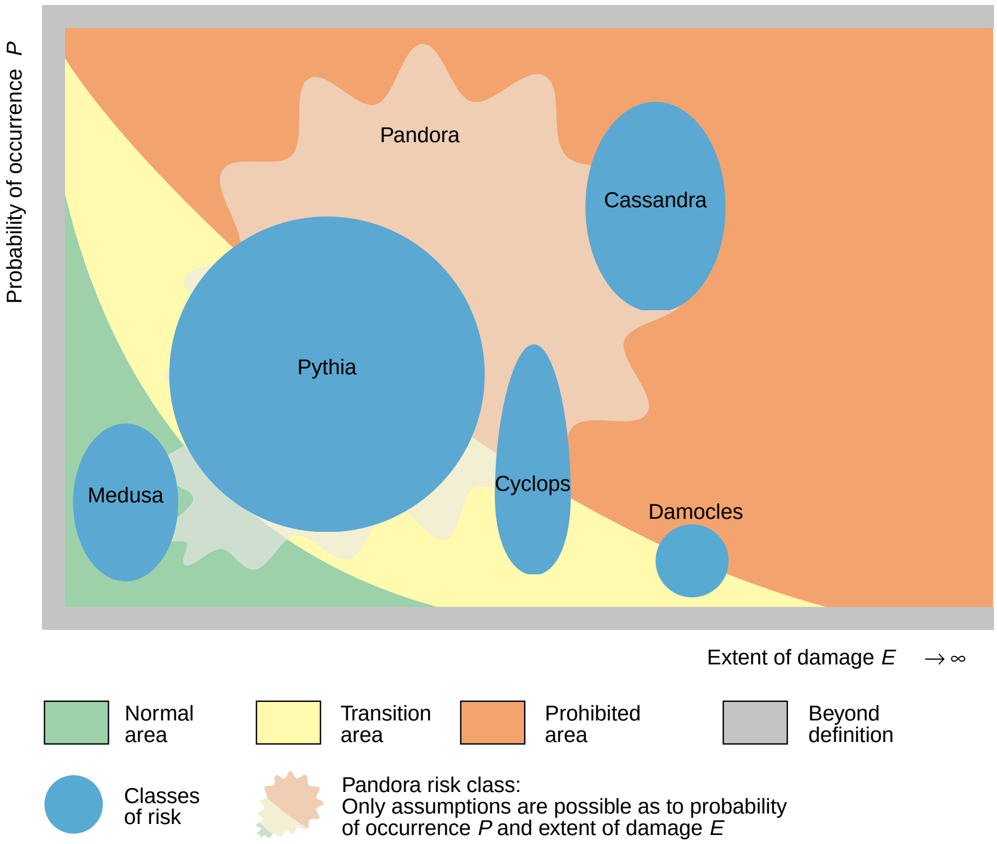


Figure C 4.7-1
Classes of risk and their location in the normal, transition and prohibited areas.
Source: WBGU

Indeed, a large part of the risk management tools presented in Sections F and G is specifically engineered to transform risks from the classes described here into the normal area. Section D systematically analyses specific risk potentials corresponding to the risk classes set out here. Sections G and H propose tools for controlling risks that are appropriate to the various classes.

D The environmentally mediated risk potentials of global change

Introduction D 1

Never before have human interventions in natural processes been so far-reaching as today. Humankind has become a crucial factor in the Earth System. This section examines risk potentials that meet two conditions: firstly, the potentials must develop global effects and, secondly, the potentials must emerge from a direct people-environment chain of effects (Section C 2.4). People-people risks are explicitly excluded from the scope of this report.

Humankind is both an agent and a victim of global environmental change. Our characterization of risk potentials spans the spectrum that lies between these two poles: environmentally mediated hazards can be caused solely by human agency, as is the case for technological risks, or solely by geological or extraterrestrial events, as is the case for volcanic eruptions or meteorite impacts. At both ends of the spectrum, the magnitude of damage to people is strongly influenced by regional features such as settlement density or infrastructure availability. Between these two poles, however, there are numerous risk potentials that only emerge from the interplay between people and nature, such as the formation of a new pathogen through natural mutation and its pandemic potential through human-induced global dispersal.

The individual chapters of Section D follow a uniform structure. After first presenting the potentials for damage, they outline the way in which the risk is presently dealt with. The criteria elaborated in Section C are then used to assign the risk to a specific class. The Council by no means intends to provide a comprehensive discussion of each risk potential, not to mention a final judgment. Our aim is rather, in view of the great diversity of potential environmental risks, to illustrate how a typological classification of risks can be used to stimulate systematic action. Consequently, the following sections also develop tools and strategies for managing the types of risk described.

D 2 Technological risks

This section is concerned with the catastrophic potentials of globally relevant technological risks, their characterization and their current management. All technological risks treated in this section were screened using the global filter presented in Section C 2.4.2. The Council is thus confident that these prototypical technological risks have global relevance.

D 2.1
Prototypical risk potentials: Nuclear energy, large-scale chemical facilities and dams

Nuclear energy

Surely no other source of risk has been the subject of so much study and controversy as the use of nuclear energy for generating heat and electric power. The present report lays no claim to doing justice to this debate in a few pages. It does not attempt to review all arguments for and against nuclear energy and still less to deliver a concrete 'yes or no' recommendation. The example of nuclear power is rather intended to serve as an illustration of a type of risk which continues to generate major unease, all risk reduction efforts notwithstanding. This is driven partly by perceptual factors (risk amplifiers) described in Section C, partly also by special physical or safety engineering characteristics of the nuclear fuel cycle, including nuclear power plants and disposal facilities.

First of all, nuclear energy is characterized by a large inventory of substances hazardous to human health and the environment. A nuclear reactor combines a high energy density with a considerable potential of radioactive fissile material (radionuclides) (Borsch and Münch, 1983). If the entire inventory of a modern 1,200 MW nuclear power plant were to be released (which is practically out of the question for reasons of physics) then, in the worst case, several million people could suffer health effects and entire regions could be rendered uninhabitable. Even a partial release of this material, as occurred in Chernobyl, leads to transboundary impacts.

The risks of nuclear energy are not limited to the utilization of fissile material in reactors. The nuclear fuel cycle begins with the extraction of natural uranium (or thorium) in open-cast or underground mining (Merz, 1983; Salander, 1995). Workers there are generally exposed to radon or other radioactive decay products. This exposure is associated with an increased cancer risk (workplace risk). In a second step, natural uranium is sent to an enrichment plant, where the fissile uranium-235 is concentrated up to 3% and more (depending upon the type of reactor). Here, too, risks for operating personnel are of prime concern. An accidental release of fissile material is largely precluded in this step. Enrichment is linked to the fabrication of fuel elements that are later 'burnt' in a nuclear reactor. In order for a nuclear reaction to be able to take place at all, a critical mass of fissile material must first be present in a reactor, and, at the same time, the free neutrons must be slowed by a moderator so that these can impact upon the nuclei of the uranium atoms. The resulting nuclear fission creates heat, which is absorbed by a coolant and then converted to kinetic and electric energy as in a conventional power plant.

In a reactor, two further risks arise in addition to the risks for operating personnel. Firstly, the energy density in a reactor is exceedingly high. If the chain reaction can no longer be controlled, then core meltdown can occur, through which a part of the fuel inventory can be released to the environment (Hocken, 1995). Owing to the high radioactivity of the radionuclides created through the fission process, a release of the inventory can have catastrophic consequences for human health and wildlife. Secondly, power plant operations discharge small quantities of radioactive particles to the environment, which can accumulate in organisms and can thus contribute to the human cancer risk directly (air and water pathways) or indirectly (through crops, meat or milk).

As soon as the fuel in a reactor is depleted, the fuel rods are consigned after interim storage in a spent-fuel storage pool to a reprocessing plant, to interim storage or to a final repository. As the radionuclides concentrated in the rods are highly radioactive, these transports must be carried out in radiation-proof casks. In Germany, so-called Castor casks are used, which have repeatedly been the subject of fierce controversies and demonstrations, as experienced again in 1998. The risks of these transports involve two aspects:

1. The possible impacts of residual radiation upon personnel and upon persons in the direct vicinity of the casks, as no cask is able to completely retain radiation emissions. This aspect also includes exposure due to contaminated water, which can be deposited on the outside of the casks during loading and unloading.
2. The possible accident risks if a Castor shipment is involved in a serious transport accident.

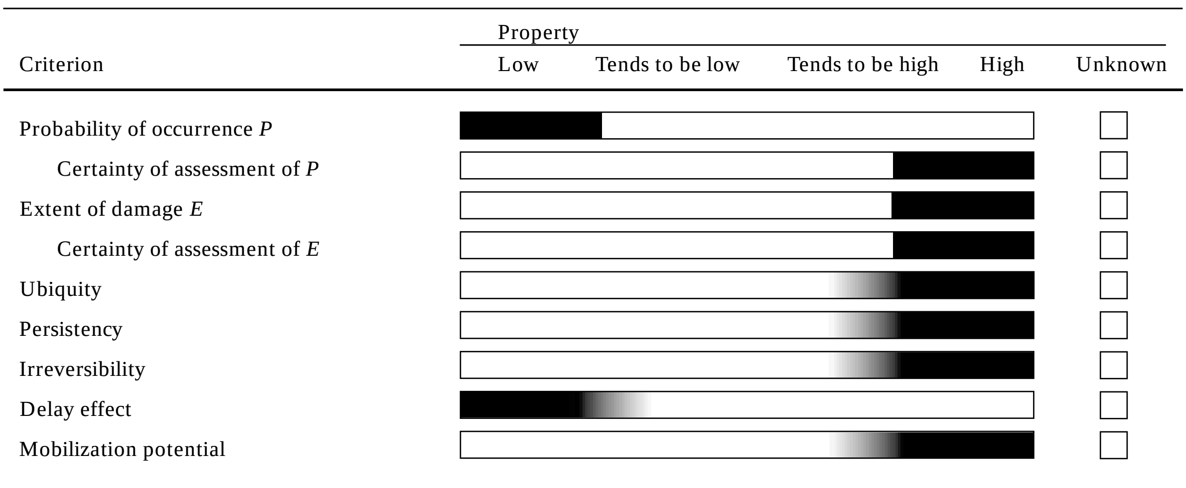
Both risks are very small. Even if serious accidents should occur, the integrity of the casks is ensured. However, the probability that a cask will rupture is not zero.

Once the Castor has arrived at a reprocessing plant or storage facility, the fuel rods are cut apart and conditioned according to the type of final storage envisaged. In reprocessing, the considerable amounts of fuel still contained in the rods are extracted and used to fabricate new fuel. In direct final storage, the conditioned wastes are initially stored in an interim storage facility, and then encased in a final repository. In reprocessing the risk is concentrated upon the release of radioactive substances to the environment, while in interim and above all in final storage the isolation of the waste from the biosphere needs to be ensured for very long periods (several millennia) in order to preclude contamination of the groundwater and associated damage to human health and the environment.

That all stages in the use of nuclear energy pose risks is not an attribute peculiar to this source of energy. Specific risks can be identified in each step of the cycle of the use of coal, indeed even of the use of solar collectors. However, there are two attributes that do distinguish nuclear energy from other types of energy production. These are, firstly, the large magnitude of the damage that would threaten humankind and nature in the event of a release of the inventory and, secondly, the long periods over which risk management must be implemented in order to contain the risks of final storage (Kröger, 1998). Both characteristics of nuclear energy make it an epitome of the Damocles class of risk, with a very high catastrophic potential but exceedingly low probability of such a catastrophe occurring (Table D 2.1-1). Safety engineers have put an enormous effort into reducing or even preventing entirely an inventory release as far as possible, in all stages of the fuel cycle. Modern Western reactors must thus be designed so as not to overheat and lead to core meltdown even in the event of a loss of coolant. All safety-relevant systems are multiple ('redundant') and diverse, in order to retain sufficient reserve for the safety function concerned in the event that one component fails (Borsch and Münch, 1983). In the final storage concepts debated today, several safety barriers are combined in order to exclude groundwater contamination as far as is humanly possible.

The vociferous controversy over nuclear energy can thus be reduced to a dispute over one basic question: can and should society trust in technical measures to reduce probabilities of occurrence to almost zero and thus also tolerate the possibility of a release

Table D 2.1-1
Application of the evaluation criteria to the risk potential of nuclear energy. This belongs to the Damocles risk class.
Terms are explained in Box D 2.1-1.
Source: WBGU



Box D 2.1-1

Terms used in the tables applying the evaluation criteria to specific risk potentials

The tables contain information in five dimensions:

1) The two classic risk factors, *probability of occurrence P* and *extent of damage E*.
2) The *certainty of assessment* of these two factors. High certainty of assessment means that the statement of a specific probability that a particular damaging event occurs (or a certain magnitude of damage materializes) or the statement of a specific magnitude of damage for a particular probability can be made with great reliability. A low certainty of assessment means that statements of the probability of a particular event or, conversely, statements of magnitude for a particular probability are subject to considerable variance. If certainty of assessment is high, the error bars around a value on the magnitude-probability function are very small, if certainty of assessment is low the bars are very large.
3) The *quality of uncertainty* attaching to the various criteria. Uncertainty prevails if there is a lack of knowledge about either the probability (indeterminacy) or the potential magnitude (obliviousness) of damage. However, there must be at least reason to assume that damage is to be expected. Under uncertainty, the certainty of assessment is by definition extremely low (approaching 0). Uncertainty is indicated in the tables separately for each criterion.
4) The risk criteria of *ubiquity, persistency, irreversibility, delay effect* and *mobilization potential*. All of these criteria are treated separately in the tables.
5) The *range of the sources of risk* within a type of risk. Most of the tables for specific risk potentials in Section D are constructed for a type of risk (such as floods) or for a risk in a particular social context (such as BSE in England or Germany). The individual sources of risk within a type can have different properties for the various criteria. This range of sources within a type is indicated by grey to black shading in the horizontal bars of the tables. The lighter the shade, the less sources of risk are situated at this point in the continuum. Dark shading indicates the median of the risks within a type.

The properties of the criteria range from 'low' to 'high'. The various meanings of 'low' and 'high' are briefly explained in the following:

- *Unknown*
  Unknown means that available knowledge does not permit any specific rating in the spectrum from low to high, nor a meaningful statement of confidence intervals (e.g. lies with a probability of 90% between x and y).
- *Probability of occurrence P*
  'Low' means 'highly improbable' (approaching 0).
  'Tends to be low' means 'improbable'.
  'Tends to be high' means 'probable'.
  'High' means 'highly probable' (approaching 1).
- *Extent of damage E*
  self-explanatory
- Certainty of assessment of *P* or *E*
  'Low' means 'poor' certainty of assessment.
  'Tends to be low' means 'still relatively poor' certainty of assessment.
  'Tends to be high' means 'relatively good' certainty of assessment.
  'High' means 'good' certainty of assessment.
- *Ubiquity:*
  'Low' means 'local'.
  'Tends to be low' means 'regional'.
  'Tends to be high' means 'transboundary'.
  'High' means 'global'.
- *Persistency:*
  'Low' means 'short-term' (<1 year).
  'Tends to be low' means 'medium-term' (1–15 years).
  'Tends to be high' means 'long-term' (15–30 years).
  'High' means 'several generations' (>30 years).
- *Irreversibility:*
  'Low' means 'restorable'.
  'Tends to be low' means 'largely restorable'.
  'Tends to be high' means 'only partially restorable'.
  'High' means 'irretrievable'.
- *Delay effect:*
  self-explanatory
- *Mobilization potential:*
  'Low' means 'politically not relevant'.
  'Tends to be low' means 'tends not to be politically relevant'.
  'Tends to be high' means 'tends to be politically relevant'.
  'High' means 'politically highly relevant'.

of major catastrophic potentials, or should it prefer to rely on technologies that have a low hazard inventory and thus, even if all safety precautions, as sophisticated as they may be, fail, have no severe impacts upon human health and the environment?

It only makes sense to do without technologies that have a high catastrophic potential if alternatives of equal utility but lower catastrophic potential are available (Kröger, 1991). This availability is more than dubious in the case of nuclear energy. Contrary to the case of fossil fuels, the range of energy supply by nuclear energy is almost unlimited. While at present levels of consumption, fossil fuels, with the exception of residual stocks that will be extremely hard to extract, will be exhausted within 2–3 centuries, reprocessing and breeder reactors could be used to meet the greater part of the world's electricity requirement by nuclear energy for at least 600 to 1,000 years (on the calculation of reserves cf. Salander, 1995). Secondly, while nuclear power plants do emit small quantities of radioactive substances (which in the worst case constitute increased health risks but no ecological risks), they do not emit any environmentally damaging or climate-endangering substances. They thus avoid a series of important and also potentially catastrophic environmental risks that attach to fossil fuels (Kröger, 1998). Thirdly, the drawback of high energy density is also an important advantage: per unit of energy generated, land use and materials consumption are substantially lower than for all other energy media.

Renewable sources of energy avoid most of the risks that attach to nuclear energy or fossil fuels, although these environmentally sound sources of energy are not entirely free of risk if one considers the entire fuel or materials cycle. For a rational energy policy, the question arises as to whether it does justice to the principle of sustainability to place all hopes for the energy supply of future generations upon renewables, or whether it would be preferable to place the supply mix of the future on the two pillars of nuclear energy and renewables – even with the possible catastrophic consequence of a serious reactor accident. The Council does not wish to deliver any recommendation concerning this issue: answers need to differentiate according to the circumstances. Nuclear power plants in a country characterized by severe institutional failure must certainly be appraised differently than in another country with functioning institutions and high technical and organizational capabilities. The Council further takes the view that this issue cannot be resolved at the scientific advisory level alone, but only on the basis of a consensus in society.

While the Council does not wish to make any recommendation concerning the basic acceptability of nuclear energy, it does consider it essential to note a number of approaches that may serve to promote rational and justifiable risk policies for such sources of technological risk that have a high catastrophic potential. One strategy is to tackle directly the problematic aspect of catastrophic potential and to seek technical solutions that promise a considerable reduction of this potential, i.e. of the hazard inventory. Lower energy density, more physically inherent safety precautions, smaller fuel inventories and reactor modularization (without coupling) are catchwords of a new reactor philosophy that not only further reduces probabilities of occurrence, as in the past, but above all limits the maximum magnitude of disaster. A second approach that can be pursued simultaneously is to introduce reactor architectures by which long-lived radionuclides are irradiated to create nuclides with shorter half-lives. Final storage safety would then only be required for a few centuries or even shorter periods. These measures would make nuclear power more expensive, but the exclusion of catastrophic consequences in even the most unfortunate possible case has a particular value for the economy as a whole that should generally justify the extra costs.

If even best efforts cannot reduce the catastrophic potential expediently or can only do so at exorbitant cost, then the Council takes the view that such a source of risk should only be approved under two conditions: firstly, if the utility of this source of risk is of existential importance and, secondly, if it can be ensured that all technological, institutional and organizational options are exploited to ensure that the catastrophic event does not occur in the first place and, should it occur after all, damage is mitigated as far as possible. This second precondition gains particular relevance if such sources of risk are exported by technology transfer to other countries.

Large chemical facilities and dams

Nuclear energy is not the sole representative of the Damocles risk class. Many large chemical plants, storage facilities or processing centers are characterized by large catastrophic potentials in conjunction with low probabilities of occurrence. Such sources of risk do not tend to be at the center of public interest so often, but are structurally related to nuclear installations. Thus, for instance, in 1984 a disaster occurred in Bhopal (India) involving the release of toxic gases from pesticide production that left more than 2,500 people dead and 150,000 injured. In Mexico City in the same year, a disastrous liquefied petroleum gas explosion killed 498 and injured 7,000.

Much the same applies to large dams: the probability of occurrence is extremely low, but the magnitude of damage associated with a disaster if a dam breaks is considerable, as illustrated by the rupture of the Teton Dam in 1976 (Perrow, 1984). The risk of disaster grows if the dam is built in earthquake prone or geologically unstable areas. After the completion of the Boulder (now Hoover) Dam on the Colorado River in 1936, some 6,000 smaller seismic events were registered in the subsequent 10 years. At the Kariba Dam, which impounds the Zambezi between Zambia and Zimbabwe, severe disturbances have been registered due to the unstable underground geology (Perrow, 1984). A major disaster occurred at the Koyna Dam in India when a strong earthquake ruptured the dam.

Common characteristics

What are the common characteristics of these sources of risk? The combination of a high catastrophic potential with a small to extremely low probability of occurrence has already been mentioned. Contrary to technologies discussed in later sections of this report, such as certain applications of genetic engineering, the two central risk criteria – magnitude and probability of damage – are relatively well known. The degree of uncertainty is low and remaining uncertainties can be estimated relatively accurately by means of appropriate statistical techniques (however, in part only by expert judgments). Medium to high values must be expected for the criterion of ubiquity. The consequences of a disaster proceeding from these technological risks often transcend national boundaries. During the Chernobyl reactor disaster, the Scandinavian countries were affected much more than the western European states, which are at a similar distance from the reactor site, owing to the prevailing wind direction. Dams on transborder rivers are often located close to borders, such as the Gabcikovo Dam on the Danube in the Hungarian-Slovak border area (WBGU, 1998a). If dam failures lead to floods, both countries are affected. Large chemical facilities are built for technical reasons on watercourses (e.g. the Rhine), which frequently form the frontier with neighboring states. This increases the probability that an accident also affects these neighboring states. The incident at Basel in 1986 entailed transboundary pollution of the Rhine.

As disasters in nuclear power plants or large chemical facilities have a particular propensity to release substances or energy, problems of persistency and irreversibility arise. Thus if the fissile inventory is partially released after a reactor disaster, the long half-lives of some nuclides mean that entire regions can be rendered uninhabitable, at least for several decades. Much the same applies to the release of substances after accidents in chemical facilities. Here the biologically effective half-lives are sometimes shorter, but human health is nonetheless affected over many years if not decades.

Many forms of damage to humans and ecological systems caused by nuclear accidents are irreversible and often also uncompensatable, i.e. the original state prior to the disaster is not restorable. Radiation and many chemical substances not only endanger the health of persons exposed, but can further trigger alterations in genetic material that then negatively affect future generations. The negative consequences of dam failures are also only restorable over long periods. However, areas flooded by dam failures in the 1960s and 1970s have at least partially recovered. Of course losses of human life cannot be repaired, and are only inadequately addressed by compensatory payments.

A very high mobilization potential generally attaches to all three of these technologies. One source of this mobilization potential is that people must be resettled for planned dam projects, who then protest against these measures (e.g. Three Gorges Dam in China; WBGU, 1998a). In some cases, people protest against the consequences of dam building, such as in the case of the planned Gabcikovo power plant on the Danube, where environmentalists have demonstrated against the hazards posed to the drinking water supply of Budapest. By now, no major dam project is launched without encountering regionally and internationally coordinated resistance by a network of NGOs (McCully, 1996). India's Narmada Valley Project is a good example of this. It is not least this criticism of the ecological and social consequences of many megadams that has now led to major dam construction projects being no longer considered viable in the USA, and relevant loan award procedures of the World Bank have been made substantially more stringent (IUCN and World Bank, 1997).

Severe accidents in large chemical facilities mobilize the public to an even greater extent, as shown by the protests after the Sandoz accident in Switzerland. The mobilization potential of nuclear energy is particularly high. Many people feel themselves existentially threatened by the development of nuclear energy, some engaging in civil disobedience or withdrawing their trust from the political decision-makers (Renn, 1984; Medvedev, 1991). Even if it should prove possible to considerably reduce the catastrophic potential of nuclear energy, a high level of mobilization must continue to be expected in the future.

D 2.2
Risks posed by nuclear weapon early-warning systems and nuclear, biological and chemical weapons systems

This section is not concerned with technological risks resulting from fabrication, transportation or storage of nuclear weapons, but rather with the risk potentials attaching to unintentional occurrences, insufficient maintenance and misuse. These risks proceed from nuclear weapon early-warning systems (there are no specific early-warning systems for biological and chemical weapons) and from nuclear, chemical and biological weapons. Military nuclear weapon early-warning systems harbor a risk potential because they can lead to a mistaken use of nuclear weapons. Their function is to detect intercontinental and intermediate-range missiles in order to be able to react in time with countermeasures such as the use of nuclear weapons. While it can be assumed that intercontinental missiles carry a nuclear payload, the detection and telemetry of the launch of intermediate-range missiles does not permit any certain appraisal of their payload. No intermediate-range missiles are stationed any more in Europe: the American and Russian stocks have been entirely removed under the Intermediate Nuclear Forces (INF) Treaty (1987), and the French stocks under a decision of the French President (1997). The second complex examined in this section – nuclear, chemical and biological weapons systems – is concerned not with the risks of early detection, but with poor maintenance, misuse and the possibility of use in the event of war. In both the early-warning system and weapons system complexes, technical, organizational and personnel deficits can heighten the risk potentials (Sagan, 1993).

Nuclear weapon early-warning systems

The risk potential of nuclear weapon early-warning systems stems from the linkage between two technologies – nuclear weapons and early-warning systems. The risks inherent in producing and transporting nuclear weapons correspond to those of the civilian use of nuclear energy (Section D 2.1). This is of course joined by the risk of their possible use. The early-warning system technology only gains its risk potential through being coupled with the technological risks of nuclear weapons. While detection of enemy nuclear weapons by an early-warning system need not automatically lead to retaliation in kind, technical gaps in the early-warning system or false evaluation of information can lead to a mistaken use of nuclear weapons. This is to be feared in the case of the Russian early-warning system (Müller and Frank, 1997).

Müller and Frank (1997) revealed in their study that the Russian early-warning system and the associated nuclear forces have considerable functional and maintenance deficiencies. Through the breaking up of the former Soviet Union, parts of the early-warning system have been lost. Several satellites are no longer utilized due to a lack of necessary maintenance. Other satellites and data processing facilities experience repeated outages due to power shortages. This creates gaps in the technical early-warning system. Paradoxically, after the end of the East-West conflict the risk stems no longer from the firepower of the Russian nuclear arsenal, but rather from its degradation.

Nuclear, biological and chemical weapons systems

The risk potential presented by the production of nuclear, biological and chemical weapons is comparable to that of the civilian use of nuclear energy and to that of large chemical facilities (Section D 2.1). This is compounded by the risk of accidental or unauthorized use. International arms reduction efforts differ substantially for the various types of weapons of mass destruction – nuclear, chemical and biological (Brauch, 1997).

Commitments to reduce stocks of nuclear weapons have been put in place through the bilateral American-Soviet or American-Russian (since 1992) agreements on intermediate-range systems (INF) and on strategic nuclear weapon delivery systems (START I and II). The Lisbon protocol to the START I Treaty further integrates Ukraine, Kazakhstan and Belarus. Since 1968, the nuclear Non-Proliferation Treaty (NPT), which has now been signed by 186 states, prohibits the proliferation of nuclear weapons to non-nuclear-weapon states (Auswärtiges Amt, 1997). However, India, Pakistan, Israel and Cuba are not parties to the treaty. This entails a continuing risk, as evidenced by the recent nuclear weapons tests in India and Pakistan in the early summer of 1998.

For many years, chemical weapons were only controlled by piecemeal agreements. However, since April 1997 a convention prohibiting them is in force and is currently being implemented. A multilateral verification regime monitors the disarmament of existing chemical weapons and their proliferation, the dismantling of production facilities and non-production in civilian industry. The Chemical Weapons Convention, which has been ratified by the USA and the Russian federation, these being the two largest chemical weapons countries, and a further 111 states, is an important step on the path towards universal disarmament of chemical weapons (Auswärtiges Amt, 1997).

The 1925 Geneva Protocol imposed a first ban on the use of biological weapons. This was joined in 1972 by the Biological Weapons Convention, which entered into force in 1975 and presently has 141 States as parties. The convention categorically bans the development, production and storage of bacteriological (meaning all biological) weapons and weapons containing toxic substances (so-called toxin weapons). As opposed to the Chemical Weapons Convention, the Biological Weapons Convention contains no provisions governing verification of compliance. In order to remedy this deficit, negotiations commenced in 1995 upon the initiative of the German government and European Union member states with the aim of strengthening the Biological Weapons Convention and arriving at a protocol on verification measures that is binding under international law.

Recent developments in Iraq surrounding the UN inspections of chemical and biological weapons and arsenals illustrate the threat perceived by the international community in uncontrolled uses. The ongoing dispute between Pakistan and India, who both carried out nuclear weapons tests in 1998, is a further example harboring considerable risk potential. An armed border and territorial conflict over Kashmir has been in progress between these two states for decades. Both sides have already repeatedly threatened to use nuclear weapons. Both India and Pakistan have not signed the Non-Proliferation Treaty and have consequently not entered into verification agreements that would fully cover their nuclear activities. They have merely concluded partial verification agreements with the IAEA that only concern the imported components of the civilian nuclear fuel cycle.

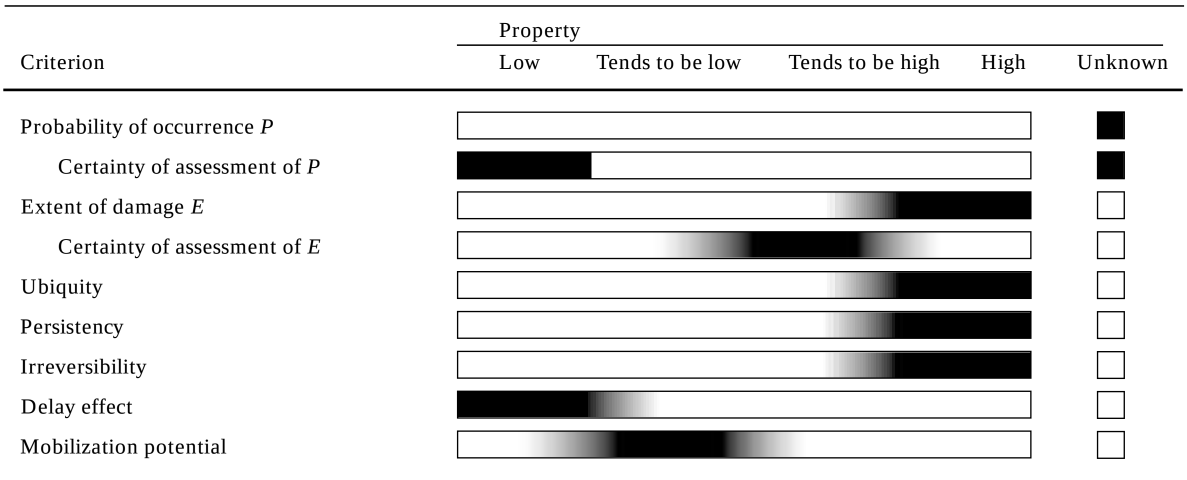
In more stable regions of the world, too, nuclear, chemical and biological weapons mean an uncertain risk potential that transcends the assessment of nuclear energy. This is exemplified by the state of the strategic nuclear forces in Russia. Most of the nuclear weapons stationed there are at high alert (Müller and Frank, 1997). This leads to an unassessable risk of unintended missile launches caused by malfunctioning technical systems. In a crisis, inadequate safety standards and human error can also lead to unauthorized or mistaken missile launches. Most of the Russian nuclear submarines are not in operation at high sea, but lie in their bases. Their missiles are held at constant high alert. These uncertain risks could be reduced by terminating or lowering the alert status of the nuclear weapon arsenals ('de-alerting').

Scrapping nuclear submarines in the Arctic ports of Russia has emerged as a special problem due to the lack of the financial and technical resources needed to dismantle the nuclear reactors and properly dispose of their fuels (Auswärtiges Amt, 1997). The submarines are confined to their bases, where they are inadequately maintained and thus gradually corrode, creating ecological risks to the Barents Sea and Kara Sea. A similar state of disarray is to be assumed for the land-based intercontinental missiles. Here, too, only a few are operational, which gives rise to the assumption that the inoperable missiles are inadequately maintained due to a lack of personnel. Only constant readiness of these weapon systems guarantees that they are serviced properly and that the accident risk potential does not rise.

Common characteristics

As opposed to nuclear energy and large chemical facilities, the two complexes discussed here – nuclear weapon early-warning systems and nuclear, biological and chemical weapons systems – do not belong to the Damocles class of risk as might be suggested by the evident parallels among these technologies, but to the *Cyclops* class (Table D 2.2-1). The two complexes are similar in many points to nuclear power plants and large-scale chemical facilities: a high catastrophic potential attaches to both early-warning and weapons systems, the magnitude of damage is quite well known and can be assessed relatively accurately. The effects in terms of ubiquity and persistency can also be high. The geographic range of a possible catastrophe is global and the temporal range concerns several generations. The decisive difference to the Damocles class is the high degree of uncertainty in assessing the probability of occurrence, as this can change continuously. Knowledge of causal connections is often inadequate, as human behavior and shifting political structures play a major role. These systems are relatively vulnerable without the actors perceiving them as such. The characterization and present management of these high-risk technologies have shown that it is particularly the human factors, such as misuse or organizational deficiencies (e.g. inadequate maintenance), that render the probability of occurrence insufficiently assessable.

Table D 2.2-1
Application of the evaluation criteria to the risk potential of nuclear weapon early-warning systems and to the risks of nuclear, biological and chemical weapons systems. These belong to the Cyclops risk class. Terms are explained in Box D 2.1-1.
Source: WBGU



D 2.3
Risks posed by certain genetic engineering applications

This section attempts neither a comprehensive discussion of genetic engineering, nor is it concerned with this technology's present or future prospects. Rather, we shall discuss certain representative applications, such as marketing of transgenic organisms and their unintentional propagation in the environment. We take the view that presently the potential risks posed by several applications cannot be assessed accurately enough – neither in terms of the probability or magnitude of damage – so that uncertainty prevails here (Section C). The aim of the examples set out below is therefore to highlight the ambiguities and uncertainties attached to certain applications of genetic engineering. This analysis is done from the perspective of risk research (Section D 4), thus complementing the natural science perspective of the report on genetic engineering authorized by the German Council of Environmental Advisors (SRU, 1998).

Although first genetic modifications succeeded more than 25 years ago, genetic engineering continues to produce new applications offering highly promising opportunities for industrial use. In certain fields of application, these opportunities and benefits also present risks whose probability and magnitude have remained largely uncertain due to a lack of experience or a lack of knowledge on consequential impacts. The consequences of commercializing transgenic plants and using transgenic microorganisms (including viruses) in an uncontrolled manner or spreading these unintentionally have the potential to assume global relevance. We have therefore devoted particular attention to the applications of genetic engineering in agriculture.

Genetic engineering is a 'generic' technology. Its applications can be subdivided roughly into two major fields and several further areas. One of these major fields is medical and pharmaceutical application, often termed 'red' genetic engineering. In medicine, applications are mainly in therapy and diagnosis, while in pharmaceutics genetic engineering is primarily used to develop and to a lesser extent to produce pharmaceuticals. Today, genetically modified alpha interferons are already being used to combat leukemia, and beta interferons to combat multiple sclerosis. Sera inoculated with genetically modified antigens promise improved protection against hepatitis. While these and other applications do present risks, we take the view that these risks do not assume global relevance. To what extent risks proceed from the production of modified pharmaceuticals, for instance through the escape of organisms from the laboratory, continues to be a matter of controversy. However, the extent of the risks of 'red' genetic engineering must be viewed as relatively slight and regionally contained.

The second major field of operations for genetic engineering is in agriculture, often termed 'green' genetic engineering. This field is concerned with genetically modified inputs for food production, resistance and intensification breeding, productivity enhancements or quality modifications (Section D 4). Here risk potentials stem not so much from the genetic engineering methods themselves, but rather from the unintended consequences of certain applications or of transgenic organisms spreading unintentionally. As a rule, transgenic organisms are initially released in a step-wise and controlled process (there are exceptions in developing countries and Eastern European states: Sojref and Thamm, 1997; de Kathen, 1996).

In some spheres of application of genetic modification, the remaining uncertainties have been largely dispelled, meaning that these risks have been moved from the transitional area to the normal area. They can thus be handled by routine management. Other applications have already entered upon the cascade movement to the Cyclops and Medusa risk classes (see Section A). Despite all efforts, several applications remain for which empirical experience is insufficient. This means that the data basis in risk research and related research is not adequate to carry out a quantitative risk appraisal, and in some cases not even adequate for a qualitative appraisal. The risks of such applications characterized by a high degree of uncertainty are assigned to the *Pythia* risk class, because uncertainties remain as to both the probability and magnitude of damage. This 'new quality' of genetic interventions associated with uncertainty potentials (von Schell, 1994) is illustrated in the following discussion for four fields of risk and their scenarios. Formulating accident scenarios is a standard procedure in risk analysis of biotechnological processes (Hungerbühler et al., 1998).

We distinguish four fields of risk for which non-implausible scenarios or analogies can be defined and where high levels of uncertainty and insecurity can be presumed. The risks outlined in the following are therefore assigned to the *Pythia* class.

When transgenic plants run to seed

Depending upon transgenic characteristics, gene transfer can generate risks because particularly competitive plants can emerge that disperse unchecked. This conclusion is illustrated by analogy to the establishment of alien plant species (e.g. neophytes) that migrate or are introduced to ecosystems outside of their former range and can cause substantial negative impacts there (von Schell, 1998). Skorupinski (1996) accordingly sees adverse ecological consequences when transgenic plants escape from cultivation. These consequences arise firstly through hybridization and secondly through 'genetic reversion'. In hybridization, genes are transferred from crop species to wild plant species, e.g. weeds. These hybrids can become a problem if they are viable and the new genes give them a selective advantage. Their spread and propagation is to be expected particularly if they are similar to the cultivated species and are thus difficult to control. Hybrids are more likely to disperse in cultivated landscapes than in uncultivated ecosystems, as in the former anthropogenic interventions have led to deeper modifications of ecosystems. The more intensively cultivated landscapes are used, the higher is the need for control in order to maintain the state desired – this in turn increases susceptibility to change. 'Genetic reversion' leads to the loss of domestication traits. This can cause yield or quality losses, and frequently also promotes the successful establishment cultivated varieties outside of agricultural ecosystems, or a hybridization among cultivated and wild plant species. This leads to a rising probability that transgenic plants run to seed, and that cultivated or transgenic species hybridize with related wild species. The complex formed by cultivated and wild species has a more or less strong gene flow, whereby a clear demarcation between the two groups is not always possible.

Uncontrolled dispersal of transgenic traits, and unintended secondary effects

Genetic engineering often employs DNA sequences that can for instance influence the resistance of plants (e.g. promoters, trailers). Critics of genetic engineering see problems in making plants resistant to viruses, insects, fungi or bacteria (Wadman, 1997). In the natural process of evolution, positive selection for a characteristic or a trait extends over long periods. Genetically engineered characteristics have not passed through this process – but nor have the traits of cultivated plants that are produced by conventional breeding methods. Undesirable effects can occur that are all the stronger for transgenic plants (Skorupinski, 1996).

Many of the risks that can be associated with applying genetic engineering in agriculture are already known from conventional plant breeding activities or can be assessed relatively well on the basis of past research findings and release trials (Section C 4.2.2.4). They can be assigned, at least partly, to the normal range of risk. However, in some fields of application large gaps in knowledge continue to prevail, as do uncertainties with regard to the assessment of possible effects within or impacts upon the environment. In such cases, the risks possibly associated with such applications are assigned at the present point in time to the Pythia risk class. This includes, for instance, the as yet inadequate knowledge in the field of soil biology, or the entire complex of virus population ecology, including the influence of viruses upon the population dynamics of natural or seminatural plant communities. Thus we can neither predict nor exclude an increase in viral resistance to the protection mechanisms conferred upon plants by genetic modification in the event of large-scale cultivation of transgenic, virus-resistant plants. The same applies to possibly severe changes in the species compositions of natural or seminatural plant communities resulting from transgenic virus-resistant plants running to seed or from a dispersal of their foreign gene. Conversely, further research may possibly reveal that the impact of transgenic virus resistance does not differ, or only slightly from the types of resistance utilized by conventional plant breeding, or that virus resistance only offers a minor selective advantage compared with other ecologically relevant traits such as enhanced growth or improved tolerance to drought.

Greene and Allison (1994) have proven under laboratory conditions that viruses can incorporate parts of the hereditary material of virus-resistant plants, and can thus assume new traits. The extent of damage of course depends upon the scenario assumed. Thus Greene and Allison 'only' proved that new combinations are possible. This does not yet tell us anything about whether these new variants pose greater hazards than the original ones, or about whether this process is more commonplace in transgenic plants than in nature or than in conventionally bred virus-resistant crops. Nonetheless, such a scenario illustrates that, hypothetically, damaging effects can be very severe, whereby only plausibility assumptions can be made concerning probabilities of occurrence. Traits such as insect resistance or modifications that were unintended can thus lead to new competitive situations or can disrupt the reproductive cycle of the modified plant, as experienced in the US state of Mississippi in the summer of 1997 with herbicide-resistant cotton (Kleiner, 1997). Hereditary information originally constructed by genetic engineering, such as resistance against insects, can also be incorporated by wild plant populations, and can propagate there and disperse (von Schell, 1998; Bartsch and Schuphan, 1998; Mikkelsen et al., 1996). These new transgenic characteristics in wild plants are then beyond human control (Sentker et al., 1994).

Another type of risk lies in the circumstance that genetically modified plants produce new substances that can be damaging to other organisms. For instance, insect-resistant plants created by genetic modification produce a toxin stemming from bacteria, the delta endotoxin of *Bacillus thuringiensis*. This also kills beneficial insects that eat larvae in which the toxins have accumulated (Hilbeck et al., 1998). No reliable statements can be made about the frequency of such events, i.e. the probability of these events occurring remains uncertain. As far as the associated magnitude of damage is concerned, very severe negative consequences could arise if information and traits transferred to wild plants give them a selective advantage in their population (Sentker et al., 1994). In this connection, high uncertainties also attach to the problem that genes only rarely transferred remain undetectable for long periods in the new population. After several reproduction cycles, a sudden surge in the dispersal of the traits can occur. A further problem in this area is the use of antibiotic resistance genes as selection markers. In order that genetic engineers can identify those cells in which the insertion of hereditary information was successful, a further trait is incorporated in addition to the one desired. This is frequently antibiotic resistance. Thus, for instance, the gene that codes the enzyme neomycin phosphotransferase is used as marker together with other disease and pest resistance traits in more than 30 transgenic plants. This is why therapy with antibiotics containing this genetic information is associated with risks if at the same time plant food containing antibiotic resistance markers is ingested (Skorupinski, 1996). The Council does not view antibiotic resistance genes as posing a severe risk, but does consider it expedient to replace antibiotics as selection markers.

Allergenicity in food

Food processing is increasingly making use of genetic modification (Jany, 1998). The inclusion of foreign gene segments in food can lead to allergic reactions in people who are allergic to the transgenic substance (e.g. strawberries). As opposed to the large number of airborne allergens that have been identified, only a small number of food allergens are known. Two prime problems arise in food processing and cooking (EC, 1997): during processing, the content and/or characteristics of the food allergens can be altered. In this process, the capacity of the initial substance to trigger allergies can be amplified or reduced. The second prime problem is that most processed foods contain additives or other hidden ingredients of natural or synthetic origin. Uncertainty thus attaches to risk assessment if genes coding for allergenic proteins are transferred from one plant (e.g. from peanuts) to another (Skorupinski, 1996). A well-known example of this is the transfer of a gene taken from the Brazil nut, which has a high allergenic potential, to oil rape seeds or soya beans in order to enhance their nutritional value (Nordlee et al., 1996; Pühler, 1998a). This branch of genetic engineering applications is partially associated with uncertainty, because even the greatest technological and financial effort cannot determine in advance all potential allergens or allergenic reactions in humans. However, this circumstance applies similarly to foodstuffs produced by conventional breeding techniques. Nonetheless, this is indeed compounded in genetically modified plants or foodstuffs by the increasing, diffuse and to some extent global dispersal of certain parts or constituent substances of transgenic plants, and thus also of potential allergens, in the most varied foods (e.g. soya). It is as yet unknown how this will affect the future emergence of allergies. This puts the issue in the vicinity of the Pythia class of risk.

However, the use of known allergens could be restricted by law, or allergic individuals could avoid these substances if the allergenic proteins inserted in other plants were labeled. If these measures were taken, this type of risk would be moved to the normal zone. The Council would thus support the assessment "that in the public debate excessive priority is accorded to the problem of allergies resulting from genetically modified foods" (Pühler, 1998a), if all transgenic substances contained in foods are listed and labeled, and if transgenic foods are subjected to allergenicity tests in addition to toxicity tests. Without labeling this modification, it is not possible to avoid the risk. Although the EU Novel Food Regulation in force for some years and its latest 1998 amendment on genetically modified soya and maize products attempts to regulate such labeling in EU member states, considerable gaps remain in the implementing provisions. Improved labeling measures could at least go some way towards distinguishing transgenic foodstuffs that give cause for concern from those that do not. However, residual risks would remain even with an allergenicity assessment. Such tests continue to be the subject of scientific controversy because every protein can develop (if with a low probability) an allergenic effect.

Accelerated decline in the diversity of crop plant varieties and the consequences for global food production

In plant breeding, targeted genetic engineering interventions can also intensify uncertain risks. This is primarily an issue of the reduction of crop plant diversity to a small number of species used worldwide and optimized by genetic engineering. This is not an intrinsic problem associated with genetic engineering applications, but is rather a logical continuation of past breeding practices. It is thus debated controversially in the literature whether crop breeding by genetic modification harbors more or new risks compared to conventional breeding techniques. Skorupinski (1996) assigns a higher uncertainty potential to the possible insecure and undesirable consequences of plant breeding by genetic modification than to conventional methods, including mutation breeding and cell culture techniques under high selection pressure, which are even further removed from natural selection mechanisms than classic crossbreeding is. The reasons for this appraisal are to be sought in the breeding methods (Skorupinski, 1996; von Schell, 1998).

The decisive point is that humans prescribe the new combination of hereditary information. As these breeding methods would call for a specific and technically appropriate presentation that cannot be given here, we shall merely briefly note those characteristics that distinguish genetic engineering from conventional breeding (Skorupinski, 1996). Skorupinski claims that breeding methods using genetic modification permit cross-species transfer, have greater precision, involve the addition of foreign information across species and geographical boundaries and are thus less error-friendly. The genes themselves are often highly modified and can be controlled externally by means of targeted interventions. It remains a matter of debate among the scientific community whether genetic engineering applications or conventional breeding techniques are more or less 'error-friendly'.

The possible consequences of large-scale cultivation of genetically modified cereals could assume global proportions. If a small number of cereal species were made so robust and delivered such high yields through genetic modification that they were used and propagated worldwide and global cereal supply depended upon them, new, previously unknown pests or virus forms could globally jeopardize this supply. While most critics consider this scenario to be improbable, it does show where the risk potentials lie. This effect is not specific to genetic engineering, as it also arises as an outcome of the one-sided use of high-yielding varieties produced by classic plant breeding. Nonetheless, a complete risk analysis must take this effect into consideration just as it does the possible risks specific to genetic engineering. We can see an analogy here to the Green Revolution. This involved, in addition to the introduction of new cultivation methods aimed at enhancing agricultural productivity, above all the use of varieties promising higher yields (WBGU, 1997a). In the developing countries, a widespread outcome of this use of high-yielding varieties produced by conventional breeding techniques has been a drastic drop in the diversity of native species. In the course of the Green Revolution, high-yielding wheat and rice varieties were developed and bred in Mexico and the Philippines as visible outcomes of international agricultural research (Nohlen, 1989).

Plant breeding by genetic modification offers benefits above all from an economic perspective, by reducing the time required for breeding. This acceleration of breeding can also be a disadvantage, as the periods in which experience can be gained are reduced – periods in which possible disturbances caused by the genetic intervention can no longer be tested and assessed over a lengthier time (von Schell, 1998).

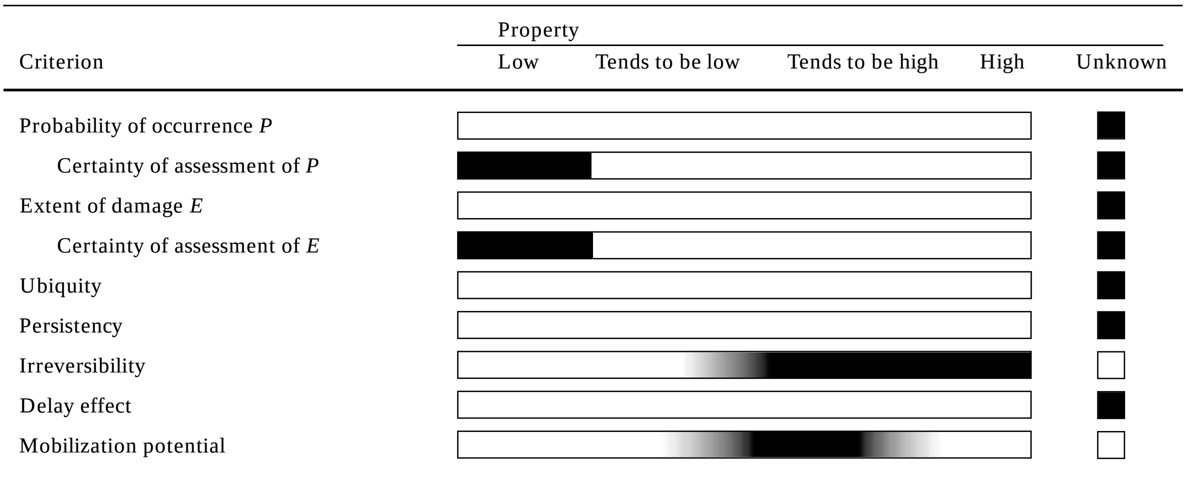
Further fields of application

Further fields of application include the use of genetic engineering in specific production processes, such as in enzyme production for laundry detergents. Genetic engineering has also established itself in environmental engineering. This includes for instance bioremediation, meaning the use of microorganisms to clean up contaminated soil and water. These applications are presently still marginal (Knorr and von Schell, 1997), although with respect to their possible ecological impacts they need to be assessed more critically than 'green' genetic engineering.

In summary, we can state that a broad array of presently still not estimable risk potentials is associated with the cultivation and commercialization of transgenic plants and with the unintentional dispersal of transgenic microorganisms. Moreover, further developments towards new gene constructs or ecologically highly relevant genetically modified characteristics such as cold, heat and salt tolerance are to be expected. It is clear that at the present point in time little can be said about the maximum probability and magnitude of various damage scenarios. With regard to the criterion of persistency, hereditary material changes can also affect following generations.

Compared with the Damocles and Cyclops risk classes, in the Pythia class probabilities of occurrence are uncertain and possible severity in the event of damage is unknown. In the opinion of the Council, this uncertainty does not apply to the majority of applications up to now, but only to certain ones involving marketing or the unintentional dispersal of transgenic organisms. It is quite possible that the extent of damage is large, but it could also transpire to be small. Similarly, no certain statements can be made as to the probabilities of occurrence in each specific case. The high levels of uncertainty that attach to both the probability and extent of damage lead to high uncertainty concerning ubiquity, persistency and the time of occurrence (delay effect). Some examples, such as genetic manipulation or interventions in reproductive cycles, show that it is impossible to reinstate the original situation. The above applications of genetic engineering thus can clearly be assigned to the *Pythia* class of risk (Table D 2.3-1).

Table D 2.3-1
Application of the evaluation criteria to the risk potential of certain applications of genetic engineering. These belong to the Pythia risk class. Terms are explained in Box D 2.1-1.
Source: WBGU



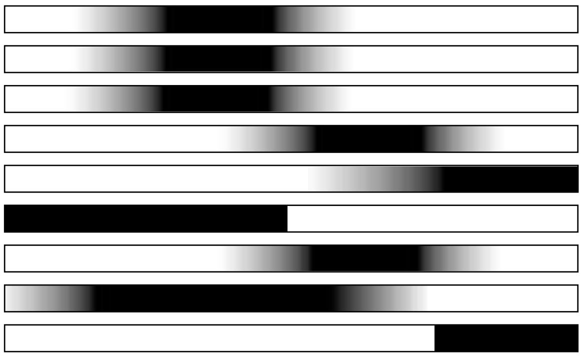
Mobilization potential
The mobilization potential of genetic engineering is not as simple to identify as that of nuclear engineering. The wider public has relatively little information, some applications are viewed as highly controversial, while at the same time opinion polls show that the public has a considerably more relaxed attitude to this technology than to nuclear engineering. Beyond instrumental assessments of benefits and threats to human health and the environment, the public debate revolves mainly around ethical concerns and arguments focusing on the possibility of abuse (Renn and Zwick, 1997). Contrary to the widespread belief that the Germans have a particularly skeptical attitude to genetic engineering, the Eurobarometer surveys carried out by the European Community show that, in a European comparison, a greater proportion of German interviewees is in favor of genetic engineering, both generally and in regard to most applications, than for instance the Danes, Dutch, British, Finns or Austrians (Hampel, 1998). Nonetheless, the Germans certainly have a considerably more skeptical attitude to genetic engineering and its applications than do the Americans. According to a cooperative survey carried out in spring 1997 by the Market Facts Institute in America and the Allensbach Institute in Germany, 52% of Americans are in favor of genetic engineering, whereas only 30% of Germans assess the technology positively. A representative opinion poll coordinated by the Stuttgart Center of Technology Assessment has shown that there are much higher levels of support in certain fields of application. The poll revealed that 74% of the public support the use of genetic engineering in medicine (Hampel et al., 1997). Thus well over ⅔ of the interviewees approve of its use for the diagnosis and therapy of disease. Well over half of the interviewees still approve of the production of vaccines and of prenatal diagnostics. However, depending upon the further development of the public debate, it is possible that in the future the now moderate mobilization potential will grow further. Protests have already occurred in Germany over, for instance, release trials of genetically modified maize and rape.

D 2.4
The risk potential of electromagnetic fields

The risks associated with 'electrical smog' are primarily due to the intensities and frequencies of electromagnetic fields (EMF). Being below established dose-effect thresholds, these fields are not registered by human sensory organs. There is no conclusive evidence that exposure to normal levels of EMF produce any harm beyond background variation. Observed symptoms most often cannot be traced back to physical damage underpinned by objectively verifiable data, but rather to subjective malaise or subjective impairment of human functional capacity, which can then lead to psychosomatic illnesses. The decisive aspect in risk evaluation is thus the question of the subjective risk perceptions by those affected (Hester, 1998; Wiedemann and Schütz 1996; Wiedemann et al., 1994; MacGregor et al., 1994). Risk potentials perceived as being linked to high-frequency EMF exposure are increasingly becoming a regular topic of media reporting, and are thus placed in the center of public attention (Wartenberg and Greenberg, 1998). The range of findings of professional or

Table D 2.4-1
Application of the evaluation criteria to the risk potential of electromagnetic fields (EMF). This belongs to the Medusa risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

	Property				
Criterion	Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					☐
Certainty of assessment of *P*					☐
Extent of damage *E*					☐
Certainty of assessment of *E*					☐
Ubiquity					☐
Persistency					☐
Irreversibility					☐
Delay effect					☐
Mobilization potential					☐



only seemingly professional risk studies is a main reason why electromagnetic radiation is perceived as a risk (Schaefer, 1995).

Well-substantiated scientific studies predominantly conclude that low doses of electromagnetic fields do cause effects, but that these are generally not hazardous to human health, i.e. neither epidemiologically nor toxicologically significant changes can be found. In cases located close to EMF sources where significant changes have been statistically verifiable, other explanations are far more plausible. For instance, the slightly elevated cancer rate among people living close to high-voltage power transmission lines in the USA can be traced to income differentials. As property prices are lower in the vicinity of overhead lines, substantially more low-income families live there than in reference areas. Low income is closely associated with certain types of cancer. If income is held constant, then the EMF influence upon cancer prevalence disappears, while the reverse does not hold true.

The EMF risk debate is not least a reflection of the discussion among experts, in which credibility is at stake (Wiedemann et al., 1994). Publicly recognized scientists often adopt contradictory positions (Covello, 1998). An important effect of this is that even the methodologically substantiated scientific findings are doubted by the public. Each expert study can be countered by another expert study. Limit values are viewed with particular distrust, being interpreted as arbitrary. The lack of a uniform position among the experts is often interpreted by the public as meaning that there is general uncertainty or even that the risk is being played down.

The risk potential emanating from electromagnetic fields is a typical representative of the Medusa class, with a fairly low probability of occurrence and magnitude of damage, the probability remaining somewhat uncertain (Table D 2.4-1). The spatial distribution of this risk potential is high, i.e. at least transboundary if not global, for in almost all industrialized and in most non-industrialized countries the exposure of the public to electromagnetic waves is high. The issue must also be viewed as politically and societally relevant in terms of mobilization potential, as the media and the public ever more frequently concern themselves with this issue and thus mobilize affected persons. It is mainly those directly affected who view the risk potential as threatening. The subjective perception of well-being and functional capacity impairments can lead to psychosomatic reactions and thus indirectly to physical damage.

A large number of people are exposed to EMF worldwide, whereby adverse effects occur most likely in the form of psychosomatic disorders, but epidemiological verification or toxicologically significant dose-response relationships cannot be established in a statistically well-founded manner for the doses that occur in reality. There is nonetheless a need for risk policy action here, for a major mobilization potential stems from risks to which many people are exposed and whose effects, while remaining below the statistical significance threshold, cannot be entirely excluded. The perceived EMF risk potential illustrates prototypically the general unease of people when confronted with novel technologies, particularly those that are an expression of modernization and globalization (Section C).

Infectious diseases as a global risk D 3

D 3.1
Perspectives on infectious diseases

Infectious diseases are the leading cause of death in the world, followed by cardiovascular diseases and cancer (Table D 3.1-1). The Council has concentrated on infectious diseases, as these constitute risks that have global relevance, can cause great damage in the event of outbreaks and mostly involve a people-environment-people chain of causation. The following discussion considers exclusively infections with an epidemic or pandemic potential.

The present report does not treat infectious diseases that require a carrier (vector) for transmission to humans, nor those that are waterborne (Favela Syndrome), despite their global relevance, as these have already been discussed by the Council in detail elsewhere (WBGU, 1998a). Here we shall focus rather on so-called new infectious diseases. These are diseases caused by pathogens that have only emerged in the past two decades and are consequently a subject of particularly intensive public debate. As prototypes of different forms of risk emergence, potentials and management, we shall examine AIDS (Acquired Immune Deficiency Syndrome), influenza A and bovine spongiform encephalopathy or the new variant of Creutzfeldt-Jakob disease (BSE/nv-CJD).

Table D 3.1-1
WHO estimate of main causes of death in 1996.
Source: WHO, 1997c

Cause	Deaths [Million]	Deaths [%]
Infectious diseases	17	32.7
Cardiovascular diseases	15	28.8
Cancer	6	11.5
Respiratory diseases	3	5.8
Others	11	21.2
Total	52	100.0

D 3.1.1
Global perspectives

HIV/AIDS and influenza A

For the occurrence of both diseases, links can be identified with a number of core problems of global change. Worldwide, 31 million people are currently infected with the human immunodeficiency virus (HIV). Roughly every 10 years, severe epidemics caused by influenza A subtypes occur, individual pandemics having claimed up to 20 million lives (as did the 'Spanish' influenza pandemic in 1918).

The spread of both diseases is promoted or indeed made possible at all by national and international mobility and by urban lifestyles, both of which greatly increase contact frequencies. Drug abuse also plays a decisive role here. Homosexual people are also particularly at risk, as are societies in which sexual partners are frequently changed.

For AIDS, the magnitude of damage can already be assessed relatively accurately. Already, 15 years after its spread, high levels of infection and mortality have led in some regions of the world to distinct damage-related structural changes (rising poverty, high number of orphans, increasing secondary infections).

For influenza A, there is a relatively high probability of occurrence of the periodic emergence of a new, highly virulent subtype (approximately every 10–20 years). The catastrophic potential is determined by both biological effects that lie in the nature of the virus itself and by increasing urban concentration and mobility.

Bovine spongiform encephalopathy/new-variant Creutzfeldt-Jakob disease

As a consequence of world population growth, food production is being intensified in order to optimize yields. Bovine spongiform encephalopathy (BSE, 'mad cow disease'), is directly associated with intensive livestock farming practices in which meat wastes have been fed to herbivorous animals with the aim of enhancing yields. Spongiform encephalopathies are special infectious diseases that occur in different forms in humans and in animals. A special characteristic is that they also - if albeit rarely - occur spontaneously without infectious contact. In 1996 a new spongiform encephalopathy was discovered in humans. This is termed new-variant Creutzfeldt-Jakob disease (nv-CJD) and has great similarity to BSE in cattle. Studies carried out to date permit the assumption that this is the human form of BSE. The issue of BSE/nv-CJD is included in this report because spongiform encephalopathies will continue to emerge *de novo* after BSE has subsided. They thus constitute a risk potential for humans.

It is completely uncertain whether major damage can occur through BSE/nv-CJD. This is because the latent period between infection and outbreak of the disease, currently estimated at 15–20 years, is not yet precisely known. If it should transpire that there is a high transmission rate from infected cattle to humans, then a considerable magnitude of damage must be expected in view of the approximately 750,000 infected cows that had been utilized for human consumption by the end of 1995.

Other infectious diseases constituting a global risk potential

Tuberculosis, triggered by *Mycobacterium tuberculosis hominis*, is presumably at present the most frequent infectious disease worldwide, causing some 3 million deaths per year. It is transmitted exclusively from person to person, and only anthropogenic factors play a role in its spread (urban concentration, wars, depressed immune status). As there is no clear environmental link, tuberculosis shall only be treated in this report as a consequence of AIDS and as an example of the development of resistance to therapeutic agents.

Much the same applies to syphilis and gonorrhea, which, as sexually transmitted diseases (STDs), spread exclusively by anthropogenic pathways and are presently resurgent. In contrast to tuberculosis, whose resurgence is a consequence of AIDS, STDs constitute a considerable risk factor for contracting AIDS. STD therapies therefore have a prime role to play in public health strategies for combating AIDS.

D 3.1.2 Environmental perspectives

In addition to the relevant anthropogenic factors that lead to the people-environment-people chain, the 'new' pandemics, in particular, are characterized by a further environmentally related aspect: AIDS and influenza are caused by viruses characterized by a high instability of their genetic material. They are thus capable of changing rapidly, which is tantamount to a high degree of adaptability to potential new hosts. Thus HIV, similar to influenza A which will be dealt with later in this chapter, is a prime exemplar of a disease whose pathogenic reservoir in mammals and birds has been able to cross species barriers and also infect humans. These pathogens thus have an environment-people component that is of a purely biological nature.

In the case of BSE/nv-CJD, transmission to cattle and possibly from cattle to humans is exclusively attributable to human action.

D 3.2 Damage potentials, present risk management and characterization

D 3.2.1 HIV/AIDS

In the 1960s, the battle against infectious disease had reached a pinnacle of success, with smallpox eradicated by WHO programs and polio and tetanus under control by efficient vaccination. However, the limits of infection control were already becoming visible then. They were apparent in the failure of the WHO program to eradicate malaria and in the beginning growth of bacterial resistance. In 1979 one of the leading medical journals published an editorial titled "Pandora's Box reopened?". The author presented an until then hypothetical scenario of a global resurgence of epidemic diseases. The emergence of 'new' epidemics was feared (Schwartz, 1979). By 1983 it was plain that a new epidemic disease of pandemic potential had indeed emerged, caused by the human immunodeficiency virus type 1 (HIV) and lethal with great certainty.

HIV viruses are retroviruses. They are named after an enzyme (reverse transcriptase) which they contain. Retroviruses were known since 1910 from ani-mal experiment systems, where they were identified as tumor-inducing agents (Peyton Rous, 1966 Nobel Prize). Human-pathogenic retroviruses were described for the first time in 1980 by Gallo (human T-cell lymphotropic virus, HTLV-1 to HTLV-3). Initially, only their tumor-inducing effect was recognized (adult T-cell leukemia in the Caribbean population). It was only later that HTLV-3, renamed HIV-1 (Brun-Vezinet et al., 1984; Gallo and Reitz, 1985), was identified as the pathogen of the AIDS syndrome. Current knowledge suggests that the HIV-1 infection (termed HIV in the following) had already emerged in the 1940s through a viral change of host from animals (chimpanzees, Central Africa) to humans by genetic adaptation of the pathogen to the new host (Williams et al., 1983; Zhu et al., 1998).

Of the above human retroviruses, only HIV has attained global relevance. It infects cells of the immune system in the blood, lymphatic nodes and spleen. This takes place exclusively via direct contact with infected blood or other infected body fluids. The viral genome, which contains ribonucleic acid, is transcribed by viral reverse transcriptase and integrated as a provirus in the genome of the host cell. After HIV infection, the immune reaction of the organism follows a characteristic cyclical course marked by an interplay between virus and immune system. Here both the viral load and the number of immunocompetent cells in the blood vary intermittently (antigenic drift), while on the viral side characteristic shifts occur in the antigenic effect of the virus which are partially caused by the formation of HIV mutants (antigenic shift). Thus after infection an evolutionary process between virus and immune system determines the period that elapses between infection and the onset of symptoms of disease (latent period). Throughout this latent period, the immune system is increasingly weakened by a steady loss of immunocompetent cells. The immune response of the organism is increasingly circumvented by mutation and integration of the virus in the host genome. A crucial aspect is that the weakening of the immune system leads to an increase of so-called opportunistic infections by agents that are normally not pathogenic to humans but if untreated are 100% lethal to people suffering from AIDS (e.g. *Pneumocystis carinii*).

The HIV/AIDS pandemic is comprised of many regional epidemics. These differ considerably in terms of time of commencement, main transmission pathways and development of new infections. Widely differing damage potentials are thus apparent in different parts of the world (Table D 3.2-1). This is conditioned by social patterns of behavior (e.g. drug abuse, promiscuity) and - of fundamental importance - major differences in the capacity to educate the public and to implement self-protection measures. This is very clear for women in Asian and African countries. WHO estimates (WHO, 1997a) suggest that 30.6 million people are infected with HIV or already suffer AIDS worldwide. Of these, 68% live in Sub-Saharan Africa and a further 24% in South Asia, South-East Asia and Latin America. 41% of HIV-infected people are women.

Owing to exclusively anthropogenic factors, the propagation pattern of the disease is country-specific, regionally different and modifiable. Apart from transmission by banked blood, it is almost exclusively transmitted by unprotected sexual contacts (in particular where there is promiscuity and prostitution) and by the joint use of injection syringes. In North America and Europe, mainly high-risk groups have contracted the disease in which these patterns of behavior often occur in combination (homo- and bisexual men, drug addicts). In North Africa, by contrast, due to regional socio-cultural features one or several of these forms of behavior are also widespread among parts of the heterosexual population (WHO, 1997b).

In Europe and North America, the number of people infected with HIV and suffering AIDS peaked at the end of the 1980s, leveling off in 1993/94 at a prevalence of 0.3–0.6% (Fig. D 3.2-1). This success was brought about by preventive measures such as education and advice on risks and protection options, medical care for those affected, effective treatment of secondary diseases and infections and strict controls on blood products. The present course of the pandemic in Europe and the USA illustrates that the spread of the virus can in principle be contained by means of deploying and further developing these measures. Since 1996, mortality has even fallen distinctly in Europe and North America. This is certainly mainly due to the introduction of effective therapies, in particular therapies combining chemotherapeutic agents with protease inhibitors. However, infection incidence is not dropping to the same degree. Indeed, in the USA, for instance, the share of heterosexual transmission is slowly rising (Fig. D 3.2-2).

In a global perspective, the damage caused by the HIV/AIDS pandemic is on the rise. With an estimated 16,000 new infections per day, more than 40 million cases are forecast for the year 2000 (WHO, 1997a). The epidemic is currently coming to a head in Sub-Saharan Africa (Table D 3.2-1). The infection rate among adults there has risen to 7.4%. In individual countries such as Uganda, severe societal changes have already occurred (age structure, decimation of the economically and socially active population). In some countries, AIDS has caused life expectancy to plummet, for instance by 22 years in Zimbabwe (UNDP, 1998). In the most densely populated regions of the world, such as South Asia, South-East Asia and China, the infection only began to spread at the end of the 1980s, and is developing a great regional dynamism. In Vietnam, for instance, the prevalence of HIV escalated within two years from 1% to 44% in certain groups of society. In India, the number of HIV/AIDS cases is currently estimated at 3–5 million. Among truck drivers in Madras, who systematically infect themselves through prostitutes, a growth in the infection rate was observed from 1.5% in 1995 to 6.2% in 1996.

There are three prime biological risk amplifiers for HIV infection: latency, genetic instability and co-infection.

Table D 3.2-1
Regional HIV/AIDS statistics and attributes.
Source: UNAIDS, 1997

Region	Outbreak of epidemic	HIV/AIDS infected adults and children	Prevalence among adults [%]	Proportion of women infected [%]	HIV-negative children having lost one or both parents to AIDS	Main transmitters
Africa/ Sub-Sahara	late 1970s, early 1980s	20,800,000	7.4	50	7,800,000	Heterosexuals
North Africa, Middle East	late 1980s	210,000	0.13	20	14,200	Intravenous drug users and addicts
South and South-East Asia	late 1980s	6,000,000	0.6	25	220,000	Heterosexuals
East Asia, Pacific	late 1980s	440,000	0.05	11	1,900	Intravenous drug users and addicts; homosexuals
Latin America	late 1970s, early 1980s	1,300,000	0.5	19	91,000	Homo- and heterosexuals
Caribbean	late 1970s, early 1980s	310,000	1.9	33	48,000	Heterosexuals
Eastern Europe, Central Asia	early 1990s	150,000	0.07	25	30	Intravenous drug users and addicts
Western Europe	late 1970s, early 1980s	530,000	0.3	20	8,700	Intravenous drug users and addicts
North America	late 1970s, early 1980s	860,000	0.6	20	70,000	Homo- and heterosexuals
Australia, New Zealand	late 1970s, early 1980s	12,000	0.1	5	300	Homosexuals
Total		30,600,000	1.0	41	8,200,000	

Latency

Due to its 10-year latency (the period between HIV infection and clinical manifestation of the AIDS syndrome) the virus is able to spread unnoticed if HIV infestation is not monitored adequately (a transcontinental prevalence of HIV already existed long before the first epidemiological registration of the AIDS syndrome). It follows that exclusively registering the incidence of AIDS cases while not registering HIV infections in the latency stage leads to a greatly delayed registration of new epidemiological developments. The 'time window' between infection and detectability of antibodies amounts to several weeks. This is why schemes for monitoring banked blood and blood products that are based on detecting HIV antibodies continue to be unable to promise absolute safety.

Genetic instability

The genetic instability of the retroviruses is an outcome of their propensity for aberrations in the two central transcription processes in the infection cycle (reverse transcription of the RNA genome and transcription of proviral DNA) and of DNA recombination events among subtypes within an infected organism. The following brief listing of the consequences that genetic instability has for the persistency of the virus illustrates impressively that high priority continues to need to be given to basic retrovirus research. Genetic instability permits

- Rapid adaptation of the virus to changing selection pressure;
- Circumvention of effective long-term natural immunity through rapid changes of immunogenic viral epitopes (components of the virus membrane that stimulate the immune system);
- High probability of the formation of resistance against antiviral drug therapies, and hampered development of vaccines;
- Transmission across the species barrier (e.g. between apes and humans);
- Further development of the virus and formation of new subtypes with negatively modified characteristics (e.g. increased virulence through changed or extended cell specificity).

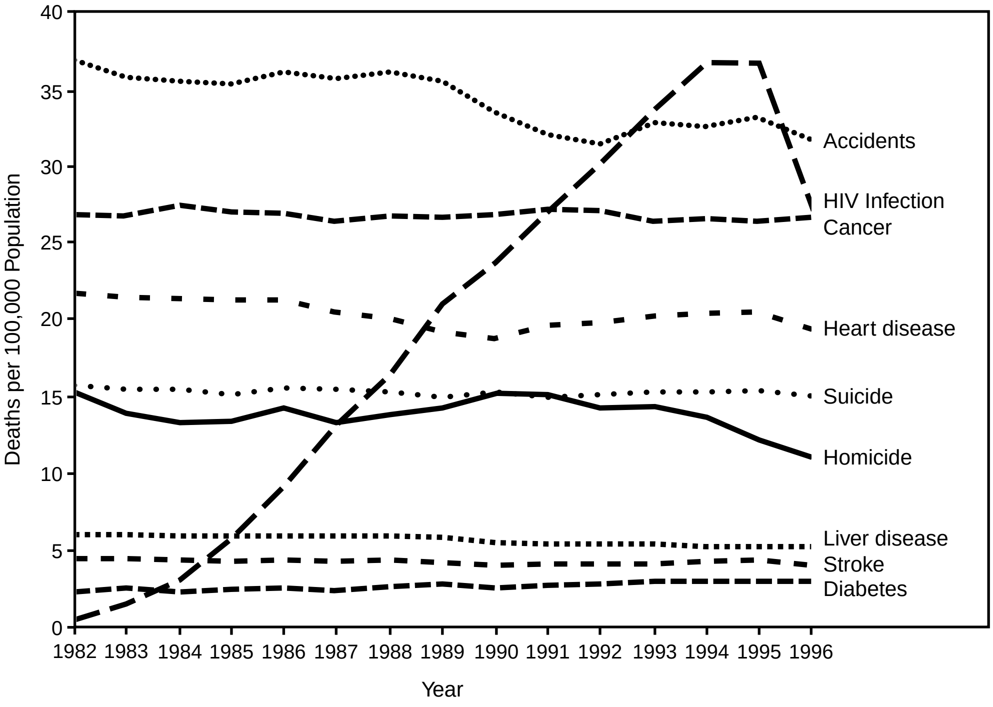


Figure D 3.2-1
Development of deaths caused by HIV in the USA (men, age group 25–44).
Source: CDC, 1996

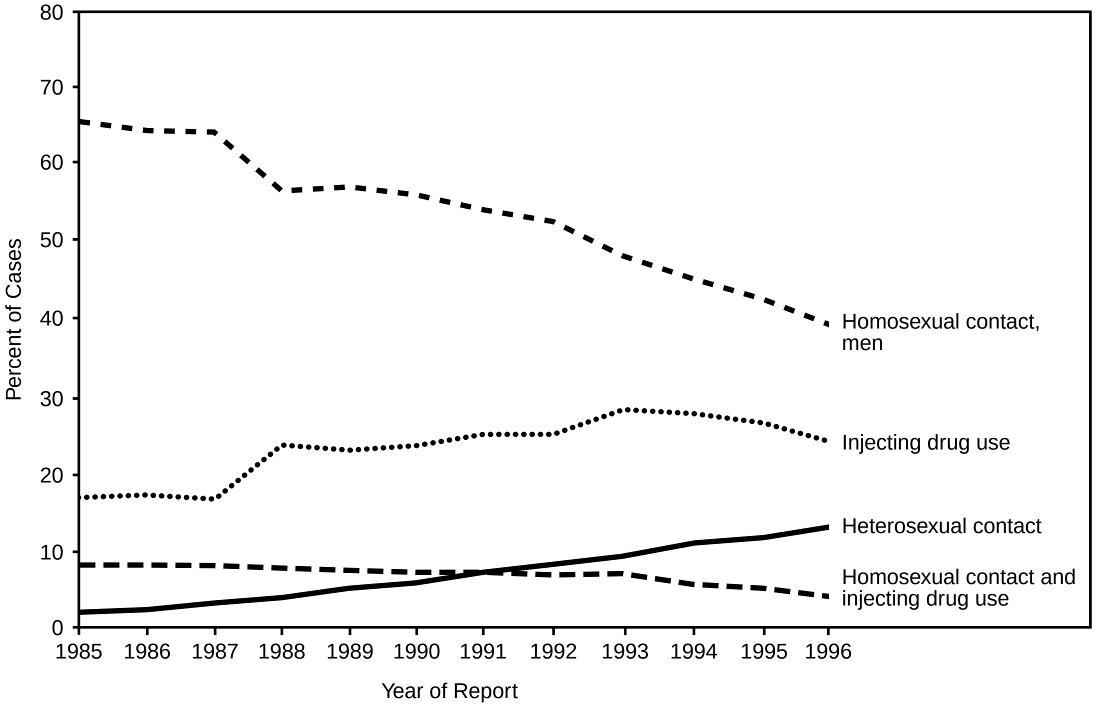


Figure D 3.2-2
Development of HIV infections in various risk groups in the USA.
Source: CDC, 1997

Co-infection

The weakening of the immune system by HIV leads not only to an increase of opportunistic infections, but also favors 'old' pathogens, particularly tuberculosis. This is the most frequent cause of death of HIV-infected individuals (40% in North Africa, and 30% of all HIV cases). Two thirds of all tuberculosis cases in the world are located in Asian countries, with their large conurbations and rising levels of HIV infection. In fact, here the two epidemics combine synergistically, which not only considerably amplifies the magnitude of damage of HIV infection, but is presently also massively influencing the epidemiology of tuberculosis.

It has recently become apparent that the strong spread of conventional sexually transmitted diseases (STDs), e.g. syphilis and gonorrhea, enhances the probability of HIV virus transmission by a factor of 10–100. Owing to their inadequate treatment in developing countries, STDs thus constitute a key mechanism in the rapid heterosexual spread of AIDS. A study in Mwanza, Tanzania, observed a 42% drop in the rate of new HIV infections in a rural population thanks to the early treatment of STDs (WHO, 1997b).

The anthropogenic risk amplifiers lead to a high division rate, with a corresponding selection pressure among HIV subtypes. This in turn harbors a biological risk potential, for in view of the known mutagenicity of the virus it is possible that new subtypes can form with modified virulence behavior. Such a scenario also entails the possibility of new waves of infection in countries where the incidence of infection has currently been brought under control.

Measures

The present anti-retroviral *drug therapy* is undoubtedly a breakthrough, as it considerably reduces the number of opportunistic infections. It costs at least US-$ 12,000 per person annually and is thus not accessible to most of the HIV-infected people of this world. In a North African country, in which typically approximately 10% of the population is infected with HIV, only about US-$ 10 is spent for health care per inhabitant and year. At the current cost of therapy, treating the HIV-infected inhabitants alone would exceed the health budgets of these countries by a factor of more than 100.

Thanks to extensive epidemiological studies, the transmission pathways of HIV/AIDS are now well known and an array of effective preventive measures have proven themselves in practice. However, in many countries a lack of effective implementation remains. In India, health system expenditure is expected to rise by 30% by the year 2010 if the spread of HIV infection continues at its present rate (Ainsworth, 1998). Evidently the way in which the HIV/AIDS risk is handled differs widely around the world and requires regionally appropriate strategies. It is essential that states set priorities. Developing countries should concentrate their scarce resources for containing the AIDS epidemic upon *prevention*, particularly upon developing efficient infection prevention. Here tools of global relevance include statutory regulations aimed at prevention, educating the public about the risks of infection and the options for protection in order to preclude new infection, and advice aimed at strengthening the responsible behavior of individuals. Programs that have concentrated preventive measures upon those at a high risk of transmission have proven highly effective (e.g. use of condoms among prostitutes in Nairobi or Thailand) and should therefore have priority (Ainsworth, 1998). Epidemiological surveillance of the HIV/AIDS epidemic that identifies new and old high-risk groups and is continuous and as comprehensive as possible is an absolutely essential precondition to effective countermeasures of this kind.

The Centers for Disease Control and Prevention (CDC) in Atlanta, USA offer an excellent example of possible nationally and internationally institutionalized surveillance tools with regard to new and already existing epidemiological risks. CDC routinely collates surveillance data from medical reports that it receives from local health authorities and checks data quality by comparing different sources. It is thanks to CDC that it was rapidly understood that the newly observed symptoms were in fact a spreading epidemic syndrome. CDC defined AIDS in 1981 on the basis of the occurrence of rare opportunistic illnesses and infections (e.g. *Kaposi's* sarcoma and *Pneumocystis carinii* pneumonia) in groups of young, homosexual men on the American west coast. Mandatory registration was introduced in the USA for newly diagnosed AIDS cases, involving the preparation of uniform case reports. These contain data on demography, the name of the diagnosing laboratory, the risk history and clinical status of the patient and information on therapy. Studies have shown that 90% of all illnesses meaning AIDS under the CDC definition are actually registered. On the basis of the almost complete epidemiological data and the transmission pathways deduced from these, the public health services of the USA were already able to issue recommendations for prevention of infection in 1983.

The example of the CDC illustrates clearly the key position that attaches to specialized, internationally operating surveillance institutions that use the analysis of epidemiological data at a high scientific level and with high efficiency to exercise control functions. Such institutions are successful in controlling global risks if they form an interface between basic scientific research and national and supranational authorities.

In structurally weak countries, in particular, developing and implementing the epidemiological surveillance of preventive measures and research projects requires support by international institutions or bilateral assistance. The global monitoring of the HIV/AIDS pandemic is conducted by WHO and UNAIDS (Joint United Nations Programme on AIDS). Epidemiological data are notified by regional offices and by the health ministries of the member states. Under WHO's Global Programme on AIDS (GPA), financial assistance was provided for activities against AIDS in more than 150 countries. The objectives were to establish national AIDS programs, to improve management capacities and to coordinate international research tasks. The program terminated formally with the establishment of UNAIDS in 1996. WHO supports and collaborates with UNAIDS through its Office of AIDS and Sexually Transmitted Diseases (ASD), which was also established in 1996. UNAIDS further receives support from UNDP, UNICEF, UNESCO, UNFPA and the World Bank.

WHO's global epidemiological surveillance is dependent upon the completeness and reliability of the data delivered by the national monitoring systems. Estimates of infection rates in regions without effective infectious disease surveillance are based on model calculations which, in turn, are based on information from countries which have relatively comprehensive data. WHO nonetheless found itself compelled to correct its estimate of HIV/AIDS infections for the year 1996 upwards from 22.6 to 27 million and its estimate of new infections in 1996 from 3.1 to 5.3 million. This was mainly due to the erroneous estimate of the development in Sub-Saharan Africa. The model calculation had been based on relatively extensive data from Uganda, where in past years infection rates have been brought under control by means of successful preventive measures. However, the calculations were confounded by the situation in Nigeria and South Africa, where robust data have only recently become available (WHO, 1997a). These events illustrate that the collection of complete epidemiological data is indispensable for high-quality risk characterization.

D 3.2.2
'Hong Kong bird flu' (avian influenza)

Influenza viruses comprise a large group of different subtypes, which cause grippal clinical pictures with infections of the upper respiratory tract through to severest lethal pneumonia. Humans are infected by types of the influenza A and B viruses. Influenza A further infects pigs, horses, marine mammals and birds. Influenza A subtypes differ by structures on their surface that have been identified biochemically as glycoproteins. The influenza subtypes are named according to these glycoproteins, which function as binding proteins for the attachment of the virus to the body cells that it infects. They thus determine the spread of the pathogen in the organism, its virulence and consequently its hazard potential. The hemagglutinins H1–H15 and neuraminidases 1–9 are such glycoproteins. In birds, all of these types can lead to infection. In humans, epidemics are caused by the influenza A subtypes H1, H2 and H3 and by influenza B. The subtypes H5 and H7 occasionally lead to very severe epidemics in birds, particularly chickens and turkeys.

Influenza A infections have a relatively high catastrophic potential, as they very regularly lead to major epidemics or pandemics at intervals of about 15–20 years. In the past these have been associated with a widely varying and partly high mortality rate, and thus constitute a major risk potential. Larger epidemics have been attributed retrospectively to different, mostly completely unknown influenza A subtypes. The influenza A H3N2 subtype was thus identified for the first time in the 1968 epidemic in Hong Kong. Influenza A H2N2 was identified and characterized for the first time as a causal agent in connection with another epidemic in 1957. Phylogenetic studies have shown that these newly formed subtypes came from avian influenza A and entered the human population after recombination with a human influenza virus strain (Webster and Laver, 1972; Scholtissek et al., 1978). The currently favored hypothesis for the emergence of the pandemic influenza viruses of 1957 and 1968 proceeds from the assumption that pigs served as a 'cauldron' for recombination between avian and human influenza viruses. In the major epidemics of the past, the recombination process with a human influenza virus has often been a precondition of effective human-to-human transmission.

The most severe influenza pandemic, viewed by some authors as the worst pandemic in human history, took place in 1918 ('Spanish' influenza) and claimed about 20 million lives. In 1997, studies of conserved lung tissue using the methods of modern molecular biology were able to identify retrospectively the responsible pathogen as an influenza A subtype. It is assumed that this virus entered the human population without recombination with a human influenza virus (Taubenberger et al., 1997).

The following events have led to the realization that avian influenza subtypes can directly infect humans without an intermediate recombination step necessarily needing to take place. In May 1997, an H5 subtype was isolated from the respiratory tract of a fatally infected child in Hong Kong. Shortly before, it had become known that influenza epidemics had occurred on chicken farms in the area. A comparison of the molecular biology of viruses isolated from chickens with that found in the child showed that the gene sequences were identical apart from three amino-acid positions. It followed that the virus that had led to lung failure of the child was genetically identical to an H5 avian influenza virus (Claas et al., 1998). In the autumn of 1997, a further 16 cases of severest pneumonia became known in which the virus isolates were of the H5 type (Marwich, 1998; Yuen et al., 1998). It was thus clear that, owing to their capacity for adaptation, H5 avian influenza A subtypes can in certain cases cross the species barrier between birds and humans. As a consequence of this finding and in view of the fact that H5 subtypes were detected in 10% of the animals on sale, all poultry in Hong Kong was culled. The fact that no further cases have yet occurred supports the assumption that fortunately so far the pathogen is only transmitted from animal to human but not from human to human.

Which preconditions must be in place to ensure such an efficient risk assessment and management effort as in the case of the 'Hong Kong flu' outbreak? A crucial element was the rapid action of an expert team deployed by CDC in consultation with local authorities. Here, as in the identification of the causes of AIDS, rapid success was brought about by the early involvement of specialized scientists from the US disease surveillance authority, with the epidemiological studies conducted immediately by this team, using state-of-the-art scientific methods on site. For the timely risk management of infections with new pathogens, it is urgently recommended that such tools are maintained in readiness in close cooperation with basic research.

The small H5 avian influenza epidemic in Hong Kong in 1997 described above was characterized by high lethality (approximately 40% of cases leading to death), similar to the 1918 pandemic. Further influenza pandemics are inevitable, the probability of occurrence of genetic recombination of a highly virulent avian virus with a human influenza A subtype is high (Walker and Christie, 1998). It must be expected in such a case that human-to-human transmission is major and the catastrophic potential is very high. Unlike in 1918, such a virus would now encounter a highly mobile global population that is more concentrated in urban areas. These factors must be expected to act as anthropogenic amplifiers, leading to damage of global magnitude.

Presently, dealing with influenza epidemics can only consist of preventive measures, i.e. vaccination targeted specifically at the relevant subtypes. One vaccine against H1 strains is currently available, which can naturally only afford protection against a limited spectrum of the human pathogenic influenza A subtypes. There is at present no efficient therapy for newly emerging subtypes, because antiviral chemotherapeutic agents are ineffective and there are no vaccines against these subtypes. In this situation, pandemics with new subtypes can only be countered by isolating infected individuals and eliminating potential reservoirs (e.g. infected poultry). The facts set out above throw in stark relief the great importance of researching infection immunology and developing vaccines. For instance, it is recommended that vaccines against influenza H5 strains be developed immediately (Belshe, 1998).

D 3.2.3
Bovine spongiform encephalopathy/new variant of Creutzfeldt-Jakob disease

Various forms of *spongiform encephalopathies*, characterized by certain morphological changes in the brain, are known in humans and in animals. Six different forms occur in humans, of which the most recent was described for the first time in 1996 as a new variant of Creutzfeldt-Jakob disease (nv-CJD). Spongiform encephalopathies are partially hereditary, while a partially infectious transmission mode has been identified. A disease transmitted by cannibalism in New Guinea (Kuru) and the transmission of hereditary human spongiform encephalopathies to apes are examples of their infectiousness (Masters et al., 1981). Common to these diseases is the special nature of the infectious agent, which has not yet been fully clarified. It is now assumed that this is not a conventional virus, but a modified form of a normal protein structure, a so-called prion. Prions are proteins highly resistant to thermal and chemical influences, and in their normal form are natural components of nerve cells. The human prion protein is a glycoprotein composed of 253 amino acids. It is expressed on the cell surface and its function is not known. Interestingly, mice in which the gene for the normal prion protein is deactivated cannot be infected with infectious prions. The infection process is based on a change in the conformation (chemical structure) of the prion proteins (conversion). There are partial species barriers to infections; for instance, mouse prion protein can be converted (infected) by the infectious form of the mouse prion protein, but not by the infectious isoform of the hamster prion protein. In rare cases, the conversion process can also occur as a spontaneous event that does not involve an externally introduced infectious prion. This happens in hereditary prion diseases among family members who already carry a mutated prion protein.

Prion diseases, also termed transmissible spongiform encephalopathies (TSEs), are overall very rare diseases. They have attracted greater public interest due to the emergence of the new bovine spongiform encephalopathy (BSE) in Great Britain. The Council has selected BSE as a topic of the present report because its emergence typifies the risks associated with intensive livestock farming. Moreover, the way in which this new disease was initially dealt with is an instructive example of the consequences of a perhaps inappropriate risk estimation.

BSE can be transmitted experimentally to many mammal species, including apes (Lasmezas et al., 1996), in which it produces a clinical profile similar to that described for the first time in 1996 in humans as nv-CJD. Unsteady gait and psychiatric problems predominate at the onset of the disease, later followed by dementia and muscle spasms. The pathological profile of the spongiform encephalopathy of these animals also corresponds to that of nv-CJD. Experts do not, however, presume that these observations already provide proof of the assumption that nv-CJD is the human form of BSE. More convincing are the findings of transmission experiments of spongiform encephalopathies of various animal species (sheep, ox), of classic CJD and of nv-CJD to genetically identical mice. These have shown that the pathological and clinical changes produced in the animals were only identical for the transmission of BSE and of nv-CJD. Leading scientists therefore assume that nv-CJD and BSE are caused by the same strain of infectious agents. This moreover causes the spongiform encephalopathies in cats, and causes other new diseases in other ruminants that have only been observed for a few years in Great Britain.

The first case of BSE in cattle was reported by the British government in November 1986 (Wells et al., 1991). In the period from 1988 to 1997, more than 170,000 such cases were confirmed (Anderson et al., 1996). Before the entry into force in 1989 of the specified bovine offals (SBO) ban, which prohibited feeding meat and bone meal to ruminants, some 440,000 to 580,000 infected animals are assumed to have been utilized in Great Britain for human consumption and at least a further 250,000 by the end of 1995. At that point the number of BSE cases, which had been in decline since 1993, dropped markedly (Table D 3.2-2). It is presently estimated that in England the meat of 200–300 infected animals that display no symptoms of disease is marketed annually. Only small numbers of BSE-infected cattle have been notified in other countries, with Switzerland leading the table with some 250 animals before 1997. However, in 1998 13 newly infected animals were notified by October in France and 67 in Portugal. Serious indications of a greater spread of the BSE pathogen have recently emerged in Portugal. In view of plain infringements of safety regulations in Portugal, the European Commission found it necessary to impose an export ban upon both beef and live cattle from that country.

Table D 3.2-2
Confirmed BSE cases in Great Britain.
Sources: MAFF, 1996, 1998

Year	BSE cases
1988	2,469
1989	7,137
1990	14,181
1991	25,032
1992	36,680
1993	34,370
1994	23,945
1995	14,300
1996	8,016
1997	3,373

Epidemiological data on the Creutzfeldt-Jakob disease have been surveyed since 1990 in Great Britain, and since 1992 or, respectively, 1993 in other European countries. In Germany, a task force supported by the Health Ministry has been working on the epidemiology and pathology of CJD since 1993. This disease has been notifiable in Germany since 1994. Attempts to cross-validate the register of notified cases kept by the Robert Koch Institute with the ongoing epidemiological studies are difficult for reasons of protection of data privacy. Data produced by a concerted action of Germany, France, Great Britain, Italy and the Netherlands launched by the EU in 1993 are shown in Table D 3.2-3.

In March 1996, the Creutzfeldt-Jakob Surveillance Unit in Great Britain reported ten cases of a new variant of CJD (Will et al., 1996). One case was observed in France. Although not all cases were published in the scientific press, there were a number of further cases reported confidentially by the CJD Surveillance Unit in Edinburgh to the group working together under the EU program. According to this information, a total of 29 cases of nv-CJD established by autopsy have been registered in Great Britain. In Germany no cases of nv-CJD have yet been observed.

Due to uncertainties that continue to prevail in important points, not even order-of-magnitude statements can be made as to how many cases of nv-CJD are to be expected in England in the future. If, as the majority of experts now assume, nv-CJD can be triggered by transmission of BSE to humans, then at least in exposed countries no prediction is possible because the incubation period is unknown. However, it can be said that if this assumption is confirmed

	Germany	France	Italy	The Netherlands	Great Britain
1993	0.65	0.78	0.54	0.87	0.78
1994	0.76	1.04	0.53	1.0	1.02
1995	0.98	1.07	–	0.4	0.77
1996	0.87	1.18	0.76	–	0.67

Table D 3.2-3
Incidence of the Creutzfeldt-Jakob disease in European countries (cases per year and million inhabitants). The figures released by Great Britain do not include the new-variant cases.
Source: Kretzschmar, personal communication

many people may contract nv-CJD, as some 750,000 infected animals have been processed for human consumption. This is why in 1998 the European Union provided considerable funding for risk evaluation.

Neither the infectiousness nor the clinical behavior of the new variant of CJD have yet been researched adequately to estimate with sufficient certainty the number of future infections. Evidently a very specific genetic constellation (methionine homocygosity at codon 129 of the gene) must be present for individuals to contract nv-CJD. Other than in the classic form of CJD, the pathogen of nv-CJD is detectable in the adenoid tonsils, lymph nodes and spleen. It is thus not improbable that the infectious nv-CJD prion is also present in the blood - perhaps only transiently. Practically nothing is known about the pathogen density in other organs. It must be noted that those who have contracted nv-CJD up until now have all been very young and have belonged to that segment of the population that frequently donates blood. If it should transpire that the nv-CJD pathogen is actually present in larger densities in the blood or in other tissues and organs, alarming consequences of epidemic magnitude cannot be excluded, e.g. through blood transfusion.

In Germany, the Health Ministry has supported, since 1993 a study program on the epidemiology, early diagnosis and molecular pathology of human prion diseases. Cases in which infection is suspected are examined clinically by a group of specialized doctors, the prion gene is analyzed and after death of a patient efforts are made to carry out an autopsy. An upsurge in the incidence of CJD or the appearance of a new variant would thus most probably be discovered, but a certain diagnosis of CJD is presently only possible by means of an autopsy of the brain. A further difficulty is that in Germany the proportion of autopsies is very low and is continuing to drop. It is therefore highly probable that despite the activities of the ministry-supported working groups a large proportion of any patients contracting nv-CJD would not be discovered, so that a major uncertainty factor continues to remain.

It is noteworthy here that in the USA a deficit of specific medical training programs on infectious diseases has currently been identified. There is particular concern over deficiencies in infection pathology, which is impacting negatively upon ongoing epidemiological studies. This has led to the establishment of a new section for infection pathology in Atlanta and to the expansion of existing facilities (Schwartz, 1997). In order to effectively counter the future challenges of 'new' and 'old' infectious diseases, it is recommended that such activities are extended and that medical training in all related branches is strengthened.

On some points, leading scientists have leveled harsh criticism at the way in which the BSE/nv-CJD risk has been managed up until now. In England, research efforts were meager until 1997, only £ 38 million having been expended by the end of that year. For culling cattle, in contrast, £ 1,500 million were spent in 1997 alone. Unfortunately, no commercially available BSE test yet exists that is suitable for examining living cattle or humans. The same applies to diagnostics during the incubation period - here a diagnostic statement can be made neither for freshly slaughtered nor living animals. Diagnostic approaches have only recently emerged, such as the development of a western blot test for detecting infected brain tissue. An EU program endowed with ECU 21.9 million was adopted in February 1998 with the aim of remedying the diagnostic deficit. In total, the EU committed ECU 50 million to these issues in its fourth Framework Programme for Research. In Germany, funds amounting to some DM 15 million have been granted for researching prion diseases in the 1993–2000 period.

In light of the thus limited options for action, the German authorities have ultimately relied on cattle owners and veterinarians to notify presumed BSE cases. This approach can of course only be as good as notification morale is. Furthermore, primary examinations are presently not centralized but are carried out by the authorities of the individual German states (Länder) so that it is hard to check the completeness of examinations. To this day, the densities in which the pathogen occurs in the different organs of BSE-infected animals is scarcely known. Germany has largely left it up to Great Britain to remedy these deficits in knowledge. In Great Britain, there has long been a state research monopoly, which has until now yielded inadequate results. It must be asked whether, when balancing the health of entire nations against the highly economically determined interests of Great Britain, the health policy interests of other EU member states should not have been given greater priority. In 1990 it was suggested that Great Britain determine pathogen densities in different cattle organs by means of inoculation in calf brains; it has taken until 1998 for such experiments to be carried out.

A further point of criticism is that BSE could be imported from third countries via large volumes of BSE-contaminated feedstuffs, and in some cases also infected beef slaughter products, sold legally or illegally to European or other countries. A scenario in which relatively cheap, potentially hazardous feedstuffs were bought up in the early 1990s by Eastern Europe and fed to animals there is conceivable and is considered by many experts to be quite probable. It is not possible to assess conclusively the extent of the hazard posed to the populations of Eastern European and also EU countries. It is similarly uncertain whether BSE was transmitted from cattle to sheep through feeding infected bone meal and which hazards this may pose.

An open, alternative way of handling new health problems and a timely promotion of independent research are fitting consequences that every government should draw from the BSE epidemic.

D 3.3 Assignment to the risk classes

HIV/AIDS and influenza A: Cyclops-type risks with transitions to Cassandra

HIV/AIDS is an impressive example of how a formerly completely unknown risk (i.e. of the Pandora type) can be moved relatively rapidly by means of continuous improvement of knowledge into the Pythia class and from there to the Cyclops and partially also Cassandra classes. The magnitude of damage becomes increasingly assessable, the overall certainty of assessment higher. This has been the outcome of an exemplary cooperation between basic (retrovirus research for 60 years) and applied research with the highly efficient surveillance of epidemiological data such as performed by the CDC. Experience collated by means of internationally coordinated data survey and infection containment measures contributed rapidly to the precision of the risk perception of the HIV/AIDS pandemic. The impacts of the pandemic, although highly variable in terms of ubiquity, can now be viewed as very large in total. Persistency is also very high, possibly even permanent, if it should prove impossible to eliminate the virus. The extent of social damage affects several generations, at least in the areas with high levels of infection, and underscores the urgent need to set state priorities in infection control. If politically underestimated, AIDS can therefore quite well assume aspects of the Cassandra class of risk. The range of the pandemic is essentially global, but effective measures are available that permit drastic containment, at least at the regional level. It is essential to disseminate these containment measures in order to move the risk into the normal area. As long as this does not succeed, AIDS is a risk that in certain aspects can still be assigned to the Pythia class. For instance, mutagenicity leaves the possibility of changes in the pathogen that can lead to an altered pattern of infection with other transmission pathways. The probability of occurrence of such an HIV variant, with the consequence of an even greater magnitude of damage, is unknown.

On the basis of historical experience and recent findings in molecular genetics, the probability of occurrence of a highly virulent influenza A infection, e.g. of the ‘Spanish’ influenza type, can be assessed relatively accurately. The occurrence of such an event is conditioned by biological factors, i.e. the risk potential is partially biologically determined. If new virus types emerge that are transmitted from human to human, a very large magnitude of damage is possible. However, the probability of this occurring cannot be stated. The risk potential for severe damage is certainly increased by human factors (high mobility, urban concentration). With its currently rather slight mobilization potential in the public, the political relevance of influenza infections does not entirely fit to its risk potential. This risk thus also has transitions to the Cassandra class.

BSE/nv-CJD: A Pythia-type risk

In exposed areas such as England, BSE/nv-CJD must currently be assigned to the Pythia class of risk, in view of the high uncertainty attaching to the probability of a large magnitude of damage (Table D 3.3-1). Although the behavior leading to the risk (feeding infected carcass meal) has probably ceased in the meantime (with the exception of Portugal), the extent of impacts cannot be assessed with certainty. This is due to a number of gaps in knowledge and a high, ultimately still unknown latency. The uncertainty attaching to the probability of major damage occurring and to the magnitude of damage is an outcome of the long latent period between infection and outbreak of disease. In this, it is similar to the early phase of AIDS. In this phase the disease spreads further (unrecognized). In the case of BSE, the disease is introduced widely to the human food chain and possibly also spreads to other animal species (e.g. from cattle to cats or, this is still unclear, from cattle to sheep). These anthropogenic factors make the estimation of

Table D 3.3-1
Application of the evaluation criteria to the risk potential of BSE (in England). This belongs to the Pythia risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

the probability of occurrence of a damage that has distinctly supranational dimensions all the more uncertain. Although a major rise in the incidence of nv-CJD has not yet occurred, risk evaluation for transmissible spongiform encephalopathies presently remains uncertain. The EU therefore set up a program on this issue in March 1998 with ECU 3.5 million grant funding. The still largely complete lack of medical data on human nv-CJD is a further major uncertainty factor that clearly places this risk in the Pythia class in exposed areas. Human-to-human infectiousness, with a possible transmission by blood, is still unknown and would add a further dimension to the damage. If, by contrast, it should transpire that the infectiosity of the pathogens is strictly linked to rare genetic preconditions then a much smaller magnitude of damage can be assumed. This constellation calls for an approach that is restrictive for the time being. There is a need for continuous and meticulous epidemiological surveillance and rapid further development of both evaluation tools (e.g. testing methods) and knowledge of infection mechanisms.

D 4.1
Introduction

This section discusses risks that proceed from living organisms or result from biological processes and reactions and that impact upon humans and other organisms. These risks concern the entire spectrum of life, from microorganisms through to humans. In the following we can therefore only treat some representative areas of concern and these only from the aspect of a global typology of risk. Risks that specifically concern human health have been treated separately in Section D 3.

Land use changes and the associated destruction and fragmentation of habitats are currently the prime cause of the continuing loss of biological diversity (Heywood and Watson, 1995). The risks that result from this for humankind and nature (such as genetic erosion, the extinction of species and varieties and the worldwide loss of ecosystem functions) shall be treated in depth in the Council's 1999 report. In the following risk classification, too, great importance attaches to the loss of biodiversity, both as a possible form of damage and as an amplifier of risk.

It is not always possible nor indeed purposeful in the context of a risk assessment to distinguish strictly between natural biological risks and such risks that result from the utilization of biological resources. We may say this in light of the circumstance that almost all of the biota of the world are modified directly or indirectly by human action or are at least influenced (Fig. D 4.1-1). Today, there is no part of the planet on which the anthropogenic influence is not noticeable: in a global perspective, humankind has become the dominant factor in the biosphere (Vitousek et al., 1997).

Moreover, it is only through human agency that biological risks attain globally relevant magnitudes. For instance, invasion by alien species becomes a global risk because the native species are put at risk in many regions of the world with differing species combinations and because this is triggered by international trade and transport.

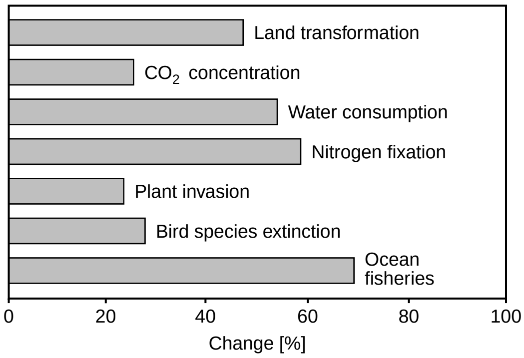


Figure D 4.1-1
Human intervention in the biota of the Earth. The figure shows anthropogenic changes in important compartments of the biosphere as a percentage of the pristine state (global transformation of land surfaces, change in atmospheric CO_2 concentration, worldwide exploitation of available surface freshwater, terrestrial nitrogen fixation, introduced plant species in Canada, bird species that have died out worldwide over the past 2,000 years, overfished or extinguished marine fish stocks).
Source: Vitousek et al., 1997

For the following risk classification, two representative risks have been selected that are ultimately the outcome of altered interactions (e.g. competition, predator-prey relationships) between anthropogenically influenced species and species in indigenous communities:

1. Ecological explosions of species and populations (pathogens, pests, weeds, alien species).
2. Release and marketing of genetically modified plants, in which humankind has not only broken through evolutive and geographical barriers between organism kingdoms (microorganisms, animals, plants) but has also implemented new DNA sequences.

D 4.2
Damage potentials, present management and characterization of globally relevant biological risks

D 4.2.1
Risks posed by anthropogenically influenced species, with particular consideration of biodiversity loss

D 4.2.1.1
Loss of biological diversity, stability and ecosystem functions

Observations of food webs suggest a positive connection between species diversity and the stability of communities in ecosystems, i.e. their capacity to withstand exogenous perturbances (such as anthropogenic exploitation, eutrophication, fire). However, this connection cannot be generalized, as there are examples of both stable species-poor and unstable species-rich systems, and species diversity changes with the degree of disturbance (Begon et al., 1996). The Intermediate Disturbance Hypothesis developed by Connell (1978) is now the widely favored hypothesis and is currently being tested experimentally in ecosystems. This posits that the largest number of species is reached if the magnitude and frequency of disturbances have intermediate values; extreme values lead to low numbers of species. The connection between disturbance frequency and magnitude on the one hand and species diversity on the other is thus not linear. Complexity – the number of structures, species and interactions – appears to be more important for the stability of biotic communities. Ultimately, the connection between stability and complexity is determined by the type, intensity and frequency of the disturbance on the one hand and the specific adaptations and capabilities of the affected species on the other. Furthermore, different levels of the concept of 'stability' need to be differentiated (Pimm, 1991): a distinction is made between constancy (steadiness), resistance (inertia vis-à-vis disturbances) and resilience (elasticity; the speed of return to the initial state after a disturbance). For the purposes of risk assessment, it is important to note that under stable environmental conditions complex communities will tend to emerge that are sensitive to exogenous disturbances, while biotopes with relatively variable environmental conditions will tend to be colonized by simple, species-poor but robust communities. The latter may be said to be already adapted to exogenous disturbances. The anthropogenic use of biological resources therefore endangers complex ecosystems such as tropical rainforests or coral reefs more than simpler communities (e.g. beech forests in temperate zones).

Environmental conditions also affect reproduction strategies. Stable environmental conditions promote K-selected species (long-lived species, with late reproduction and a small number of offspring). Variable environmental conditions promote r-selection (short-lived species, reproducing early with a large number of offspring; MacArthur and Wilson, 1967). K-selected species are initially relatively insensitive to disturbances, but have a poor capacity to recover after disturbance. R-selected species have a poor capacity to withstand disturbances, but recover relatively rapidly (Begon et al., 1996; cf. on this also the CSR strategy after Grime, 1977). Multifarious anthropogenic disturbances – such as land use, fire or chemical inputs – are leading to a worldwide trend towards the one-sided promotion of r-selected communities with a capacity for rapid regeneration, and

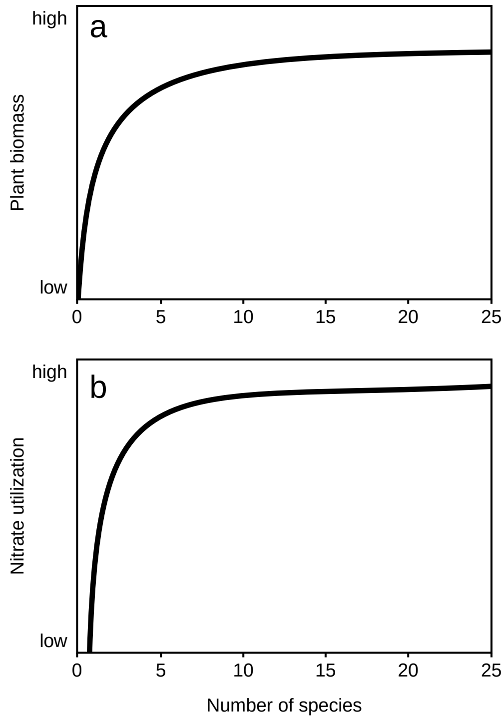


Figure D 4.2-1
a Vegetation biomass and **b** nitrate utilization as a function of the number of species. Diverse root structures in conjunction with changed biomass presumably lead to an improved utilization of the nitrogen resource. With regard to the risk of nitrate pollution of groundwater, it is particularly important that this function is not linear.
Sources: **a** adapted from Tilman et al., 1997; **b** adapted from Tilman et al., 1996

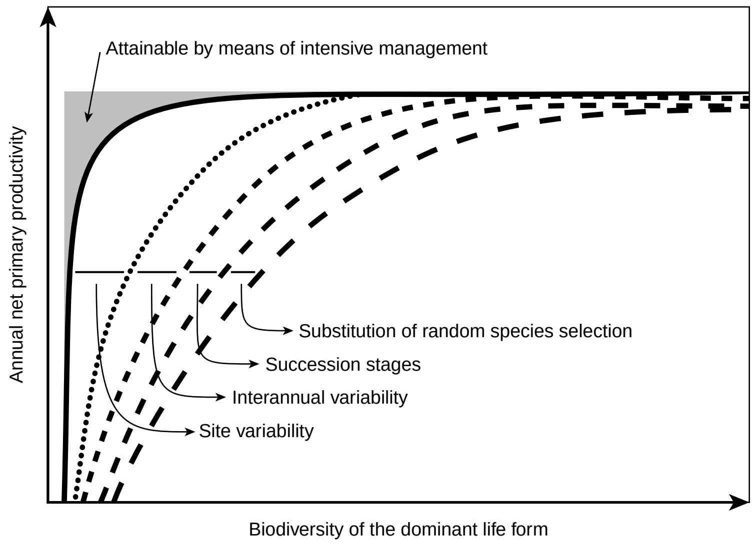


Figure D 4.2-2
Schematic illustrating the dependence of mean net primary production (NPP) upon the diversity of plant species or of genotypes in the dominant life form. The mechanisms may be combined. At a specific site and within 1 year, ecosystems with low diversity can be brought by means of intensive management to almost the same level of NPP as highly diverse ecosystems. Under natural conditions, climate and resource variability and succession dynamics after disturbances increase biodiversity, as a function of which NPP changes. The larger the entire spectrum of climate and site variability is, the more species or genotypes are requisite for a high NPP.
Source: Heywood and Watson, 1995

thus to a qualitative change in biological diversity ('homogenization' of communities).

This excursus in population biology may serve to illustrate that when analyzing and assessing biological risks, it is essential to consider species characteristics (e.g. genetic constitution), the complexity of ecological structures, the variability of environmental conditions and the type and intensity of disturbances.

To assess the risks posed by the use of biological systems, it is important to also consider the findings of the worldwide research efforts that are currently under way on connections between biodiversity and ecosystem function (e.g. Schulze and Mooney, 1994; Mooney et al., 1996; Chapin et al., 1998). Findings to date indicate that there is a relationship between species number and ecosystem functions, but that this is *not linear* (Fig. D 4.2-1–4). It is thus extremely difficult to assess risks presented by the effects of disturbances and species loss upon ecosystem functions. Peak levels of productivity can be attained with a small number of species (e.g. in agriculture), but this productivity is sensitive to variable environmental conditions. For a sustainable level of productivity that does justice to the spatial and temporal variability of sites and climate, a considerably larger number of species (or genotypes) is necessary (insurance hypothesis, Fig. D 4.2-2). Discontinuities in the relationship between species number and ecosystem functions can further result from the complex effects of the composition or frequency distribution of species (Fig. D 4.2-3). If a disturbance leads to the eradication of a dominant species (e.g. in the event of forest damage), then the impacts upon ecosystem functions are far larger than if a rare species (e.g. an orchid) is absent. If, however, a keystone species (a species having a key function in the ecosystem) dies out, then, despite its relatively small total biomass, ecosystem functions will be impaired to a far greater degree than if species are removed whose function can be compensated (e.g. the mycorrhizal fungi, which are affected by nitrogen deposition in forests). There is presently no way of identifying keystone species of an ecosystem before they are lost or removed from the ecosystem. Predictions of impacts of disturbances upon ecosystem functions are thus highly uncertain.

Moreover, due to the complex interrelations between species composition, reproductive behavior, competitive constellations and environmental changes, unpredictable singularities can occur. These are singular events in which the system can flip between different states (Fig. D 4.2-4). An example of this would be the formation of a grassland after insect damage in a boreal forest (Pastor et al., 1996). The probability of such singularities occurring is particularly high for marginal sites on which humans wish to cultivate high-yielding crop varieties. If in future a further intensification of agriculture meets ecological and economic limits, the cultivation of marginal sites will increase worldwide. This will entail a correspondingly intensified risk (Sahel Syndrome: WBGU, 1995a, 1997a). The Council's 1999 annual report will provide an in-depth discussion of the sustainable use of biodiversity.

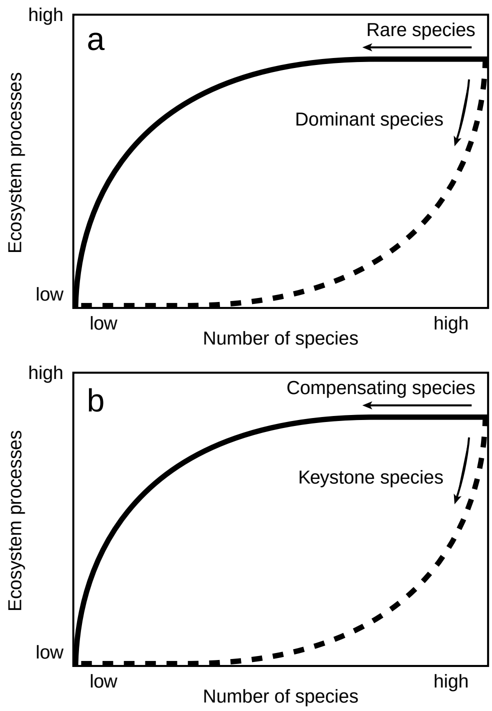


Figure D 4.2-3
Significance of the dominance and function of individual species for ecosystem functions. **a** If a dominant species is eradicated by a disturbance, the impacts upon ecosystem function are far greater than if a rare species is absent. **b** However, if a keystone species is eradicated, then despite its comparatively small overall biomass ecosystem functions are impaired to a far greater degree than if species are lost whose function can be compensated. The *arrows* indicate the direction of change in ecosystem processes as a function of declining number of species.
Source: Heywood and Watson, 1995

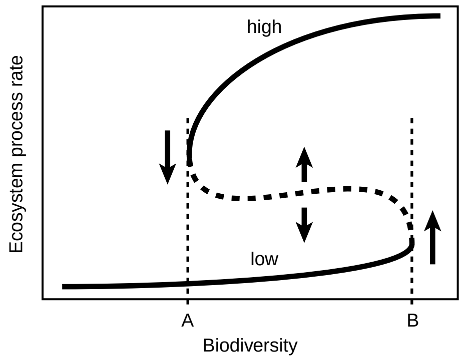


Figure D 4.2-4
Hypothetical relationship between ecosystem functions (expressed as ecosystem process rates) and biodiversity. The *solid lines* represent alternative stable states or relationships to which an ecosystem returns after modest perturbation. The *dashed curve* indicates a 'breakpoint' (unstable state). If an ecosystem continues to be perturbed across the breakpoint, it will move to the other, stable state. The points *A* and *B* are biodiversity thresholds. If biodiversity falls below the value of A, the ecosystem collapses from the state with high ecosystem process rates to a state with low rates. In order to restore the high state, biodiversity must first reach threshold value B.
Source: Heywood and Watson, 1995

D 4.2.1.2
Population cycles

Relationships between the organisms in an ecosystem are governed mainly by resource availability, competition, predation (predator-prey relationships) and parasitism. In undisturbed, stable ecosystems most species and individuals are in a dynamic balance. Natural cyclic population explosions, which are widespread in the animal world (e.g. lemmings, bark-beetles), represent extreme manifestations of dynamic equilibria. They are generally triggered when weather conditions and food supply greatly promote reproduction. They are further controlled by interactions with one or several opponents (predator-prey or parasite-host relationships).

Ocean fisheries display a particular form of predator-prey relationship (Vitousek et al., 1997). Starting with a phase of natural fish abundance (Phase I), a fishing ground is initially developed by decimating possible other opponents. Yields of the harvested species rise (Phase II). This leads over a more or less extended period to a high catch rate (Phase III) which, however, crashes abruptly over a very short period (Phase IV). A reason for this crash is that in the late part of Phase III more and more young fish are caught, and reproduction is thus prevented. Oscillations thus occur between population explosion and severe population crash. At present, the stocks of some 60% of ocean fisheries are endangered.

In agriculture and forestry, the economic damage caused by pest population explosions (outbreaks) and the incessant competition of weeds can be estimated quite well. The data shows that despite all control measures that have been implemented, current yields are about 45% lower than the potentially achievable yields (Table D 4.2-1). These losses are caused equally by animal pests (15%), plant diseases (14%) and weeds (13%; Table D 4.2-2). If no pest control measures were carried out at all, yields would be a further 25% lower. The pest control efforts undertaken up until now thus fall far short of securing the potential yields. Future increases in harvested yields are very difficult to bring about, as even small populations of the above-mentioned ‘opponents’ already constrict yields, and each opponent calls for different control approaches. Nonetheless, in many of the countries that have undergone little or no industrialization, intensifying agriculture on the

Table D 4.2-1
Attainable world production of cereals and other crops compared with actual yields and the estimated unprotected yields (i.e. if no crop protection measures were implemented).
Source: Gregory et al., 1998

Crop	Production [mill. t]		
	Attainable	Actual	Unprotected
Maize	729	449	295
Rice	1,047	509	184
Wheat	831	548	400
Potatoes	464	273	123
Cassava	623	157	21
Groundnuts	87	23	5
Sorghum	184	58	9

Table D 4.2-2
Actual and potential (in the absence of control measures) losses caused by pests, diseases and weeds to the world's harvests.
Source: Gregory et al., 1998

Crop	Actual losses [%]			Potential losses [%]		
	Pests	Diseases	Weeds	Pests	Diseases	Weeds
Maize	15	11	13	19	12	29
Rice	21	15	16	29	20	34
Wheat	9	12	12	11	17	24
Potatoes	16	16	9	26	24	23
Cassava	13	12	10	50	50	70
Groundnuts	13	12	10	30	50	75
Sorghum	13	12	10	30	50	80

presently cultivated areas would appear to have better prospects and to be ecologically more expedient than extending cultivation to marginal soils (Gregory et al., 1998; on the Sahel Syndrome cf. WBGU, 1995a, 1997a).

The example of agricultural crop species illustrates clearly:

- The risk of yield losses in agriculture and forestry caused by harmful organisms is very high, particularly in intensive monoculture management.
- The probability of occurrence of such damage is very high, also in a worldwide perspective.
- The magnitude of damage is regularly large worldwide.

For population outbursts of native pests, persistency and ubiquity are low compared with outbursts of alien species as discussed below. Sustainable agricultural and silvicultural methods (e.g. crop rotation, intercropping) and risk management (e.g. agro-meteorological forecasts, integrated pest control, food and seed depots) can reduce risks.

In Europe, the political mobilization potential among the public with regard to population explosions is generally rather low (e.g. potato beetle calamities), but on certain issues it can also be high (e.g. algal blooms, Section D 4.2.1.3). In countries where damage caused by pest outbreaks is far larger (e.g. locust plagues in many African countries) and less risk management capacities are in place, the public is more acutely aware of the problem.

D 4.2.1.3
Algal blooms

In the aquatic environment, population explosions occur mainly in planktic microalgae (algal blooms). However, population explosions are being observed increasingly in soil macroalgae. Algal blooms have been reported for many hundreds of years and are a natural manifestation of biotic variability in ecosystems. However, there is scarcely any doubt that toxic algal blooms and blooms causing severe ecological damage have been occurring increasingly over the past decades, both in freshwater ecosystems and in coastal waters and marginal seas (Smayda, 1990; Anderson, 1995). Many algal blooms are caused by formerly non-native species (Bederman, 1990).

It is estimated that there are 4,000–5,000 plankton species. Of these, some 300 species are known that are capable of population explosion. Only about 60–80 species, some 2% of floral-forming algae, are considered to be harmful, for instance because they form toxins or lead after their death to oxygen deficiency and thus to the death of fish (Smayda, 1997). Motile species (flagellates) dominate the harmful algae, accounting for 90%. The majority of the other

Table D 4.2-3
Examples of harmful algal blooms.
Source: Expanded and adapted from Horner et al., 1997

Algae	Active agents or effect	Damage
Algae of various groups, e.g. *Noctiluca* (causes marine phosphorescence), *Chrysochromulina* bloom in Europe in 1988	Oxygen deficiency, disturbed food webs, toxins	Water discoloration (red tides), fish kill, death of invertebrates, destabilization of the ecosystem
Diatoms of the genus *Chaetoceros*	Mechanical impairment of branchia (gills) etc.	Fish kill, loss of all mussels of a year
Dinoflagellate *Gambierdiscus toxicus*	Ciguatoxin	Ciguatera: fish poisoning, particularly through consumption of predatory fish
Diatoms of the genus *Pseudo-Nitzschia*	Domic acid	ASP (Amnesic Shellfish Poisoning) caused in humans by the consumption of mussels, also in piscivorous seabirds
Dinoflagellate *Pfiesteria piscida*	Largely unknown	Lesion in fish, leading to fish kill; neurotoxic to exposed humans
Cyanobacteria, e.g. *Anabaena*	Hepatotoxins and others	Liver damage and death in humans and livestock

species are cyanobacteria. Manifestations of damage vary depending upon the species, effect and biomass reached by the algae (Table D 4.2-3).

In many cases, eutrophication and changed nutrient composition are implicated in the emergence of harmful algal blooms (Paerl, 1997; Burkholder and Glasgow, 1997). For instance, in the catchment area of Tolo Harbor, Hong Kong, the rise in nutrient inputs from anthropogenic sources between 1976 and 1986 correlates closely with the rise in the incidence of red tides (water discoloration caused by algal blooms; Lam and Ho, 1989). In Japan, long-term studies have shown a steady rise in the incidence of red tides from 44 in 1965 to more than 300 in 1975 (Murakawa, 1987). After nutrient reductions were implemented, the number of red-tide events has now dropped by half.

In many instances, hazards to human life have been averted by cost-intensive food monitoring. Algal blooms cause the greatest economic damage in aquacultures, coastal fisheries and drinking water supply. In the mussel cultures on Seto Island, Japan, the loss over an 18-year period has been estimated at more than US-$ 100 million (Smayda, 1997). In New York Bay, losses in the scallop fishery have come to about US-$ 2 million annually (Kahn and Rockel, 1988). Experts of the ECOHAB (Ecology and Oceanography of Harmful Algal Blooms) program in the USA describe the economic effect as 'significant, but hard to quantify overall'. The financial costs of individual algal bloom events permit an order-of-magnitude estimate of total damage, but there are no national, not to mention global, assessments of total costs.

D 4.2.1.4
Invasion by alien species

In the following, 'invasion by alien species' refers to the deliberate or accidental anthropogenic introduction, establishment and spread of species outside of their original territory. Throughout the world, these processes have changed terrestrial biota and coastal waters and rank beside land-use change and population over-exploitation as one of the prime causes of the loss of biological diversity (Heywood and Watson, 1995; Sandlund et al., 1996). Widely known examples of devastating invasions include wasps and the opossum in New Zealand, rabbits in Australia, Mediterranean weeds in North America and the dissemination of algae from the Pacific to the Mediterranean.

The risk potentials attaching to invasion by alien species generally also involve the population explosion of these species. This differs from cyclic population outbursts of native species in two aspects. These aspects are of major significance to risk evaluation:

1. In its present, essentially human-caused extent, invasion by alien species is novel and is associated with far greater uncertainties than the natural spread of species.
2. Alien species are often not subject to effective control by opponents (competitors, parasites, predators, pathogens), so that the persistency and

magnitude of damage can be far higher than for mass outbursts of native species. If at all, effective control is often only possible by means of biological pest control methods (e.g. prickly pear in Australia by *Cactoblastus*, thistles in Canada by *Rhiniozyllus conicus*; Box D 4.2-2).

The spread of alien species

It is only through human agency that the spread of alien species has reached a level at which it becomes a serious threat to native communities and ecosystems. The human-induced spread of species can follow several pathways:

- Species are introduced accidentally through trade (wool, timber, cereals), are transported adhering to vehicles, and are imported as domestic animals and fishes for aquaculture etc. In the marine environment, exotic aquatic organisms are mainly disseminated through the ballast water of ships and organisms growing on ship hulls. Through intensive air traffic, the worldwide spread of pathogens, in particular, is a growing problem.
- Species can be imported for a given purpose but then escape, for instance from botanical or zoological gardens (e.g. vine louse, raccoon, *Caulerpa* alga), aquaculture and scientific institutions (e.g. *Varroa mite*).
- Species are deliberately released to the wild, above all agricultural crop species, silviculturally utilized tree species and grazing animals.

Today, the greater part of global human food supplies are produced from introduced species that originally had a very limited range (e.g. maize, potato, rice; Hoyt, 1992). In no region have these plants established themselves in the wild and introgressed with the natural vegetation. Only the weeds that were introduced unintentionally in the process have established themselves in other flora, in some cases with considerable adverse effects (Mooney and Drake, 1986). A different assessment must be made of the worldwide spread of grazing animals (cattle, sheep, goats, horses, camels). These have not only caused considerable damage to native vegetation (horses in North America, cattle in Australia, goats on ocean islands), but have moreover drawn in their wake the establishment of European pasture plants (e.g. *Festuca pratensis*, *Trifolium subterranaeum*, *Bromus* ssp.). In conjunction with grazing pressure, the pasture plants have competed with the natural vegetation and have partially usurped it (e.g. *Bouteloua* Steppe in North America). European Mediterranean weeds have displayed particular competitive vigor, and have completely changed the vegetation of the arid regions of the Earth.

Ecological impacts of invasion by alien species

The consequences of invasion by alien species in natural or near-natural ecosystems can vary greatly from region to region. In some regions, for example, it can enrich the natural flora and fauna (e.g. in Germany). As a rule, however, it leads to great diversity in endemic species, and with it valuable genetic resources, being displaced by a small number of species distributed worldwide.

The manifold ecological impacts of alien species have been well documented by numerous authors (e.g. Vitousek, 1986; Drake et al., 1989; D'Antonio and Vitousek, 1992; Sandlund et al., 1996; see also Box D 4.2-1). Possible primary consequences include:

- Damage to human health (e.g. Asian tiger mosquito as a vector of dengue and yellow fever),
- Crop losses and failures (e.g. European starlings on the American continent),
- Altered geochemical cycling (e.g. the crab *Mysis relicta* modifies the surrounding terrestrial ecosystem in the lakes of Montana),
- Modification of entire landscapes (e.g. woody vine *Cryptostegia grandiflora* from Madagascar in Australia),
- Displacement or extermination of elements of the native flora and fauna (e.g. Purple Loosestrife *Lythrum salicaria* of European origin in the USA),
- Clogging of pipes and waterways (e.g. zebra mussel in North America),
- 'Extinction' (loss of oxygen supply) of lakes and ponds (e.g. water hyacinth in African wetlands),
- Elevated risk of fire (e.g. Asiatic cogon grass and Brazil peppertree in Florida).

Numerous further secondary effects occur:

- Habitat degradation (e.g. African grasses in former rainforest areas of Brazil),
- Dissemination of further exotic species by an already established invasive species (e.g. the Indian mynah, a bird species, promotes the spread of guava seeds on Hawaii),
- Consequential damage caused by pesticides used to control alien organisms (e.g. in the USA the control of Dutch elm disease with DDT poisoned numerous song-birds),
- Hybridization (crossbreeding) with native organisms (e.g. North American grass in England).

It can generally be assumed that invasions by alien microorganisms and animals will lead to a greater extent of damage, ubiquity and persistency than invasion by alien plants. Microorganisms, including fungi, have been spread worldwide, generally unintentionally, and their establishment has in some cases led to very considerable ecological and economic damage.

Box D 4.2-1

Case study: the golden apple snail in Asia

Situation
The golden apple snail originates in the Paraná swamp regions of Paraguay. In 1982, it was introduced officially under a government program to the Philippines as a foodstuff and to raise income in rural regions. In the late 1980s, it was also introduced in China, Indonesia, Malaysia, South Korea, Taiwan, Thailand, Vietnam and the Pacific island states. The hope that the snail would be suitable as a protein source for domestic consumption and as a commodity for export to Asia and Europe soon proved to be misplaced. Due to their poor taste, the market price of the snails remained low, and even farmers with low incomes refused to eat them. However, the snails then spread in the rice paddies, causing considerable crop losses, rice saplings being a preferred feed.

The Consequences on the Philippines
On Luzon, the largest island of the Philippines, the snail inflicted a harvest loss of more than 25% upon more than half of all farmers in 1990–1991; every tenth farmer even suffered a total failure. Moreover, the snail has secondary effects upon human health, as it is the intermediate host for a lungworm that causes meningitis in humans. Attempts are now under way to contain the plague by means of organized collection campaigns, keeping ducks, improving the management of water levels and applying snail poisons. These poisons, however, are extremely toxic to fish and pose further health hazards to the farmers.

What was the mistake?
If market analyses had already been carried out prior to introduction, these would have shown that the golden apple snail was neither suited to boost exports nor to supplement the food supply. Since the beginning of rice cultivation in Surinam, the snail was already known there as a prime pest in rice fields. Ecological characteristics would have identified the snail as a potential invader, but in the Philippines there is no statutory requirement to carry out an evaluation of exotic organisms prior to introduction.
The losses of US-$ 28–45 million correspond to 25–40% of the annual costs of rice imports to the Philippines (Table D 4.2-4). This sum would have permitted the establishment of a functioning quarantine program for all new agricultural introductions in the Philippines.

Type of cost	Cost estimate [mill. US-$]
Harvest loss with replanting and control	12.5–17.8
Cost of replanting and control	2.8–10.3
Control with molluscicides and collection by hand	12.5–17.2
Total costs to the farmers	27.8–45.3
Harvest loss without control and replanting	48.0

Table D 4.2-4
Estimation of the economic damage inflicted upon the rice farming sector in the Philippines.
Source: Naylor, 1996

Examples of this are the potato famine in Ireland (1845–1851) caused by the potato fungus *Phytophthora infestans* and the elm and chestnut diseases in central Europe and North America (caused by *Ceratocystis ulmi* and *Cryphonectria parasitica*). The high mobility and higher reproductive potential of microorganisms play an important role here. However, in a broader perspective it must be noted that species extinction caused by the establishment of alien species has as yet 'only' been observed on islands or in aquatic ecosystems. A worldwide extinction of a terrestrial, continental species caused by alien species has not yet been reported anywhere (Heywood and Watson, 1995). However, it is probable that, depending upon the species, ecosystem and environmental conditions in question, the establishment of alien species will cause damage through local pressures, population losses and the associated loss of genetic diversity.

To eradicate alien plant and animal species that have firmly established themselves in native communities is not possible or only at high cost (Box D 4.2-1). The regeneration of damaged ecosystems can take decades. It is most probably impossible to control damage caused by alien microorganisms. Losses of endemic species on islands or in aquatic ecosystems represent an irreversible damage.

Among the German public, the risks associated with invasions are not generally a politically relevant issue. Alien species are only perceived by the public as being problematic if damage becomes extremely large or very plain (e.g. Dutch elm disease). By contrast, the international global change research community devotes great attention to this issue.

Economic impacts of invasion by alien species
The economic damage resulting from an invasion in agriculture, forestry or fisheries can be estimated in terms of harvest failure, compensation for income lost through harvest loss or the costs incurred for restoration or damage limitation. By contrast, an economic valuation of a possible loss of biodiversity presents major methodological difficulties (Hampicke, 1991; WBGU, 1994, 1997a).

Box D 4.2-2

Case study: biological control of European rabbits in Australia

The establishment of the European rabbit in Australia is a classic case of the unpredictable and costly consequences of introducing alien species (Williams, 1998b). The rabbits were introduced from England in 1859 for hunting purposes. After 50 years, they had already colonized most of the Australian continent. The main cause for this rapid spread was the absence of natural enemies such as weasels and foxes, which regulate rabbit populations in Europe. The rabbit population explosion led to severe degradation of the terrestrial environment (e.g. vegetation cover destruction and soil erosion) and the endangerment and extinction of native plant and animal species.

Control strategies and their effects

After all attempts had failed to control the rabbit population outburst by means of chemical or mechanical measures (e.g. poison, traps, fencing and intensive hunting), an attempt at biological pest control was made in 1871 with the introduction of the European red fox. It soon became clear that the fox not only killed rabbits, but also native species which, due to their special characteristics (predominance of marsupials, which generally cannot withstand the competitive pressure of mammals when in direct competition), reacted particularly sensitively. They recovered much more slowly from decimation by the fox than the highly fertile rabbits. The fox thus threatened the native fauna without controlling the rabbits effectively and durably.

Rabbit control by means of the pathogen of myxomatosis was much more successful. This is a virus disease that has been used since 1950 specifically to control rabbits. The mosquito-borne virus spread rapidly in more humid regions, where it killed about 90% of the rabbit population. However, in drier seasons and regions the effect was found to be far weaker. Although rabbits resistant to myxomatosis have in the meantime been reported, in the temperate regions of Australia the virus still provides an effective form of biological control.

An even more efficient control of the rabbits was achieved by means of the rabbit calicivirus, which causes a form of hemorrhagic fever known in Asia, Europe and Mexico. Despite extensive precautions, the virus escaped from an experimental island in 1995 and entered the south of Australia. Within 1 year, the pathogen had already spread across the entire range of the rabbits, in which it caused mass mortality. The native flora has recovered appreciably since then. Fears that the native fauna might be damaged by the virus have not been confirmed. In the meantime, a preparation with the virus has been officially approved and is being used under the Rabbit Calicivirus Disease Program. To ensure continued efficacy of control in the future, use of the preparation is combined with conventional methods. Further work is under way to modify genetically the myxomatosis virus.

The costs of rabbit introduction

It is very hard to put an economic figure to the loss of biological diversity. The costs to agriculture can be estimated indirectly from the benefits or costs of control measures, although no data are available from the period prior to introduction of myxomatosis. The government of Victoria spent 3 million Australian dollars (A$) annually and the government of South Australia A$ 1.1 million for rabbit control programs. The costs to South Australian cattle farming are estimated at A$ 17 million annually and the costs to arable farming at A$ 6.2 million annually. The benefit of myxomatosis to the Australian sheep farming industry come to A$ 30 million in 1952–1953, that to the wool industry A$ 115 million annually. More recent calculations of benefit based on an 80% reduction in rabbit abundance arrive at a figure of A$ 600 million annually across the whole of Australia.

A complete economic analysis of the damage caused by established alien species has only been carried out in a few cases. Nonetheless, these examples (Boxes D 4.2-1 and D 4.2-2) illustrate that the losses and costs of control can be considerable and unpredictable. The issue arises as to the point in time at which control makes the most economic sense. In many cases prevention would appear to be the most effective measure (e.g. exchanging ballast water at high sea, inspecting timber imports). Control measures that are only undertaken when massive ecological and economic damage have occurred can be very lengthy and costly (e.g. rabbits in Australia; Box D 4.2-2).

Ecological susceptibility and risk management

Since its inception, applied ecology has discussed the question of whether alien species will be able to establish themselves successfully or not, but generalizable predictions continue to be impossible (Mooney and Drake, 1986; Heywood and Watson, 1995). In view of the extensive trade in plant and animal products and the great number of organisms that are dispersed by international ship and air traffic, the risk of a successful and harmful establishment of alien species would generally appear to be low. In addition to the characteristics of the alien species (such as genetic variability, reproductive potential), the success of invasion depends upon the characteristics of the native flora and fauna. In Central Europe, for instance, the risk of invasion by alien species is far lower than that of invasion by European species in other regions of the world (Mooney and Drake, 1986; Niemelä and Mattson, 1996). European weeds adapted to an agricultural cropping regime have been more successful in all parts of the world than the corresponding species from other regions have been in Europe. Many more seeds of Australian flora were brought to Europe with wool and cereals than were transported in the opposite direction, but no Australian plant has run to seed in Europe. In other regions, however, Australian species have become weeds (e.g. *Melaleuca* in the USA, *Hakea* and *Acacia* in South Africa). Kowarik (1996) reports that in Central Europe only 0.2% of the alien plant species introduced up to now have established themselves successfully and have led to undesired effects.

Very great ecological damage has been caused in aquatic ecosystems by alien species. The unintentional introduction of the comb jellyfish *Mnemiopsis* in the Black Sea is an example of this (Mee, 1992; Zaitsev, 1993; Kideys, 1994). As the main dispersal pathway of aquatic alien species is the ballast water of ships, exchange of ballast waters at high sea or their treatment would appreciably reduce – although not eliminate – the danger of dispersal (Bederman, 1990). Australia has already put forward a proposal for such an international regulation under the MARPOL regime (International Convention for the Prevention of Pollution from Ships).

Comparisons of the proportions of alien species in relation to native flora and fauna show that island vegetations are more endangered by alien species than continental ones (Heywood and Watson, 1995) and that anthropogenically disturbed ecosystems are more vulnerable than natural ones (Vitousek, 1990; Smallwood, 1994; Kowarik, 1995). As endemic species tend to occur particularly on islands, the high ecological vulnerability of island flora leads to a particularly high risk of losing species and genetic resources. The high vulnerability of disturbed ecosystems makes it probable that an intensified or changed land use regime or changes in geochemical inputs to ecosystems will also elevate the probability of a successful establishment of alien species (Scherer-Lorenzen et al., 1998). Risk assessment is further hampered by the circumstance that decades or centuries can elapse between the introduction of an alien species and its sudden, explosive spread, triggered e.g. by land-use changes or climatic changes (Bazzaz, 1986; Crooks and Soulé, 1996; Table D 4.2-5).

In future, high priority needs to be given to studying, mapping and monitoring the spread of known invasive species. Systematic collection and international dissemination of information can be utilized as a basis for early warning systems and management strategies for other countries that are not affected as yet but may possibly be threatened (e.g. for the European shore crab; Lafferty and Kuris, 1996; FAO, 1996). FAO activities have delivered a highly promising approach towards closing gaps in knowledge with the development of GPPIS (Global Plant Protection Information System). This is an interactive database that is currently under development. However, it is at present limited to terrestrial ecosystems and agricultural crop species. In the context of DIVERSITAS – The International Programme on Biodiversity Science, an interdisciplinary, practically focused and proactive program for the improved control of harmful invasive species is currently being developed (GISP, Global Invasive Species Programme).

It is not practicable to carry out a preventive risk analysis of the spread of all potential new arrivals in all regions of the world. If, however, the new introduction of a species is planned, a comprehensive ecological risk analysis should be carried out in advance. A risk analysis is thus required and implemented for most classic biological pest control projects that employ the introduction of alien species. The experience made with biological pest control and the findings of theoretical and practical ecology now provide a valu-

Table D 4.2-5
Application of the evaluation criteria to the risk potential of population explosions of alien species. This belongs to the Cyclops risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					■
Certainty of assessment of *P*					■
Extent of damage *E*					□
Certainty of assessment of *E*					□
Ubiquity					□
Persistency					□
Irreversibility					□
Delay effect					□
Mobilization potential					□

able stock of knowledge from which to proceed in the quest for suitable control organisms (Murdoch et al., 1985; Murdoch and Briggs, 1996). In consultation with experts, FAO has elaborated a code of conduct for the import and release of exotic biological control agents (FAO, 1996). This standard sets out the respective responsibilities of government organizations, exporters and importers and is intended to contribute to minimizing risks.

International regulations restricting uncontrolled introduction (e.g. so-called white lists) are also desirable for the release of organisms introduced not for purposes of biological control but for food production, hobby and sports purposes (aquariums, sport fishing, hunting, gardening) and other uses (e.g. wind barriers and erosion control).

D 4.2.2
Risk potentials associated with the release and marketing of transgenic plants

The comprehensive risk evaluation of the entire complex of genetic engineering is an issue debated controversially in both the academic and policy communities, and goes beyond the scope of this report. It is not the aim of this section to perform such an evaluation. Our aim is rather to discuss the release and marketing of transgenic plants with a view to a *typological* classification of global, environmentally relevant risks. As the present report concentrates on environmentally mediated risks, it only treats the representative sphere of the utilization of genetic engineering in crop production (applied 'green genetic engineering') and its potential impacts upon natural or near-natural ecosystems. The use of genetically modified microorganisms (e.g. for biofertilization, medical purposes, food production or the remediation of contaminated soil) is only briefly discussed (Section D 2). The risks associated with the engineered cloning of animals are to be sought less in the technology or cloning as such than in its use and in its ethical and social dimension. They are therefore not treated here.

The state of the debate at the national level in Germany has been set forth in numerous publications and expert opinions on the opportunities and risks of genetic engineering, and shall not be repeated here (cf. e.g. van den Daele et al., 1996, 1997; Schulte and Käppeli, 1996, 1997; BMBF, 1997; Rat für Forschung, Technologie und Innovation, 1997). In addition to possible environmental risks, this section shall also examine the opportunities or risks that would result if genetic engineering methods were not utilized in plant production.

The stipulation of the Convention on Biological Diversity (CBD; Article 19, para 3) that the Parties consider the need for and modalities of a protocol on biological safety ('biosafety') is presently being implemented in a dedicated negotiation process. This is expected to yield in the course of the coming year a finalized draft for a protocol that will be binding under international law (Box F 6.3-2). This underscores that identifying possible risk potentials associated with some applications of genetic engineering is an issue of considerable import in the international arena, too (Heywood and Watson, 1995; Macilwain, 1998).

In the following, we first discuss genetic engineering techniques and a number of biological interrelationships that are of importance to risk classification. The subsequent discussion of examples of transgenic properties illustrates that some of the risks associated with applied 'green genetic engineering' are not specific to that technology, but can already be deduced from experience made in modern plant production (e.g. high-yield varieties, pest control and resistance formation) or in microbiology. These risks can be assessed relatively well. Nonetheless, risks do remain whose assessment is currently uncertain.

The global relevance of possible risk potentials associated with the release and marketing of certain transgenic plants results from the globally growing, large-scale cultivation of transgenic crops and the diffuse dispersal of their products in the most varied foods and consumer goods (e.g. soya). This is further compounded by the circumstance that, with a comparatively clear set of methodologies, genetic engineering work is under way at very many different locations throughout the world and under legal framework conditions (e.g. concerning laboratory safety, approval procedures) that diverge from those in Europe or North America.

D 4.2.2.1
From selective breeding to genetic engineering

Gene modification (mutation) and the exchange of genetic material are events that occur continuously in nature – indeed, they are the point of departure for selection and evolution. Since the Stone Age, humans have promoted and modified certain species by means of selection. Today, the food supply of humanity is based on a small number of species (such as maize, rice and wheat) that were produced by crossbreeding when arable farming began. Modern crop breeding techniques artificially elevate the mutation rate (using mutagens) in order to receive specific products more rapidly. Here the side effect of unintended mutations is tolerated. These then need to be eliminated again through subsequent selection. The boundaries are fluid from classic selection over modern breeding through to the targeted modification of the genome. Genetic engineering can thus be used to amplify or suppress already existing properties of plants. The essential difference between genetic engineering and classic plant breeding lies in the enormous potential of the former to structure and modify genes and combinations of properties – the form and speed of this potential did not exist previously, neither in classic breeding nor in natural evolution:

- Classic breeding generates undirected changes in the existing genome of plants. Genetic engineering, by contrast, permits a targeted exchange of genes among organisms in different kingdoms (microorganisms, animals and plants). Genes can further be transferred among organisms that live in completely different habitats. New combinations of genes are feasible which, due to evolutive interbreeding barriers between the kingdoms of organisms, would not have come about naturally.
- The foreign genes can be endowed with promoters (DNA segments that determine where transcription, i.e. the formation of complementary RNA, begins) that are alien to the species, and with enhancer sequences (regulatory base sequences that enhance gene transcription) in order to overcome natural restrictions in the target organisms. Gene transfer can also lead to a recombination of genes among the kingdoms of organisms through natural processes (Pühler, 1998b), but under natural conditions the speed and frequency of this process is extremely low, as is the probability that structural genes, promoters and enhancer sequences are transferred simultaneously and are expressed successfully. The use of species-specific, tissue-specific or inducible promoters is thus an important step towards reducing possible risk potentials.

A further aspect is that selection markers (marker genes) are employed to identify successful gene transfer. Depending upon the type of property thus transduced (e.g. antibiotic resistance genes), these markers can entail risks. However, expert opinion is increasingly viewing a transfer of these markers from genetically engineered plants to microorganisms (horizontal gene transfer) as extremely improbable (Schlüter et al., 1995; Gebhard and Smalla, 1998; Heidenreich, 1998). This risk potential could be precluded by removing possibly risky markers before marketing transgenic plants, or by using unproblematic markers (Section D 4.2.2.4).

In addition to speed, it is above all the novel combination of genes or traits that imbues genetic engineering with a new quality compared with classic plant breeding. Little is known at present about the stability of these novel combinations and about the behavior of transgenic plants or of foreign genes in natural or near-natural ecosystems and under variable environmental conditions. This is often due to the inadequate knowledge of the biological setting of the transgenic plants or their hybrids. Due to this lack of knowledge, both the probability of occurrence and the magnitude of possible damage cannot be assessed.

The novel possibilities of design and modification that genetic engineering offers to crop cultivation open the way towards great *opportunities* and utilization potentials, such as reducing the application of biocides and precluding yield losses caused by pests (Schulte and Käppeli, 1996, 1997; Rat für Forschung, Technologie und Innovation, 1997; Korell et al., 1997). On the other hand, in the event of an uncontrolled dispersal of transgenic plants or their foreign genes (Section D 4.2.2.2) *risks* to natural or near-natural ecosystems cannot be excluded (such as changed geochemical and energy fluxes, loss of population and possibly also species diversity; Heywood and Watson, 1995; SRU, 1998).

D 4.2.2.2
Risks associated with the unintentional dispersion of foreign genes inserted in transgenic plants

As the inadequate knowledge of the biological setting means that the dispersion of inserted foreign genes in natural or near-natural ecosystems can be associated with a risk that largely escapes assessment, particular attention must continue to be devoted to the possibility of a transfer of foreign genes to wild populations (Heywood and Watson, 1995; Schulte and Käppeli, 1996; Ahl Goy and Duesing, 1996; BMBF, 1997; Korell et al., 1997; Pennisi, 1998).

An uncontrolled dispersal of cultivated transgenic crop species (running to seed) is rather unlikely, as it can be assumed that genetic modifications tailored exclusively to utilizable yield will lead to a loss of 'fitness' of the cultivated species. Crop species have been selected exclusively to yield certain products, and without human support they are generally unable to persist in competition with natural species. This does not, however, apply in the same way to crop species that have been modified only slightly by breeding (e.g. woody plants; Regal, 1994; Ammann et al., 1996; SRU, 1998).

For a dispersion of inserted foreign genes to be possible via pollen (outcrossing), cross-breeding mates (sexually compatible, related species) must be present in nearby ecosystems. As in Europe no related species of soya, cotton or maize occur, the outcrossing risk posed by releasing and marketing these species is low. In the countries of origin of these plants, however, this risk is high. For rape and sugarbeet, by contrast, hybridization with wild relatives has repeatedly been shown to have occurred in Europe (Ammann et al., 1996; Korell et al., 1997). With a view to the risk potential of gene transfer at the global level, particular attention needs to be given to protecting centers of genetic diversity and countries in which wild relatives of cultivated plants occur, as here a greater risk must be expected (for instance, central America is the origin of maize and cotton, and China is the origin of soya). If in these regions transgenic seed should unintentionally be used that has traits conferring selective advantages in the wild population of the cultivated plant, then the wild population would be endangered by hybridization and competitive pressure. The possibly resulting loss of population diversity may ultimately even impact upon food security because of the restrictions it places upon the gene pool available in the future.

In the debate on the risks associated with the release and marketing of genetically engineered plants, the issue of horizontal gene transfer (nonsexual transfer of genes between individuals that can also belong to unrelated species) continues to be a source of controversy. While transfer between bacteria and from bacteria to fungi and plants has been proven in the laboratory, the reverse transfer from animals to bacteria or from plants and fungi to bacteria has not yet been proven. It is generally assumed that this is also possible (Pühler, 1998b). However, a transfer of foreign genes inserted in plants to other groups of organisms can be viewed as an event that is very rare or only occurs under very specific conditions (Pühler, 1998b). Nonetheless, as such an event cannot be excluded entirely, possibly associated risks must also be considered within the risk classification undertaken in this report (Section D 2.3).

Beyond the probability of gene transfer as such, the extent to which an undesired transfer is relevant to the wild population and to the environment at large needs to be examined in each individual case. This depends crucially upon whether the foreign genes also confer a competitive advantage outside of the agro-ecosystem (Regal, 1994) or influence important ecosystem functions and structures (e.g. geochemical cycles). If the foreign gene leads to competitive disadvantages of the transgenic individuals vis-à-vis the wild population, then the foreign gene will most probably not be able to establish itself outside of the anthropogenic system (e.g. microorganisms with an implanted gene for insulin production). On the other hand, foreign genes that impart to their carriers selective advantages within the wild population (e.g. disease resistance, cold, drought or salt tolerance, transgenic growth factors) will probably lead to a shift in the competitive balance within the wild population and will promote the establishment of the transgenic plants or their foreign genes. It is not clear to what extent engineered genes that offer neither benefits nor drawbacks in nature will be able to stabilize over the long term in wild populations with selective neutrality. It has been assumed until now that due to an absence of selection pressure these genes will be lost again in the course of time or will at least become rarer (van den Daele et al., 1996). However, this is by no means a definite outcome, for the modifications may possibly impart an evolutive advantage at a later time under changed environmental conditions (preadaptation).

Pleiotropic effects (manifestation of several traits through one and the same gene), position effects (altered expression of a gene depending upon its position in the genome) and insertional mutagenesis (modification or destruction of a gene specific to the plant) are viewed as being problematic under certain circumstances (Franck-Oberaspach and Keller, 1996; van den Daele et al., 1996; Lips, 1998). Such effects, which are also known in classic plant breeding and in nature (e.g. through plant transposons, 'jumping genes'), can result from the integration of the foreign DNA in the genome of the target organism and are in many cases unpredictable. It is supposed that these processes confer traits that were not intended and that may have unexpected effects in nature (e.g. increased or reduced damage by herbivores, changed flowering times). It is not clear whether this risk is fundamentally higher in genetically engineered plants than in conventionally bred plants. In classic breeding, hundreds of unknown genes are exchanged so that the probability of such secondary effects of gene exchange may be expected to be larger. On the other hand, it is argued that the mixing of genes from all parts of the kingdoms of organisms and all regions of the Earth presents a new quality of hazard in this respect, too.

In conjunction with the possibility of gene transfer, including the transfer of promoters, enhancers and markers, and with due consideration to the historically unique speed of change, the novel combinations of genes and traits that can be created by means of genetic engineering lead to the conclusion that potential and presently unassessable risks cannot be excluded entirely (Regal, 1994; Heywood and Watson, 1995; SRU, 1998). Possible negative environmental impacts would be regional to global, depending upon the efficacy of natural or anthropogenic mechanisms of dispersal and depending upon the ecosystems concerned. In the event of a harmful establishment of transgenic plants or the dispersion of foreign genes in non-agrarian ecosystems, the persistency of damage would probably be far more than 30 years. If the extinction of another population or species is triggered,

Table D 4.2-6
Application of the evaluation criteria to the risk potential of the release and marketing of certain transgenic plants. This belongs to the Pythia risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

persistency is unlimited and damage irreversible. If, in contrast, an inserted foreign gene proves to be unstable in a wild population, it can be assumed that no irreversible damage will arise, or that damage will be limited in space and time.

A first understanding of the possible dispersal dynamics of transgenic plants or of their hybrids, and of the possible consequences of their establishment in natural or near-natural ecosystems, can be derived from the findings of research on invasion by alien species (e.g. Regal, 1986; Kowarik, 1996; Section D 4.2.1.4). For a typological classification of these risks, it is important to note that many decades can elapse between the introduction of an alien plant species and its sudden, massive spread (similar to the evolutive efficacy of preadaptive mutation; Kowarik, 1996).

For each of these risk potentials, the boundaries between the normal and transition areas (as defined in Section C) are flowing. This range of varying risk potentials of 'green genetic engineering', the prevailing gaps in knowledge and the uncertainties regarding the possible effects of transgenic plants or their foreign genes in ecosystems are the reasons why the risk evaluation criteria cannot always be attributed unequivocally and why comparatively large uncertainty attaches to the certainty of assessment (Table D 4.2-6). This applies particularly to interactions with soil flora and fauna, and to ecosystemic long-term effects (Driesel and Danneberg, 1996; UBA, 1996).

D 4.2.2.3
Present approaches to dealing with the risks

In practice, the release and marketing of transgenic organisms calls for a case-by-case assessment, as is stipulated by the German Genetic Engineering Act (Gentechnikgesetz, GenTG) and advocated by various advisory bodies (e.g. Schulte and Käppeli, 1996, 1997; SRU, 1998). Such an assessment is applied in most (but not all) countries (Heywood and Watson, 1995; Nöh, 1996). This is closely linked to a step-wise and controlled procedure when releasing and marketing transgenic organisms. In addition, generic risk categories are being discussed increasingly for transgenic crops that could supplement a case-by-case assessment (Heywood and Watson, 1995; Ahl Goy and Duesing, 1996; SRU, 1998). At present, risk analysis proceeds mainly from the following criteria: type of engineered modification, biology of the engineered organisms, possibility of gene transfer, ecological relevance and possible environmental impacts (e.g. the German procedural code for genetic engineering 'GentechnikVerfahrensordnung, Gen-TVfV'; EU Directive 90/220/EEC; Nöh, 1996). It is a matter of some controversy to what extent past safety research efforts have done justice to the requirements of, in particular, ecologically oriented risk assessment and evaluation (Kareiva, 1993; Regal, 1994; Heywood and Watson, 1995; Blatter and Wolfe, 1996). For instance, the Scientific and Technological Options Assessment Unit (STOA) of the European Parliament is seeking ways to improve the limited ecological information provided by release trials following the step-by-step approach (von Schomberg, 1998). As a further point, the use of transgenic plants should continue to remain subject to long-term ecological supervisory and safety research and continuous monitoring (post-approval monitoring) after and beyond approval for commercial cultivation (UBA, 1996; SRU, 1998; Section H). There is a particular need to promote comprehensive long-term monitoring in view of the large-scale cultivation of transgenic crops that is to be expected in the future. Research on this is already being promoted by the German Federal Ministry of Education, Science, Research and Technology ('Bio-Monitor' grant guidelines; BMBF, 1997).

Studies carried out on behalf of the German Federal Environmental Agency (UBA) have shown that in many developing countries and Eastern European states statutory regulations and guidelines on biological safety are absent or are only at the drafting stage (de Kathen, 1996; Sojref and Thamm, 1997). In order to promote the development of national regulations and thus a safe use of biotechnology in developing countries, International Technical Guidelines for Safety in Biotechnology were adopted in 1995 under the auspices of UNEP. Moves towards an international harmonization of assessment procedures and statutory regulation of biotechnology are also under way at the EU level, in the OECD context and under the aegis of the Convention on Biological Diversity (on the Biosafety Protocol see Box F 6.3-2).

Looking at the numerous popular publications on genetic engineering, the mobilization potential in the German public concerning possible environmentally relevant risks of 'green genetic engineering' would appear to be smaller than, for instance, the potential concerning potential risks to human health. Concerning 'green genetic engineering', it is mainly the opportunities and risks to agriculture and to world food supply that are discussed in the German public.

D 4.2.2.4
Representative risk potentials of 'green genetic engineering'

A number of risks are debated in connection with the release and marketing of transgenic plants that are often not in fact specific to genetic engineering and can already be assessed and reduced on the basis of available knowledge. The following examples illustrate the flowing transition between these known or deducible risks on the one hand and the novel risk potential of genetic engineering applications set out above on the other.

Selection markers

In addition to risks that may proceed from the transgenic properties desired for agricultural applications, risks can stem from marker genes, whose main function is to indicate the successful transposition of genes to the target organism. In many cases, antibiotic resistance genes have been used as markers, as these can be detected simply and reliably. The cultivation of transgenic plants could, albeit with a very low probability, lead to an unintended dispersion by gene transfer of the markers. If antibiotic resistance genes of relevance to human medicine were used for marking, impacts to human health could ensue (Section D 3). It is difficult to prove experimentally that antibiotic resistance genes have been transferred between transgenic plants and microorganisms (horizontal gene transfer), as this transfer is below the current detection limits of laboratory tests (Pühler, 1998b).

However, when compared with resistance development through the direct application of antibiotics in humans or animals, the probability of a dispersion of antibiotic resistance mediated by genetic engineering is extremely low in natural or near-natural ecosystems without high selection pressure. The – very small – risk of dispersion of antibiotic resistance genes is an avoidable risk which, as a relict of earlier research phases, could be removed by appropriate legislation. Moves must be made towards completely phasing out the use of antibiotic resistance markers in transgenic plants intended for release and marketing, or at least removing the antibiotic resistance genes from the transgenic plants prior to their agricultural use. In Germany, this requirement is broadly shared in accordance with the precautionary principle, or at least for reasons of acceptance (ZKBS, 1997; SRU, 1998), and is technically feasible. In the global arena, opinion is still divided.

Restriction of species and variety diversity in food production

Regardless of the type of transgenic properties transferred, a danger of environmentally relevant secondary effects follows from the economic benefits of cultivating genetically modified plants. In this, they are similar to the high-yielding varieties produced by conventional plant breeding. Thus, particularly in the developing countries, the intensified marketing and use of genetically modified crop species harbors the risk of accelerating the already ongoing process of concentration of arable farming upon a small number of varieties – a process that already began with the one-sided use of high-yielding varieties stemming from traditional or modern plant breeding. This would lead to a further rapid constriction of the genetic diversity of crops. That this is indeed a risk to food security and has global relevance is borne out by past experience with intensive agriculture in many industrialized countries, where plant production has become almost entirely reliant upon a small number of high-yielding varieties (Mooney, 1985; BML et al., 1997). In the USA, for instance, the epidemic spread of southern corn leaf-blight (caused by *Bipolaris maydis*), a fungal disease, caused significant harvest losses in maize farming in 1970 (Shand, 1997). More than 80% of the hybrid corn varieties (from conventional breeding) cultivated were susceptible to the fungus, which had until then been harmless. It was only through intensive breeding programs that a further disaster in the maize sector was prevented. In 'green genetic engineering', too, mutations and the formation of resistance among pest organisms will require permanent new breeding of crop varieties. This will remain dependent upon the gene reservoir of traditional varieties and their wild relatives. It is precisely these traditional varieties that could be further displaced by the cultivation of high-performance, genetically modified varieties, particularly if these are cultivated in regions that are home to centers of genetic diversity (see also the Green Revolution Syndrome; WBGU, 1998a).

Genetically engineered resistance

Different types of resistance in plants can be conferred by genetic engineering: resistance to certain plant protectants (herbicide resistance), resistance to pests such as insects (insect resistance), and resistance to pathogens (e.g. virus or fungus resistance). Genetically engineered pest resistance is effective against the target pests without any further measures – this may be called a 'built-in' plant protection factor. Herbicide resistance, by contrast, only functions in combination with a complementary herbicide that kills the weeds but not the transgenic useful plant, which has been engineered to be resistant (or at least tolerant) to the complementary herbicide.

Herbicide resistant plants

Herbicide resistance in useful plants that permits the application of highly effective complementary herbicides has been engineered until now in, inter alia, maize, sugar-beet, rape, cotton, soya and potato varieties (RKI, 1998). The main rationale for its use in arable farming, in combination with the complementary herbicides, is to reduce pressures upon the natural environment by means of reducing herbicide applications, while at the same time securing yields. Whether this reduced environmental impact can be maintained over the long term depends upon the extent to which the herbicides used in combination with the herbicide-resistant seed are toxicologically and ecologically harmless, and the extent to which a responsible, i.e. restrictive use of the complementary herbicide (e.g. no prophylactic or routine applications) actually leads to reduced herbicide inputs. In natural or near-natural ecosystems, no competitive advantage is to be expected from the acquisition of herbicide resistance genes, as here there is no selection pressure from herbicide use. In the immediate surroundings of the field, however, hybridization and selection pressure could promote the development of herbicide resistant weeds, which would reduce the efficacy of the herbicide. This is an issue that at first concerns mainly farmers and the manufacturers of the transgenic plants and complementary herbicides. From the environmental perspective, a risk arises if herbicide applications grow due to increasing resistance of the weeds. However, this vicious circle of resistance formation and increased herbicide application is not a problem specific to genetic engineering, but is a consequence of the increasing intensification of agriculture. Van den Daele et al. (1996, 1997) offer an extensive discussion of the opportunities and risks of transgenic herbicide resistant plants in the context of a proposed technology assessment approach.

Insect resistant plants

One of the presently most important forms of genetically engineered resistance to insects is conferred by one or several endotoxins originating from the soil bacterium *Bacillus thuringiensis* (B.t.). Here genes which encode corresponding toxins in B.t. bacteria are either extracted directly from B.t. cells or are synthesized artificially and then inserted into the plant genome. The most frequently applied B.t. toxin genes are effective against butterflies and a number of leaf-eating beetles. Until now, B.t. genes have been inserted in, inter alia, maize, cotton and potato varieties.

The risks of engineered resistance to insects are different in nature to those of herbicide resistance. For one thing, the transgenic plants produce the insect toxin themselves. The second main difference is that this resistance to insects can be expected to confer a competitive advantage in natural or near-natural ecosystems, too. The continuous expression of the toxin in the plant is the main difference between genetically engineered insect resistance and the natural insect resistance found in many plants, or the use of microbial B.t. toxin preparations (for spraying). Natural deterrents in plants are often distributed among the plant parts according to those that are most exposed to feeding damage, and their production is often only induced or is increased by insect feeding itself. In contrast, the transgenic plants engineered to date normally produce the B.t. toxin throughout their growth. This can lead to three main risks:

1. An unintended dispersal of transgenic insect-resistant plants or of their foreign genes in wild populations could lead to changed interactions between the plants and the harmful insects and thus to shifts in competitive constellations. The conse-

quences of this are hard to predict.

2. The toxin could increasingly affect non-target organisms. Little study has yet been devoted to this risk (Blatter and Wolfe, 1996; Deml, 1998). It could however be reduced by using tissue-specific or inducible promoters.
3. Resistance in pest insects to the B.t. toxins could be increased (Deml, 1998). This would not only impair the efficacy of the engineered resistance to insects, but would also render ineffective one of the most environmentally sound biological pest control agents (namely conventional B.t. toxin preparations). The risk of this form of resistance to insects becoming ineffective or of the resistance gene introgressing with wild populations rises with the number of species or varieties endowed with the gene in question and with the size of the area cultivated under transgenic insect resistant plants.

The first two risks impact directly upon the environment. The third risk is, like herbicide resistance, initially an issue of the economic costs and benefits of farmers and of the manufacturers of transgenic insect resistant plants. However, in view of the loss of efficacy of one of the most environmentally sound insecticides that may possibly be substituted by less environmentally friendly insecticides, this risk also has an environmental dimension. As noted above, this is not a risk specific to genetic engineering, for the improper use of conventional B.t. toxin preparations also accelerates resistance formation in pests. It must be kept in mind, however, that the prospective breadth of application of transgenic plants must be appraised differently than the scope of an improper use of conventional microbial preparations. In order to prevent the increased formation of resistance in harmful insects to the B.t. toxins of transgenic plants, the industry has developed numerous 'resistance management' strategies. These include, for instance: provision of sufficient refuges in combination with high B.t. toxin concentrations; parallel application of different B.t. toxins (gene pyramids); inducible toxin genes; farmer training; monitoring programs for timely identification of resistances etc. (overviews are provided in McGaughey and Whalon, 1992; Brandt, 1995; Stein and Lotstein, 1995; Stone and Feldman, 1995; Korell et al., 1997). Presently, the most promising approach would appear to be to combine several of these strategies. Moreover, further research on the development of resistance in harmful insects is indispensable, particularly as the conditions prevailing under field conditions are not yet fully understood (Tiedje et al., 1989; Blatter and Wolfe, 1996).

Virus resistant plants

As viruses are much harder to control than weeds or pest insects, great hopes are placed in the genetically engineered resistance of crops to viruses. One strategy pursued to engineer virus resistant plants is that of pathogen-derived resistance, in which gene sequences derived from the virus itself are integrated in the vulnerable plant variety. Techniques of pathogen-derived resistance include the frequently discussed coat protein gene mediated resistance, and satellite RNA mediated resistance.

The risks associated with these genetically engineered forms of resistance to viruses have a very different quality than herbicide resistance, and require an evaluation differentiated according to the mechanism (inserted viral gene sequences) utilized (Farinelli and Malnoë, 1996; BfN, 1997; Tepfer and Balázs, 1997b). In the case of coat protein gene mediated resistance, viruses with modified properties (e.g. altered host spectrum; Driesel and Danneberg, 1996; Tepfer and Balázs, 1997b) could be created through heterologous encapsidation (enclosure of viral RNA in the coat of another virus or in coat proteins formed by the plant) or through recombination – processes that occur in principle in non-transgenic plants, too. Recombination is particularly problematic in situations where the biological setting in which the virus resistance is introduced is not understood sufficiently, this raising the possibility of unknowingly promoting the development of viral defenses against transgenic virus resistance in plants. A further aspect is that in natural ecosystems resistance to viruses represents a competitive advantage, so that in the event of a spread of resistance traits shifts in populations and species may occur in natural or near-natural ecosystems. There are still major gaps in the knowledge on pathogens of wild plants and thus on the possible ecological impacts of genetically engineered virus resistance (Driesel and Danneberg, 1996; Tappeser and Wurz, 1996; Bartsch, 1997).

The risks of an unintentional modification of viruses resulting from the application of coat protein gene mediated resistance are presently rated as unproblematic, or are viewed as being reducible by means of an array of precautionary measures (Farinelli and Malnoë, 1996; Driesel and Danneberg, 1996). No development of new viruses has been found to result from field trials carried out with transgenic virus-resistant plants. However, large-scale cultivation of transgenic virus resistant plants and the constitutive expression of the viral genes in the plant throughout the entire vegetative period could alter this evaluation (Korell et al., 1997). In contrast, the use of satellite RNA genes to confer protection against viruses is very controversial. The satellite sequences are highly unstable, and can have opposite effects, depending upon ambient conditions, the host plant and the infected viruses (helper viruses; Tepfer, 1993; Farinelli and Malnoë, 1996). The associated financial risk makes a commercial application of satellite RNA mediated resistance appear improbable at present (Farinelli and Malnoë, 1996; Tepfer and Balázs, 1997a).

Concerning the ecological relevance of an unintentional spread of genetically engineered resistances, it can be stated in summary that for the case of herbicide resistance no competitive advantage is to be expected in natural or near-natural ecosystems, as here there is no selection pressure through herbicide application. In contrast, for the case of virus or insect resistance a selection pressure must indeed be expected, leading to competitive advantages for transgenic plants or their hybrids. This aspect has not always been taken into consideration adequately in earlier risk assessments (van den Daele et al., 1996, 1997). Future developments such as genetically engineered cold, heat or salt tolerance may well have greater relevance to agriculture and to the environment than past applications of ‘green genetic engineering’.

D 4.3
Assignment to the risk classes

D 4.3.1
Risk potentials associated with population explosions of alien species: A Cyclops-type risk

The probability of damage occurring can be high for pathogens, but can vary greatly for alien plant and animal species invasions. While the probability of mass propagation of native pests can be assessed relatively well, the invasion and population explosion of alien species is characterized above all by a high degree of uncertainty. This suggests an assignment to the Cyclops class of risk. Depending upon the species, ecosystem and environmental conditions, the magnitude of damage, delay effects, persistency and ubiquity can tend to be low or high. In cases involving the establishment of alien species, the possibly high delay effect implies transitions to the Cassandra class of risk.

D 4.3.2
Risk potentials associated with the release and marketing of certain transgenic plants: a Pythia-type risk

In light of the gaps in knowledge about the probability of occurrence and magnitude of possible environmental impacts, the risk potentials associated with the release and marketing of certain transgenic plants must be assigned to the Pythia class of risk (Table D 4.2-6). The probability of occurrence, the magnitude of possible damage, the ubiquity, the persistence and the irreversibility depend upon the type of engineered modification and its ecological relevance, the biology of the transgenic organisms, the ecosystems concerned and the extent of their utilization (e.g. world market and trade in transgenic seeds, size of cultivated areas). The available knowledge of the possible (long-term) effects of transgenic plants or their foreign genes in natural or near-natural ecosystems is presently inadequate, particularly with regard to a large-scale cultivation of transgenic plants. Compared to the establishment of alien species, risk potentials are compounded here by the new quality of possible gene and trait combinations and the associated lack of experience with possible effects. Further aspects that need to be considered are the speed and the ubiquity with which engineered modifications are implemented in crop species under very disparate framework conditions. It nonetheless remains conceivable that, in future, transitions result between the Pythia class of risk and the Medusa or Cyclops classes.

It needs to be stressed here that the above evaluation only applies to the release and marketing of transgenic plants. A release of transgenic microorganisms (e.g. for cleaning up contaminated soil) is associated with substantially larger risk potentials. This is due to their high reproductive potential, their small size and mobility. Once a microorganism strain has been released, it can no longer be recalled in its entirety (Pühler, 1998b).

D 5.1
Chemical time bombs

Many substances – be they of natural or anthropogenic origin – in the soil, water, air or foodstuffs have the potential to constitute risks to human health. When such substances impact upon the biotic environment, they can damage organisms and can cause adverse changes in ecosystem structures and functions.

For many substances, making a clear-cut distinction between opportunity and risk poses considerable difficulties. This is because both their deficiency and their surplus can be damaging to living organisms and communities (Fig. 5.1-1). Paracelsus (1493–1541) succinctly set out the difficulties involved in assessing biogeochemical and chemical risks when he stated: "all substances are poisons, there is none which is not a poison; the dose makes the poison."

A further aspect hampering assessment is that there are also substances which are toxic at all events, i.e. have no threshold values and for which damage tolerance values need to be defined. This is e.g. the case for genotoxic (mutagenic) substances. In addition to direct effects of substances, expressed in toxicology as dose-response relationships, increasing attention has been devoted in recent years to those biogeochemical and chemical risks for which the probability or magnitude of damage can not be assessed readily. Many substances have complex mechanisms of distribution and accumulation in the environment and can become effective in complex ways. Scientific

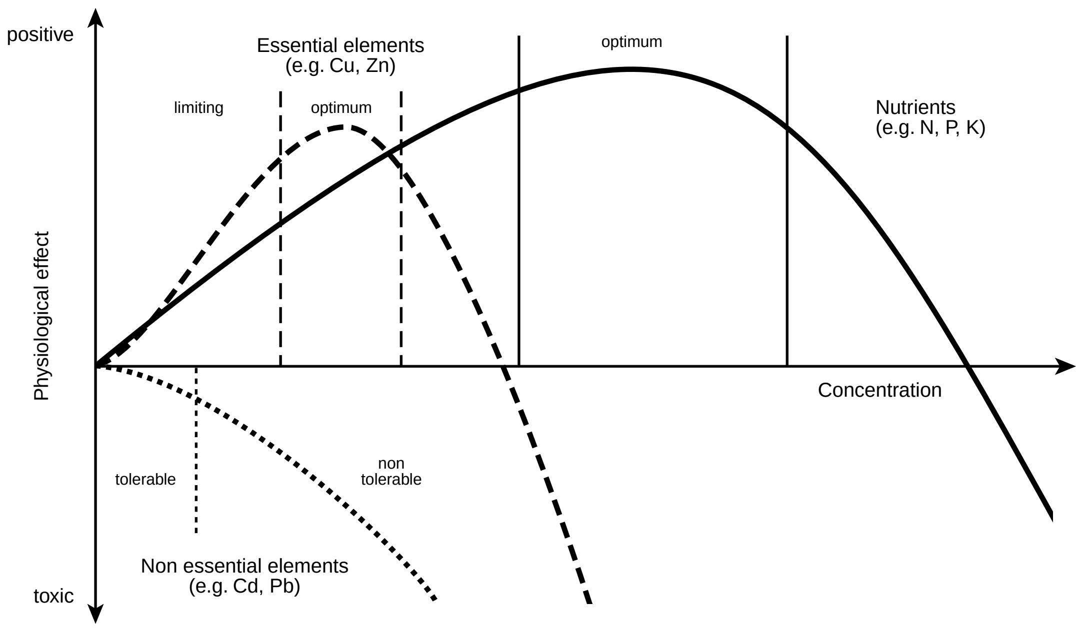


Figure D 5.1-1
Dose-response curves for different groups of chemical elements. Essential elements are indispensable to the metabolism of organisms.
Source: WBGU

risk estimations thus also acquire the function of early warning indicators.

Today, human intervention in natural biogeochemical water, carbon, nitrogen and sulfur cycles is already substantial. As these elements and water are essential preconditions to the life of animals, plants and microorganisms, these interventions cannot but impact upon the ecosphere. Furthermore, humans produce a great array of substances that do not occur in nature (xenobiotics). Experience yet remains to be collected on the behavior of these substances in the environment.

According to the Chemical Abstract Service, more than 11 million chemical substances have been described today. This number is growing by approximately 400,000 per year, of which approximately 100,000 are put into circulation. In Germany, 5,000 substances are produced annually in quantities of more than 10 t per substance (Streit, 1994).

Almost all industrial chemical synthesis processes lead to by-products. Their composition is not always known. It follows that the resultant risks cannot be assessed conclusively. In industrialized countries, management of the risks presented by known chemical substances is largely regulated by law. However, in many parts of the world this cannot be assumed. Even the known chemical compounds are associated in some cases with insidious changes whose long-term effects can not be predicted – neither with respect to the time of occurrence nor the magnitude of damage.

The following discussion focuses on three representative, different types of global risk induced by anthropogenic emissions of chemical substances:

- Changed biogeochemical cycles of carbon, nitrogen and sulfur,
- Persistent organic pollutants (POPs),
- Endocrine disruptors.

D 5.2 Anthropogenic interventions in biogeochemical cycles

Carbon (C), nitrogen (N) and sulfur (S) are required in relatively large amounts by all living organisms for their growth, development and reproduction. At the same time, availability of these elements is limited in many terrestrial ecosystems. In the course of evolution, organisms and ecosystems have adapted in different ways to these limiting conditions (e.g. low-N coniferous boreal forests). The high levels of anthropogenic emissions of various compounds of these elements has created a situation unique in the history of the biosphere:

- Increasingly, all three elements are simultaneously available in large quantities (regionally even in surplus). This leads to the eutrophication of ecosystems.
- Anthropogenic interventions in the elemental cycles have both growth-promoting effects (fertilization effects) and a growth-inhibiting and destabilizing effect. These are mediated by various reaction products and interactions (e.g. acidification and cation impoverishment; Ulrich and Sumner, 1991).
- The three elements and their compounds do not have a primary acute impact, but can develop insidious effects. Recognizing the risk potential of altered biogeochemical cycles is thus difficult and is generally only possible with a considerable time lag. Such insidious risks suggest that there is no need for immediate action. Moreover, due to secondary effects such as acid accumulation or potential loss of biodiversity, a full reversal of processes and developments occurring in an ecosystem is not possible or only over long periods (Alewell et al., 1997).

The direct reactions and reaction patterns of organisms and ecosystems to changes in the individual elemental cycles of C, N and S are largely known (Section D 5.3.1.6). However, how the biosphere will react to the novel 'exposure cocktail' is largely unclear. Due to the novelty, the assessment of such reactions is subject to major uncertainties.

D 5.2.1 Anthropogenic sources

Both in terms of causes and consequences, changes in global biogeochemical cycles are one of the most important components of global change, leading to the destabilization of natural material/chemical cycles. To name but one example, annual anthropogenic nitrogen fixation (fertilizer industry, legume cultivation, combustion processes) is larger than the nitrogen fixation of all natural processes taken together (IPCC, 1996a). Anthropogenic ammonia emissions are more than twice those of natural sources (70% of total ammonia emissions). Anthropogenic releases of nitrogen oxides (NO_x) and nitrous oxide (N_2O) are also of roughly the same order of magnitude as those caused by natural processes.

Combustion processes in industry, transportation and households are the main anthropogenic sources of C, S and N compounds. Beside releasing carbon dioxide (CO_2), land-use changes and forms are one of the main sources of emissions of methane (CH_4), carbon monoxide (CO) and N_2O (Vitousek, 1994; Flaig and Mohr, 1996; Schlesinger, 1997). In some regions, biomass burning (fire cultivation, firewood) plays an important role in the S and N cycles. The share of biomass burning in global sulfur dioxide (SO_2) emissions only amounts to 2–5%, but in Amazonia or West Africa it is the main source of SO_2 (Berner and Berner, 1996). N-intensive agriculture in the industrialized countries is one of the prime sources of N emissions, particularly of ammonia (NH_3) and N_2O (Isermann, 1993; Flaig and Mohr, 1996; van der Voet et al., 1996; van der Ploeg et al., 1997).

D 5.2.2
Global distribution and deposition of nitrogen and sulfur

Acids and acid precursors are dominated by sulfur and nitrogen compounds which enter terrestrial ecosystems via dry and wet deposition. The anthropogenic share of total acid inputs comes to 40–50% (Berner and Berner, 1996).

In order to image distribution and deposition, model calculations permitting a geographical depiction have been carried out (WMO, 1997). The deposition of oxidized sulfur compounds has been simulated using the coupled atmosphere-ocean circulation model ECHAM4/OPYC (Roeckner et al., 1996); that of oxidized nitrogen compounds with the atmospheric model ECHAM4. The global cycle of reduced nitrogen compounds (ammonia and ammonium) is less well understood. Ammonium deposition has been computed using the global atmospheric transport model MOGUNTIA (Zimmermann et al., 1989).

The deposition of oxidized nitrogen compounds on land surfaces is larger by a factor of 5–25 than that over the adjoining oceans, where deposition comes to only 5–100 mg N m^{-2} $year^{-1}$ (Fig. D 5.2-1).

Reduced nitrogen compounds have elevated deposition rates of 500–1,000 mg N m^{-2} $year^{-1}$ over large parts of Europe, China and India (Fig. D 5.2-2). This is due to emissions from arable and livestock farming, as opposed to the primarily industrial and transport-related emissions of oxidized nitrogen compounds. Nonetheless, the regions with elevated deposition of reduced nitrogen compounds correlate largely with those of oxidized nitrogen compounds. Parts of South America and Africa depart from this rule. It is further remarkable that the sheep breeding centers in Australia and New Zealand are clearly visible, with a deposition rate of reduced nitrogen compounds elevated by a factor of 4–10.

In the northern hemisphere, oxidized sulfur compound loads follow a pattern similar to that of oxidized nitrogen compounds (Fig. D 5.2-3). In contrast, the southern hemisphere has several narrowly localized centers of deposition, which characterize conurbations with industrial centers. However, at deposition rates of some 2,500 mg S m^{-2} $year^{-1}$ these do not reach the intensity of the hotspots of the northern hemisphere.

The acid loading of terrestrial ecosystems follows from the distribution of N and S deposition. In order to illustrate the range of possible acid loadings, the minimum and maximum acid inputs were calculated (Figs. D 5.2-4a–b). In the minimum scenario bioconversion in the plant-soil system was taken into consideration, in the maximum scenario nitrogen saturation of the system was assumed. Due to a lack of data, the deposition computations could not take into consideration the neutralizing effect of the release of basic alkali and alkaline earth cations from soil dust or fly ash. In the minimum scenario, acid loadings over the conurbations of the northern hemisphere reach levels of 450 mg H^+ m^{-2} $year^{-1}$. They are thus higher by a factor of 40–200 than over the unloaded continental regions. In the maximum scenario, the full acidic effect of ammonium nitrate and ammonium sulfate lead to deposition rates of up to 1,000 mg H^+ m^{-2} $year^{-1}$.

With increasing industrialization, increasing traffic volumes and intensifying land uses, S and N compound emissions will continue to rise and may also lead to acidification and nutrient imbalances over large regions of the developing countries of the southern hemisphere. These effects are associated with an imbalanced accumulation of the principal nutrient, nitrogen, and a rise of CO_2 levels in the atmosphere. At a regional level, this development is modified by global biomass fluxes associated with international trade in agricultural products (Box D 5.2-1).

D 5.2.3
Impacts of CO_2 emissions upon terrestrial ecosystems

In addition to CO_2-related global warming and the associated redistribution of precipitation (WBGU, 1998a), which can lead to a changed distribution and structure of terrestrial ecosystems, rising CO_2 levels in the atmosphere can cause an elevated carbon uptake of plants (CO_2 fertilization effect). According to IPCC figures (1996b), some 0.5–2 Gt C were sequestered annually by the terrestrial biosphere throughout the 1980s due to the CO_2 fertilization effect.

However, the photosynthesis capacity of the biosphere is limited and it is expected that the doubling of CO_2 levels in the atmosphere projected to take place over the course of the next century will only lead to an increase in net primary production by 5%

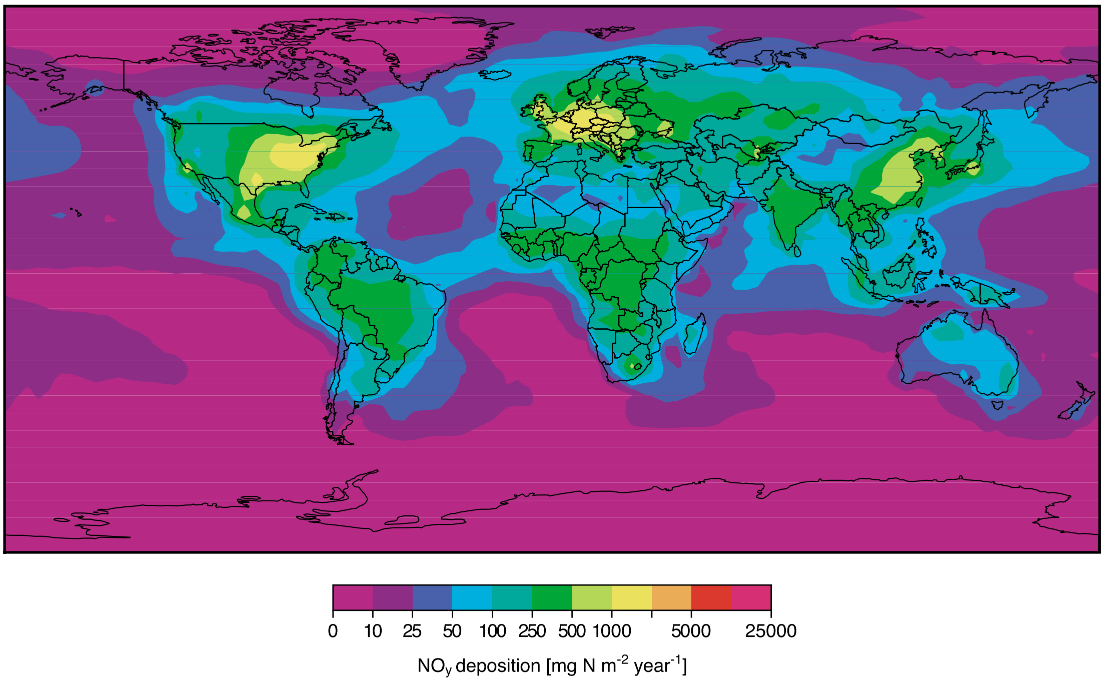


Figure D 5.2-1
Distribution of the mean annual deposition of oxidized nitrogen compounds (NO_y) in 1980–1990.
Sources: Max Planck Institute for Meteorology and WBGU

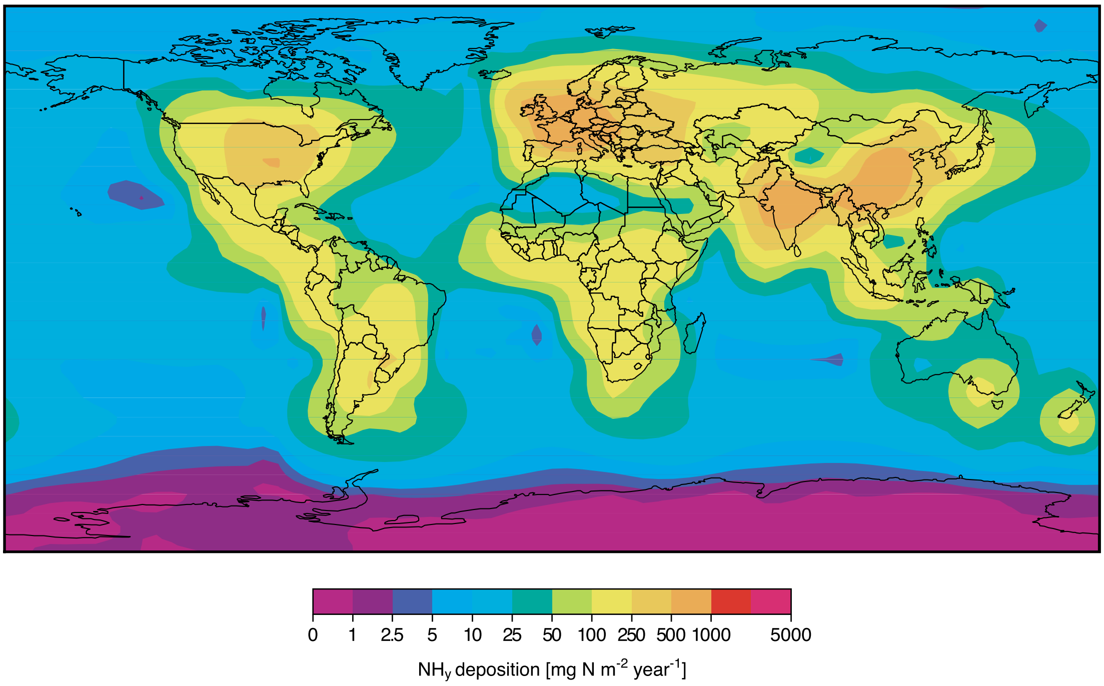


Figure D 5.2-2
Distribution of the mean annual deposition of reduced nitrogen compounds (NH_y) in 1980–1990.
Sources: Max Planck Institute for Meteorology and WBGU

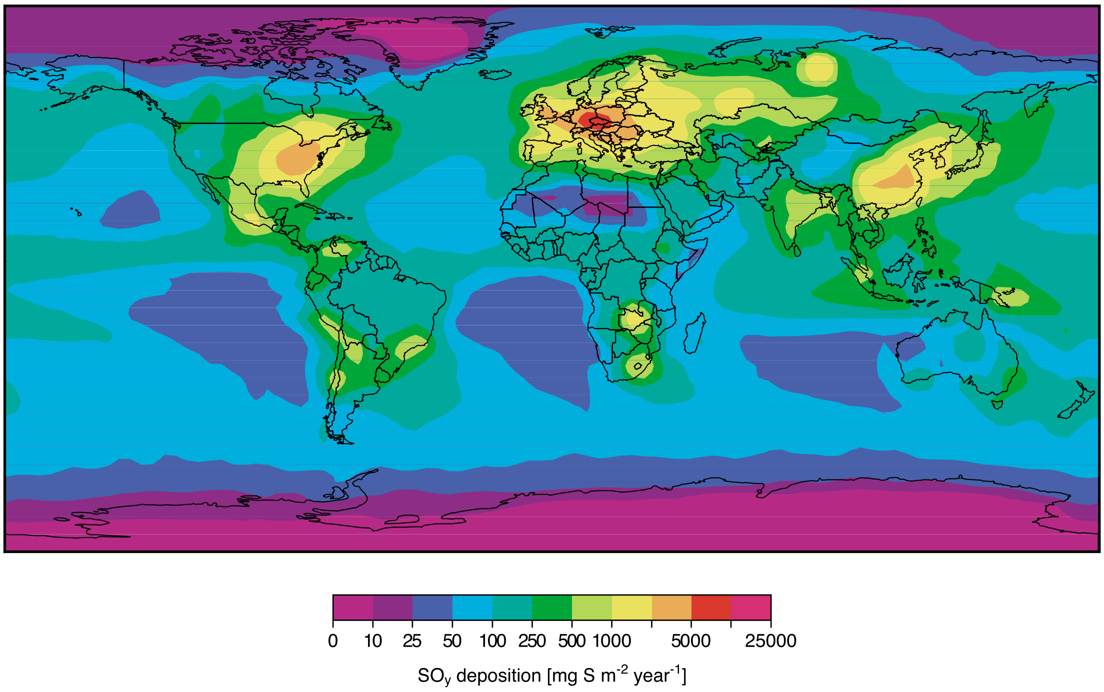


Figure D 5.2-3
Distribution of the mean annual deposition of oxidized sulfur compounds (SOy) in 1980–1990.
Sources: Max Planck Institute for Meteorology and WBGU

(Mooney et al., 1998; WBGU, 1998a). Moreover, the low rises in net primary production are expected to be compensated or exceeded by the further rise in temperature and the associated increase in respiration (Scholes et al., 1998). It is unclear how the nitrogen eutrophication described above and the simultaneous acidification and nutrient leaching will affect carbon sequestration, species composition and the structure and function of terrestrial ecosystems over the long term. Given the size of the areas concerned, an unassessable risk can emerge from this.

D 5.2.4
Case study: destabilization of forest ecosystems

Changed processes of mass and energy transfer can lead to irreversible changes in the structure and function of ecosystems if loadings overstep the regulatory and repair capacities of the system. In addition, loadings may not only cause internal changes, but can also induce pollutant emissions from soils that stress neighboring terrestrial and aquatic systems and the groundwater and atmosphere. As these processes are generally slow and buffered, it is difficult to recognize changes and effects, so that the risks associated with substance loadings are frequently underestimated (Box D 5.2-2).

Not only are the structures of forest ecosystems altered, but so too are their functions (habitat, regulatory, utilization and social functions). Soil acidification and the associated inadequate or imbalanced nutrient supply destabilize forest ecosystems and render them susceptible to biotic and abiotic stressors. In regions where soils have a low buffering capacity and are shallow, acidification also affects the groundwater or surface waters. Acids formed through emissions of oxidized sulfur and nitrogen compounds enter the soil directly through precipitation, while emissions of reduced nitrogen compounds have a neutralizing effect in the atmosphere and only contribute to acidification through oxidation in the soil (nitrification). A further indirect source of acid is the uptake of gaseous SO_2, NO_x and dissolved NH_4^+ by the plant, which is compensated by uptake of cations or release of H^+. In order to reflect total acid deposition, the vegetation must also be taken into consideration, as its filter effect modifies acid loading. In Germany, for instance, it has been found that deposition levels are elevated in beech stands compared with open unforested terrain by a factor of 1.1–2.0, and in spruce stands by a factor of 2.1–3.6 (Veerhoff et al., 1996).

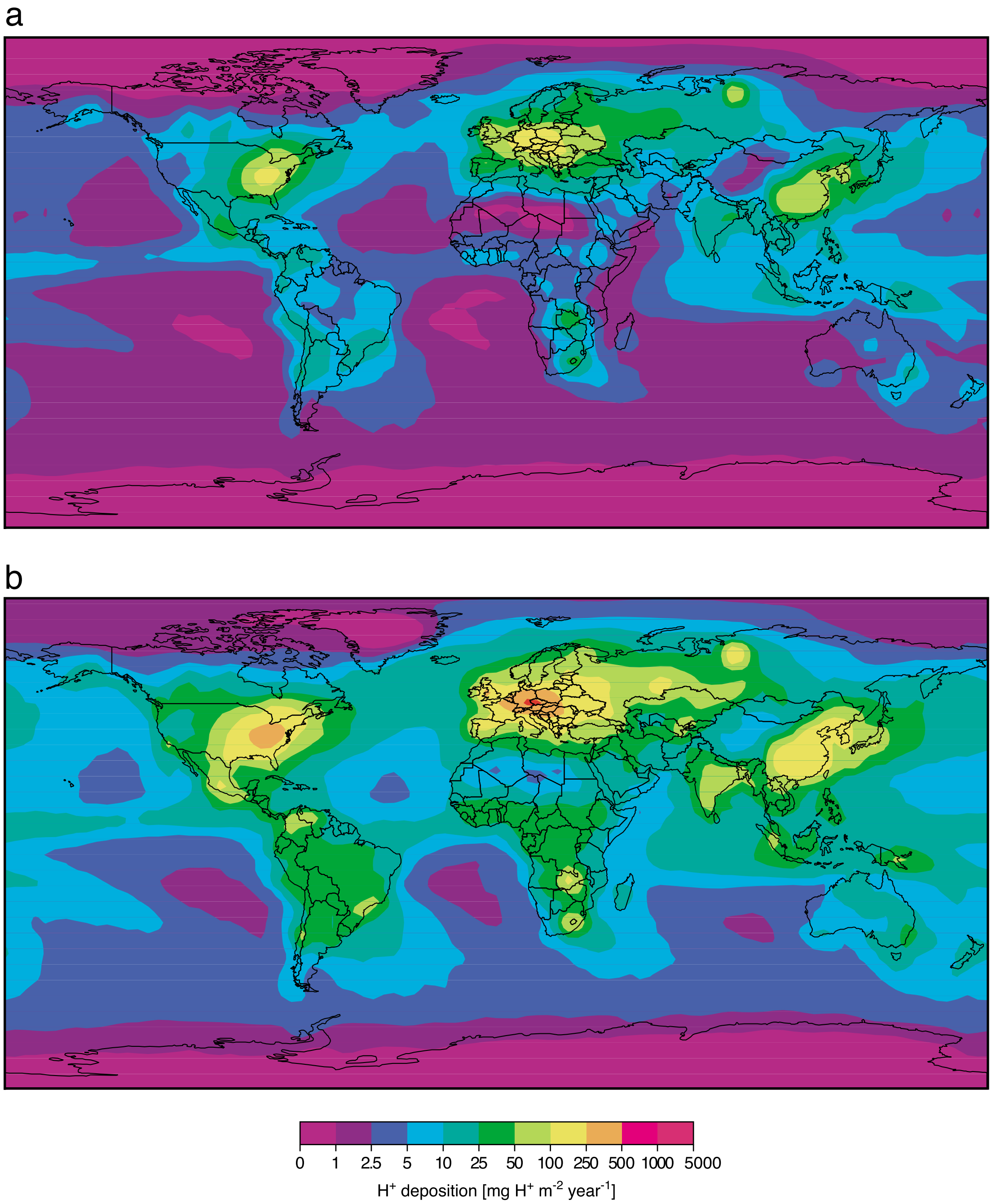


Figure D 5.2-4
Distribution of annual acid deposition (H^+) in 1980–1990. **a** Minimum scenario, **b** Maximum scenario.
Sources: Max Planck Institute for Meteorology and WBGU

As no global data are available for the determination of the acid neutralization capacity of soils, the FAO world soil map (1995) was used to identify regions poor in nutrients and with a low buffering capacity. Here the topsoils (0–30 cm) were taken into consideration, being the ecologically most important stratum for vegetation and soil organisms. Soil buffering capacities were calculated and placed in relation to acid loading (Fig. D 5.2-4) and global forested areas, in order to estimate where buffering capacity is exceeded (forest inventory: WCMC, 1997; Fig. D 5.2-5a). This method delivers a conservative estimate

Box D 5.2-1

Nitrogen imports through world trade in agricultural production

Agricultural production depends greatly upon the nitrogen supply of plants and animals. While plants utilize nitrogen uptake fully, animals require great amounts of nitrogen as they utilize it very inefficiently. Thus animal products from intensive livestock farming only contain ⅙–¼ of the nitrogen contained in the feed. In order to meet high levels of meat demand in Europe, not only large-scale intensive livestock farming is necessary, but nitrogen-rich feedstuffs such as soya bean and oil-seed meal are imported. In 1992–1993, European countries imported 2.4 million t nitrogen (N) per year in the form of feedstuffs (Lammel and Flessa, 1998). In relation to the utilized agricultural area in Europe, this corresponds to a specific N import of some 13 kg N ha^{-1} $year^{-1}$. On the other side of the equation, Latin America exported 2.4 million t N in the form of feedstuffs. Worldwide, the intercontinental trade in the main agricultural commodities amounted in 1992–1993 to some 11 million t N $year^{-1}$ (fertilizers 6.3 million t, feedstuffs 4.6 million t, fresh meat and live animals approximately 0.5 million t; Lammel and Flessa, 1998).

The outcome of this is that the N cycle is decoupled not only regionally, but also globally. In the recipient countries, an N surplus is available and causes nitrate pollution of the groundwater, eutrophication of surface waters (WBGU, 1998a) and increased ammonia release to the atmosphere, with the associated risks to natural and near-natural ecosystems (Fangmeier et al., 1994; Box D 5.2-2). In large-scale intensive livestock farming, animal excrements arise primarily in the form of slurry, whose storage and application to the fields is associated with particularly high ammonia releases. Feedstuff imports thus entail a larger risk potential than their quantity alone might suggest. In England, for instance, livestock farming is responsible for 95% of agricultural ammonia emissions (Skinner et al., 1997). In Germany, too, the proportion is estimated at about 90% (Flaig and Mohr, 1996). Moreover, there are great differences in the regional distribution of animal production and thus of feedstuff imports.

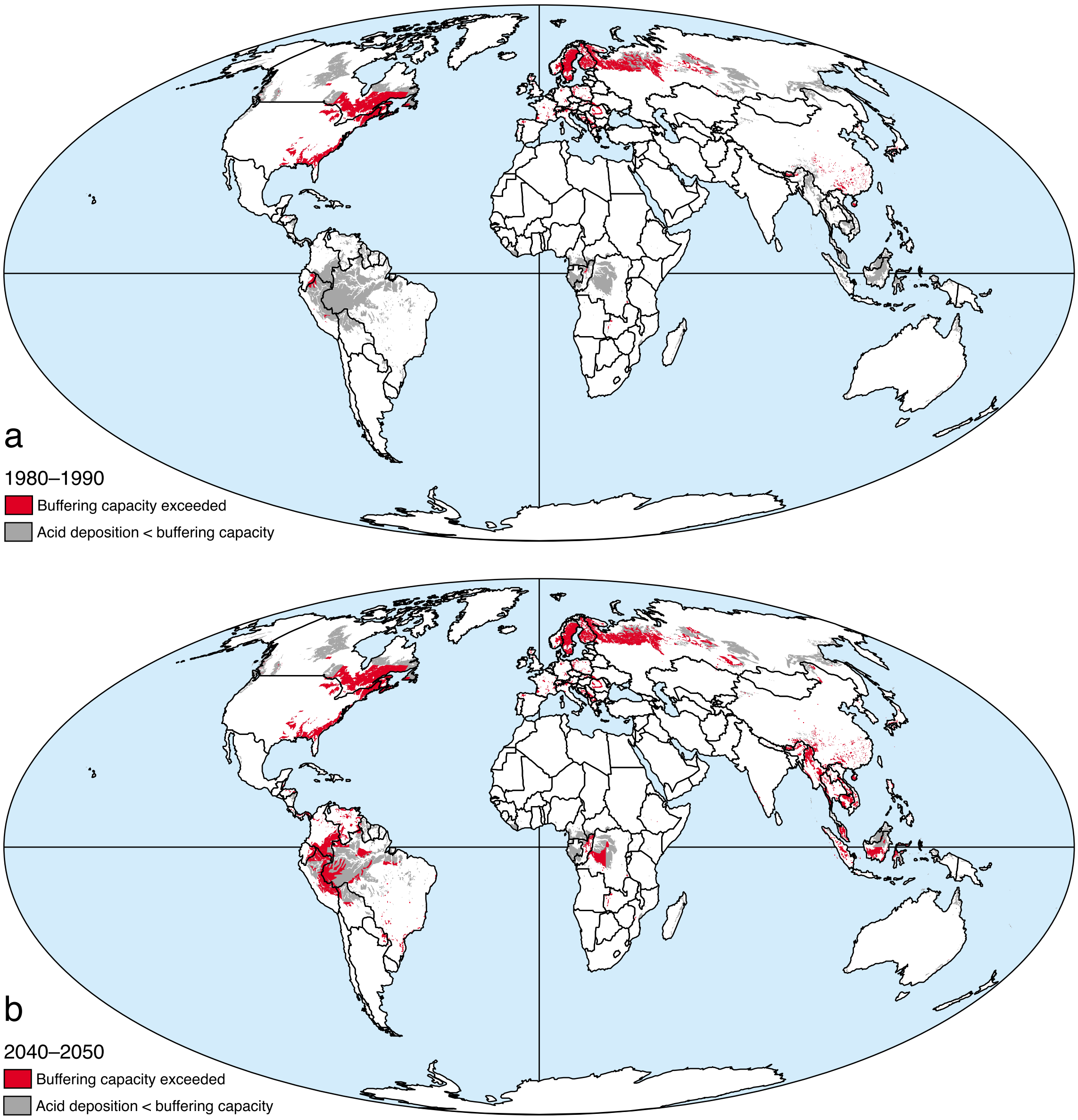
In the feedstuff exporting countries of Latin America, the withdrawal of N does not play any role (the exported N is extracted from the inert N_2 pool of the atmosphere). However, a great array of secondary effects arise, starting with the clearcutting of primary forests for soya cultivation (e.g. in Pantanal, Brazil; WBGU, 1998a), followed by CO_2 release, hazards to biodiversity, soil acidification and base impoverishment caused by nitrogen-fixating legumes through to socio-cultural consequences such as the loss of the territories of indigenous peoples. Little consideration has yet been given to the risks of these secondary effects in the feedstuff exporting countries and the magnitude of damage has yet to be identified.

Reducing meat consumption in the importing countries is the most effective measure by which to reduce the global trade in N-rich agricultural products and the associated risks. Moreover, reducing N surpluses could serve to reduce in the recipient countries the risks associated with the pollution of non-agricultural ecosystems and of the groundwater. These surpluses could be reduced by means of improving fertilization efficiency, selecting the form of fertilization so as to be appropriate to the specific site, and shortening the storage periods of excrements.

as e.g. in forested areas with acid deposition in Central Europe the pH-values and base saturation are substantially lower than indicated in the FAO soil map (UN/ECE and EC, 1997). The same approach was taken to estimate acid loading for the years 2040–2050 (Fig. D 5.2-5b), using an intermediate IPCC scenario of future emissions (IS92a; IPCC, 1992).

Large areas of the still existing forests in the temperate regions receive acid loads of more than 50 mg H^+ m^{-2} $year^{-1}$. In Central Europe, the modeled acid inputs in 1980–1990 come to 250–500 mg H^+ m^{-2} $year^{-1}$ (maximum scenario). These values correlate well with the findings of the Solling project, which arrived at 480 in the year 1980 and 260 mg H^+ m^{-2} $year^{-1}$ in 1991 (Manderscheid et al., 1995). It is striking that in Central Europe scarcely any acid-loaded forest areas on soils with poor buffering capacity are indicated (Fig. D 5.2-5), although in EU states 53% of forest soils have pH-values lower than 4.0 and 42% of these soils have a base saturation of less than 20% (UN/ECE, 1997). Due to the considerable fragmentation of Central European forests, the proportions of forested areas are often not taken into consideration in the FAO soil map. These forested areas were thus assigned the soil indexes of the forest regions that have better buffering and nutrient supply. The figures show that the regions in which the limits of buffering capacity are reached or exceeded will spread over the coming 50 years into the tropics. This will particularly affect South America and South-East Asia. In addition, these forests are exposed to an increased N input, which, as a plant nutrient, promotes growth, so that forest ecosystems can assimilate more carbon. IPCC (1996b) estimates put this potential at 0.2–1 Gt C worldwide. However, this enhanced growth is faced with destabilization proceeding from numerous physiological and ecosystemic effects (Table D 5.2-1). Moreover, elevated N inputs intensify the release of nitrous oxide. In global warming terms, this runs counter to the additional storage of CO_2.

Fig. D 5.2-6 shows the forest ecosystems that are subject to N loading higher than the natural level of 100–500 mg N m^{-2} $year^{-1}$ (Kimmins, 1987; Flaig and Mohr, 1996). Based on the concept of critical load inventories in Europe (Bobbink et al., 1992), the figure further shows the forest regions with N loads of more than 1,500 mg N m^{-2} $year^{-1}$. These areas simultaneously receive acid loads that lead to buffering capacities being exceeded considerably (Fig. D 5.2-4).



Figures D 5.2-5
Acidified or acid-sensitive soils under forest ecosystems in which buffering capacity is exceeded. **a** estimate for 1980–1990, **b** estimate for 2040–2050.
Sources: Institute for Soil Science and Forest Nutrition (IBW), Max Planck Institute for Meteorology and WBGU using data from IPCC, 1992; FAO, 1995 and WCMC, 1997

In addition to changes in photosynthesis or respiration, the reaction of the forests to elevated CO_2 concentrations include changes in interrelationships with other organisms in the ecosystem. At the ecosystem level, the CO_2 fertilization effect can scarcely be quantified as yet, as it, too, depends upon numerous subprocesses (N storage, structural change in the system, decomposition, respiration; Houghton et al., 1998). In addition, CO_2, as a greenhouse gas, also contributes indirectly through climate change (Section D 6) to alterations in the spatial distribution and structure of ecosystems, with consequences for e.g. species composition, population dynamics, interactions between organisms and succession.

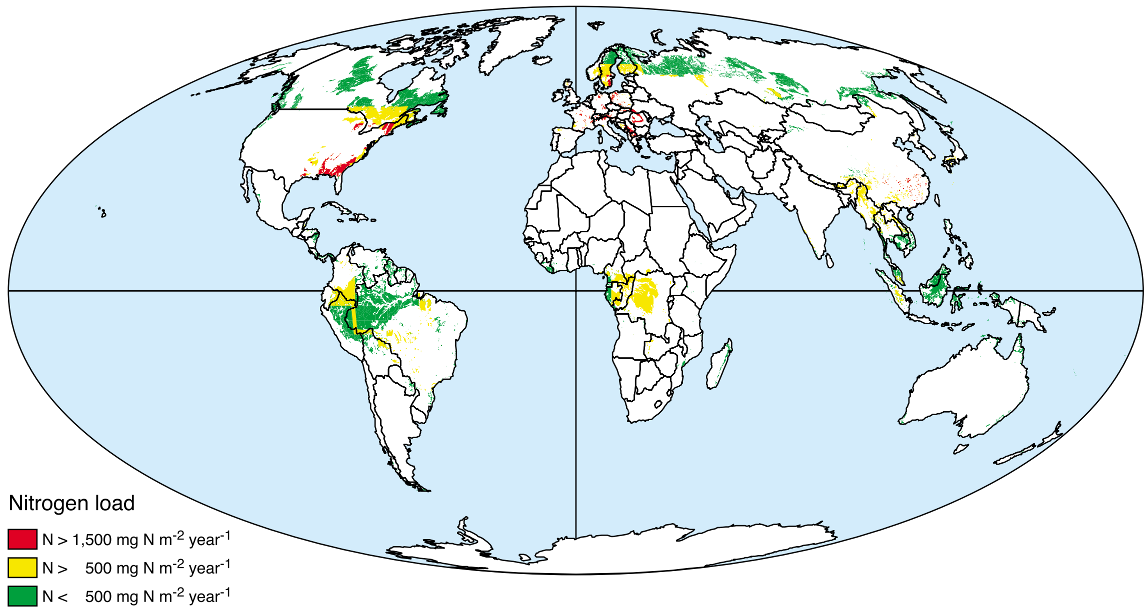


Figure D 5.2-6
Forest ecosystems on acidified or acid-sensitive soils with elevated nitrogen loads.
Source: Institute for Soil Science and Forest Nutrition (IBW), Max Planck Institute for Meteorology and WBGU using data from FAO, 1995 and WCMC, 1997

D 5.2.5
Combined interactions

Table D 5.2-1 summarizes the combined effects of the stress factors and the possible resulting risks to ecosystems. Although these risks cannot yet be fully assessed, the known consequences of changes in biogeochemical cycles already demand an immediate reduction of anthropogenic substance emissions. The mechanisms and risk potentials listed in the Table are

Box D 5.2-2

Forest ecosystem destabilization: fact or fiction?

In the early 1980s, a debate began on forest damage in Central Europe. This debate was intense and, as must be expected with complex systems, controversial. Strong media attention focused on 'Waldsterben', and scenarios were set out predicting the complete deforestation of Central Europe. Following this, research on 'patient forest' was intensified. Proceeding from a broad array of hypotheses, a causal complex for the destabilization of the forests was identified in which human activities play a pivotal part. The forests that remained in Central Europe after clearcutting were in many cases overexploited for many centuries, leading to changes in species diversity, acidification of soils and impoverishment of nutrients. 60% of the acids released during the industrial era were emitted after 1950. Over the past 20–30 years, nitrogen deposition rates have exceeded those required by forests for annual biomass increment. At the same time, CO_2 concentrations in the atmosphere have risen over the past 100 years by 25% and tropospheric ozone concentrations by about 100%.

The effects, both individual and combined, of nitrogen, carbon dioxide, acids, ozone and contaminants depend upon the location of a forest. Generalizations of observations made at specific sites can thus lead to misinterpretations. While timber increment is greater at various sites than ever before, this is not in effect a contradiction to the observations and research findings of the past. For one thing, the destabilization of forest ecosystems cannot be measured by timber increment alone. A forest is more than the sum of its trees. Over the long term, the damage to habitat and regulatory functions are not only severe for the forest itself, but also for its environment (groundwater, climate). For another thing, the measures taken in the 1980s (SO_2 emission control, fitting catalytic converters for NO_x control, reduction of heavy metal emissions, forest liming and ecologically adapted silviculture) have had positive effects. They have prevented forest dieback from spreading from the exposed higher altitudes to the lowlands.

That catastrophic developments have not occurred does not suggest erroneous assumptions, but is the outcome of correct action after the recognition of emerging risks. However, these are by no means yet dispelled. The discussion in this section illustrates clearly that forest ecosystems are still overloaded, albeit at a lower level. The long-term effect upon our forests of the cocktail of SO_2, NO_x, NH_4 and CO_2 is highly uncertain.

Table D 5.2-1
Overview of possible effects and risk potentials of anthropogenic interventions in biogeochemical cycles
(↑: rising; ↓: falling; -: no change; ≠: change; NPP = net primary production).
Sources: Schulze et al., 1989; Mohr and Müntz, 1994; Vitousek, 1994; Amthor, 1995; Dixon and Wisniewski, 1995; Heywood and Watson, 1995; Woodwell and Mackenzie, 1995; Drake et al., 1997; Flaig and Mohr, 1996; IPCC, 1996a; Körner and Bazzaz, 1996; Koch and Mooney, 1996; Walker and Steffen, 1996; Arnone III and Hirschel, 1997; Berg and Matzner, 1997; Foster et al., 1997; Hungate et al., 1997; Kinney et al., 1997; Vitousek et al, 1997a; Gundersen et al., 1998; Mooney et al., 1998; Walker et al., 1998

Substances and substance combinations	Possible effect mechanisms	Examples of possible risk potentials
N	↑ N contents, ↑ mineralization, ↑ N turnover, ↑ NPP, ↓ mycorrhizal fungi, ↑/↓ humus	↑ nitrate in groundwater, ↓ frost, drought or pest resistance, ↓ biodiversity, ↓ ecosystem functions
N + SO_y	↑ soil acidification, ↑ toxic ions (Al), ↓ fine roots and mycorrhizae, ↓ cations	↑ nitrate in groundwater, ↑ water acidification, ↓ drought resistance, ↓ nutrient equilibrium, ↑ forest damage, ↓ biodiversity, ↓ ecosystem functions
CO_2 with low N availability	-/↑ NPP, ↑/↓ C/N ratios, ↑/↓ mineralization, ↑/↓ shoot/root ratio, -/↑ water and nutrient-use efficiency	≠ vegetation composition, ≠ population dynamics of herbivores
CO_2 + N	↑ C and N accumulation through ↑ NPP, ↑/↓ humus	≠ species composition, ↓ biodiversity, ↑ N and ↑ C after exogenous disturbances (e.g. land use, fire, climatic changes), ↑ climate change
climatic changes + CO_2 + N + S	↑ mineralization, ↑ NPP, ↓ C storage	↑ vegetation shifts, ↑ invasion of alien species ↑ desertification, ↑ climate change

merely examples drawn from a broad array of possible reactions and interactions.

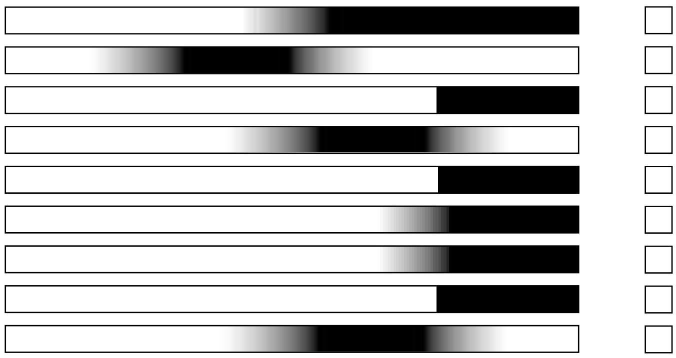
D 5.2.6 Present management of the risk

Through ratifying the 1979 Convention on Long-Range Transboundary Air Pollution (LRTAP), the (European and North American) parties have for the first time responded collectively to the diverse impacts and risks of air pollution. Analogous progress in other regions of the world has not taken place – as illustrated above, this would be particularly necessary for East and South-East Asia. Since then, international collaboration in the UN/ECE region has produced further agreement (e.g. the 1994 Sulphur Protocol) on air pollution control, and, moreover, has led to expanded aims and strategies. Efforts now no longer focus only on determining maximum permissible limits of individual pollutants, but also sensitivity ranges for ecosystems. Using an ecosystem approach, the ecological loads are determined that plant communities or soils can tolerate without suffering damage. The methodology for determining critical loads and critical levels is based on findings and recommendations of a 1988 UN/ECE working group.

The critical loads approach was extended in 1995, when for the first time an integrated modeling of critical acid loads was performed and applied to 31 ecosystems, using a regional model (RAINS; Alcamo et al., 1990) and a global integrated assessment model (IMAGE 2; Alcamo et al., 1995). Emission profiles were modeled in 13 different world regions, taking into consideration socioeconomic driving forces. These profiles form the basis for scenarios that clarify the sensitivity of ecosystems in Europe and Asia with regard to the combined stresses of climate change and acid loading (Alcamo et al., 1995). These tools permit a risk evaluation that illustrates the dynamics of terrestrial ecosystems and highlights the potential impacts of political actions or failure to act. The possibilities of such integrated modeling notwithstanding, it must be demanded that the critical loads approach is expanded so as to move from the analysis of static equilibria towards a consideration of dynamic equilibria and that the boundary conditions are extended so as to cover a greater number of ecosystems. Carbon compounds should also be included in addition to nitrogen compounds and acid precursors. In order to reflect the combined effects of substances, the approach would also need to take into consideration the synergistic or antagonistic interactions among the substances concerned. Here a major need remains for basic research in order to

Table D 5.2-2
Application of the evaluation criteria to the risk of destabilization of ecosystems caused by interventions in global biogeochemical cycles. This belongs to the Cassandra risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					
Ubiquity					
Persistency					
Irreversibility					
Delay effect					
Mobilization potential					



provide a foundation for risk assessment. Following WBGU (1995a), the Council recommends extending the concept so as to include 'critical operations', 'critical states' and 'critical outputs', in order to be able to reflect critical structural properties of ecosystems. Linking an extended critical load approach with coupled global circulation models would be an important method by which to assess insidious risks and a valuable tool by which to screen potential impacts of political measures. However, this can only succeed if the ecological assessment bases are improved, indicators are developed for ecological and ecotoxicological assessment and the data basis for risk assessment is expanded.

D 5.2.7
Assignment to the risk classes

In view of the projected growth of world population and industry, carbon, nitrogen and sulfur emissions are set to rise, although their spatial clustering will change. The risk of a destabilization of terrestrial ecosystems thus has a high probability of occurrence. In accordance with spatial clustering, the extent of damage will vary greatly from region to region, and both its ecological and economic consequences are associated with a high uncertainty of assessment because of the diverse and partially unclear interactions. The conflict potential engendered by spatial disparities can be high, as the processes can only be reversed very slowly, if at all. Due to the insidious character and high complexity of the processes involved, the delay effect of the risk is high both with regard to consequences and with regard to its perception, so that the mobilization potential is lower than for other risks with directly perceptible impacts. The risk accordingly attains less political priority. Due to these properties, the risk is assigned to the Cassandra class (Table D 5.2-2).

D 5.3
Persistent organic pollutants

D 5.3.1
Characterization of the risk

Organic contaminants that decompose slowly or not at all lead to acute toxic effects when arising at high concentrations close to their sources. At large distances to the site of emission, even traces of these substances can still have chronic toxic effects. Due to their physico-chemical properties (e.g. vapor pressure, water-solubility, fat-solubility), these persistent substances are dispersed globally via atmospheric and hydrospheric pathways and accumulate in various environmental compartments. This constitutes a risk, even if effects are unknown. The effects have only been determined for a few species and only for some of the roughly 5,000 xenobiotics that are released in larger quantities to the environment (BUA, 1976). These substances enter the environment through e.g. leaks in non-contained production processes and applications, and in the course of disposal. Biocides are applied deliberately in pest control. Despite major gaps in knowledge, ecotoxicological risks are tolerated for both deliberately and unintentionally distributed substances. Although pest control agents are subjected to ecotoxicological testing prior to market approval in Europe and the USA, cases of unexpected consequential ecological damage have occurred repeatedly. The established ecotoxicological testing methods are inadequate in a number of respects: possible combinatory effects upon individual organisms, effects upon the overall ecosystem and consideration of complex environmental processes (Lammel and Pahl, 1998). A part of the biocides does not reach the target organisms, but enters flowing waters or the atmosphere. Pesticides can thus accumulate even in remote regions. For instance, endosulfan and fenthion, insecticides which are also used in OECD countries, are viewed as critical in this connection (UN/ECE, 1997). Various pesticides, including the important triazine herbicides, can further have an endocrine-disrupting effect. In flowing waters receiving surface runoff from agriculturally utilized areas, disturbances observed in the aquatic ecosystem have been attributed to insecticides (Liess, 1998).

Important persistent organic pollutants (POPs) are mono- and polycyclic aromatic hydrocarbons, halogenated aliphatic and aromatic hydrocarbons, chlorinated ethers or nitrosamines (Callahan et al., 1979). The prevalence of these substances in the environment is determined by the applications in question, the transport patterns in the specific environmental compartments and the physico-chemical properties of the substances themselves. Thus the concentrations of critical substances such a hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs) and DDT in environmental compartments and organisms are higher in the northern hemisphere than in the southern hemisphere, while chlordane is distributed evenly across the globe. Some readily volatile substances such as HCB have a reduced atmospheric residence time at lower temperatures, so that they tend to be deposited more at high latitudes. In contrast, less volatile substances, such as DDT, dieldrin and PCBs, are generally found in lower concentrations at high latitudes distant from the emission source. Water-soluble substances, gaseous or particulate, are washed out rapidly. Most POPs, however, are poorly soluble in water. With rising relative molecular mass (e.g. from less to highly chlorinated PCBs) of poorly soluble substances, the ratio between substances transported in gaseous and particulate form drops, so that the mean atmospheric residence time drops.

As opposed to the risks associated with the accumulation of most of the conventional pollutants and nutrients in the environment, the risks generated by POPs escape direct perception: their input to marine and terrestrial ecosystems is dispersed and typically via the atmospheric pathway. At the prevailing concentrations in the environment and food chain, they are not immediately toxic to animals and humans (except for cases of high emissions). A direct damage potential does nonetheless arise if the substances are already toxic to humans or the environment at low concentrations – so low as to be organoleptically imperceptible. Even low doses already cause disturbances of the reproductive system, of metabolic processes, of the immune system and of behavior, and tumors. Toxicological studies and cases of source-close exposure have shown many POPs to cause severe effects (e.g. skin diseases and other illnesses caused by dioxin exposure due to chemical accidents, or illnesses of farmers after improper use of pesticides). In many countries, workplace exposure is subject to statutory controls (such as the 'MAK – maximale Arbeitsplatzkonzentrationen' threshold limit values in Germany; DFG, 1997). Inhalation and food intake are the main exposure pathways for humans. Particular relevance attaches to those substances that, due to their longevity, accumulate in the ecosphere or – if they are fat-soluble – in the food chain. Carcinogenic substances present a risk even without such an accumulation. For instance, the biodegradability of phthalic acid esters is high in carnivores, but low in plants (Giam et al., 1984). A small, not quickly excreted proportion accumulates in the liver, the fatty tissue and the brain. Furthermore, there is still a major lack of knowledge regarding the toxicological relevance of products of metabolism. It is suspected that di-(2-ethylhexyl)phthalate (DEHP) which acounts for more than ¼ of world phthalate production, is carcinogenic (Giam et al., 1984; Koch, 1989) and that its main metabolite in animals, mono-(2-ethylhexyl)phthalate (MEHP), may impair human reproductive functions (Stahlschmidt-Allner et al., 1997). An estrogenic activity of dibutyl and benzyl butyl phthalate has recently been reported (HHS, 1993; Soto et al., 1995). Phthalic acid esters are used as softeners in plastics, of which they are a main component (50–67% of PVC products). Their global production amounts to several million t year^{-1} (2 kg per capita and year in the USA). Their long-distance transport is through the hydrosphere and in large part also via the atmosphere.

D 5.3.2
Present management of the risk

Ozone-depleting substances are the only trace substances that are as yet subject to global regulation. Chapter 19 of AGENDA 21, which is devoted to the environmentally sound management of toxic chemicals, calls for global cooperation to control hazardous xenobiotics subject to long-distance transport. Regional pollution hotspots in aquatic ecosystems have already led to international cooperation, such as the Canada-USA Great Lakes Water Quality Agreement, the Convention on the Protection of the Marine Environment of the Baltic Sea Area (1992 Helsinki Convention, not yet in force), the Convention for the Protection of the North-East Atlantic (1992 OSPAR Convention, not yet in force) and the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (1995 Barcelona Convention, not yet in force). Here commitments have been agreed to return the concentrations of not further specified, persistent and bioaccumulating substances to harmless levels by the year 2000 (North-East Atlantic) or 2005 (Mediterranean).

Following on from recent multinational agreements, such as the POPs protocol to the Convention on Long-Range Transboundary Air Pollution of the UN Economic Commission for Europe (UN/ECE; the 'Aarhus Protocol') adopted at the end of June 1998, which is limited to Europe and North America, a global POPs convention is now to be adopted. This was demanded at the 1995 Washington conference on land-based marine pollution by the assembled representatives of states. In 1997, UNEP received a report and recommendations of the Intergovernmental Forum on Chemical Safety (IFCS) on the need for action on POPs. The decision to establish IFCS was supported in 1994 by 130 states. This ultimately extends the previous EU- and OECD-wide chemicals policy (not legally binding in the latter forum) to all states. IFCS is charged with addressing the 6 program areas proposed in Chapter 19 of AGENDA 21:

- Expanding and accelerating international assessment of biogeochemical and chemical risks,
- Harmonization of classification and labeling of chemicals,
- Information exchange on toxic chemicals and biogeochemical and chemical risks,
- Establishment of risk reduction programs,
- Strengthening of national capabilities and capacities for management of chemicals, and
- Prevention of illegal international traffic in toxic and dangerous products.

These activities comprise strong elements of capacity building, e.g. duties to provide information and the PIC principle (Section F 6). IFCS implements the Agenda process in collaboration with international organizations (OECD, WHO, ILO, FAO, UNEP, UNIDO and UNITAR) and non-governmental organizations (NGOs, in various major groups: industry, labor unions, conservation/consumer associations and the scientific community). NGOs have been involved in the whole process from the very outset with a right to speak at meetings (IFCS, 1997).

In June 1998, an International Negotiating Committee came together for the first time to prepare a legally binding convention on the protection of human health and the environment against damage by POPs. The list of priority POPs identified by UNEP to be regulated by the convention comprises 12 substance groups (the 'dirty dozen'): 9 pesticides (aldrin, chlordane, DDT, dieldrin, endrin, HCB, heptachlor, mirex, toxaphene – several hundred individual compounds), polychlorinated biphenyls (PCBs, 209 individual compounds) and polychlorinated di-benzo-p-dioxins and -furans (PCDD and PCDF – 75 and, respectively, 135 individual compounds). In many states, including most industrialized countries, the application of the above pesticides is already banned or greatly restricted. PCB production is already banned in all states. It can be assumed that global production, application and use have been in decline since the 1970s. However, the international trade and use of these pesticides is not fully inventoried (UNEP, 1996). One outcome of this first negotiating session was to establish a Criteria Expert Group (CEG) with the remit to develop criteria and procedures for including further POPs in the convention. Substances presenting an urgent need for action also include those that are presently produced and used in industrialized countries.

The preparations for the POP convention have been influenced by the negotiations for the PIC Convention (Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, Section F 6.3.2).

D 5.3.3
Assignment to the risk classes

Table D 5.3-1 shows the evaluation of the risk of persistent organic pollutants (POPs). The uncertainty of the probability and magnitude of damage is characteristic for this risk. For both criteria, there are generally only assumptions. As POPs persist over long periods in the various environmental compartments, they are distributed globally. They are ubiquitous and cause persistent damage with a considerable delay effect. The risk taken by releasing POPs into the environment is thus an example of the Pandora class. Considering the possible damage to human health, animal organisms and ecosystems, the mobilization potential is low, for instance compared with the prevailing perceptions of the risk of climate change. There is little interest among the public in the negotiations for the POPs convention.

Table D 5.3-1
Application of the evaluation criteria to the risk potential of persistent organic pollutants (POPs). This belongs to the Pandora risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					■
Certainty of assessment of *P*					■
Extent of damage *E*					■
Certainty of assessment of *E*					■
Ubiquity				■	□
Persistency				■	□
Irreversibility	■				□
Delay effect			■		□
Mobilization potential		■			□

D 5.4
Endocrine disruptors

In 1991, the Wingspread Consensus Statement – the outcome of a consultation process of an interdisciplinary group of scientists – launched the debate in the USA on endocrine disruptors. The scientists agreed that many of the substances present in the environment may be capable of exerting a negative influence upon the internal secretion system of humans and animals, and thus upon human health and the environment.

Substances with potential endocrine-disrupting properties include plant protectants, pharmaceuticals, PCBs, plastics additives and organometallic compounds, but also natural substances such as the phytoestrogens contained in plants. They are emitted from the most varied sources, such as agriculture, industry, motor vehicles or antifouling paints on ships. Many of these substances are by now ubiquitous and are known for other damaging effects. Many endocrine disruptors belong to the group of POPs.

Risk characterization – Human effects

Some aspects of the debate on whether hormone-disrupting chemicals may cause carcinomas, deformities, falling sperm counts, impaired brain development in children and effects upon genital organs in humans are the subject of much controversy. Most attention is currently being given to possible effects upon the reproductive system, in particular by estrogens. The following discussion revolves around this aspect. Epidemiological studies have not yet been able to prove causal agency for any of these effects. While the findings of culture and animal experiments suggest that such effects can be assumed in humans, too, transferal of these findings to humans is problematic, particularly as there are as yet scarcely any substances for which the dose-response relationship has been clarified.

The validity and reproducibility of some findings is dubious. This has recently been highlighted by repeated revocations of animal experiment findings (Arnold et al., 1996; Sharpe and Turner, 1998). Beside animal experiments, performing painstaking epidemiological studies is the main source of knowledge on effects in humans. Workplace exposure and exposure after chemical accidents can make the main contributions here. However, even such studies deliver no proof unless numerous other variables are controlled. The fundamental difficulties in proving causal connections are compounded by the circumstance that substances with potential endocrine-disrupting properties are often mixtures of substances with antagonistic or additive effects.

In its response to the interpellation of the German Social Democratic Party ('Hormonal risks and side-effects of chemicals'), based in part on a study of the German Research Foundation, DFG on hormonal substances in foods (DFG, 1998), the German government arrives at the conclusion that the great majority of findings fails to support the presumption that chemicals ingested through food or drinking water pose a hazard due to their hormonal effect. On the other hand, expert opinion holds that there is at present no convincing alternative hypothesis to the estrogen hypothesis for the rising prevalence of testicular cancer and the repeatedly voiced assumption of declining sperm quality in men.

Some scientists suspect that the dose-response curve of endocrine disruptors takes the form of an inverted U. In pharmaceutics it is known that the effect of a substance can initially rise in step with rising concentrations, then to decline again at higher concentrations. This has been shown e.g. for DES (diethylstilbestrol). If it should emerge that such a non-monotonic dose-response relationship also applies to further substances, this would call into question substance assessments based on experimental findings with concentrations in the declining effects part of the curve. New testing approaches and management strategies would then be necessary.

Environmental effects

The presumed effects of endocrine disruptors upon animals include behavioral and fertility disturbances, feminization and rising incidence of disease. In young individuals and males of various fish species, hormone disruptors have been found to lead to reproductive disturbances and to the formation of a precursor of a yolk protein (vitellogenin; Karbe, 1997). Masculinization of female animals (imposex) caused by tributyl tin (TBT) has now been found in more than 110 species of marine mollusk (Oehlmann et al., 1995). In birds, damage to eggshells and reproductive disturbances caused by DDT were already reported in the 1960s. Birds feeding on contaminated fish have developed behavioral abnormalities (Fox et al., 1978).

It is presently scarcely possible to judge finally whether the sum of individual findings suffices to conclude a considerable contribution of endocrine disruptors to problems of global change, such as the loss of biodiversity and the degradation of natural habitats. As yet, clear cause-effect relationships between certain endocrine disruptors and environmental damage have only been identified in a few cases. Substances with a relatively certain effect include TBT, octyl- and nonylphenol and bisphenol. Measures to reduce emissions of these substances are in place in many states or are due to commence soon.

Management of the risk and assignment to the Pandora risk class

Octyl- and nonylphenols are degradation products of alkylphenolethoxylates (APEOs), which are used worldwide in many product groups, including detergents. In Germany, the industry groupings concerned have entered into a voluntary commitment to dispense with the use of APEOs in detergents and cleaning products from 1986 onwards. In 1989, the European Community adopted a directive banning the use of TBT on ships of less than 25 m length. In the meantime, bans on TBT-containing antifouling paints on boats shorter than 25 m apply in almost the whole of Europe, North America, Australia and the Far East. Switzerland and New Zealand have already enacted a complete ban on the use of organotin compounds as antifouling paints.

In many cases only assumptions are possible as to the probability and magnitude of damage associated with the risk of anthropogenic emissions of endocrine disrupting substances. No final evaluation of the risks presented by endocrine disruptors can be made. This has several reasons: the diversity of substances implicated; the generally inadequate data on occurrence and behavior in the environment and organisms, the generally unclear dose-response relationships; possible synergistic effects and a potential latent period between cause and effect. The German Federal Environmental Agency (UBA) has presented a study proposing concrete recommendations for research (Gülden et al., 1997). The high uncertainty attaching to both the probability of occurrence and the magnitude of damage justify an assignment to the Pandora class of risk. Many endocrine disruptors belong to the group of persistent organic pollutants (POPs), whose risk was also assigned to this class in the previous section.

Through establishing the application of the precautionary principle in the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR, Article 2), the signatory states responded in 1992 to new risks with high levels of uncertainty. The German government already formally established the precautionary principle as early as 1982 (BverwG, 1985), and adopted in 1986 guidelines for precautionary environmental care through the prevention and step-wise reduction of damaging chemicals. It is conceivable that, in the future, gains in knowledge or precautionary measures may move the risk posed by endocrine disruptors partially or in whole into the normal area. In this case further precautionary measures could be dispensed with. At present, such an 'all-clear' would be premature.

D 6 Climate risks

D 6.1
Introduction

Climate variability and climate change: Characteristics

Climate is influenced by many processes. These include the physical processes in the atmosphere that make up the weather, the storage and transport of energy and materials (such as carbon dioxide) in the oceans, changes in snow and ice conditions in the cryosphere and, finally, biological and chemical cycles that impact upon the distribution of greenhouse gases in the global climate system. Slower processes of change in the lithosphere also exert an effect on climate where they interlock in energy and chemical cycles. Climatic processes, while describable (namely through substance, energy and momentum balances), can only be predicted to a limited extent. In particular, climatic variables can not be characterized adequately by average values such as a mean state and its time evolution. The variability of climatic phenomena operates over time scales ranging from seconds to millions of years. These include the interannual fluctuations of which humans have long been aware, such as the periods of torrential rain or the 7 fat and 7 lean years (Noah and Joseph noise). Similarly, the spatial effects of climate can operate on almost all scales, ranging from local events (excessive rain, tornadoes etc.) through to geographically major changes in atmospheric-oceanic circulation patterns.

The emission of substances to the atmosphere harbors a danger of disrupting the climate system if these substances are radiatively active. So-called greenhouse gases let short-wave solar radiation pass, but absorb the longer-wave heat radiated from the Earth and thus exert a warming effect. A different type of perturbation of the radiation balance is caused by gases that lead to the formation of aerosol particles. These deflect solar radiation and therefore have a mainly cooling effect, but in some cases also a warming effect.

The orders of magnitude of the perturbations of the heat balance may appear relatively small, but due to non-linear coupling in the form of amplification and feedback mechanisms their impacts can cause wide-ranging changes in climate.

Climate variability and climate change: Risks

Natural climate variability can lead to the occurrence of extreme weather conditions entailing risks for ecosystems, agriculture and human infrastructure: storms, floods, droughts and large-scale fires can cause enormous damage, with greatly varying probabilities of occurrence from location to location. Due to our still patchy understanding of natural climate variability, the predictability of such events is very limited.

If climate change is added on to natural climate variability, further risks loom: regional weather patterns can shift gradually and/or their statistics can change qualitatively. The occurrence of new extremes previously unknown at a specific location is an indication of climate change. Potential damage can assume magnitudes ranging up to the loss of the preconditions for existence – both for humans and the climatically adapted biosphere.

Gradual climate change, such as longer-term shifts of climate zones, need not be problematic in all cases. Whether it is possible for humans and ecosystems to adapt depends decisively upon the speed of change. Anthropogenic emissions of greenhouse gases are currently leading to global warming at a speed that has not occurred during the past 10,000 years (IPCC, 1996a). Ecosystems vulnerable to such rapid climate change will generally be those that are confined geographically and those located close to the margin of their niche, for instance in regions where disposing factors are subject to great spatial variability. These are marine and terrestrial ecosystems in coastal areas, inappropriately managed agro-ecosystems and forest ecosystems close to the timber line at high latitudes or in mountains (IPCC, 1996b, 1998). A further risk resulting from shifting or spreading climate zones is posed by climatically adapted pests and disease-carrying pathogens whose habitat is expanded; due to the species composition found in the new

habitat, these pests and pathogens gain large competitive advantages.
Because of the non-linear interactions prevailing in the complex climate system, human impacts upon climate may not only lead to gradual changes but also to sudden, dramatic swings. These may include the cessation of ocean currents that determine the climate of a region, or strong positive feedback effects such as the sudden release of large quantities of greenhouse gases through the warming of permafrost soils.

Human-induced climate change is a core problem of global change, with global-scale impacts that are already visible today. This is a matter of risks associated with climate and weather phenomena which, according to our present knowledge, must be seen in this connection or where there are at least strong grounds to assume that such a connection exists. Other manifestations that are not linked to human-induced climate change are then global environmental risks if they manifest themselves at the global scale as extremes of climate variability. Only for these global-scale manifestations are supranational adaptation and prevention strategies appropriate.

This section initially characterizes risks associated with natural climate variability (Section D 6.2.1) where such risks have global relevance owing to their magnitude and range of damage. These include the risks associated with agricultural practices not adapted to natural weather fluctuations, and the El Niño phenomenon. Subsequently, human-induced climate change is discussed (Section D 6.2.2), which is one of the core problems of global change and harbors a great array of risks. Both gradual climate change (Section D 6.2.2.1) and the danger of triggering sudden climatic swings (Section D 6.2.2.2) are examined. The present management of these risks is determined largely by internationally coordinated research efforts and by the UN Framework Convention on Climate Change (FCCC) process (Section D 6.3.1). To manage the risks of human-induced climate change, scientific advisory processes are delivering new findings and ideas for risk analysis and risk management (Section D 6.3.2). The Council revisits its already repeatedly submitted proposal to tackle the problem using the methodological approach of 'tolerable windows' (Section D 6.3.2). Finally, the various risks associated with the variability of the climate system are assigned to the classes of risk identified in this report (Section D 6.4).

D 6.2
Risk phenomenology and damage potential

D 6.2.1
Natural climate variability and extremes

In the following, we discuss, firstly, risks associated with agricultural practices that are not adapted to natural weather fluctuations and, secondly, the El Niño phenomenon as an example of a global pattern of natural climate variability.

Agro-ecosystems
Climate risks arise above all in agro-ecosystems that are narrowly adapted to climate and soil, and where cultivation has been extended to areas that are climatically marginal for the crops in question, i.e. poorly suited. Crop losses can then be caused by frost, heat or drought. Frost events can disrupt agricultural production in temperate regions. The plants are generally well adapted to winter frost, but alternating and late spring frosts can cause considerable damage. In fruit cultivation, a single late frost event during the blooming period can severely reduce the year's yield. Drought is a well understood agricultural production factor. In a seasonal climate, the farmer faces the risk that precipitation does not suffice to supply cereal crops with water during the maturation period. Irrigated cultivation reduces this short-term risk. However, as irrigation is applied in order to ensure maturation during the warm season or for a second harvest, this increases the longer-term risk of soil salinization (WBGU, 1995a).

Global population growth will lead to food demand rising considerably in the future. Over recent decades, global cereal production has outstripped world population growth by 15% (Gregory et al., 1998; FAO, 1998), so that – the regional distribution problem not considered – over the global mean the situation has not deteriorated. This may well change if in future food production does not grow in step with population; there are already indications of such a reversal of the past trend (Gregory et al., 1998). In this case, natural climate fluctuations may already jeopardize global food security in about 20 years from now (Section E 3.2).

The increasing orientation of agriculture to yield maximization is increasingly restricting the available options to respond to pests and climatic stress (declining resistance). Plants are internally coordinated organisms. One-sided changes in metabolism (such as promoting assimilate transport to the seeds) must necessarily reduce a number of other metabolic pathways (e.g. the formation of secondary substances such as phenols). The outcome is that with rising per-hectare yields, the risk of crop losses caused by pests or extreme weather conditions also rises (Chapin et al., 1990; Marschner, 1990; WBGU, 1998a). The global food risk is further exacerbated if agriculture is not well adapted to present natural climate variability, for it is then also more vulnerable to human-induced climatic changes (Section D 6.2.2.1; IPCC, 1998).

El Niño

The El Niño/Southern Oscillation phenomenon (ENSO) is a good example of the regional risks that stem from the natural variability of the global climate. ENSO refers to a change in the dynamics of the coupled oceanic-atmospheric system in the equatorial Pacific. Normally, the climate in the eastern equatorial Pacific is characterized by a cold ocean current and high air pressure with low precipitation, while in the western tropical Pacific the surface waters are very warm, air pressure is low and precipitation is generally high. About every 2–7 years, this pattern is reversed: the zone of warm surface waters, associated with low air pressure and high precipitation, moves eastwards, the eastern Pacific becomes warm and rainy and the cold ocean current along the South American coast is replaced by a warm one. This alteration of the climatic pattern has supraregional impacts upon the climate of almost all regions of the world. Typical manifestations include floods in Central and South America, droughts in South-East Asia and in parts of Australia and southern Africa, and greater precipitation and higher hurricane frequency on the Pacific coast of North America. In El Niño years, fishing yields on the Peruvian coast collapse.

It is the internal dynamics of the coupled oceanic-atmospheric system that brings about the occurrence of El Niño events and their disappearance, the latter involving a cooler ocean (La Niña) and an oppositely polarized distribution of the centers of high and low air pressure (Southern Oscillation). This normally takes place at intervals of 2–7 years, but in recent decades the interval has shortened to 3–4 years. This may be due to a superimposition of an internal, multiannual dynamism with decadal climate variability (Latif et al., 1997). In the 1990s, an unusual clustering of El Niño events has been observed. An anthropogenic impact upon ENSO dynamics cannot be proven, nor can it be discounted at the present time. In 1982/1983, the strongest El Niño event of this century before that of 1997 caused or intensified droughts in Australia and the Sahel, and led to extensive bush fires in Australia and atypical weather conditions in South Asia and North America. The resultant losses have been estimated at about 2,000 human lives and US-$ 8–13 billion in property values (crop losses and disaster damage). The 1997/98 ENSO event had even greater impacts upon South-East Asia, Australia, Central and South America and Africa. Most regions were affected by abnormally low rainfall, in parts of South-East Asia only 25% of the long-term average, while other regions such as Ecuador and Peru experienced unusually heavy rainfall.

An El Niño event can neither be prevented nor controlled by human actions. However, the first correct prediction of the El Niño event in 1997/98 was a major success for climate research (Section D 6.3.1). Further successes in ENSO prediction could contribute to mitigating the risk for the regions affected.

D 6.2.2
Human-induced climate change

The radiation balance of the Earth is such that an unabated emission and thus accumulation of greenhouse gases in the atmosphere (Box D 6.2-1) would unavoidably entail considerable climatic changes in the long run – with a potential for catastrophic damage to humans and ecosystems in all climate zones. The rise in global average surface-air temperature by 0.5 °C observed in this century is exceedingly rapid compared with the climate history of past millennia.

Due to natural climate variability, it is very hard to prove whether humankind has played a part in causing this observed climate change. However, in recent years the methods by which to prove a 'human fingerprint' on observed climate change have been improved considerably. They are based on comparing measured spatial patterns of the development of the climate system over time with computed simulations of climate models. In cases where it is extremely improbable that these patterns can be explained by natural climate variability, human-induced climate change is considered statistically proven. Today, a number of spatial patterns of observed temperature change can be explained satisfactorily by the complex interplay of three human influences (greenhouse gas emissions, ozone layer depletion and aerosol emissions; WBGU, 1998a). With due regard to possible sources of error such as deficits in climate models, and in consideration of the incomplete knowledge of individual human contributions and partially erroneous or heterogeneous measured data, the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) comes to the conclusion that "the balance of evidence suggests a discernible human influence on global climate" (IPCC, 1996a). This probability was estimated at 95% (Hegerl et al., 1997) – a figure that must yet be considered uncertain; the data sets used for comparing (model-based) expected and observed developments

Box D 6.2-1

Interactions between biogeochemical cycles and climate

Because interventions in the biogeochemical regimes of large-scale ecosystems shift the balances of radiatively active gases between the biosphere and the atmosphere, such interventions can impact upon global climate. For instance, the conversion of forests to cropland triggers a net CO_2 release, because the mineralization of the organic matter in the former forest ecosystem is now accelerated. As a consequence, less atmospheric CO_2 is stored in the newly created agro-ecosystem. Moreover, the nitrogen regime is altered, leading to more N_2O – a potent greenhouse gas – being emitted from the soil. Conversely, altered near-surface atmospheric concentrations of the greenhouse gases CO_2 (Section D 5.1), ozone and water vapor have a direct impact upon ecosystems.

Fig. D 6.2.1 gives a schematic representation of the global warming effects caused by biogenic and anthropogenic emissions. The figure is complex because many of these effects are controlled by processes of atmospheric chemistry, and several additionally by the biosphere (so-called indirect global warming effects). Interactions are shown with their sign (amplifying or attenuating), but not their relative impact. The latter can vary greatly from region to region and as a function of altitude in the atmosphere, so that partial compensations can lead to opposite net effects. While some processes develop their impacts over only weeks and rapidly lose them again, the time scale of others can be up to 1,000 times longer. In addition to long-lived greenhouse gas emissions (CO_2, CH_4 and N_2O), nitrogen oxides (NO_x) as acid precursors in conjunction with hydrocarbons intensify the greenhouse effect through forming ozone in the troposphere. This process is further promoted by the emission of N_2O from soils, which is stimulated by inputs of NO_x and ammonia (NH_3) progeny formed by chemical processes in the atmosphere. Through these processes and through the

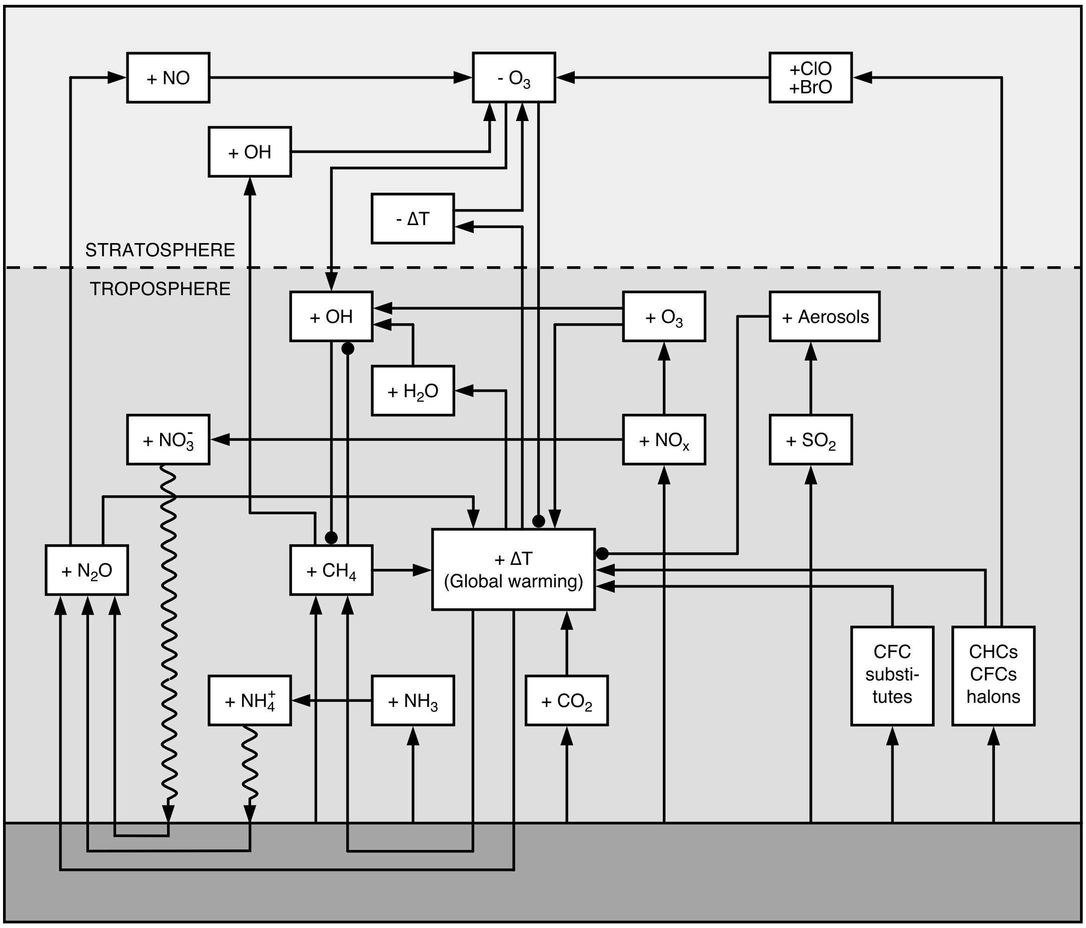


Figure D 6.2-1
Direct and indirect (i.e. mediated by ecosystems or atmospheric chemistry) climatic effects of substance emissions, illustrated qualitatively by amplifying (*arrows*) and attenuating (*dots*) interactions among present tropospheric and stratospheric trends (sign: + rise, - fall). Substances: *NO* = nitric oxide, O_3 = ozone, *ClO* = chlorine monoxide, *BrO* = bromine monoxide, *OH* = hydroxyl radical, NO_3^- = nitrate and nitric acid, NO_x = nitric and nitrous oxide, SO_2 = sulfur dioxide, N_2O = nitrous oxide, CH_4 = methane, NH_4^+ = ammonium, NH_3 = ammonia, *CFCs* = fully halogenated chlorofluorocarbons, *CHCs* = fully halogenated chlorinated hydrocarbons.
Source: WBGU

▶

role that N_2O additionally plays in depleting stratospheric ozone, emissions of nitrogen oxides and ammonia, which themselves (together with their atmospheric progeny) are already removed from the atmosphere after a few days, still generate perturbations in the radiation balance and in the stratospheric ozone layer after more than 100 years (Lammel and Graßl, 1995).

Emissions of SO_2, NO_x (and further combustion products) and of NH_3 intensify aerosol formation, which attenuates global warming. The depletion of stratospheric ozone also operates in the same direction, whereby this effect is not too strong due to the small contribution of stratospheric ozone to radiative forcing. Aerosols have high variability over space and time and – depending upon their sources – differing properties. As they also exert indirect radiative forcing effects, namely through their influence upon clouds, their global warming effect can not yet be quantified accurately (Schwartz, 1996; Lohmann and Feichter, 1997). Over the global average, it is in the same order of magnitude as that of greenhouse gases (IPCC, 1996a).

are incomplete and do not cover a period lengthy enough to be able to isolate beyond any doubt the anthropogenic signal from all – even the longest – natural cycles and dynamics.

Global warming must be expected to lead to an increasing incidence of weather extremes (IPCC, 1996a). However, such trends are not observable uniformly in all regions, so that it is not possible at present to speak of a global rise in weather extremes (IPCC, 1996a).

Sea levels will most probably continue to rise in the future. For the scenario of unabated greenhouse gas emissions, projections for the coming 100 years indicate a sea-level rise of 15–95 cm (IPCC, 1996a). Thermal expansion of the water and the melting of glaciers deliver the largest contribution to the expected sea-level rise. Major uncertainties presently still remain concerning the mass balances of the great polar ice sheets (IPCC, 1996a). Most projections assume a negative mass balance for Greenland and an accumulation of inland ice in the Antarctic. However, there is a possibility that the West Antarctic ice sheets become unstable. Their collapse would lead to a dramatic sea-level rise, which would be far in excess of the above projections and would threaten millions of people in the densely populated coastal regions (IPCC, 1996b). It is estimated that even now 46 million people are statistically exposed to a storm surge every year. With a sea-level rise of 50 cm this figure could double to 92 million people, with a rise of 1 m it could almost treble to 118 million people (IPCC, 1996b; WBGU, 1998a).

D 6.2.2.1 Vulnerable regions

Extreme weather events and shifts in precipitation and temperature patterns have the potential to cause major damage to climatically vulnerable regions. These are regions where risks are significantly heightened e.g. by sensitivity of the climate to perturbing influences and by a lack of capacities to adapt to climatic changes. What are the decisive parameters that can be applied to diagnosing and analyzing climatically vulnerable regions? Can strategies be formulated for these regions that serve to improve their climatic resilience?

Many developing countries are viewed as particularly susceptible to climate change. This is because of the frequently unfavorable environmental conditions and the lack of societal capabilities to implement compensatory measures. Many countries are already overburdened with the task of adapting to natural climate variability (IPCC, 1998). Africa is considered to be the continent most vulnerable to climatic changes, as adaptation capabilities are particularly scarce there.

Mountain and coastal regions, marginal agro-ecosystems

Mountain zones are particularly sensitive due to their natural physical-geographical structure. Their complex topography, marginal soils and lower ecosystem stability make them susceptible to consequential damage resulting from climatic changes. This is further intensified by inappropriate land uses. Winter and summer tourism, inappropriate agricultural practices or infrastructural development can operate as triggering factors for hazards with partially irreversible damage.

Coastal zones are among the most densely populated regions. As the catastrophic potential is particularly high for these regions, the risk is considerable even if the probabilities of extreme weather events (severe storms, storm surges etc.) are only low. Whether vulnerability to extreme weather continues to rise depends mainly upon future uses and upon the development of the sea level.

Climatic changes (e.g. increased temperatures), in conjunction with elevated CO_2 concentrations and altered nitrogen loading, can lead to changes in the plant physiological reactions of agro-ecosystems to weather extremes (Section D 5.1). The combined action of anthropogenic nitrogen loading and reduced winter cold, the probability of late spring frost remaining the same, can lead to increased physiological sensitivity. This can exacerbate the impact of a ‘normal' late frost. As almost ⅔ of all temperate regions are affected by excessive loading, this is a globally growing risk with a high probability of occurrence and a potentially very large magnitude of damage. The impact of short-term interventions and outgoing material fluxes due to extreme weather conditions (snowmelt, drought) is more severe upon ecosystems that are already stressed by anthropogenic material fluxes. Farms or regions specialized upon single crop species are particularly sensitive to climatic fluctuations.

D 6.2.2.2
Ocean circulation

Thermohaline circulation is the flywheel that drives interbasin exchange of waters in the world ocean. It is the reason why winter temperatures in Europe are some 5–10 °C higher than in North America or Asia at similar latitudes. This circulation system comprises three branches in the Atlantic Ocean: the Gulf Stream, a shallow, warm northward flow comparable in quantity to a 100-fold Amazon flow; the downward flow of cold, salty and thus denser water in the Labrador Sea and Greenland Sea; and, finally, the deep water that then flows southwards through the Atlantic. This circulation system can collapse abruptly in the North Atlantic if the production of high salinity deep water is interrupted. For this, even slight regional reductions in the density of upper water would suffice (Stommel, 1961), caused e.g. by increased freshwater inputs from continental outflows, glacier melting in the fjords of Greenland or precipitation changes in the region of the North Atlantic storm tracks. Reorganizations of deep water formation have occurred repeatedly in the past in the transition between interglacial and glacial periods, and most probably were the factors that triggered or terminated ice ages. The last interglacial episode in the North Atlantic region (Eem Interval) was terminated by an ice age with a transitional period of only a few decades (Broecker, 1997; de Menocal and Bond, 1997). Simulations using climate models have predicted the cessation of large-scale thermohaline circulation as a result of global warming if greenhouse gas emissions continue unabated. In this scenario, a change in the freshwater balance caused by global warming plays the main role (Maier-Reimer and Mikolajewicz, 1989; Manabe and Stouffer, 1993; Stocker and Schmittner, 1997). This would mean a new ice age for Europe: within decades, Europe's climate would approach that of Siberia or Canada. This possibility of an abrupt crash in temperatures is certainly one of the largest direct risks associated with anthropogenic climate change. Under present conditions the consequences would be catastrophic – particularly if we consider that Europe feeds some 300 million people on comparatively good soils, but Canada only about 30 million (Fig. D 6.2-2).

Present model simulations cannot yet be taken as definitely indicative that such a development is pending. The probability of occurrence is thus unknown. However, these findings express the presently best available knowledge, and must thus be understood as a well-founded warning that needs to be taken very seriously.

D 6.3
Present management of the risk of climate change

D 6.3.1
Climate research and climate policy

Where human counteraction is not possible, extreme climate events cannot be prevented, but their damaging effects can be mitigated by adaptation, particularly if they are recognized in time. Thus the 1982/83 El Niño event prompted a broadly based research program (Tropical Ocean Global Atmosphere, TOGA, within the framework of the World Climate Research Programme, WCRP, 1985–1994) with the aim of gaining systemic understanding, early recognition and prediction of singular events. As one outcome of this research, an operational monitoring and forecasting system is now in place (NRC, 1996). The agricultural services of many countries use ENSO predictions (up to 12 months in advance) to formulate specific recommendations. ENSO impacts dominated the world markets of a number of important agricultural products (cereals, coffee, cocoa) in 1997/98. Some markets already reacted in anticipation of impending scarcities (maize price in South Africa in summer 1997; Tait and Mead, 1997).

With the First World Climate Conference convened in 1979 by the World Meteorological Organization (WMO), the risk of anthropogenic climate change – an issue already debated intensively in the academic community throughout the 1970s – became a part of the international environmental policy agenda (Coenen, 1997). In 1988, following a proposal of the UN General Assembly, WMO and UNEP established the Intergovernmental Panel on Climate Change (IPCC; Box D 6.3-1). IPCC's First Assessment Report was submitted in 1990 in time for the Second World Climate Conference. This intensified the pressure upon the international community such that the UN General Assembly instituted an international negotiating process on climate protection. This process, involving the participation of 150 states and

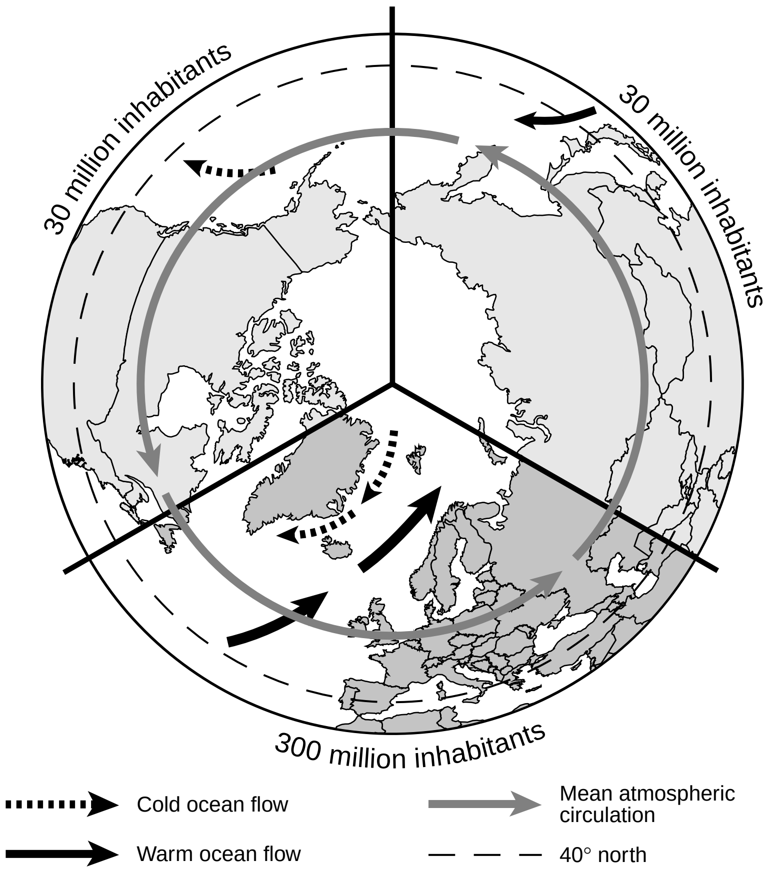


Figure D 6.2-2
Climatic living conditions in three sectors of the northern hemisphere, at latitudes north of 40°N.
Source: after Krauß and Augstein; Augstein, 1991

Box D 6.3-1

The IPCC: providing scientific advice to international policymaking

The Intergovernmental Panel on Climate Change (IPCC) was established jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988 on behalf of the UN General Assembly.

The task of the IPCC is to collate and assess the state of knowledge on global warming, its possible impacts and political options for action. However, the IPCC is not a purely academic body (Coenen, 1997): the plenary sessions of government representatives adopt the Summaries for Policymakers and the Syntheses of Scientific-Technical Information.

In order to permit an assessment process that is as free and scientifically rigorous as possible, the IPCC formed three scientific working groups in 1988, focusing on: analysis of the climate system ('Science'), assessment of the consequences of climate change ('Impacts') and prevention and adaptation strategies ('Response Strategies'; Bolin, 1997). These working groups are composed of scientists and commission a great number of further experts to review their reports. The statements of the IPCC are based exclusively upon published scientific literature. More than 300 scientists from 25 countries were involved in the preparation of the First Assessment Report on the Science of Climate Change (IPCC, 1990). This provided the scientific arguments for preparing and negotiating the Climate Convention (FCCC). The IPCC provides the parties to the Convention with a supporting mechanism that reviews advances in knowledge, and synthesizes and assesses this knowledge in a manner largely uninfluenced by non-scientific purposes, publishing its outcomes in the form of assessment reports. The Second Assessment Report was presented in 1996 (IPCC, 1996a, b, c). Furthermore, upon request of the Conference of the Parties to the Convention or its subsidiary bodies, the IPCC prepares special reports and technical publications, and methodologies and guidelines such as that on greenhouse gas emissions inventories (IPCC, 1997). The latest special report was concerned with the regional impacts of climate change (IPCC, 1998). The Third Assessment Report is due to be presented in the year 2001.

the support of WMO and UNEP, led to the drafting of the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in May 1992 and was signed by more than 150 states at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992. It entered into force in 1994.

The ultimate objective of the Convention is to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (UNFCCC, Article 2).

The Convention makes no concrete statement as to which level of greenhouse gas concentrations would present no danger. Nor does it stipulate concrete reduction targets beyond the year 2000. At the Third Conference of the Parties held in Kyoto in December 1997, a protocol to the Convention (the Kyoto Protocol) was adopted. This stipulates for the first time legally binding commitments of the industrialized countries to reduce their greenhouse gas emissions (Box D 6.3-2).

D 6.3.2
Risk research

To assist in addressing the risks of anthropogenic climate change, the academic community supplies policymakers with new findings and proposals. At present, three main techniques are applied to take into consideration uncertainties: sensitivity analysis (in the narrower sense), stochastic models and decision analysis. These are techniques of risk analysis and procedures of risk management. The Council recommends in this connection an integrated approach for precautionary risk management, presented in the following as the concept of 'tolerable windows'.

Risk analysis: Sensitivity analyses

Sensitivity analysis aims to estimate the influence that uncertain values of input variables can have upon the outcome of model calculations of risk. In the simplest variant of such an analysis, it is examined how model results will respond to a slight variation (e.g. by 10%) of only one input variable, i.e. how sensitive the results are to such a variation. If it is possible to further quantify the uncertainty range of such an input variable (e.g. by stating an uncertainty interval or a probability distribution) then the model results for a (fairly) extreme choice of input data (e.g. values of the 10th and 90th percentiles) are of interest. Such analyses have been carried out for various integrated models (IPCC, 1996c; Nordhaus and Yang, 1996). These have shown that the outcomes of economic cost-benefit analyses depend considerably upon uncertainties in the discount rate applied. This underscores the great importance of applying appropriate discounting methods.

Risk analysis: Stochastic models

Stochastic models go beyond the separate examination of the influence of individual uncertain parameters. Rather, they integrate the entirety of all uncertainty prevailing in the input data. To this end, proceeding from given or subjectively estimated probability distributions, a so-called Monte-Carlo simulation is undertaken to determine a set of possible permitted combinations of the input data and to identify the model outcome for each combination. The set of model results can then in turn be described by a probability distribution that permits an estimation of the range of possible future developments (IPCC, 1996c).

Risk management: Decision and cost-benefit analysis

Decision analysis offers an approach to evaluating proposed development pathways in the context of climate policy risk management that also takes uncertainties and learning processes into consideration (Nordhaus, 1994; Section F 1.2.3). Here it needs to be considered that in many cases it is not possible to describe the uncertainty of input data by objective probabilities. Instead, subjective probabilities are used, whose validity is a subject of controversy (IPCC, 1996c). Secondly, this technique frequently only models the aspect of data uncertainty. Moreover, there continues to be considerable uncertainty concerning the model structure to be used. The simplified climate models used in optimization models (e.g. cost-benefit models), in particular, are unable to make statements on possible climate instabilities as a cause of climate risks. A result of this is that one of the most recent cost-benefit models (RICE: Nordhaus and Yang, 1996) recommends an optimum emissions pathway that – when compared with the results of other studies (Stocker and Schmittner, 1997) – would lead over the long term to the thermohaline circulation being turned off. As other and presently much less well understood climate instabilities are conceivable in addition to the danger of thermohaline circulation collapsing (IPCC, 1996c), it would appear prudent to steer a precautionary course until such time as an improved understanding of such processes is available. The Council has set out a cor-

Box D 6.3-2

The Kyoto Protocol: Moving towards international risk management

The Kyoto Protocol is an international agreement supplementary to the UN Framework Convention on Climate Change (FCCC). It was negotiated in December 1997 in Kyoto, Japan, stipulating for the first time binding, quantified greenhouse gas emission limitation or reduction commitments. Should they ratify the Protocol, the states listed in Annex I to the FCCC (the industrialized states) must reduce their emissions of six greenhouse gases during the 2008–2012 period to levels at least 5% lower than those in 1990. The six greenhouse gases comprise the three most important anthropogenic greenhouse gases – carbon dioxide, methane and nitrous oxide – and the radiatively active fluorinated compounds (hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride).

The commitments of the individual parties are differentiated, their average amounting to a 5.2% emissions reduction. The European Union and most of the Eastern European states have committed themselves to the highest reductions, at 8%, followed by the USA (7%), Canada, Hungary, Japan and Poland (6%) and Croatia (5%). The Russian Federation, Ukraine and New Zealand must only stabilize their emissions at 1990 levels, Norway is permitted to increase its emissions by 1%, Australia even by 8% and Iceland by 10%. In addition to emissions from the energy sector (including transport), industrial processes, agriculture and waste management, those changes in emissions are also accounted for that result from afforestation, reforestation and deforestation measures since 1990. Emissions resulting from international ship and air transport are excluded. Industrialized countries can also meet their commitments through trading emissions permits ('emissions trading') and through the joint implementation of reduction measures in another Annex I state, but only as a supplement to measures undertaken domestically. A new financial mechanism (clean development mechanism, CDM) has also institutionalized the accounting of projects in developing countries. In order to monitor reduction commitments, the reports and greenhouse gas inventories of Annex I parties are reviewed by experts appointed by the contracting parties. However, no sanction mechanisms have yet been agreed. This issue shall be resolved at the first Meeting of the Parties to the Protocol.

Assessment

Considering the major disparities between the negotiating positions of the individual industrialized countries, and considering the conflicts between industrialized and developing countries, the German Advisory Council on Global Change welcomes the Kyoto Protocol, with its binding reduction commitments, as a first step towards a binding climate protection policy. It should be ratified as swiftly as possible. Nonetheless, it remains to be noted that a reduction in the greenhouse gas emissions of the industrialized countries by 5% by the year 2010 remains far behind climate protection exigencies – in its study presented in the run-up to the Kyoto negotiations, the Council proposed reduction rates of 11% by 2005, 23% by 2010 and 43% by 2020 for the three main greenhouse gases (WBGU, 1997b). In this connection, it is regrettable that no automatic mechanism for adjusting commitments has been introduced, such as under the Montreal Protocol ozone regime.

The Council welcomes the introduction of flexible instruments by which to implement reduction commitments, such as the joint implementation of measures among industrialized countries (Article 6 of the Kyoto Protocol) and emissions trading (Article 17) (WBGU, 1995a, 1997a, b). However, as concerns the possibility introduced by the CDM of offsetting measures in developing countries against the reduction commitments of industrialized states, the Council sees a danger that this increases the total permitted emissions quantity and thus undermines reduction commitments, as long as no concrete commitments have been agreed for the developing countries. This is a further reason to integrate the developing countries in the reduction commitment regime soon. Emissions trading, too, is only then expedient if the total quantity of emissions permitted is actually limited and reduced through significant reduction commitments. This precondition is not given by the Kyoto Protocol, as the aggregate of the Annex I states had already met the 5% target in 1995. This is due to the permitted amount of emissions assigned to Russia and Ukraine: these have surplus emission entitlements resulting from the collapse of their economies, which they will be able to sell to the OECD states.

The Council has prepared a special report dedicated to the issues surrounding the offsetting of terrestrial carbon sinks against reduction commitments (WBGU, 1998b). In this report, the Council evaluates the form in which afforestation, reforestation and deforestation can be offset against reduction commitments under the Kyoto Protocol as being inadequate and in need of improvement if the interests of both climate protection, biodiversity conservation and soil conservation are to be served. The accounting of sources and sinks in the 2008–2012 commitment period that result from afforestation, reforestation and deforestation since 1990 can lead to negative incentives. Uncertainties and problems that hamper the estimation of emissions and of changes in carbon stocks during the commitment period can give rise to abuse. Offsetting terrestrial sinks against reduction commitments fails to take into consideration the temporal dynamics of carbon stocks and fluxes in the biosphere. For instance, the long-term sink effect of afforestation projects cannot be guaranteed. Even slight climatic changes can make sinks become sources. Energy-related emissions therefore cannot be compensated by the terrestrial biosphere.

A final assessment of the effects of the Kyoto Protocol is not yet possible, as a series of decisive agreements need to be made. These include the technicalities of emissions trading and of joint implementation, the regulation of the CDM mechanism and the possible future inclusion of further land-use change and forestry activities. Whether international climate policy is successful must be measured by whether it succeeds in stabilizing greenhouse gas concentrations in the atmosphere at a level that poses no danger (Article 2 FCCC). With this objective in mind, the Council has proposed a long-term risk management regime following the concept of 'tolerable windows' (WBGU, 1997b). On the basis of per-capita emissions, the Council further derives from this a scenario for the medium- and long-term integration of developing countries in commitments, with due regard to aspects of equity. The sooner the industrialized countries exploit their own savings potentials and significantly reduce their emissions, the sooner will they be able to credibly demand the integration of the developing countries.

responding proposal in detail in its study for the Kyoto climate conference (WBGU, 1997b).

The basic assumptions of cost-benefit analysis include reference to an individual actor (or a perfectly cooperating group), the conversion of costs and benefits into a uniform, e.g. monetary standard of valuation that integrates all preferences of humanity, and, moreover, the quantifiability of prevailing uncertainties. As these preconditions are not given for the issue under consideration here, the IPCC (1996c) notes that qualitative decision analysis cannot serve as the primary basis of international decision-making in the sphere of climate change. In light of the impossibility of identifying a globally optimal climate risk management approach solely on the basis of decision analysis, and considering the absence of effective and quantitative alternatives, decision-makers must take recourse to problem-solving through a negotiated process (IPCC, 1996c).

Risk management: The tolerable windows approach

In contrast to the above techniques, the Council presents its concept of tolerable windows (the 'windows approach'). The Council is of the opinion that this is a more appropriate procedure for managing climate risks. The approach is characterized by the normative stipulation of non-tolerable risks, termed *guard rails* (WBGU, 1996, 1997a, b; Toth et al., 1997). The purpose of limiting tolerable developments of climate change by means of guard rails is to prevent the climate system from moving dangerously close to possibly unstable states, which, considering the extremely high potential for damage, could lead to dramatic climatic hazards. Due to the considerable uncertainties that still prevail, the stipulation of corresponding limit values, e.g. for the absolute change in global average temperature or for the rate of temperature change, must be so restrictive that present knowledge indicates that the occurrence of such instabilities can be largely excluded. At the same time, however, society must not be overburdened by emission control measures. Particularly in modern industrialized nations, value-added activities are intimately linked to the use of fossil fuels. To fully switch these energy systems to alternative sources of energy would require, if at all realizable, considerable inputs of capital and above all time. This is why, in addition to defining guard rails relating to the climate system or climate impacts, the window approach further requires the stipulation of maximum burdens upon society, e.g. in the form of maximum emission reduction rates.

Moreover, further guard rails can be formulated that – as normative stipulations – integrate value judgments regarding risks that are socially unacceptable. Such limits, particularly those concerning possible tolerable risks, need to be set by political decision-makers, and it is they who must take responsibility for these limits. In democratic systems, such limit-setting must be adapted to advances in knowledge and must be argued in a discursive process. Understood thus, specific guard rails will most likely never be finally accepted, but will be subject to permanent review (Turner et al., 1991). All sectors of society should be involved in the process of continuous consultation, which presupposes that they have access to the necessary information.

As soon as the specific guard rails have been defined, a purely scientific analysis can identify the totality of all climate protection strategies compatible with these guard rails. Minimum requirements upon global and – with additional consideration of equity aspects – national climate protection strategies can then be derived immediately (WBGU, 1997b).

The Council's window approach is excellently suited to meeting the requirement of effective and legitimated decision-making set out above. Rather than seeking to determine the optimum emission pathway for the global community, it identifies, on the basis of normative stipulations of non-tolerable developments, a range of all climate protection strategies compatible with these restrictions. Properly understood, the approach thus does not primarily attempt to immediately gain international consensus on possible limit values. Instead, all major actors should first themselves exclude such strategies whose pursuit would certainly lead to overstepping the guard rails. Only such measures are admissible whose effects remain within the guard rails. Beyond this, each society can decide for itself how it wishes to further abate emissions. The leeway for action thus gained can form an essential basis for fruitful international negotiations on further compromise solutions in climate risk policy.

As regards the integration of uncertainty aspects in the guard rail concept, the following points can be distinguished: the concept copes with uncertainties concerning possible, partially still largely unresearched climate instabilities as causes of new climate risks by stipulating climate-related stress limits that, according to present knowledge, can be expected to largely preclude non-tolerable climate developments. It is expedient to increasingly make use of paleoclimatological, i.e. historical-empirical findings in addition to model computations.

Data uncertainties can be integrated in principle in two different manners: if uncertainty can be described by objective probability distributions or by subjective distributions capable of gaining consensus, then it should be taken into consideration as such. This can be done, for instance, by means of a probability interpretation of the guard rails: at a certain

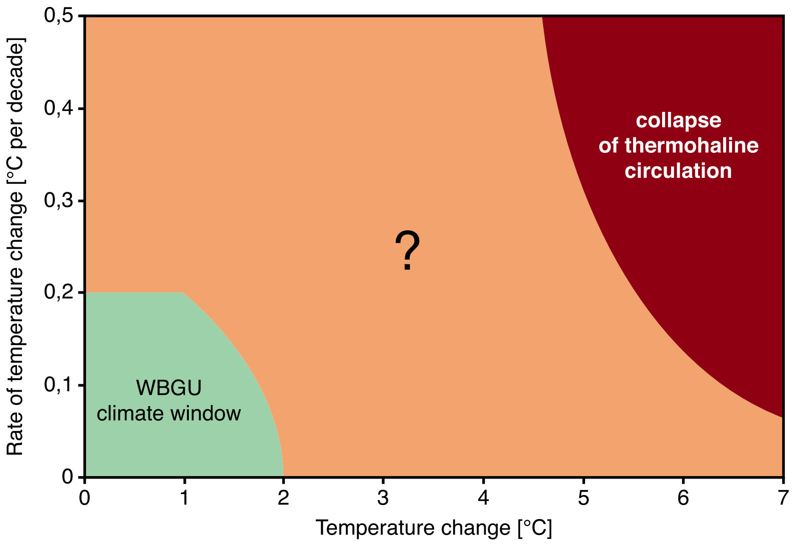


Figure D 6.3-1
Climate window of the Council (WGBU; *green*) and juxtaposed instability region of the thermohaline circulation (*dark red*). In this region of instability, i.e. with larger temperature changes (compared with the pre-industrial value) or higher rates of temperature change, the model computations of Stocker and Schmittner show that a complete and permanent collapse of the thermohaline circulation must be expected.
Sources: WBGU; Stocker and Schmittner, personal communication

level of uncertainty, it is often impossible to finally exclude the possibility that deterministic guard rails are overstepped. It is then expedient to demand that such guard rails are only overstepped with a probability lower than x%.

Some risks concern singular events, such as the cessation of ocean circulation. There are no statistics that might permit statements as to their probabilities of occurrence or their variance. The various models available cannot substitute such statistics because of their systematic weaknesses. This is thus a type of risk with unknown probability of occurrence for which reliable probability distributions cannot be defined.
The specifics of a guard rail can be outlined for the example of the possible collapse of thermohaline circulation (Fig. D 6.3-1). As set out above, recent studies support the assumption that an increase of atmospheric CO_2 concentrations may under certain circumstances lead to a cessation of the large-scale thermohaline circulation (THC). The systematic, model-based sensitivity analyses of Stocker and Schmittner (1997) have shown that the absolute, long-term rise in concentrations is relevant in this connection, and that their rate also plays an important role. Their model findings show a complete and persistent collapse of the thermohaline circulation, with potentially catastrophic impacts upon Europe (Stocker and Schmittner, 1997; Fig. D 6.3-1). This first attempt at a systematic study is of particular value because in the past such a collapse of the THC has frequently been viewed as one of the highly improbable consequences of an increase in CO_2 concentrations. Even the Second Assessment Report of the IPCC (1996c) still rated a disappearance of the THC as most improbable, although it noted that this can move from an event with a low probability of occurrence to one that must be basically expected if over the long term no greenhouse gas abatement efforts are undertaken (IPCC; 1996c). The Council sees its approach confirmed by these latest findings of climate research, namely to stipulate appropriate guard rails (WBGU, 1996) in order to prevent the climate system moving into regions of instability. In defining this climate corridor, the Council does not rely solely on the present state of quantitative knowledge, but also integrates qualitative insights and precautionary aspects. Sole reliance on presently quantifiable knowledge could lead to extremely undesirable outcomes. If, for instance, we were to choose the climate protection pathway identified as optimum on the basis of presently quantifiable costs and benefits (following the findings of a cost-benefit model; Nordhaus, 1997), then pursuance of this pathway would lead to a temperature increase of 6.2 °C within 500 years. The model calculations show that if such a rise in temperature occurs a collapse of the THC is not out of the question. The indications pointing towards a potentially unstable behavior of the THC that were already available before 1997 (Mikolajewicz and Maier-Reimer, 1990; Manabe and Stouffer, 1993; Rahmstorf, 1995) and the debate on further possible climate instabilities have therefore moved the Council to narrowly define the 'climate window' (Fig. D 6.3-1) on which its previous recommendations have been based, in order to do justice to such hazards (WBGU, 1995b, 1997a, b). Climate instabilities result notably from positive feedback effects (self-reinforcing global warming). For instance, if permafrost soils are warmed, methane is increasingly released (IPCC, 1996c; on feedback effects in the water and carbon cycles: WBGU, 1994, 1998a).

The climate window chosen here should neither be taken to mean that significant climate impacts can be entirely excluded if developments remain within the window, nor is it proven beyond doubt that catastrophic developments must occur under all circumstances if we move beyond the window. What the window does do is to delineate, in the opinion of the Council, the future climatic leeway in a manner that does justice to a great extent to the remaining major scientific uncertainties. It should be noted when comparing the climate window with the instability line of the THC that the latter in fact only indicates the threshold to instability, thus defining the region in which a transition to a new state of equilibrium is to be expected. There are already climate states below the instability line that may lead to a considerable weakening of the THC which, while not final, may extend over several centuries (Manabe and Stouffer, 1993; Stocker and Schmittner, 1997). This, too, must be viewed as extremely hazardous in terms of its potential climate impacts. Only when this range of hazard can be quantified more precisely would it be expedient to expand the climate window or, if necessary, to narrow it down. Here it needs to be taken into consideration that, in addition to the THC, the climate window must also do justice to other instabilities and hazards stemming from continuous processes of climate change.

All of these analyses are conducted on the basis of mathematical-physical models. While these reflect presently quantifiable knowledge, they do not yet cover all relevant influences. Particularly with respect to the instability line indicated here, it must be stressed that the underlying model may possibly neglect the stabilizing influence of winds at the ocean surface. On the other hand, a reduction in oceanic CO_2 assimilation possibly triggered by a weakening of the THC, which could then lead to enhanced global warming, has not yet been taken into account in the model (Stocker and Schmittner, 1997a). Moreover, in addition to the instability mechanism analyzed by Stocker and Schmittner, a further mechanism is assumed whose effect depends greatly upon local changes (which are very hard to model) in freshwater inputs to certain points of the North Atlantic. Particular attention needs to be given to this mechanism because it may lead to a much faster change of the THC (Rahmstorf, 1995, 1997).

D 6.4
Assignment to the risk classes

The magnitude of damage associated with anthropogenic climate change cannot be predicted for individual regions, but for vulnerable regions it must be expected to be high throughout. Gradual global warming develops its effect only slowly and with a time delay, mainly due to the inertia of the oceans. The greenhouse gases emitted in the past will already lead to climate change and sea-level rise, even if emissions are cut back immediately. The probability of occurrence is high – anthropogenic climate change is already observable (IPCC, 1996a). The uncertainties attaching to both the probability and magnitude of damage depend upon the spatial and temporal scale and upon the climate parameters under consideration (Table D 6.4-1). Expected changes at the con-

Table D 6.4-1
Application of the evaluation criteria to the risk associated with natural climate variability. This does not belong to any risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property				
	Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					
Ubiquity					
Persistency					
Irreversibility					
Delay effect					
Mobilization potential					

Table D 6.4-2
Application of the evaluation criteria to the risk associated with gradual human-induced climate change. This belongs to the Cassandra risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					
Ubiquity					
Persistency					
Irreversibility					
Delay effect					
Mobilization potential					

Table D 6.4-3
Application of the evaluation criteria to the risk associated with a collapse of the thermohaline circulation. This belongs to the Cyclops risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurrence *P*					■
Certainty of assessment of *P*					■
Extent of damage *E*					
Certainty of assessment of *E*					
Ubiquity					
Persistency					
Irreversibility					
Delay effect					
Mobilization potential					

tinental scale can be assessed more accurately than at the regional scale. Changes in the hydrological cycle are harder to assess than those relating to temperature. The certainty of assessment is high with respect to the hazards posed to marginal, natural and agricultural ecosystems. This applies particularly to many coastal areas that are at risk of flooding. Gradual human-induced climate change is thus a Cassandra-type risk (Table D 6.4-2).

The magnitude of damage associated with climate collapse due to cessation of the Atlantic thermohaline circulation is most certainly very high, but the probability of occurrence is unknown. This risk can therefore be assigned to the Cyclops class (Table D 6.4-3).

For other possible abrupt climatic changes with catastrophic consequences, such as could be caused by positive feedback effects or by the possible instability of the West Antarctic ice sheets, neither the probability nor the magnitude of damage can be assessed at present. These risks are therefore assigned to the Pythia class.

An examination of the risks posed to site-inappropriate agro-ecosystems by natural climatic fluctuations reveals that the risk evaluation criteria have no extreme properties, so that these risks fall in the normal area. However, as noted above, these risks can also gain global relevance if they accumulate and if the countries concerned lack the necessary risk management capacities.

Evaluation of the risk associated with the ENSO phenomenon using the criteria chosen by the Council shows that this risk no longer falls in the Cyclops class. Particularly since ENSO warnings have become possible several months before the event occurs, normal risk management tools can be applied.
Thus, in contrast to the risks of natural climate variability, the risks of anthropogenic climate change are clearly located in the transition area and, as representatives of the Cassandra, Cyclops and Pythia classes of risk, even partly in the prohibited area.

D 6.5
Synopsis of strategic research recommendations

More than 20 years ago, 'The Limits to Growth' (Meadows, 1972) and then 'Global 2000' (Council on Environmental Quality, 1980) set out the risks attaching to an unrestricted use of natural resources and loading of the global environment, and issued a call to handle environmental resources sparingly and responsibly. These warnings have not been without effect upon international climate protection. To promote a precautionary approach and a prudent handling of ambiguity and uncertainty, a number of states have considerably intensified their environmental and climate research (BMFT, 1987). The example of stratospheric ozone depletion has made it very clear that global change research cannot and must not be a matter of applied research alone: in important areas, the fundamentals are not yet known (in the case of ozone, the physical chemistry of multiphase processes at low temperatures). The stratospheric ozone layer is only one subsystem of the climate system, so that researching the effects of increased concentrations of greenhouse gases and aerosols upon the global climate is a far more complex task.
Natural climate variability can be modeled only inadequately – be it by inferal from available empirical observation series or by numerical simulation on the basis of physical models. Where an anthropogenic signal is superimposed upon natural climate variation, the former is scarcely perceptible against the background of the natural, notably long-phase, fluctuations. The prime goal of climate research should therefore be to gain an improved understanding of natural climate variability and thus of regionalized climate predictions. To achieve this goal, the understanding of the climate system needs to be enhanced by means of models and observations. The focus should be placed on the hydrospheric (clouds, cryosphere, oceans) and biospheric subsystems, and upon the interactions between the subsystems. This includes elements of basic research in relevant neighboring fields (non-linear systems, chaos theory, predictability).

D 7 Natural disasters

Natural disasters embrace a broad range of violent manifestations that can have very different causes. Floods, drought, hailstorms and storms are outcomes of extreme meteorological events, while earthquakes and volcanic phenomena are triggered by geophysical processes. Meteoric impacts even have extraterrestrial sources. Natural disaster risks can have global causes (e.g. global climate change) and global effects. The latter occurs for instance when volcanic phenomena eject aerosols and ashes into the stratosphere, where they disperse around the globe and influence global climate. Impacts of meteorites with diameters of 1.5 km or more also have global effects (Morrison et al., 1994). In addition, risks may have a global dimension if their management requires international efforts or if they occur at many locations. This is often the case for floods and drought, as it is for earthquakes. Other natural disasters such as landslides and hailstorms will tend to be local to regional.

The primary causes of natural disasters generally escape human influence. Risks arise from the exposure and vulnerability of people to the hazards stemming from the natural events. The precondition to risk mitigation measures is that the probabilities of occurrence of the causal natural events can be forecast as precisely and as far in advance as possible. The goal of preventive measures must be to reduce the exposure and vulnerability of potentially affected areas.

For natural disasters with a catastrophic potential, the probability of occurrence is generally low. It can be expressed intuitively as a recurrence interval (in years). This is the interval within which – statistically speaking – an event occurs once with a certain magnitude. This does not however give any information as to when an event will actually occur. At best, probabilities can be stated for possible future natural events caused by geotectonic and hydrological processes. In contrast, with an adequate data basis, most meteoric impacts would be predictable with high temporal precision and long in advance. However, the magnitude of damage to be expected cannot be stated, as this depends greatly upon the vulnerability of the area of impact, which can scarcely be predicted. In the following, representative types of globally relevant natural disasters are discussed: floods, earthquakes, volcanic phenomena, tsunamis and meteorite impacts.

D 7.1 Natural risk potentials

D 7.1.1 Floods

Flood hazards are concentrated in river valleys and coastal areas. While in the first case it is the intensity and duration of precipitation and the water retention capacity of the catchment area that is decisive, in coastal areas sea water swelling caused by long and strong storms can cause flooding. In the estuaries of large rivers, hazards often arise simultaneously from the inland side and from the sea. Areas at risk of flooding – both along rivers and on flat coasts – often offer considerable economic benefits and settlements are therefore expanding here. The thus increased exposure and vulnerability (above all in developing and newly industrializing countries) heighten the risk potential considerably (WBGU, 1998a). Among the various types of natural disasters, flooding has the largest damage potential worldwide (IDNDR, 1993). Each year, flood events affect by far the greatest number of people (DRK, 1997). However, there are considerable regional, national and even continental differences in the frequency, magnitude of events and extent of damage. The recent flood disasters in China and Latin America are ample proof of this. Where we present illustrative examples from Europe in the following, this reflects the better data availability here and not the risk potential.

Causative mechanisms of flood risks

Meteorological-climatological factors

The question of whether the frequency of extreme weather events leading to flooding or storm surges has already increased or will soon increase as a consequence of global climate change is presently hotly debated (Section D 6). However, there is agreement that global climate change can in principle affect the probability of extreme weather conditions. For instance, warmer and drier summers make a further retreat of mountain glaciers appear probable. As a consequence of this, the capacity to retain precipitation in winter is reduced, and runoff peaks are shifted into the winter, which would be further intensified by a trend towards milder winters (IKSR, 1997; Berz, 1997a). As a consequence, it must be feared that climate change will cause increased flood hazards.

Runoff regime

The discharge of flowing waters depends upon the size of the catchment area, the quantity of precipitation per unit area and the retention of water within the catchment area. In most catchments, there is a delay in discharge after precipitation events. This is caused by the distance between the precipitation focus and the discharging stream and by the retention of water through soil infiltration and water uptake in above-ground reservoirs (Dyck and Peschke, 1997). Flooding can occur if the water retention capacity of vegetation and soils in the catchment area is exceeded. The magnitude of flooding is thus determined by the temporal and spatial distribution of precipitation, the storage effects of vegetation and soils and the topography of the terrain.

Anthropogenic influences have considerably increased both the probability of occurrence and the damage potential of flooding, despite the high expenditures for flood control in some areas. The following factors are the main causes of the increased probability of occurrence (IKSR, 1995; UBA, 1998):

- Regulation works on watercourses with the main goal of accelerating water discharge, with a simultaneous loss of natural floodplains caused by dike construction close to river channels.
- Reduction in natural water retention capacity (particularly of slopes) due to reduced forest stocks caused by clearcutting and forest damage and by site-inappropriate cultivation.
- Surface sealing in the catchment area by settlements, commercial development and the construction of transport infrastructure (local and regional impacts).

Incoherent flood control systems as risk factors

Today, the development of rivers as waterways has high priority. The dikes lining many rivers have been built over several centuries and their dimensioning has been based on a variety of criteria. The materials and techniques used are similarly disparate. In some places, such as on the Oder river in Germany, structures were built on unstable subsoil.

In Germany, flood control structures are generally dimensioned so as to withstand a 100-year flood. However, downstream areas have not always been considered adequately in planning. For this reason and because of differing topographic conditions, flood control structures often do not present coherent protective systems (Grünewald, 1998). On the various stretches of the Rhine, too, for historical reasons flood control measures have very different degrees of effectiveness (IKSR, 1997).

Damage potential

Floods cause losses of human life, economic damage to property (buildings, transport routes and other structures, utilized land areas) and damage to social values (image loss of regions, loss of cultural goods). Ecological damage (e.g. erosion) occurs in previously stressed areas. Secondary damage results above all through the release of contaminants (IKSR, 1997).

Rich industrialized nations such as the Netherlands have undertaken considerable flood control efforts over recent decades. Severe losses of human life and property have thus become very much rarer (IKSR, 1997). In river estuaries, flood hazards are particularly large if high river discharges coincide with spring tides and wind-related swelling of sea water. Inland river regulation reduces sediment loads in the delta. Sediment eroded in the delta by the action of the sea can thus no longer be replaced by outflowing sediment loads. This considerably increases hazards to delta inhabitants.

The situation is more severe in countries where the means for constructing flood control structures are not available. Bangladesh is an extreme example in this respect. Flood hazards have both inland and seaward sources, both influenced strongly by the regularly recurring monsoon winds. The greater part of the country is no more than 10 m above sea level. As a consequence of its low-lying terrain and its inadequate flood control structures, large parts of the country are exposed to flood hazards. A difficult economic situation and extreme population density lead to high vulnerability in these intensively cultivated and fertile areas. Large parts of the country are flooded every year, catastrophic flooding occurring about once every decade. Between 1960 and 1970 alone, the country suffered 13 tornadoes and subsequent flooding. The 1988 flood disaster affected 46% of the country, more than 45 million people (almost ⅓ of the total population) lost their homes and property, 2,000 people drowned (Jessen, 1996).

D 7.1.2
Earthquakes, volcanic phenomena and tsunamis

Most earthquakes are caused by movements of the continental plates (tectonic earthquakes). They occur predominantly at the boundaries of tectonic plates that are approaching or moving laterally to each other. In addition, earthquakes may also occur within plates, in connection with volcanic phenomena (volcanic tremors) and the collapse of cavities in the Earth's crust (subsidence earthquakes). Some 80% of worldwide seismic energy release, 95% of all quakes triggered and many volcanoes are concentrated around the Pacific basin (Pacific 'rim of fire'). These disasters can also have wide-ranging secondary consequences. Prime among these in terms of catastrophic potential and spatial scope are the tsunamis (Japanese: 'great port wave'). These are generated by submarine earthquakes, volcanic eruptions and submarine landslides close to the coast. Tsunamis thus occur predominantly on the Pacific coasts and in adjacent seas.

Damage potential

The extent of damage caused by geotectonic disasters is a function of the intensity of the primary event and the vulnerability of the area affected. As opposed to vulnerability, the strength of the primary event can be assessed by simple indicators. Earthquake strength is expressed as magnitude or intensity. Magnitude is a logarithmic measure of the energy released at the focus of the earthquake, and is expressed on the logarithmic Richter scale, which is open upwards. It is determined by registering the ground motion generated by the seismic waves. The intensity of an earthquake is characterized by its impacts upon natural and artificial objects, and is expressed on the macroseismic earthquake scale (Mercalli scale). This scale permits a comparison with historic earthquakes on the basis of the damage caused.

To characterize the strength of volcanic eruptions, the Volcanic Explosivity Index (VEI) introduced some 15 years ago has become generally accepted (Newhall and Self, 1982). This links quantitative data on the volume of material ejected and the height of the eruption column with qualitative observations. Like the magnitude of earthquakes, this index is a logarithmic measure.

The hazard potential of tsunamis stems from the extreme rise in wave heights when they reach shallow water at the coast. Wave height in the direct vicinity of the coast is a suitable measure by which to assess their damage potential.

Extent of damage

Earthquakes have been responsible for between ⅓ and ½ of the 4 million deaths caused by natural disasters in this century (Table D 7.1-1). Volcanic eruptions are responsible for less than 2% of deaths, and tsunamis for about 0.5%. Earthquakes are also by far the leading cause of property losses attributable to geophysical disasters (Zschau, 1998). The marked rise in losses caused by earthquakes since 1970 is an outcome of the increasing vulnerability of the areas concerned, e.g. due to advancing industrialization, expanding infrastructure and rising population density. Particular hazards are posed by industrial plants that handle hazardous materials (e.g. nuclear power plants, chemical industry).

Growing vulnerability is also leading to the number of people affected by volcanic eruptions growing considerably. By the year 2000, it is expected that at least 500 million people will be threatened by volcanic eruptions (Zschau, 1998). Tsunamis pose a hazard to low-lying terrain in the immediate vicinity of the coast. The major vulnerability resulting from the high population density of such areas necessarily leads to a high magnitude of potential damage.

Table D 7.1-1
Deaths and property losses caused by earthquakes and volcanic phenomena in this century.
Source: Münchner Rückversicherung, 1997

	Earthquakes		Volcanoes	
	Deaths	Losses [mill. US-$]	Deaths	Losses [mill. US-$]
1900–1909	178,626	950	34,200	not recorded
1910–1919	49,378	60	6,585	20
1920–1929	408,113	2,840	not recorded	not recorded
1930–1939	195,122	137	1,369	not recorded
1940–1949	47,470	1,155	2,000	80
1950–1959	6,634	204	4,942	not recorded
1960–1969	45,647	4,030	3,870	not recorded
1970–1979	422,136	17,248	64	200
1980–1989	48,059	46,238	23,060	1,090
1990–1996	64,445	139,880	875	750
Total	1,465,630	212,742	76,965	2,140

D 7.1.3
Asteroids and comets

The risks associated with the Earth being struck by meteorites are quite comparable with those of other natural events. Bodies with diameters exceeding 10 m generally do not vaporize completely in the atmosphere, and strike the Earth as meteorites (Morrison et al., 1994). The last larger natural disaster of this kind happened in 1908 in Siberia (Tunguska event), where it destroyed forests over an area of 2,000 km^2. This event did not claim any human lives, as the area affected was uninhabited. If it had taken place in a densely populated region, the number of deaths might well have exceeded that of all other natural disasters of this century taken together (some 4 million). Small cosmic particles can also harbor risks: in near-Earth space, they endanger manned and unmanned space flight alike.

Damage potential

The effect of a meteorite impact is proportional to the impact energy, which is expressed in terms of the explosive force of TNT (trinitrotoluene), i.e. the same measure that is used for the explosive force of nuclear weapons. If the speed at impact is known, the impact energy can be placed in relation to the mass (and thus also to the size) of the asteroid.

The frequency distribution of lunar craters delivers the most reliable statistics on the probability of meteorite impacts over the past 3,300 million years (Morrison et al., 1994). There is an inverse relationship between the size and the impact frequency of meteorites. This can serve as a basis for estimating the probability of occurrence and potential magnitude of damage of meteorite impacts (Fig. D 7.1-1). Events with global effects occur on average every 300,000 years, and are caused by meteorites having a diameter of at least 1.5 km.

The analysis of nuclear explosions, scaled-down experiments and model calculations have been used to predict the effects of meteorite impacts. These studies can serve as a basis on which to assess the potential extent of damage. Objects with diameters larger than 10 m pass through the atmosphere and create an impact crater. The resulting brief blast wave causes devastating storms (Toon et al., 1994). Blast waves can also be created when asteroids explode in the atmosphere and their fragments vaporize. This was probably the cause of the Tunguska event in 1908, as no remnants of a meteorite have been found. When meteorites impact on the ocean surface, huge tsunamis are produced. For the Eltanin asteroid (with an estimated diameter of maximun 4 km) that struck the south-east Pacific 2.15 million years ago, the height of the tsunami wave is estimated at 20–40 m. When a tsunami reaches shallow coastal waters, wave height grows 10–25 fold (Gersonde et al., 1997).

When meteorites strike, solid materials or water are hurled up into the atmosphere. If smoke, dust and water reach the stratosphere, they remain there for ca. 6 months and can disperse worldwide. As a result, the atmosphere is darkened (turbidity) by dust and aerosols, which drastically reduces the intensity of incoming solar radiation at the Earth's surface. If radiation at the Earth's surface is reduced to less than 1%, plant photosynthesis ceases. The increased reflection of sunlight back into space (albedo) and the absorption of solar radiation in the air column leads to a brief but dramatic drop in temperatures, similar to that predicted for a 'nuclear winter' (Turco et al., 1982).

Through the blast wave, nitrogen oxides are formed from atmospheric oxygen and nitrogen. In addition, large-scale fires caused by the impact can release greenhouse gases (carbon dioxide, carbon monoxide, methane and nitrous oxide). When meteorites hit the ocean, water vapor is thrown up into the atmosphere (Crutzen, 1987; Toon et al., 1994). After atmospheric turbidity has subsided, these greenhouse gases cause global warming (Section D 6). However, the combined consequences of atmospheric turbidity on the one hand and heat absorption on the other are not predictable. Gaseous releases, notably of nitrogen oxides, have a strong depleting effect upon the stratospheric ozone layer. Whether this results in increased stresses on the biosphere due to UV radiation is not yet known. The nitrogen oxides resulting directly from impact also lead to acid rain, with its associated effects upon the biosphere (Section D 5).

Extent of damage

Meteorite impacts have not yet caused losses of human life. This gives the false impression that the factual risk to life and property presented by meteorite impacts is negligible and does not require any risk management measures. While at least theoretically the probability of occurrence and the primary magnitude of damage can be predicted fairly well, no precise statements can be made on actual losses of human life and property. This is mainly because the consequences of meteorite impacts depend greatly upon the specific vulnerability at the site of impact, which cannot be predicted. If the risk is quantified statistically as the product of probability of occurrence and damage potential, meteorite impacts at the threshold to the global dimension (diameter ca. 1.5 km; recurrence interval ca. 300,000 years) constitute the greatest risk to the safety of human life (Morrison et al., 1994).

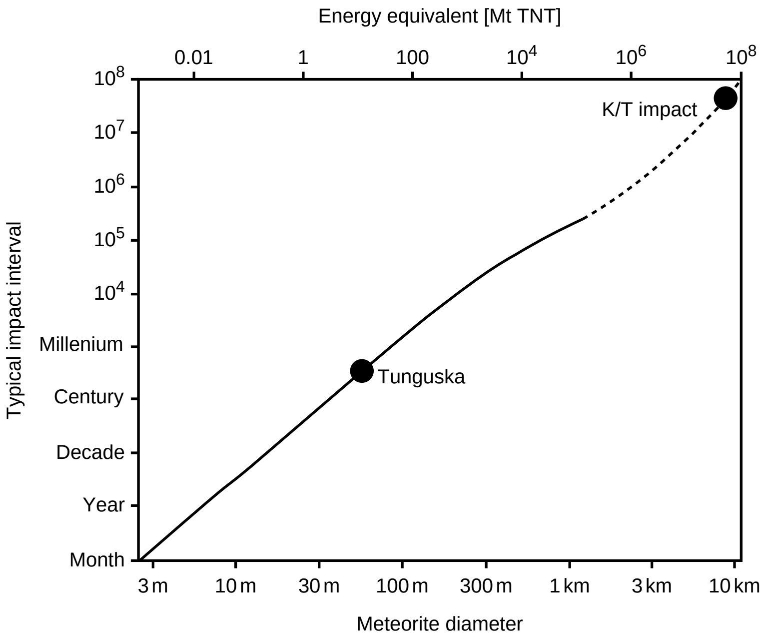


Figure D 7.1-1
Cumulative energy-frequency distribution of meteorite impacts on the Earth, based on the size-frequency distribution of lunar craters. The K/T impact was a disaster caused by the impact of a large celestial body (comet?) approximately 65 million years before present. The mass extinction of plant and animal species at that time (most notably, the dinosaurs) is attributed to this event which marks the transition between the Cretaceous and the Tertiary.
Source: Morrison et al., 1994

D 7.2
A typology of natural disasters

As set out in Section D 7.1, natural disasters are characterized by a particularly large variance of damage potential. This is not only decisive for the question of whether the causes and effects of a natural disaster assume global dimensions, but also whether internationally coordinated action is necessary. Therefore the typology cannot be as clear cut here as it is for other types of risk discussed in this report.

D 7.2.1
Floods, earthquakes and volcanic phenomena

Risks associated with major floods where data availability is good (Table D 7.2-1) belong to the Damocles class, earthquakes and volcanic eruptions rather to the Cyclops class. The risk disposition is known in most areas – from historical information and from the knowledge of the hydrological or geophysical setting. However, the predictability of specific natural events and the assessability of their potential magni-

Table D 7.2-1
Application of the evaluation criteria to the risk of major flooding (with good data availability). This belongs to the Damocles risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion	Property: Low	Tends to be low	Tends to be high	High	Unknown
Probability of occurence *P*					
Certainty of assessment of *P*					
Extent of damage *E*					
Certainty of assessment of *E*					
Ubiquity					
Persistency					
Irreversibility					
Delay effect					
Mobilization potential					

tude of damage is generally poor. Prediction of the probability of occurrence of floods depends upon the reliability of prediction of the causative extreme weather situations, and is still subject to considerable uncertainties that grow rapidly with the length of the prediction interval. However, considerable progress can be expected here in the coming years. A particular characteristic of earthquakes is that after they have happened the warning times for potentially affected areas are extremely short, even at great distances from the focus of the earthquake, and generally do not suffice to undertake risk reduction measures (e.g. evacuation). Tsunamis offer greater scope for predicting the arrival time and height of a surge.

The potential magnitude of damage caused by river and coastal flooding is high. In principle, it can be predicted and correlated with the runoff rate or water level. As assessing potential damage is an important precondition to planning and appraising protective measures, there is a considerable need for relevant information, particularly in many developing and newly industrializing countries. Exposure to flood hazards can be reduced locally by means of protective structures (dikes, water control engineering measures on rivers). However, the past has also shown that control engineering measures, for instance on the upper courses of rivers, can lead to increased exposure elsewhere. Such measures can therefore only be evaluated comprehensively if the entire catchment area is considered. Particularly in less affluent countries, the tendency to settle in and utilize economically attractive but potentially flood-prone areas can further exacerbate vulnerability.

D 7.2.2
Meteorite impacts

The risks associated with meteorite impacts belong to the Damocles class (Table D 7.2-2). Strikes of large meteorites are highly improbable, but their time and size can generally be predicted readily. However, these predictions offer little information for the evaluation of the actual risk, as the extent of the damage to be expected depends upon the vulnerability of the impact site, which cannot be predicted. From a certain size of the colliding celestial body upwards, the magnitude of damage caused by meteorite impacts exceeds that of all other natural disasters. In addition to the immediate consequences of impact, larger meteorites must be expected to also cause effects upon the world climate and harvest yields. In view of the high magnitude of damage, smaller meteorite disasters, too, call for relief and compensation measures at the international level. Nonetheless, as opposed to other Damocles-type risks (such as that associated with nuclear energy), the mobilization potential associated with meteorite impact risks is rather low.

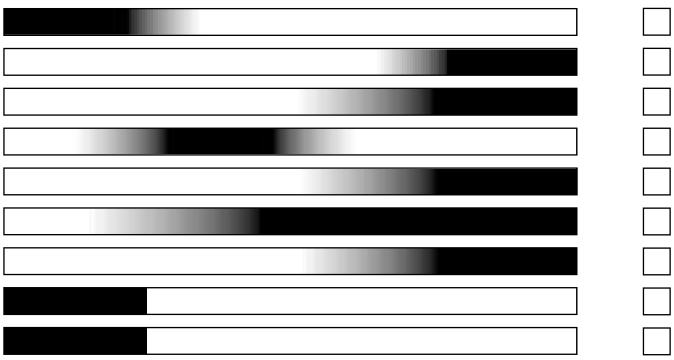
D 7.3
Options for action

Because natural disasters cannot be prevented by human action, the mobilization potential is low. It is thus hard to politically enforce the necessary protective measures. The reasons for this are:

- The low probability of occurrence of some types

Table D 7.2-2
Application of the evaluation criteria to the risk of meteorite impacts at the threshold to global effects. This belongs to the Damocles risk class. Terms are explained in Box D 2.1-1.
Source: WBGU

Criterion Low	Property: Criterion low	Tends to be low	Tends to be high	High	Unknown
Probability of occurence P					
Certainty of assessment of P					
Extent of damage E					
Certainty of assessment of E					
Ubiquity					
Persistency					
Irreversibility					
Delay effect					
Mobilization potential					



Box D 7.3-1

The International Decade for Natural Disaster Reduction (IDNDR)

Natural disasters and development

The number of deaths caused by natural disasters is particularly high in the developing and newly industrializing countries. Economic losses there amounted to some US-$ 47 billion per year in the 1980s, and thus substantially exceeded the development assistance inputs of Western donors. USAID estimates indicate that an expenditure in the order of global development assistance would have prevented about 70% of all natural disaster damage and could have saved a great number of human lives. Total property losses were higher in the industrialized countries (Berz, 1997b), but the number of deaths was comparatively low. This shows that, due to more effective mitigation measures in rich countries, the impacts of major natural disasters are far smaller there.

Disaster reduction as an integral component of development assistance

It is against this background that the United Nations declared the 1990s the Decade for Natural Disaster Reduction (IDNDR). An IDNDR Secretariat and a Scientific and Technical Committee (STC) have been established in Geneva. Germany is among the countries supporting this initiative. By the year 2000, all countries, be it alone or in the context of regional agreements, are encouraged to have:

- Comprehensive national assessments of risks from natural hazards integrated into national development plans;
- Mitigation plans of practical measures for application at national and local levels that address long-term disaster prevention, preparedness and community awareness;
- Ready access to warning systems at global, regional, national and local levels.

Disaster mitigation as a social policy measure

The effectiveness of risk management measures depends greatly upon the economic framework conditions and an appropriate information basis. Disaster reduction thus also has an essential social component (Clausen, 1993).

This is why strong attention has been given in the IDNDR to the social context of disaster mitigation. Disaster reduction is viewed as an important element of development assistance. This was formulated in the 1994 'Yokohama Strategy' and Plan of Action for a Safer World, which also guides the work of the German IDNDR National Committee (Eikenberg, 1997).

of natural disaster make people assume that the next event will only occur in the distant future.

- The high damage potential of the natural events (e.g. of meteorite impacts) exceeds the imagination of many people.
- The uncertainty attaching to the prediction of natural disasters leads to people ignoring or denying their hazard potential.
- An additional 'repression' effect arises if lengthier periods have elapsed since the last disaster.
- The willingness to make financial sacrifices for risk reduction measures declines considerably in groups that are not affected directly by a natural risk or do not appear to be affected (for instance, paying for the costs of flood prevention measures that only benefit areas further downstream).
- Existing structural protection measures (e.g. dikes in flood-prone areas) give the population the illusion that there is no residual risk any more.

D 7.3.1 Floods

The political objectives stipulated in the Rhine action plan on floods ('Aktionsplan Hochwasser'; IKSR, 1998) offer a model for flood management on international watercourses, as these objectives comprise the basic elements of integrated flood control including structural and organizational measures and steps towards raising awareness among the affected public.

Flood risk management comprises a diagnostic and an operative step. The diagnostic step proceeds from the determination of flood hazards on the basis of meteorological and hydrological conditions. Risk assessment then attempts to estimate the effects of a flood upon the safety of human life, the economy and the environment (Plate, 1998). The operational step includes structural measures and steps aimed at reducing the vulnerability of areas affected. Disaster relief requires international efforts, particularly for developing countries. The International Decade for Natural Disaster Reduction (IDNDR) is guided by the will to view disaster mitigation and response at all levels as an integrated package and to develop this as an integral component of sustainable development and of development assistance (Box D 7.3-1).

Risk analysis

The hydrological basis of flood risk analysis is to quantify discharge events by means of statistical procedures and simulation models of flood formation. The subsequent second step is to assess damage to human life and property with due regard to vulnerability. Calculation of the relationship between precipitation and runoff rate or water level forms the basis for a mechanistic flood forecast. If an adequate data basis is available, models also permit statements on the impacts of land-use changes and on precipitation quantities and frequencies. On the basis of topographic maps, overflow areas can be depicted, and in conjunction with precipitation forecasts rough predictions can be made of flood events and their hazard potential (WBGU, 1998a; Plate, 1998).

Risk reduction measures

When planning and implementing measures, the question of acceptable residual risk must always be considered and defined by means of rigorous cost-benefit analysis. Specifically, the following measures can be distinguished:

- Enhancing water-retaining capacity in the water catchment area by means of reactivating floodplains, extensifying agriculture, afforestation measures, building high-water retaining structures.
- Structural flood control through building new and maintaining existing dikes, and adaptation to the desired level of protection.
- Preventive measures at the planning level through designing flood-appropriate land uses and through mapping risk zones.

Structural solutions above all serve to raise the critical limit value at which floods occur, and thus reduce the probability of occurrence. In such efforts, the following points need to be taken into consideration:

- River levees (flood protection embankments) reduce flood hazards, but if they rupture the damage can be all the greater.
- The construction of retention basins and polders does increase water retention and permits a reduction of the risk of short-term extreme flows with attendant flooding. However, over the long term the reclamation of natural floodplains offers the best prospect of success.
- On large rivers it is generally not possible to construct retention basins. Regulating the water level across the longitudinal section of lakes through which rivers pass would be expedient from a hydrological perspective, for instance in the case of the Rhine (water level regulation of Lake Constance; Plate, 1998). However, there are considerable reservations concerning such measures, for reasons of nature conservation and water protection (above all bank protection).
- The conservation or restoration of forests enhances water-retaining capacity in catchment areas and thus reduces the magnitude of peak flows through reducing the runoff coefficient.
- Flood impacts can be reduced by means of emergency preparedness and response measures. Early warning can only prevent property loss to a limited extent. However, to save human lives by evacuation, sufficient early warning is a precondition to success. In addition to flood early warning, operative disaster relief mechanisms must also be established (Box D 7.3-2).

D 7.3.2
Earthquakes and volcanic phenomena

No universally applicable method is yet available by which individual earthquakes might be predicted reliably. Predictions of the probability of occurrence of earthquakes proceed from an analysis of the events that have occurred in the region in question over the past 500 years. Seismic zonation is used to identify the geographical distribution of earthquake risk. Beyond the magnitude, epicentral distance and focal depth, earthquake impacts depend crucially upon the vulnerability of the specific region (Section E 2). Volcanological studies only permit statements on the probability of hazards posed by future events with certain intensities. They can provide no exact information on the actual occurrence and intensity of the next eruption. Presently available techniques make it possible to give people who are not located in the immediate vicinity of the volcano warning times of several hours after an eruption has happened. This time can be used for evacuation measures.

Tsunami predictions are based on analyses of the correlation of precipitating geophysical events (earthquakes, volcanic eruptions) with the frequency of occurrence and wave heights of tsunamis in areas at risk. However, due to the rarity of tsunamis, the data basis for such correlations is poor in most regions. It is nonetheless possible in principle to predict the arrival time of tsunamis, due to their relatively low speed and readily predictable linear propagation.

Structural measures and a broad range of technical systems for the analysis of processes relating to earthquakes can contribute considerably to reducing earthquake risks. But there are only few possibilities to reduce the impacts of volcanic eruptions upon infrastructure, buildings and agriculture. It may in certain cases be possible to deflect lava flows by means of barrier structures, but such measures are only feasible in rare, exceptional cases.

D 7.3.3
Measures by which to prevent meteorite impacts

Several asteroid search programs are already in place that collect and exchange data on a continuous basis and at relatively low cost (Carusi et al., 1994). The trajectory elements of near-Earth asteroids and comets with diameters of 500–1,000 m can mostly be determined with adequate certainty by means of already existing monitoring systems at great distances, which provides long early warning periods for collisions. However, many, notably smaller, objects can

Box D 7.3-2

Lessons learnt from the 1997 flooding of the Oder river

The Oder flood in summer 1997 highlighted a number of issues that should be considered in the future in efforts to reduce flood damage.

- Apart from meteorological conditions (which were by no means exceptional), the disastrous impacts of this flood were crucially determined by the circumstance that the embankment structures on the Oder had not been built with the primary goal of flood protection. The much smaller magnitude of damage on the German side is due partly to better control structures and partly to more effective risk management measures.
- Under the difficult economic conditions that prevailed particularly on the Polish side, highly flood-prone areas have been used in the past for housing and economic activities. The resultant increase in vulnerability of the areas endangered has raised the risk potential considerably.
- The differences in assessment of the flood on various stretches of the river and among the three riparian states are due both to real differences in the manifestation of the flood in the various parts of the river, and to different quantification techniques and assessment standards applied in Germany, Poland and the Czech Republic.

Flood management as an integrative and multinational task

Flood control needs to be an integral component of water resource management, regional planning, agriculture, forestry and nature conservation. Transboundary flood risk management planning needs to take into consideration the disparate economic and administrative framework conditions in the riparian states. The following goals have particular urgency:

- *Enhancing water retention*. In addition to the historical shortening of the river channel, forest damage on the ridges of the Sudetic Mountains and the Beskids have played a considerable role in the acceleration of runoff and thus in the increasing incidence of discharge peaks. To reduce their effects, in addition to further technical measures such as constructing retention basins and reservoirs, old arms of the Oder river and its tributaries could be reactivated, and the causes of forest damage could be abated and their effects mitigated. This would further serve to meet other ecological objectives.
- *Internationalizing flood forecasting and flood protection*. Particular importance attaches to improving or activating international flood forecasting models and systems in a manner appropriate to specific problems and tasks. The availability of sufficient and comparable primary data on water levels and discharge rates is an essential precondition to this. Improved regional flood risk management in the Oder river basin particularly needs to harmonize regional flood models, increase the forecasting lead time and continuously implement the effectiveness of both planned and implemented flood protection measures.
- *Harmonizing different planning objectives*. Germany's operative objectives are formulated in the 'Oder flood action plan'. Under this action plan, the possibilities of retaining water throughout the river basin are to be utilized by means of securing existing and reclaiming former floodplain areas. Flood control structures with the purpose of limiting damage are to be dimensioned according to protection priorities. All planning goals are to have as positive an effect as possible upon natural assets in the river plains and tributaries. The 'Oder 2000' project on the Polish side, which aims to develop the Oder as a waterway (construction of barrages, modernization of locks and weirs, flow regulation, construction of the Ratibor reservoir) needs to be integrated into an international plan.

only be identified at much shorter distances, with correspondingly shorter warning times. Due to the given size-frequency distribution of asteroids, these are precisely the objects which are to be expected with the greatest probability.

To prevent an object that is on collision course with the Earth from striking, its trajectory must be changed. Although concrete proposals have already been made for technical procedures by which to prevent meteorite impacts, considerable doubts as to their technical feasibility remain (Weissman, 1994). Using rocket-delivered explosives or laser sources, a motional impulse can be created with the aim of deflecting the object. However, some experts fear that the risk potential is increased in the event that this does not deflect the meteorite, but fragments it (Ahrens and Harris, 1994; Shafer et al., 1994).

Synopsis: An overview of global risk potentials D 8

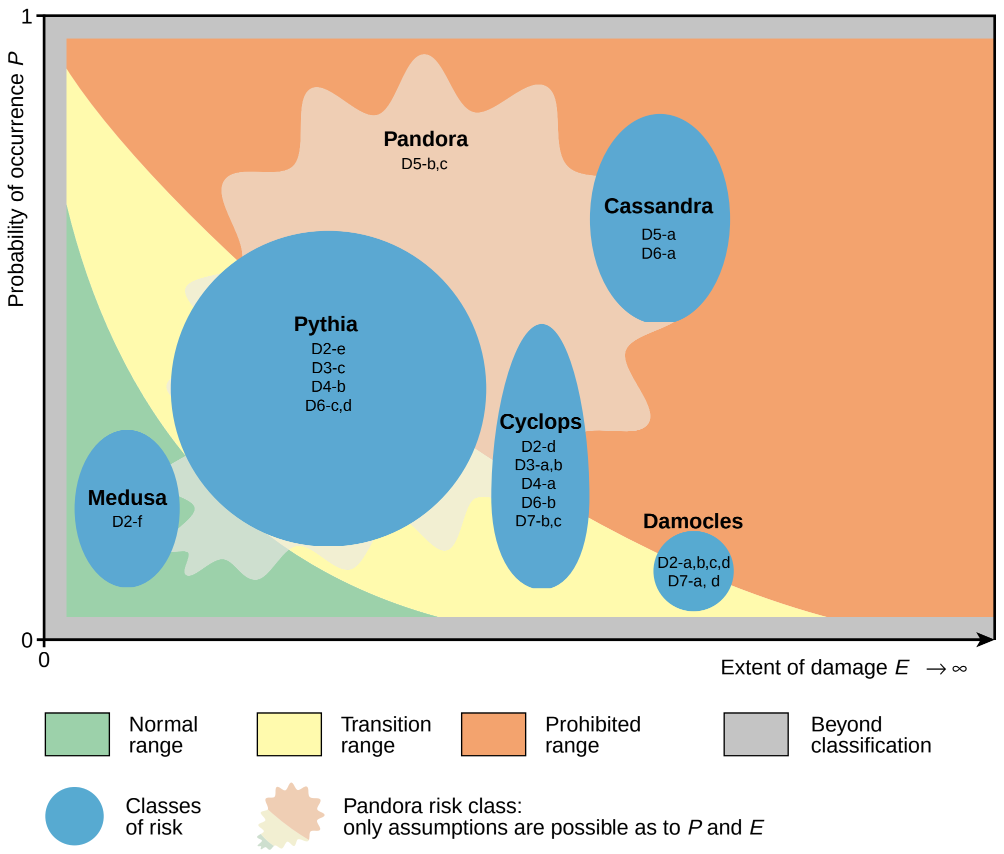
This synopsis provides a comparative overview of all global environmental risk potentials discussed in Section D. The overview concentrates upon the assignment of specific risks to the classes of risk identified in this report (Fig. D 8-1). It further presents the criteria characteristic of each class and the grouping of each specific global environmental risk in the various classes (Table D 8-1). In total, the Council has selected and classified 24 representative global risks. Of course there are many more global risks in each class. The risks discussed here are to be understood as characteristic representatives of their classes.

In addition to the risks of global change covered in Section D, the Council examines in the following Section E the risk potentials of complex environmental systems. Here the concept of syndrome analysis is applied (Section E 4.2). The global health crisis and the risks attached to future food security are presented as examples of complex risks in the Sections E 3.1 and E 3.2.

The overview of risks treated in Section D shows that many of these must be assigned to those classes in which one or both of the two prime criteria – probability of occurrence and extent of damage – are unknown. In the Pythia class, both of these criteria are unknown. In the Cyclops class, the probability of occurrence is unknown. In the Pandora class, there are only assumptions concerning probability and extent. In the Damocles class, there is no uncertainty as to the two prime criteria, but the extent of damage can be extremely high, the very low probability of occurrence notwithstanding.

The overview illustrates that the three risk classes to which the great majority of specific global risks discussed here are assigned – Pythia, Cyclops and Damocles – are not only situated in the transition area but also extend into the prohibited area. Risks situated in the prohibited area should be reduced under all circumstances. For the risks treated in the present report, it needs to be assessed and decided from case to case whether they are still located in the transition area or have entered the unacceptable prohibited area. Only the global risks assigned to the Cassandra class – human-induced climate change in vulnerable regions and destabilization of ecosystems through intervention in elemental cycles – are definitely situated in the prohibited area. The risk associated with persistent organic pollutants (POPs) is also situated in the prohibited area, and assigned to the Pandora class because initially only assumptions could be made concerning global relevance and were confirmed only retrospectively.

For risks in the Pythia and Cyclops classes, the uncertainty attached to the probability of occurrence or to the extent of damage mean that the certainty of assessment in the transition area is low. Nonetheless, there are plausible reasons to assume that large damage can occur. Where there are grounds to suspect that major damage can occur, persistency, ubiquity and irreversibility are in most cases particularly relevant criteria. In the transition area, a valid and reliable scientific risk assessment is often scarcely possible. Risk policy strategies must then contribute to resolving the uncertainties and to reducing the possibly large extent of damage (Sections A and F 9).



Representative risks (in order of the Sections of this report)

D2 Technological risks
D2-a Nuclear energy
D2-b Large-scale chemical facilities
D2-c Dams
D2-d Nuclear early warning systems and NBC-weapons systems
D2-e Certain genetic engineering applications
D2-f Electromagnetic fields

D3 Infectious diseases as a global risk
D3-a AIDS infection
D3-b Influenza-A infection
D3-c BSE/nv-CJD infection

D4 Biological risks
D4-a Mass development of anthropogenically influenced species
D4-b Release and spread of transgenic plants

D5 Chemical risks
D5-a Destabilization of terrestrial ecosystems
D5-b Persistent organic pollutants (POPs)
D5-c Endocrine disruptors

D6 Climate risks
D6-a Gradual human-induced climate change
D6-b Collapse of thermohaline circulation
D6-c Self-reinforcing global warming
D6-d Instability of the West-Antarctic ice sheets

D7 Natural disasters
D7-a Floods
D7-b Earthquakes
D7-c Volcanic eruptions
D7-d Meteorite impacts

Figure D 8-1
Synopsis.
Source: WBGU

Table D 8-1
Overview of risk classes: characterization and substantive examples. *P* signifies the probability of occurrence and *E* the extent of damage.
Source: WBGU

Risk class	Characterization	Representative examples
Damocles	*P* is low (approaching 0) Reliability of estimation of *P* is high *E* is high (approaching infinity) Reliability of estimation of *E* is high	• Nuclear energy (D2-a) • Large-scale chemical facilities (D2-b) • Dams (D2-c) • Floods (D7-a) • Meteorite impacts (D7-d)
Cyclops	*P* is unknown Reliability of estimation of *P* is unknown *E* is high Reliability of estimation of *E* tends to be high	• Earthquakes (D7-b) • Volcanic eruptions (D7-c) • AIDS infection (D3-a) • Mass development of anthropogenically influenced species (D4-a) • Nuclear early warning systems and NBC-weapons systems (D2-d) • Collapse of thermohaline circulation (D6-b)
Pythia	*P* is unknown Reliability of estimation of *P* is unknown *E* is unknown (potentially high) Reliability of estimation of *E* is unknown	• Self-reinforcing global warming (D6-c) • Release and putting into circulation of transgenic plants (D4-b) • BSE/nv-CJD infection (D3-c) • Certain genetic engineering applications (D2-e) • Instability of the West Antarctic ice sheets (D6-d)
Pandora	*P* is unknown Reliability of estimation of *P* is unknown *E* is unknown (only assumptions) Reliability of estimation of *E* is unknown Persistence is high (several generations)	• Persistent organic pollutants (POPs) (C5-b) • Endocrine disruptors (D5-c)
Cassandra	*P* tends to be high Reliability of estimation of *P* tends to be low *E* tends to be high Reliability of estimation of *E* tends to be high Long delay of consequences	• Gradual human-induced climate change (D6-a) • Destabilization of terrestrial ecosystems (D5-a)
Medusa	*P* tends to be low Reliability of estimation of *P* tends to be low *E* tends to be low (exposure high) Reliability of estimation of *E* tends to be high Mobilization potential is high	• Electromagnetic fields (D2-f)

Integrated risk analysis E

Risk modulators (amplifiers and intervening factors) E 1

E 1.1
Introduction

Risks can manifest themselves to people as threatening events in the form of a mishap or accident. In this manifestation, there are various factors – such as the people themselves, their institutional arrangements or the vulnerability of technological systems – which influence the probability of occurrence, the magnitude, perception, evaluation and management of risks. Risk research has identified causal structures that decisively determine the ways in which risks are managed, their outcomes and their consequences.

An important initial distinction is that between events and consequences. If a risk occurs as an event, it only then becomes a threat to humans and ecosystems if consequences are evaluated by humans as being harmful. For instance, both localized forest fires and extensive conflagrations may well have a natural function in ecosystems that need not entail any threatening consequences for humans or nature. On the other hand, fires may also be caused or intensified by human agency, for instance in order to gain new areas for farming or other uses. This can endanger human life and health and damage ecosystems. A further problem in such cases, exemplified by the recent forest fires in Indonesia, is that damage is not linked to the generator.

Often several simultaneous events, of which each, taken by itself, may not pose any major threat, precipitate an outcome with consequences hazardous to humans and ecosystems.

The example of large-scale forest fires in Indonesia is again illustrative of this. Here several events lead to the outcome. On the one side, El Niño, a natural phenomenon, makes the fires possible at all through the dryness that it causes, and determines the prevailing winds. On the other side, the fires are almost always started by humans, be it that farmers wish to gain new fields, loggers hope to cover up illegal felling or speculators aim to buy cheap land. The consequences also have different dimensions, as both humans and ecosystems are damaged. The function of primary forests as a carbon sink is impaired and biological diversity is lost. People experience difficulty of breathing and suffer smoke poisoning. The dense fumes have even contributed to ships colliding and aircraft crashing. Fig. E 1.1-1 illustrates the 'pathways' between the stages. It is at these points that risks must be controlled and managed.

For the sphere of technological risks, we need to expand and refine this simple structure. Hohenemser et al. (1985) have identified a seven-stage causal sequence or chain for technological risks. Fig. E 1.1-2 illustrates both the seven stages of the 'risk chain' for technological systems, and the opportunities and points at which to control and reduce the risk potential, reduce or even eliminate the probability of occurrence, and minimize the extent of damage and consequences. This topology underscores the interrelationships between events and human behavior. Simple 'risk chains' naturally do not reflect the full complexity of reality, as they fail to consider many details. Complex risk chains generally have a tree structure. Even simple technologies can generate a variety of significant outcomes. What is important here is the logic behind the concept of the causal chain, distinguishing between events and consequences and offering opportunities for control and management. If there are no controls and management strategies that take effect between the individual stages or control individual events, then the confluence of several events or the addition of several causes can amplify the probability, the magnitude and the consequences of a risk.

The factors contributing to the amplification or attenuation of risks presented in Section E 1 take effect at certain points in the causal chain. At the level of the individual, risk amplifiers and attenuators may be found inter alia among human needs and wants or in the choice of technology, which may for instance affect political participation. The amplification or attenuation of risks by organizations and their systems mainly take effect in the steps following the choice of technology. Institutional arrangements play a role where it is a matter of establishing higher level warning systems and protective and contingency measures

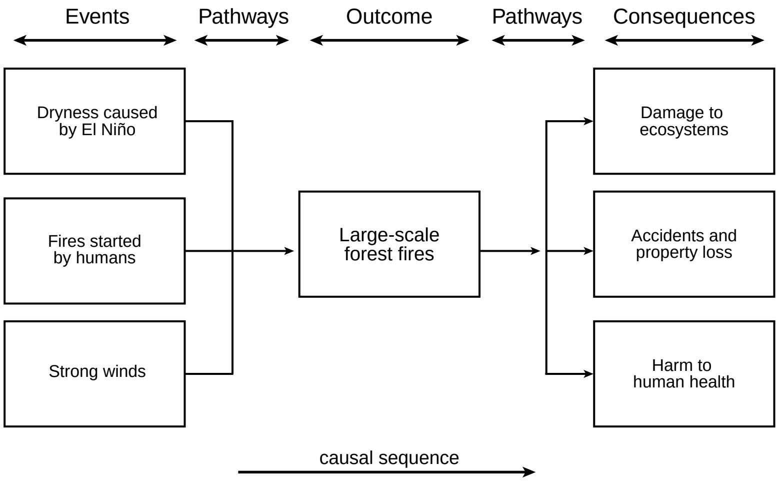


Figure E 1.1-1
Events and consequences: the example of the 1997 forest fires in Indonesia.
Source: WBGU

in order to deal with the event, its outcome and the ensuing consequences.

In the following, we illustrate the stages of the chain for the example of nuclear energy. Modern societies consume increasing amounts of energy. People want a 'clean' and durable energy supply. In the age of environmental concern, the generation of this energy should spare non-renewable resources and should not contribute to increasing greenhouse gas emissions. As nuclear energy can satisfy the rising needs and the ecological aspirations of people in this point at least, this technology might be chosen. The causative event can now be a reactor accident or a technical failure. The outcome is the release of ionizing radiation. If this occurs, people living in the neighborhood of the nuclear power plant, if they have not already been evacuated, are exposed directly to the radiation for a certain time at least. People living further away from the plant can also be affected by the intake of contaminated food, as shown by the case of Chernobyl. The consequences to people include considerable damage to human health, such as acute radioactive contamination, cancer, congenital deformities, heritable impairments and so forth. The environment is contaminated radioactively.

We can now deal with the risk of a nuclear power plant at various points, as indicated in Fig. E 1.1-2. At the individual level, human needs can be modified such that 'new' lifestyles demand less energy. Human aspirations can be redirected towards alternative technologies, such as wind or solar energy. These may even do greater justice to the desire for ecologically

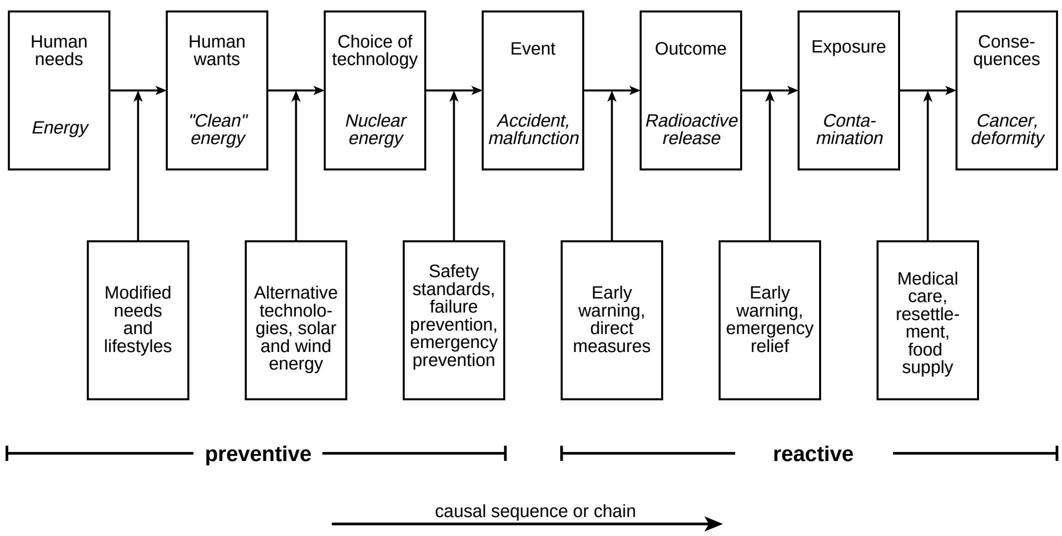


Figure E 1.1-2
Seven steps of a 'risk chain': the example of nuclear energy.
Source: WBGU (after Hohenemser et al., 1985)

acceptable and durable energy supplies. These 'new' individual aspirations could then be taken up in policymaking processes relating to technology choice. At the organizational level, operational management can establish higher safety standards and can develop more intelligent strategies for failure prevention, in order to reduce the probability of an accident or malfunction. If a hazard event then actually occurs, management strategies such as in-plant early warning, preventive radiation protection or direct countermeasures would need to be in place in order to prevent or at least minimize the release of ionizing radiation. At this point, and possibly also at the previous point, institutional arrangements established by national and international authorities take effect. In addition to reviewing safety standards and failure prevention strategies, national supervisory authorities or international organizations such as IAEA should also stipulate preventive accident protection standards and direct relief actions, and should establish early warning systems. Institutional arrangements and a well-functioning infrastructure for direct emergency relief are essential when people are exposed to a hazardous dose of ionizing radiation. This includes immediate and post-event medical care, evacuation and resettlement, food supply etc. The better and more rapidly direct relief measures take effect, the smaller are the long-term consequences.

The description of the 'risk chain' has shown that a risk evolves through a causal sequence, whereby generally the interplay of several causes amplifies the risk and thus leads to the hazardous event. The event in turn is not an isolated occurrence, but is usually composed of several compounded mishaps. The resulting consequences are diverse. The 'risk chain' also illustrates the points at which control mechanisms and management strategies must take effect in order to reduce the amplifying effect of causes or events. Hohenemser et al. (1985) call for risk management that informs society about risks, decides what is to be done and puts in place appropriate measures by which to control or mitigate the risks. Such risk management oriented to the 'risk chain' in Fig. E 1.1-2 comprises four main elements, each of which entails several steps:

Risk evaluation
- Risk identification
- Priority setting
- Risk assessment
- Social values assessment

Control analysis
- Appraisal of tolerance capacity
- Identification of control tools
- Assessment of implementation methods
- Evaluation of cost distribution

Strategy choice
- Risk acceptance
- Risk distribution
- Risk reduction
- Risk attenuation

Implementation and evaluation
- Control interventions
- Supplementing methods
- Output evaluation
- Impact evaluation

E 1.2 Sociocultural and individual risk amplifiers

E 1.2.1 Introduction

Why do people react differently to one and the same risk? Why do some refuse to take seriously a risk that is so plain to others? Why do the media seize on some risks while ignoring others?

Individuals often have very different perceptions of one and the same risk. The way in which they deal with it will differ accordingly. There are a variety of reasons for these disparate perceptions and evaluations. For instance, cultural traditions, past experiences, conditions of life, emotional and cognitive styles of processing differ greatly. Moreover, there are disparate social roles (e.g. 'expert', 'victim') or specific circumstances that lead to a divergent perspective when appraising a risk. If then different groups of people have quite different views on what constitutes a risk and above all on how it is to be handled, we might argue that in reality there is no such thing as one and the same risk for all. Ultimately, a risk cannot be determined objectively but has quite different meanings for different (groups of) observers (Johnson and Covello, 1987; Wiedemann et al., 1991). The question of which observer group has made the 'proper' appraisal often remains unresolved.

In the following, we shall discuss in more detail some of the sociocultural, personal and cognitive factors that play a role in the appraisal of risk. We shall first examine the culture of a society. This is the basic setting within which people experience the world and within which they act (Section E 1.2.2.1). Within a culture, various subcultures emerge, conveyed and evolved by specific social communities (Section E 1.2.2.2). The experience of individuals is influenced by the subculture of their reference group. In addition, a series of individual factors is relevant to the appraisal of events (Section E 1.2.4). These factors can also influence and change the social community. The distinction between individual and social factors is thus not always clear-cut. Furthermore, the media exert an influence upon the experience of individuals and groups. The media are of course also a component of culture, but are discussed separately here (Section E 1.2.3). Fig. E 1.2-1 gives an overview of the factors.

E 1.2.2 Cultural and social factors

E 1.2.2.1 The cultural setting

Both risk appraisals and behavior in risk situations are shaped decisively by cultural belief systems, the value systems contained in these and social roles. The cultural belief system determines extensively the collective notions of how the world functions (Douglas and Wildavsky, 1982; Rayner, 1992). These collective notions are also termed social representations, as they contain socially constructed 'images' of the world. Social representations comprise the knowledge of 'facts' and 'events' (e.g. what constitutes an insult, how to resolve conflicts, whether the forest is dying etc.) shared within a group. This knowledge is

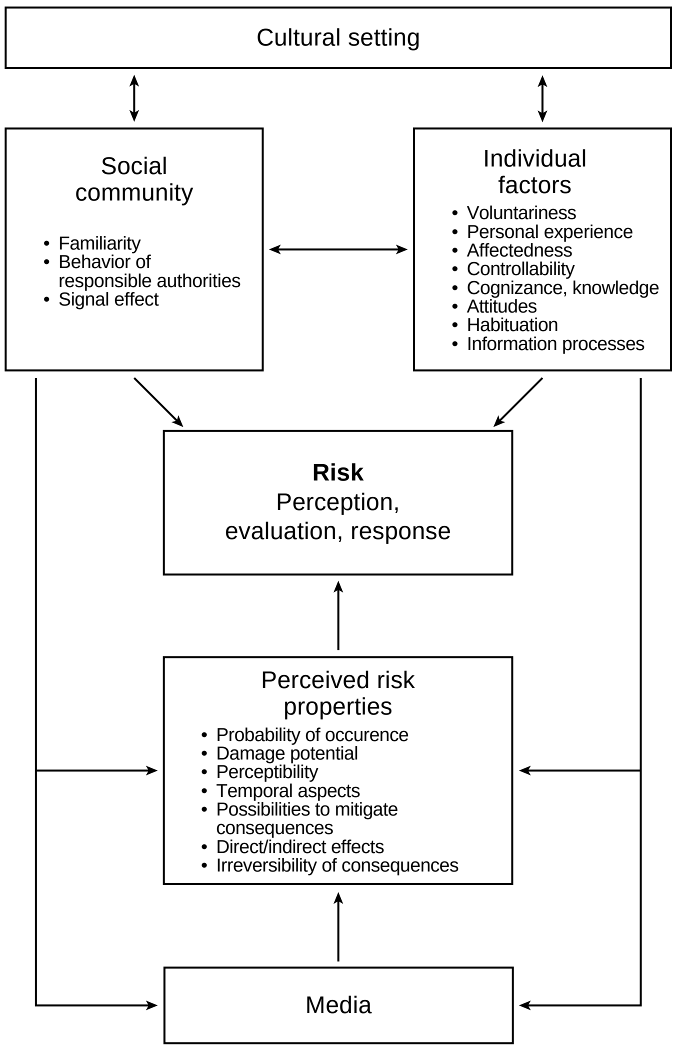


Figure E 1.2-1
Overview of sociocultural, social and individual risk amplifiers.
Source: WBGU

essential for people to appraise situations, evaluate them and act. This knowledge is propagated, stabilized and modified by communicative processes (interpersonal communication, media; Wagner, 1994).

To understand the ways in which risks are dealt with, it is essential to take into consideration the sociocultural setting. This means not only rough distinctions according to 'Western' and 'Eastern' cultures, different religions or nations. Disparate social representations (subcultures, group-specific knowledge) can prevail in various groups within, for instance, Western culture or a nation. For instance, the people living in tornado-prone regions of Alabama, USA, are largely convinced that what happens to them depends upon God or good fortune. In contrast, the inhabitants of Illinois, USA, who are exposed to a similar threat, believe that it is above all their own behavior that determines their fate. They accordingly implement protective measures, with the result that the number of deaths caused by storm disasters in Illinois is much lower than in Alabama (Sims and Baumann, 1972). These disparities, that arise among different social communities, will be discussed in more detail below (Section E 1.2.2.2). Often, however, the concept of culture is associated with the national level. In such a perspective, the analysis is relatively wide-meshed. This may be quite appropriate for certain issues, but a more precise analysis will always be able to differentiate between further subcultures or groups.

Most cross-cultural risk studies have chosen this wide mesh for their analysis, thus e.g. comparing the risk perceptions of Americans with those of Japanese, or those of Australians with those of Germans (Rohrmann, 1995a). Many of these studies submit questionnaires to participants on which they rate their evaluation of various risk aspects on a multilevel scale (Slovic et al., 1986). These aspects have included the controllability of risks, voluntariness of exposure to them, the dreadfulness of possible accidents, catastrophic potential etc. (Section E 1.2.4). Participants have generally been asked to appraise a great range of risks: in addition to technology and natural risks also those related to sports activities, a certain lifestyle or occupational activities. Comparability among the studies is beset by methodological problems, so that statements such as 'worldwide, Indonesians accept the most risks' cannot be made, nor are they meaningful.

In direct cross-cultural comparisons, studies have partially indicated differences in the appraisal of risk magnitudes. Japanese consider many risks to be more uncontrollable and dreadful than Americans do, and assess the catastrophic potential as being higher (Kleinhesselink and Rosa, 1991). However, a more recent study has found that both differ scarcely in their appraisal of the controllability of the risks surveyed. One difference did however emerge concerning nuclear risks. The Japanese tend to view these as being higher, but the voluntariness of exposure to the risk is also viewed as being higher than it is by Americans (Hinman et al., 1993).

A comparative questionnaire study of Chinese and Australian probands has shown that the Chinese perceive the risks associated with cycling and lifestyle-related health risks (smoking etc.) as being lower. For almost all other risks surveyed, however, they display a lower acceptance than the Australians. Scarcely any differences were found in perceptions of natural and technological risks. However, the Chinese have a much more positive perception of the social benefits of nuclear energy than the Australians do (Rohrmann and Renn, 1998).

Where studies examined the issue at all, it became apparent that disparities between different social groups (e.g. differentiated according to more 'technological' versus 'ecological' attitudes) were often larger within a country than between different countries (Rohrmann, 1995a).

As in all studies, the findings depend decisively upon which questions are posed and which parameters are calculated. Standardized questionnaires are poorly suited to identifying differentiated cultural disparities. At best, tendencies can be ascertained. Box E 1.2.-1 describes an example of a different methodological approach. Here very much finer and more qualitative methods were applied, yielding a more differentiated picture of cultural specificity. However, this study made no direct comparisons with other cultures.

E 1.2.2.2
The social community

In addition to cultural traditions, the immediate social community has an important influence upon the perception of risks. Communicative processes (talking with neighbors and friends, but also communication mediated by e.g. the press and TV) produce social norms and knowledge that influence risk perceptions. Depending upon the type and extent of a risk, the associated social representations can have a wide geographical scope or can be locally contained. The discourses on nuclear power or on climate change are examples of widely shared social representation. The discourse on the construction of a specific waste incineration plant is an example of local scope.

Divergent reactions despite similar constellations (Box E 1.2-2) illustrate how important social structures and processes are to the perception, evaluation and management of risks. The two case studies high-

Box E 1.2-1

Perception and meaning of volcanic eruptions on Java, Indonesia

The Merapi on Java counts among the hazardous volcanoes of the world. The people living there are threatened not only by regular eruptions, but also by hot clouds of cinders, ash rain, toxic gases or mudflows containing volcanic material caused by rainfalls. Nonetheless, the area is densely populated. At least 50,000 people live on the south-west flank, some villages being as close as 5 km to the crater. During the last major eruption on 17 January 1997, with a 6 km long lava flow and hot dust and gas clouds, 18,000 people were evacuated for a brief period. While international teams of scientists worked on an optimum early warning systems, many people living close to the Merapi were not willing to leave their villages – despite a variety of indications of the impending outbreak. How can this be explained? Are the people unable to appraise properly the risk to their life and health?

The anthropologist Judith Schlehe has analyzed the specific cultural and religious interpretations and their relevance to actions in relation to the Merapi. The forms of perception of nature can explain why the people of Java do not flee the danger.

The Merapi is considered holy by the rural population. It is viewed as a manifestation of the power of supernatural beings and as a realm of spirits. There is a link between the realm of spirits and the people. The spirits can communicate with certain people through dreams or inspiration, thus e.g. warning them of a volcanic eruption. Many spheres of life are placed in relation to the invisible powers. Thus political dominion continues to be legitimated today by mystic links to nature. According to old writings and myths, the assumption of power by an earlier ruler (Senopati, 1575–1601) was recognized and confirmed as being legitimate by the realm of spirits of the Merapi and by the realm of the queen of the southern sea, Ratu Kidul. Since that time, there is the promise of Ratu Kidul to give protection and support to the sultan and all his successors. The realm of spirits ensures that the town of Yogya, in which the sultan's palace is located, has until now always remained untouched by the eruptions of the Merapi. This is why the inhabitants of Yogya continue to feel safe against these eruptions. However, the spirits can withdraw their legitimation from the rulers if the latter prove to be greedy and dishonest. Volcanic eruptions are explained accordingly. The 'paranormal expert' Pak Permadi in Yogya formulated it thus: "if the people are not satisfied with the way they are treated by the ruler, but cannot defend themselves, their anger, which expresses itself as energy, is taken up by nature. If nature is angry, a disaster occurs such as a volcanic eruption; for nature does not fear human rulers." (Schlehe, 1998). The knowledge that only those fall victim to the volcanic eruption who have fallen foul of the realm of spirits of the Merapi, have forgotten the ancestors or have violated the traditional system of norms and rules gives the people certainty that they are secure. After the eruption in 1997, it was above all the inhabitants of the villages of Turgo and Kinahrejo who did not leave their dwellings. These villages have a pivotal role. As long as nothing happens to Kinahrejo, all the other villages will also be safe. The inhabitants feel themselves bound to their destiny and duty to remain at the place of their ancestors. Mbah Marijan, an important opinion leader whose statements carry more weight for most people than the warnings of the volcanologists, explains why the people stay: "remember, if fate wishes it thus, we can die everywhere. The inhabitants of Kinahrejo feel their destiny, that they have been born to make a protective wall in order to watch over the well-being of the Kraton (palace in the realm of spirits) and of the people of Mataram." (Schlehe, 1998).

Moreover, the volcano is not only a threat to the people, but is also the source of fertile soils and, together with sufficient rainfall, permits good harvests. On the basis of their traditions, the people are well able to cope with the risks of volcanic eruptions. Because of these traditions, people of Java are loath to resettle. The Rukun concept is important to understand this: this means social harmony and positioning of the individual in a certain spiritual setting that is not simply exchangeable. All the above cultural values pose serious impediments to governmental resettlement policies.

light a series of factors that influence social processes of risk perception. These factors have been confirmed by other studies, too.

In both cases set out in Box E 1.2-2, no direct health impacts of the chemical substances were to be observed; there was thus no identifiable damage. Other examples similarly show that this is not a necessary precondition to vehement conflict over risks. What is decisive is rather the evaluation of the risk by the social community. This evaluation process must by no means be interpreted as something arbitrary whose outcomes can be neglected. The process is determined by social norms and rules formed within the setting of cultural values (Renn et al., 1992). In the TCE case the social norm could be formulated thus: "members of our community are law-abiding citizens and should not be punished without reason". In the Love Canal case it might be: "the state should support victims of scandalous disposal practices". These rules and normative notions are developed through communication, in the course of which pivotal opinion leaders often emerge.

The formation of a social group generally presupposes a certain degree of perceived similarity in terms of attitudes, interests, situations in life etc. among the group's members. For individual people, such a community has various functions. It may offer psychological and material support in coping with stresses, and it is a more effective basis on which to exert influence, as groups generally have a greater potential than individuals (Edelstein and Wandersmann, 1987). Above all, however, the social community constitutes for its members a source of information and evaluation of that information. Through communicating with other members of the community, expert studies, newspaper reports, talks with officials etc. are comprehended and interpreted. These communicative processes thus have crucial functions of providing purpose and meaning, as it is here that the group and the individuals come to terms with the

Box E 1.2-2

Two case studies: The Love Canal and TCE communities

The Love Canal case
At the end of the 1970s, it became known in a community at Love Canal, Niagara Falls, New York State, that the soil was severely contaminated with substances considered toxic. These substances had been emitted from a nearby industrial plant. After the government health authority had warned of the risk of severe health impairments, 26 people (pregnant women and small children) were evacuated as a first measure. In view of the uncertainty as to the possible consequences of the chemical contamination, this measure appeared inadequate to most inhabitants. After vociferous protests, the community gained within one week the concession of the possibility of government financed resettlement of a further 239 house owners. Over the next two years, the conflict between the inhabitants and the responsible authorities heightened. Aggressive confrontations at hearings and meetings and protracted legal disputes determined the discourse. A main source of conflict was the question of how far the toxic substances had spread or would spread, and who, on the basis of these limits of dispersion, could be viewed as affected and thus as entitled to assistance. Many no longer saw themselves able to remain in the community under these circumstances. However, they were faced by considerable financial difficulties, as for obvious reasons their land and houses were no longer easily marketable. The war of nerves ended when the decision was taken to provide financial assistance to a total of more than 550 house owners, insofar as these were willing to resettle voluntarily.

The protests and the burdens engendered by this situation were not borne equally by all Love Canal residents. Two dominant, contradictory patterns of perception and interpretation of the situation emerged, and thus also two patterns of action. While about ⅓ of the affected people assumed a narrowly contained spread of chemical contamination and rated the health risks as low (the minimalists), the remaining ⅔ viewed the entire area as contaminated and feared serious health hazards (the maximalists). The group of minimalists was dominated by pensioners or persons soon to be pensioned, whose children no longer lived at home. Their greatest worry was the loss of economic security in old age, represented by their own home. The minimalists were further characterized by a relatively long time of residence in Love Canal but only few long-standing social contacts. By contrast, most maximalists were younger house owners who were concerned about the health of their children and further commanded over a tighter network of social communication. These factors of social structure were not the cause of the different perceptions, but influenced to a high degree the perspective from which information was collected and evaluated (Fowlkes and Miller, 1987).

The TCE case
Quite a different picture developed in another community, also located in New York State, in which it became known that the groundwater was contaminated with tri-chloroethylene (TCE). Among other consequences, this substance can have a carcinogenic effect. TCE was released to the groundwater from a nearby chemical works. Many households extracted drinking water from wells that were contaminated with the substance.

Nonetheless, throughout the entire four years of water analyses, the residents displayed neither noteworthy signs of alarm over possible health damages nor any kind of organized activity. As the local company was viewed as the generator of the pollution, the residents were wary of raising accusations for fear of economic consequences (job loss). Above all, however, the emitter was perceived as a member of the social community. It was felt to be unjust to hold him responsible for formerly unknown consequences of waste disposal. Attendance at public hearings was consequently poor. The longer the issue persisted, the less important the health aspect became. The main reason for the disinterest of the residents was their trust in the local administration and politicians to sort out the affair in their interests. Furthermore, no severe health impairments occurred. As TCE is a chemical not perceptible by the human senses, the citizens were dependent from the outset upon expert judgments. Little attention was given to the analyses of these experts, for two reasons: firstly, the engineering consultancies commissioned by the federal authorities to sample the groundwater were not recruited from the community and, secondly, many residents were acquainted with TCE through their work in local industry. Instead of the health aspect, attention began to focus on entry to private property (for groundwater sampling) and the burgeoning analysis costs. Opinion leaders presented the fear that these costs might be passed through by the federal authorities to the responsible local companies. To most residents, making the water analyses stop again was more important than establishing the culpability of the companies (Fitchen et al., 1987).

meaning of the situation (Matthies et al., 1995). Such discursive processes do not take place in isolation from the specific situation or risks in question (Section E 1.2.4), but can quite well lead to differing evaluations due to different interpretation filters. A number of situative background variables can be distinguished that may influence communicative evaluation processes.

Risk causation
In the two case studies, these situative variables include the causation of the chemical pollution. In the TCE case, the pollution generator was viewed as 'one of our own people', who was not guilty of causing the situation. Quite on the contrary, the company owner was seen as a community member of importance and integrity who had ensured the well-being of most of the other members. This was thus a case of damage for which no one could be held responsible, as the company owner had neither intentionally nor knowingly brought about the toxic emission. The perception of the situation is different in the Love Canal case, as here a clear polluter (the company on the river) is viewed as culpably responsible for the chemical pollution. This is not a member of the social community, but an external culprit. The causal attribution of (potential) damage often plays a major role in risk perception, as human decisions and actions – causing

risks and evaluated controversially by the various actors in society – are the central element in the social processes involved in dealing with risk (Luhmann, 1991; Jungermann and Slovic, 1993a). For these conflicting evaluations, disparate notions of what constitutes an equitable cost-benefit distribution of potential damage and of what the potential benefit might be are also relevant.

In contrast, damaging events and risks that can be attributed to natural causes are generally evaluated less controversially, as the question of causation can scarcely be posed in a meaningful way. However, the distinction between natural and technological risks is becoming increasingly less clear-cut, as anthropogenic influences are playing an ever greater role in the creation or intensification of natural risks. This is illustrated by the causative contributions to flooding events provided by surface sealing, forest logging and river regulation.

Familiarity with the risk

Risks with which people have been familiar for some time are generally perceived as less hazardous, as familiarity often imparts a feeling of controllability. Such phenomena are also known in workplace safety, where protective measures are neglected in a dangerous way because workers believe they can cope well with the associated risks. The members of the TCE community were *well* acquainted with the substance. Many were used to dealing with it at work and thus did not feel particularly threatened. By comparison, the members of the Love Canal community were *not* acquainted with the chemical substances and had no precise knowledge of them – for most of them a highly discomforting fact (Section E 1.2.4).

Life situation of persons affected

It is known of the members of the Love Canal community that the active campaigners were in a different phase of their lives than those who had scarcely any interest in change or in compensation. The active persons were younger, had not yet lived there so long and often had children. To most of them the prospect of spending their whole life in this situation, which was perceived to be hazardous, and possibly also jeopardizing the health of their children, was highly discomforting and cause enough to put up resistance. In contrast, the older members of the community had no interest in changing their situation. The economic situation of persons affected can also influence their way of dealing with risks. For instance, Mexican field workers, whose economic situation leaves extremely little leeway for action, have stated that they do not worry about health impairments caused by the pesticides used at work (Vaughan, 1993).

Behavior of responsible authorities/organizations

Confidence in the responsible authorities has proven to be a crucial factor for the development of a situation after damage has occurred. In the Love Canal case, the authorities were evidently incapable of reacting appropriately to the concerns of the community. It is known from other studies, too, that the behavior of the authorities can exacerbate an already stressful situation (Guski et al., 1991). If these bodies do not adopt a way of handling the event that is credible and appropriate to the safety preferences of the persons affected, a situation often arises in which all other institutions are also met with great distrust. As the information coming from 'that side' cannot be trusted, the affected persons find themselves forced to take action themselves. The feeling of permanent disinformation often intensifies the stresses that are largely brought about by the uncertainty of the situation.

In the TCE case, interactions between the authorities and inhabitants were rather characterized by an atmosphere of trust, in which the citizens found their interests well represented. They thus felt less necessity to take action themselves. The behavior of the authorities can thus influence the communicative evaluation processes of groups concerning certain risks or disastrous situations. However, it needs to be stressed that this is by no means decisive by itself for the interpretation of the events.

Signal effect of local events

Local events such as contamination of soil or groundwater with chemical substances or accidents in industrial facilities (e.g. in Chernobyl) often have effects that extend beyond the region concerned. Local processes can thus develop a *signal effect* for the whole society or even for global risk communication (Jungermann and Slovic, 1993a). It therefore does not suffice to evaluate risks only from the perspective of their *direct* effects such as fatalities, persons injured or economic losses. *Indirect effects* also need to be taken into consideration. These may include:

- Changed political climate (pressure upon policy-makers to avoid certain risks from the outset, social unrest).
- Changed economic factors (higher costs due to safety requirements, reduced value of real estate, diminished attractiveness for tourism).
- Emergence of major social movements, often sparked by individual damaging events (e.g. the reactor accidents at Three Mile Island and Chernobyl; Opp, 1996).
- Changed attitudes of broad segments of the population to certain issues (e.g. skepticism vis-à-vis large-scale technologies), which can influence the

Box E 1.2-3

The importance of culture in coping with the risks of global change: Examples from empirical research

Studies on action under uncertainty and susceptibility to crisis have focused on, for instance, the adaptive behavior of various West African tribes when faced with desertification and famine, interpreted as a chain of problems and attempts to solve them (Mortimore, 1989). The role of indigenous institutions and alternative opportunities to make a living when faced with drought and famine are also issues that have concerned empirical research (HussAshmore and Katz, 1989). The organizational capacity of societies, in particular cooperation and communication, play a key role in interpreting coping strategies (Rau, 1991). Further themes of empirical research include opportunities to fall back on common property resources, the use of loans and patronage, but also gambling and theft in situations of food crisis (Richards, 1986). A number of historically oriented studies have examined food risks and gender relations (Vaughan, 1987; Bryceson, 1990).

Responses to famine were also the subject of a study carried out by Spittler (1989), who lived with the Tuareg nomads in northern Niger during the severe drought of 1984. He observed pastoralism under normal conditions and during drought, researched strategies for procuring food during famine, described forms of solidarity but also of egoism when sharing food, showed how the Tuareg prepare food, specifically in times of famine, and finally examined the question of how those affected interpret drought, history and mortal threat. The study shows that the Tuareg are not the passive victims of a devastating, unexpected natural disaster, but tackle the threat actively, targetedly and innovatively. Nor are they concerned solely with hunger and survival, but rather above all with leading a life in dignity despite disaster: "the individual is faced with many decisions: to flee or stay, to save the cattle or oneself, to help others or only think of oneself. Great efforts must be undertaken to procure accustomed foods. The course that such a famine takes does not depend solely and not even primarily upon the efforts of each individual, but upon relationships among people and upon their joint interpretation of the situation. It is a widespread but false cliché that in times of famine life is only a matter of survival and each thinks only of himself. A famine does not necessarily lead to a state in which each individual is only struggling for his own survival" (Spittler, 1989).

Compared with these spectacular famine disasters in Africa, relatively little research has been conducted on chronic risks, seasonality and drought coping in Asia. For the example of the way in which vulnerable groups in the Indian state of Gujarat cope with the seasonal uncertainties of a semiarid environment, but also with the severe drought of 1985/1987, Chen (1991) introduces the concept of the household livelihood system. This concept describes a mix of individual and collective strategies of a household to mobilize resources and create action alternatives. Resources are understood to include physical assets such as land, time, capabilities, family and ethnic-religious group relations, collective goods and public sector services. The concept further highlights various dimensions of livelihood security in rural India that appear generalizable to chronic forms of vulnerability and risk susceptibility (Section E 2). These dimensions include the relevance of gender, the integration of the household in markets and institutions, social relations, income diversification, the importance of seasonality and the various dimensions of risk reduction strategies. Finally, a more recent study in West Bengal shows that the rural poor struggle not only for resources but also for respect and the recognition of their rights to common village resources (Beck, 1995). Here the enormous importance of mutual support among the poor becomes apparent, particularly in times of disease. Although many of them receive larger loans from rich village inhabitants, this is not viewed as assistance but rather as a contract among unequals in which the poor are often cheated. Access to natural resources that are common property (timber, wild fruit, fish, sal leaves), the collection of harvest residues and the joint rearing of cattle provide up to 25% of the total annual income of the rural poor. In these strategies, women and children play a key role of which outsiders often remain unaware.

perception, evaluation and acceptance of other risks (Renn et al., 1992).

The social science analysis of coping with risks has frequently concentrated on case studies characterized by Western cultures. A further focus has been placed on the analysis of human action under conditions of uncertainty and susceptibility to crisis (e.g. famine) determined e.g. by seasonality in semiarid regions. Prompted by the second major drought disaster in the Sahel zone in the mid-1980s, such studies have concentrated above all upon the question of the possibilities and limits to human adaptation to life-endangering disasters (de Garine and Harrison, 1988; Box E 1.2-3).

E 1.2.3
The role of the media

Social communication on risks and processes of social judgment are initiated, amplified or attenuated in and by the media, too. There is indubitably a connection between media reporting and the attitudes of the media audiences. However, there is substantial controversy over the role played by the media in the risk perceptions of individuals. Propositions range from 'the media influence society' to 'society influences the media'. Positions assuming a complex interplay of media and society are situated somewhere between the two extremes. Media might influence the opinions, attitudes and also the levels of knowledge of broad sections of people, but they might also reflect processes already taking place. Moreover, both aspects can exert a reciprocal influence. Specific propositions concerning the effect of the media have been put forward and empirically tested (Peters, 1995). Media influence

- Knowledge acquisition and levels of the recipients,
- The selection of topics considered problematic (agenda setting),
- Opinions and attitudes of recipients,
- The image of actors,
- The capacity of recipients to deal actively with risks and to cope with them better.

On the first three assumptions, empirical findings are available that permit a more precise consideration of the hypotheses. However, it needs to be considered that it is methodologically exceedingly difficult to separate purported media influences from other possible influences, such as interpersonal communication, so that unequivocal causal relationships cannot be postulated. Furthermore, there is a lack of studies concerned explicitly with the particular features of presenting and processing information related to global environmental problems.

Knowledge acquisition of media recipients

In the selected and analyzed studies it became apparent, as was to be expected, that recipients receive knowledge from the media on risks (associated with technology and environmental problems; Peters, 1995). However, the items of knowledge received are filtered strongly by individual information processing. It is easier to retain information that has a connection to everyday experience or is personally relevant to the recipient in some other form. For instance, when queried as to the causes of the depletion of the ozone layer, it has been found that people usually only remember the 'spray can', although other causes had also been covered. For technologies (such as nuclear power or genetic engineering) whose presentation often involves individual disadvantages faced by collective advantages, the disadvantages will tend to be remembered more than the advantages, even if media coverage of both sides was balanced.

Agenda setting

Media reports can direct or heighten attention and problem awareness of certain issues. It is beyond doubt that many items of information are disseminated exclusively through the media. To what extent does this bring about a collective setting of priorities? In a study carried out by Atwater et al. (1985), newspaper articles were evaluated over a period of two months and classified according to topics such as waste disposal, water quality, hazardous substances, soil quality, air quality and nature conservation. In a subsequent survey of the public, the connection between media reporting and responder perceptions was tested. It was found that, firstly, the persons interviewed were able to state the thematic priorities of the media very accurately and, secondly, there was on average a fit between the personal assessment of importance of topics and the priority set by the media. However, it must be stressed here that the assessment of a topic as 'important', as assessed by this technique, is not automatically associated with consequences for behavior or changes in attitudes.

In another study that tested the creation of problem awareness by a 3-part investigative TV reporting series on hazardous waste treatment, no effect was found (Protess, 1987). The persons interviewed had no different appraisal of the importance of the issue of hazardous waste than persons who had not seen the series. However, a different, interesting effect was observed. After the series had been broadcast, responsible decision-makers attributed a higher priority to the problem and made preparations for problem-solving steps in the expectation that enquiries and protests would come from the public. Thus in this case the attribution of medial influencing power led by itself to a change in the situation.

Opinion and attitude modification

If the media are able to influence the attitudes of recipients, then we might expect that the media tenor on an issue is reflected in their attitudes. But even if parallels are indeed found between media tenor and recipient attitudes, we cannot yet conclude that it is the media that have caused these attitudes. The conclusion is equally possible that the media merely reflect people's attitudes and changes in attitudes. Available data indicate that this question must remain unresolved, at least in this general form, and needs further research.

In some cases parallels can be identified between media tenor and the attitudes of the public, while in others there are divergencies (Kepplinger, 1989). That risk-supportive or risk-averse reporting leads to corresponding attitudes among media recipients thus cannot be concluded so simply. In addition to reporting tendencies, the extent of media coverage of an issue can be a cause of corresponding attitudes. Regardless of whether a controversially assessed risk is mentioned largely negatively or positively in reporting, recipients who have heard or read more about it will tend to evaluate it more negatively. It would appear that the frequency of coverage of an issue is perceived as an indicator of its hazardousness.

In summary, we may state that the media do have an influence upon knowledge, opinions and attitudes of recipients, but that this influence should not be overestimated. It needs to be considered that recipients are not passive consumers, but selectively receive, actively process and modify information. These processes take place through individual cognitive processing (perception, memory) and also through interpersonal communication (Section E 1.2.2.2). Recipients are embedded in their social environment and generally share with this a certain stock of prior knowledge, preferences, attitudes, interests etc., which guide the selection of information and also certain interpretations. Media effects are influenced by these processes, so that immediate manipulation is improbable. More attention has recently been devoted to interpersonal communication processes in which media contents are processed. It is, however, conceivable that the media can exert considerable influence in areas in which the recipients do not already have experience or attitudes of their own. The effectiveness of the media further depends upon the characteristics of reporting: are topics addressed that interest the recipients? In which manner are the issues presented? At what time are they presented? How credible is the source of information considered to be?

E 1.2.3.1
Accuracy and balance in media coverage

Media coverage of technology, environment and risks is frequently accused of being inaccurate, erroneous and imbalanced in presentation, aiming at sensation effects and contributing to an undifferentiated aversion to technology and risk among the public. To test these accusations, media coverage must be analyzed accordingly.

Accuracy of presentation

Are facts presented correctly, is the presentation distorted, is it exaggerated or downplayed? It is not easy to answer these questions, as different standards can be applied to the accuracy and completeness of news stories. Nonetheless, three selected studies (Peters, 1995) conducted in New Zealand, the USA and Germany arrive at the result that the proportion of stories classified as entirely correct is very low (approximately 6–30%). The errors could not only be attributed to lack of scientific experience on the part of journalists. This is proven in more detail by the study in New Zealand, which was concerned with global climatic changes (Table E 1.2-1).

However, it needs to be noted here that even a very high proportion of entirely accurate reports will not always guarantee correct knowledge representation on the part of the recipients, as the processing of information on their part is subject to cognitive and social processes (see above).

In addition to such studies, the question of correctness of media coverage has also been examined from the aspect of uneven weighting (extent of coverage, tendentious presentation). These analyses (Kepplinger, 1989; Singer and Endreny, 1993) have assumed that media reporting delivers an accurate portrayal of the true environmental and risk reality and that changes in reality should consequently be reflected in equal degrees in media coverage. If the environmental situation actually deteriorates, the number of media reports on this should rise, and vice versa. However, all studies arrive at the result that there is no systematic connection between coverage on the one hand and technical-statistical data on the state of the environment or the level of risk on the other. The frequency of coverage thus by no means corresponds to the appraisal of hazardousness of a situation by experts. It can be assumed that for journalistic reporting other rules and goals apply (recipient demand for certain reports, access to sources of information, opportunities to position the issue as a headline, scandal, serious report etc.) than the adequate presentation of technical-statistical risk data.

Balance and bias of presentation

Media coverage of risks is often accused of having an anti-technology bias. In contrast, studies carried out on this issue – above all on the presentation of nuclear energy after Chernobyl – show that coverage is generally balanced. The media analyzed (daily newspapers and publicly owned television broadcasters in Germany) reported the views of roughly the same proportion of proponents and opponents of nuclear

Table E 1.2-1
Inaccuracies in the coverage of global climatic changes found in newspapers in New Zealand.
Source: Peters, 1995

	Number of inaccuracies	% of articles
Incorrect title	22	12
Incorrect 1st paragraph	17	9
Incorrect illustration or caption	3	2
Scientific/technical inaccuracy	139	34
Non-scientific inaccuracy	72	32
False citation	110	34
Omission	64	25
Exaggeration	81	26
Distortion	54	20

energy. The journalistic assessment of the statements reported then appears to depend above all upon the general political attitude of the medium in question. Journals and newspapers considered 'left' will tend to support attitudes rejecting nuclear energy, while newspapers considered 'conservative' will tend rather to support attitudes in favor of nuclear energy (Rager et al., 1987). Thus we cannot so much assume a basic anti-technology attitude than rather target-group specific opinion trends.

The accusation of 'panic mongering' reporting aimed at arousing unfounded fears has just as little empirical basis as that of a general anti-technology attitude. This can be said for the presentation of radiation exposure after the reactor accident in Chernobyl. Studies that have examined media reports on the accident in Germany and the USA show a tendency towards balanced and reassuring reporting (Peters, 1995). More than half of the pieces that treated the issue of radiation exposure contained reassuring assessments.

Findings of empirical study of the German media landscape show that reporting on technology and risks has experienced fundamental changes in the post-war period, regardless of the political attitudes of the media. The number of statements with an exclusively positive evaluation has declined. Instead, there has been a shift towards presentations of controversy. Risks and technology are reported on mainly under the rubrics of politics and law, less under science and economics. Their media presentation is thus characterized above all by political actors. Experts voice their views comparatively rarely. This may be one of the reasons why risk reporting, while generally not panic-mongering, does tend to focus on possible negative consequences and scarcely on their probabilities of occurrence. Further items of risk characterization, such as the annual mortality rate, the population group affected by the risk, the duration of damage or the relevance for future generations, are presented relatively rarely. Singer and Endreny (1987) summarize their analysis as follows: "the media do not report on risks, they report on harms".

E 1.2.4
Individual factors

The individual factors of risk perception and evaluation are linked to the social ones. Each individual is always embedded in the interpretative culture of a society or social group, which can be understood as a filter for many individual processes. It is essential to know the individual processes in addition to the social ones, as the former often contribute to establishing or modifying the social and societal interpretative culture.

Voluntariness

Voluntariness of exposure plays a key role in risk perception. Risks to which people are exposed against their will are usually felt to be larger than those which they have taken voluntarily (Renn, 1992; Jungermann and Slovic, 1993b). Acceptance is generally lower for non-voluntary risks (e.g. pollution by industrial emissions), for they must be tolerated on the basis of decisions taken by other people. In such a situation the individual has scarcely any influence over what happens to him or her, which for most people is a good reason to put up resistance. Voluntary risks (e.g. smoking) are generally perceived as actions within the responsibility of the individual that are potentially controllable.

People not only try to avoid risks, but even intentionally seek certain types of risk. Many experience the thrill and challenge of mastering risky situations as an essential enrichment of their life. The importance of this characteristic, which varies greatly from person to person, should not be underestimated. The pursuit of increasingly hazardous sports and leisure activities is only one example of this phenomenon.

Personal experience

Personal experience is a further determinant of risk perception. Adverse previous experience with a hazard contributes to an individual feeling that the risk is very high and taking active preventive measures. However, this is not universally valid. It is known that people who have repeatedly become the victim of a hazard (e.g. have experienced the third flood within a short period) resign and take no further precautionary measures (Evans and Cohen, 1987). On the other hand, even if people have no personal experience with acute hazards, as is e.g. the case for the possible consequences of climate change, risks can be viewed as very high. This is particularly the case if such hazards are hard to perceive, are not individually controllable and the potential damage is very high.

A quite different outcome of lacking previous experience with the negative consequences of a risk is described by the phrase 'captives of experience'. This concerns cases where people have had no previous adverse experience with possible damage, and therefore underestimate the risk and take no precautions to protect themselves against it.

Affectedness

As is to be expected, people who do not feel affected by a potential damage generally view the risk as lower than others who expect to be seriously harmed in the event that the risk occurs (e.g. residents of an earthquake-prone area). This applies equally to insidious risks that are often linked directly to everyday life, such as eating. For allergic people, for instance, the prospect of eating food that might contain unexpected constituents presents a greater threat than for those who can consume everything without further thought.

Controllability

Risks that appear uncontrollable to the individual are felt to be very threatening. These include events that cannot be changed by the actions of the individual. People living in a high-risk situation that escapes their control usually have few alternatives for coping with the threat. In such situations people frequently deny the risk entirely, lull themselves into a false sense of security with the simplest solution strategies (wishful thinking), seek refuge in religious trust or express fatalistic thoughts (Rippetoe and Rogers, 1987). Which form of behavior is ultimately chosen also depends upon the social reference group, in which behavioral models are offered or other forms of behavior are sanctioned. Through these processes of reinterpretation, many are able to regain control over events (Bell et al., 1996).

Risks that cannot be directly changed but appear to offer opportunities for flight or protection are viewed as less threatening. The ozone hole is an example of this. People can protect themselves indirectly from the potential negative consequences by avoiding exposure to the sun (Matthies, 1995). This is why the ozone hole is perceived as less threatening than the hazards of radioactivity.

knowledge

Risks can be evaluated differently depending upon the level of knowledge. It is often assumed that people feel such situations to be very threatening that they do not know precisely and whose potential for harm they cannot assess. However, the relationship between knowledge and assessments of hazardousness is more complex. For instance, after they had taken radon samples themselves and had received further information, schoolchildren have viewed the harzardousness of this substance as lower than was the case before the measurements (Hazard and Seidel, 1993). But it can just as well happen that it is the precise knowledge of a risk that leads to a high perception of threat. Home owners in Florida who had a higher level of knowledge about radon have been found to perceive the threat as higher than those whose level of knowledge was lower (Schütz et al., 1997). Knowledge alone is not decisive for the assessment of threat. It is always mingled with other factors, such as values, attitudes or opportunities for protection.

Attitudes

For the perception and acceptance of large-scale technologies in particular, attitudes have proven to be an important factor. Evaluations of nuclear energy, for instance, are regularly embedded in general values and ideologies (Rohrmann, 1995b). People with conservative value orientations will thus tend rather to stress the opportunities and benefits of using a technology. People with liberal values will tend rather to stress the catastrophic potentials (Wildavsky and Dake, 1990).

Habituation

Well-known and familiar risks are generally perceived as less threatening than new, still unknown ones (e.g. mining versus genetic engineering; Slovic et al., 1986). Here it needs to be taken further into consideration that in such risk comparisons other dimensions also play a role (e.g. catastrophic potential, spread of secondary damage etc.). Furthermore, there are also risks with which people are familiar but which, for various reasons, they cannot become accustomed to, and can still less accept (e.g. contaminated food, air pollution; Matthies, 1995).

E 1.2.4.1
Cognitive factors

Among individual determinants, particular weight attaches to cognitive factors (see also WBGU, 1994). The elements of information processing (reception, recall, reproduction) are of great relevance to risk perception. In research on this issue, subjects are generally asked to assess the probability of occurrence of certain events. It has been found that such probability estimates are frequently subject to certain systematic errors. These estimation errors are caused by cognitive 'rules of thumb' (heuristics) which most people use successfully in their everyday life to assess events. For the probability estimation of risks, however, they are often unsuited. Studies on heuristics have mainly concentrated on the different estimations of so-called laypeople and so-called experts (Slovic et al., 1985).

Experts generally refer to statistical data, from which risk probabilities are calculated according to a variety of methods. Their perspective on risks is accordingly characterized by an exclusively technical analysis (Renn et al., 1992; Rayner, 1993). Experts thus frequently use risk assessments of the following kinds (Jungermann and Slovic, 1993b; Section C):

- Risk as the probability of a certain damage,
- Risk as the extent of possible damage (e.g. the number of expected fatalities),
- Risk as a function (usually the product) of proba-

bility and extent of damage,
- Risk as the variance of the probability distribution of all possible consequences of a decision etc.

For laypeople, a variety of further factors (values, attitudes, social influences, cultural identity) play a role in addition to the probability of occurrence when assessing risks. However, even experts are by no means always in agreement on the assessment of risks, for the statistical-technical methods offer much leeway for interpretations and misjudgment. It has thus been shown for the example of the assessment of lead exposure of children that experts took recourse to highly disparate heuristics and previous experience, and thus arrived at disparate evaluations of the given situation (Nothbaum, 1997).

Heuristics typical for laypeople

Availability heuristic. Events that are easy to remember are rated as more probable than events that are less mentally available (e.g. the risk of an airplane crash versus that of a cardiovascular disease). Events are mentally available that are frequently or have recently been reported in the media or that make a particular impression. Less spectacular risks, in contrast, are underestimated although the risk of dying from a cardiovascular disease is many times higher than that of dying in an airplane crash.

'*Gamblers' fallacy*'. Laypeople are prone to the gamblers' fallacy. Developed from observations of people playing dice, this means in risk research that people who have just suffered damage believe that such events are not to be expected in the near future. This is based on the often misleading assessment that an event which is improbable in any case will not occur several times in succession. This is fallacious because the probability of occurrence permits no statement as to the time or sequence of events (Burton et al., 1978).

Prospect theory (framing). Events are assessed as more risky when framed in terms of (potential) losses and not of 'gains' (e.g. survivors). Thus one and the same risk is viewed as being higher if expressed in terms of an expected death rate of 60% and viewed as lower if expressed in terms of a survival rate of 40% (Kahneman et al., 1982).

Beyond cultural, social and individual factors, a series of characteristics specific to risks and their consequences determine perceptions. There is generally a high degree of social consensus on the properties of these characteristics (such as the accessibility of a risk to the human senses). For instance, it makes a difference to most people whether very many people die at once or the same number die over a longer period.

The sociocultural, social and individual factors set out above are decisive for the perception and handling of risks. It is these factors that lead at times to major disparities among countries, communities, certain social groups and individuals in their risk-related actions. To successfully deal with the impending challenges of global change and the associated global risks, it is essential to give greater consideration to these factors. The various values and perceptions need to be taken seriously and to be integrated appropriately in the negotiation of risk acceptance. This must be taken up both in the policymaking context and in research. In many cases, the data basis on which to identify and evaluate global environmental risks is very poor. There is a particular lack of cross-cultural studies, which could play an important role in underpinning global risk strategies.

E 1.3 Organizational risk amplifiers and attenuators

E 1.3.1 The amplification of risk potentials through organizational structures

Large-scale technical organizations, as epitomized by nuclear power plants, large-scale chemical facilities, dams, weapons systems etc., have characteristics that unavoidably harbor risk potentials, so that if organizational or technical failures or unpredictable sequences of events occur, accidents and disasters may follow. At the same time, however, organizational structures can offer a high degree of protection against risk potentials, if they are carefully planned and applied. The amplification of risks often stems from complex organizational structures, characteristics and ordering principles.

Today, organizations and their management are playing an ever more important role, in order to do justice to the growing demand for effective and efficient regulation and control. Organizations can reach enormous levels of complexity – a complexity that makes errors probable and harbors risks. This no longer applies only to large-scale technologies, but increasingly also to politico-societal, economic and infrastructural organizations. It includes, for instance, a nuclear power plant as a specific organization, but also the organizational interplay of all nuclear power plants in a country, or organizational structures in which large-scale technologies are linked with political or economic organizational structures. The organization and control of these complex linkages are usually neither unequivocally decentralized nor centralized. Often they are hybrids attempting to unite centralized and decentralized control approaches –

the inherent contradictions that this causes can lead to problems and risks.

The issue here is not one of the conventional causes of risks, such as operator errors, design or equipment deficiencies or failure to observe safety regulations. Nor is it one of risk factors resulting from excessive size of an organization or its poor management. Here we are rather concerned with the fundamental characteristics of organizations that can lead to failure, such as overcomplexity and coordination effort among interlocking organizational elements and human actors.

Within an organizational structure, there are varying degrees of complexity at the different levels of organization. At the lowest level, the elements, units and associated actions and interrelations have relatively simple structures. At the following levels, however, the degree of complexity rises continuously. The higher the organizational level, the more complex on the one hand are the necessary elements, units and aggregates at that level, and, on the other hand, the associated functional actions and interrelations with other organizational elements and levels.

The elements, units and aggregates in the organizational structure are often coupled very tightly with each other in order to minimize frictional losses. In such constellations, no provisions are made for leeway, buffers or elasticities, so that each process directly influences other processes or elements and often generates erratic consequences. An unexpected event in the shape of an error or disturbance then inevitably draws in its wake further processes and events. Their consequences can lead to chains of events and thus to accidents or even catastrophes if no organizational safety standards, error prevention strategies, countermeasures, early warning systems etc. are in place to stop the proliferation of events between the various stages of the sequence (Section E 1.1). However, as appropriate strategies for dealing with such occurrences cannot be in place at every point and for all situations, it is in many cases essential to have leeway, buffers and elasticities in order to be able to cushion and deal with unexpected changes without losing organizational stability.

Moreover, among the organizational levels, their processes and elements, there are diverse junctions, multiple functional linkages, feedback loops and sequences of complex interrelations. The processes associated with unchanging actions and relationships are expected by the participants. Insofar, they are evident and do not entail increased susceptibility to risk. In contrast, complex actions and relationships that are often not expected by the participants entail critical points at which risk potentials can be amplified. In such situations, ambiguous and indirect information is frequently misinterpreted, thus amplifying the problem of unexpected complexity.

E 1.3.2
The attenuation of risk potentials through organizational structures

Just as organizational structures and their characteristics can amplify risk potentials, if appropriate organizational efforts are made they can also attenuate risk, thus offering high reliability in dealing with e.g. large-scale technologies. Here the improvement of organizational structures is just as important as technical improvements. However, it is not by strengthening authoritarian command structures that organizational risk potentials are reduced. On the contrary, on-site operatives must receive greater competency to take actions and decisions. This follows from the observation that higher-level decision makers and senior managers often have a conception of real-world processes that corresponds inadequately to reality.

The question of the optimum structure of an organization depends above all upon which organizational objective is pursued and how the hierarchies of responsibilities and competencies are composed that are necessary to implement this objective. In order to be able to answer this question, we shall distinguish in the following between four categories of organizational structure (Perrow, 1984).

Low-complexity organizations with leeway

In organizations with low complexity and sufficiently large leeway and buffers in operative sequences, such as are to be found e.g. in manufacturing industry, responsibilities and decisions can be controlled both in a centralized and decentralized fashion in order to attenuate risk potentials. In these organizational structures, complexity is low, nor is it required by the organizational objective. Errors or disturbances can thus be handled equally well by a central superordinate decision-making level, or in a decentralized fashion directly on site.

Low-complexity organizations without leeway

For organizations with low complexity but direct interactions, such as large dams, a central control of responsibilities and competencies is best suited to attenuate organizational risk potentials. Almost the entire decision-making process can be drawn together at a senior management level. This is purposeful because functions and tasks always remain the same, and organizational processes are evident and direct. Errors and disturbances are a part of process planning from the outset. For such expected events, central management makes provision for countermeasures that are implemented by staff on site without feedback. Due to the directly interlocking actions and interrelations, reactions must be fast, direct and precise in order to prevent errors cascading.

Complex organizations with leeway
In complex organizations that have leeway and buffers and elasticities in interrelations, such as universities or ministries, responsibilities and competencies should be as decentralized as possible in the interests of attenuating organizational risk potentials. The distribution of functions and tasks among a variety of posts and competencies counters the organizational risk potential inherent in complexity. When errors or disturbances occur, components and equipment can thus be replaced and alternative strategies chosen without the need for prior planning. There is sufficient leeway in the form of time, resources and alternatives to handle disturbances and minimize impacts. For this, the staff operating at the source of disturbance must be in a position to analyze and assess the situation itself, in order to then institute the appropriate countermeasures.

High-complexity organizations without leeway
For a highly complex organization with almost no leeway or buffers in organizational interrelations, neither a decentralized nor a central structure is adequate. This is because such organizations place highly disparate demands upon the handling of errors and accidents. Immediately interlocking actions and interrelations suggest a central control structure, which permits immediate implementation of decisions. At the same time, the high degree of complexity suggests a decentralized structure, which is better able to cope with unexpected events or disturbances. Decentralized structures ensure a careful search for errors by on-site personnel. Meticulously designed hybrid forms will perform best. Here 'subsidiarity' needs to be established such that most tasks are implemented independently at the respective levels and only important central decisions are taken by higher levels of the hierarchy. A part of this principle is that sufficient leeway, buffers and elasticities are given in every situation and at every location. Although this is the best possible structure for highly complex organizations, a considerable organizational risk potential will always remain.

The four categories illustrate that low-complexity organizational structures are capable of controlling and regulating themselves, as they can enhance their structures out of their own resources. This is contrasted by more complex organizational structures whose risk potential can only be reduced with major effort. Moreover, modern society has produced highly complex organizational structures that require exceedingly large organizational efforts in order to reduce the high risk potential. An organizational risk potential will always remain because there is no optimum structure for these highly complex organizations. Here, as elsewhere, the question of expected societal utility and of the social acceptance of the increased risk potential plays a crucial role.

E 1.3.3
High-risk technologies versus high-reliability organizations

E 1.3.3.1
Perrow's high-risk technologies

Charles Perrow (1984) distinguishes in his theory of high-risk technologies four levels of complexity: parts, units, subsystems and the system. Parts are the lowest level, i.e. the smallest components of a system; in the case of a large technical organization, these are construction elements. The second level is a functionally interconnected structure formed of related parts, the unit. At the third level, various units fuse to form an aggregate, the subsystem. All subsystems join at the uppermost level to form the overall system. What extends beyond the overall system belongs to a possible fifth level, the system environment. Depending upon the systemic level, the specific degree of complexity entails differing risks. The direct outcomes of risks in the event of incidents or accidents at the various levels thus have differing qualities and magnitudes for the system environment. Singular incidents or accidents may trigger chain reactions (Section E 1.1).

Among the systemic levels, processes and elements, there are closely knit junctions and bifurcations, functional links, feedback loops and shifts from linear to complex interactions. Linear interactions in organizational procedures are known, expectable and evident. Complex interactions are unfamiliar, unplanned and unexpected. Complexity is the first and central category in Perrow's analysis of organizational handling of risk. In terms of interactions, complex systems are characterized as follows:

- Close proximity among elements and system levels, with linkages that are not linear, but complex,
- Numerous nonlinear links of multiple functions among the system levels,
- Novel or unplanned feedback loops,
- Numerous, interrelated multiple controls and points of interaction,
- Ambiguous or indirect information,

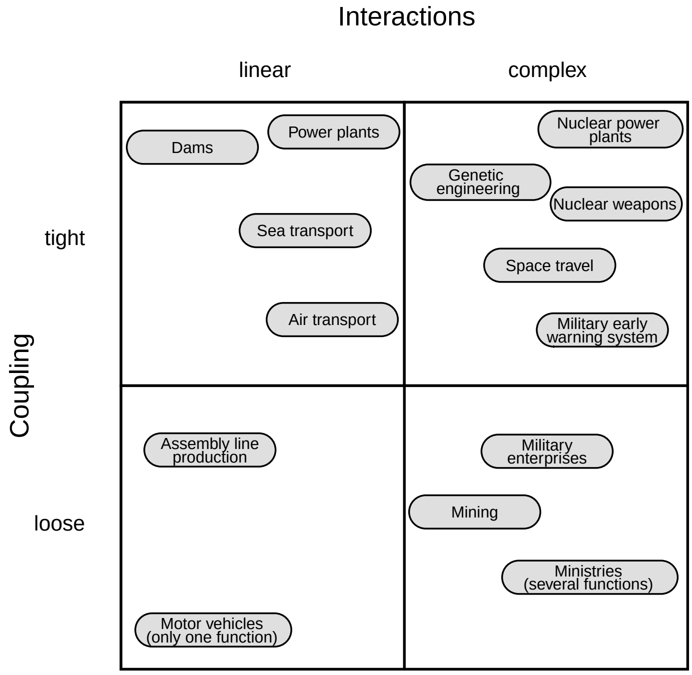


Figure E 1.3-1
Complexity-coupling matrix showing the positions of various organizations.
Source: Perrow, 1984

- Incomplete understanding of certain procedures and processes.

In contrast, *linear systems* have the following tendencies:

- Spatial separation of elements and levels,
- Fixed linkages and separated subsystems,
- Few feedback loops,
- Independent controls with only one function,
- Direct information and comprehensive knowledge.

Coupling is the second main dimension in Perrow's theory of organizations. Tight coupling means that there is no leeway or buffering between the interacting elements. The elements themselves have no elastic capacity, so that every process or event affecting one element will directly influence the processes of another element. In contrast, where there is loose coupling, events, disturbances or unexpected changes can be cushioned and processed without loss of stability. Tightly coupled organizations react much more directly, so that a string of events and reactions can follow. Tightly coupled systems are characterized by the following tendencies:

- Process delays are not possible,
- The process is unalterable,
- The organizational objective can only be realized by means of one procedure or approach,
- Materials, equipment and personnel all have small leeway,
- Buffers and redundancy are planned ahead by the organization,
- The replacement of materials, equipment and personnel is only possible to a limited extent and after prior planning.

Loosely coupled systems exhibit the following tendencies:

- Process delays are possible,
- Processes are alterable,
- Alternative procedures or approaches are possible,
- Materials, equipment and personnel are available with more or less great leeway,
- Buffers and redundancies are available through chance circumstances,
- Materials, equipment and personnel can be replaced as required.

Perrow links the dimensions of complexity and coupling in order to identify the different positions of organizations in this 2-dimensional matrix. Fig. E 1.3-1 positions various organizations in such a matrix.

In Perrow's opinion, the amplification of risks by organizational structures and systemic properties can be summarized in terms of three determining characteristics of modern large-scale organizations that make accidents involving complex technologies almost inevitable: hierarchical decision-making structures, diffusion of personal responsibility and, finally, time-consuming communication structures. However, subsequent empirical studies have identified structural characteristics of 'high-reliability organizations' specially geared to the management of the risks of large-scale technologies. Nonetheless, these studies, too, arrive at the conclusion that particular organizational efforts and innovations are necessary in order to meet the additional need for safety management entailed by the risks of large-scale technologies (Perrow, 1984, 1992).

The risk potentials produced by tightly coupled and highly complex organizations (Fig. E 1.3-1: top right-hand box) remain problematic in terms of finding an appropriate organizational structure for managing risks. Empirical studies have shown that US commissions responsible for regulating the nuclear industry have indeed concerned themselves with proposals for optimized organizational structures in nuclear power plants. In one such case, the commission recognized that an optimum structure required a mix of both centralized and decentralized structures. However, the introduction of decentralized structures, for instance at the operator level, was not compatible with the centralized overall structure of the organization. The commission and the senior management therefore supported a centralized structure.

E 1.3.3.2
Rochlin's high-reliability organizations

Which characteristics are typical for large, complex organizations which have proved their capability to handle complex risks? Research on 'high-reliability organizations' has yielded a number of answers to this question (Weick, 1987; Roberts and Gargano, 1990; Roberts, 1989; LaPorte and Consolini, 1991; Rochlin, 1993; Schulman, 1993). In this perspective, reliability is understood as a management, not a technical, property, whereby intervention, anticipation and monitoring are the driving forces. Organizations that strive for high reliability pay attention to the following issues (Rochlin, 1993):

- Errors and mistakes are omnipresent and insidious and can emerge everywhere; incessant vigilance is the price of success.
- Error sources are dynamic, not static, so that monitoring mechanisms themselves need to be continuously renewed and re-invigorated.
- The operating environment is a permanent source of hazard calling for continuous vigilance, even (and particularly) at times when things would seem to be going well (thus creating a danger of negligence).
- The operational level needs to maintain redundant problem-solving procedures and methods. It is essential to resist pressures to resolve or 'rationalize' processes by introducing a sole 'best' solution.
- Multiple, simultaneous informal organizational structures must be created, maintained and implemented in order to adapt to contingencies (structural variations according to the nature of specific problems).
- Both organizational commitments to anticipation and reactive procedures and methods dealing with real and potential problems must be in place.
- Certain organizational units must be capable of identifying incipient or latent errors and mistakes.
- High-reliability organizations are unable or unwilling to test the limits of reliability. Learning by trial and error is considered secondary.
- As long as organizational resources and time are available, self-improvement and self-regulation should not be restricted. The marginal costs of acquiring additional information as a means of controlling and limiting uncertainties are thus always cost-effective.
- Even if a complete formal analysis is available, the task of actively searching for errors is only simplified, but not rendered redundant or diminished in importance.

In summary, we may state that reliable organizations, while striving for perfection, never expect to attain it. They demand complete safety but do not expect it. They fear surprises, but anticipate them. They speak of reliability, but never take it for granted.

E 1.4
Economic factors

Democratically oriented political systems, particularly those with a federal state structure and an economic system oriented to market principles, can certainly exert a risk-reducing effect and also display elements of long-term orientation. However, it is also indubitable that they harbor a series of institutional or economically relevant risk amplifiers, whose influence needs to be attenuated.

From a global perspective, institutional deficits play a particular role here. These include the absence of property rights to globally relevant environmental goods or resources. The outcome of this is that no claims can be raised for damage to property, with the attendant danger of an overexploitation of important resources (the 'tragedy of the commons'). The oceans or the Earth's atmosphere exemplify this. In such cases, solutions generally need to be found through negotiation, and prove hard to enforce. In its previous annual report, which focused on water resources (WBGU, 1998a), the Council has noted the implications of such institutional deficits and has submitted proposals by which to remedy them.

Similar influences are exerted by the absence of a global body of liability law that might permit claims for compensation for property loss, and the still highly fragmented international competition regime. The latter particularly needs to address the question of

Box E 1.4-1

An economic perspective on the development of new technologies

The development of national economies is generally determined by their resource endowment and by the institutions (understood as sets of rules) that give incentives for certain behavior (North, 1992). Different institutional arrangements produce different incentives for individuals to produce, acquire and utilize knowledge. This applies equally to risk knowledge. Different norms and rules give different incentives to generate, to not generate or to reduce risks. Economic theory basically proceeds from the assumption that decentrality of decisions serves to attenuate risks (Hayek, 1991). This assumption is based on the notion that future developments and states of economies cannot be preordained. Instead, only more or less plausible individual expectations can be formed. As the individual state of knowledge, processing capacity, will to collate and evaluate information, risk attitude and other factors differ among individuals, a great diversity of expectations that guide actions will be formed. The diversity of expectations leads to such actions being carried out whose benefits exceed their costs. In contrast, the more centrally developments are controlled and the less alternatives are available, the more probable it becomes that pathways are taken whose (longer term) outcomes fail to be accepted in a society, because the associated benefits are too low or the costs are too high.

Under certain circumstances, economic incentives can lead to certain development pathways of technology development becoming dominant over time (David, 1985; Arthur, 1989). This can be because considerable ‘sunk costs’ are associated with investments. This term refers to costs that can only then be amortized if investments in fixed assets or human capital are utilized exclusively for a certain purpose, namely the one originally planned. Utilization for other purposes offers neither technical nor economic benefits. Such capital will continue to be utilized even if more cost-effective alternatives are available. So-called network effects can intensify the effects of sunk capital, but can also exert an effect of their own. A ‘network’ can be for instance a rail network. Once a rail network with certain technical specifications has established itself – possibly due to chance historical processes – it becomes advantageous to expand this network in the same mode, as then the benefits of a larger network can be utilized and the costs of adaptation at interfaces between different networks are avoided. In a broader sense, specific production structures can also be understood as such a network. Once such structures have emerged – such as relationships between feedstock suppliers, processors, equipment manufacturers, final product manufacturers, recyclers and disposers – it becomes advantageous in many ways for new entrants or users to adapt to the existing structures and to become a part of the existing network. This enlarges the network and increases the future incentive to join it.

Fig. E 1.4-1 charts the average costs of utilizing technologies 1, 2 and 3 over time t. Cost reductions shall result from network effects. If we first only consider technologies 2 and 3, then until t_2 technology 3 is the most advantageous, from t_2 – and thus from a certain network size – onwards technology 2 is more advantageous. However, this technology may possibly not be used because in t_2 a network has been established for technology 3 that is lacking for technology 2. In this situation, individual demanders switching to technology 2 would incur high costs unless a large part of users switches almost simultaneously from 3 to 2. If there are sunk costs, even such a simultaneous switch may possibly not be profitable. If it had been known from the outset how the number of users of a network and the costs of network use would develop over time, then technology 2 would have been used from the start if it is the more cost-effective over the longer term. There is however a lack of this information at first, because of the absence of knowledge of the concrete evolution of the individual pathways. If, on the other hand, risks associated with the technologies could be compensated for, such as by a liability regime, then no special risk problems would be associated with the choice of a certain pathway. Problems only arise if risks cannot be compensated for or if leaving a path once taken harbors new risks, e.g. in the environmental sphere.

Because knowledge is only collected through experience, it is unavoidable that developments arise which, looking back, would better not have been realized. Such risks are amplified if certain developments are forced from the outset, so that the leeway for alternatives is constrained and new risks cannot be identified early on. Institutions thus need to give incentives to ensure that certain processes and products are not promoted one-sidedly, that risks can be identified in a targeted manner through monitoring and that no artificial incentives are given that might make it appear advantageous to lock into certain development pathways.

With reference to Fig. E 1.4-1, this means that individual technologies must not be given preferential treatment over others. If for instance curve 3’ represents the actual costs of pathway 3, then subsidization of development (3 instead of 3’) prevents technology 2 from being pursued from the very start. If it should transpire in the course of time that high risks are associated with path 3, then it is no longer possible to switch to alternatives. If, in contrast, technology 3 bears its full costs from the outset, the probability is at least higher that alternative techniques or products are available. Rules that permit preferential treatment of specific technologies and products for reasons of political or bureaucratic preferences must thus be rejected as a matter of principle. The question presents itself here as to whether instead of concentrating support solely on certain mainstream pathways it might not be advantageous to also support alternatives to these pathways.

It is not out of the question that, despite full cost allocation to each development pathway from the outset, only one pathway is pursued, with state support, because it (supposedly) offers a decisive cost benefit. It is further possible that after a certain time only one pathway remains because others have not proven competitive (pathway 1 in Fig. E 1.4-1). Problems arise in this case if risks are associated with this pathway that only become apparent in the course of time. The later these risks are identified, the higher are the societal costs of leaving this pathway. If for instance it is realized at time t_1 that considerable risks are associated with the pathway that push costs upwards (technology 1’ instead of 1), the costs of leaving this pathway depend upon when the risks are discovered and upon whether at least basic experience has been collected with alternative pathways. Here institutions need to give incentives. This can be achieved by means of liability rules for development risks incurred by private actors, and by means of incentives to bring together dispersed knowledge of risks realized. At the same time, the state must commission the production of knowledge as a collective good, e.g. knowledge on the function of ecological systems. In many instances, it is only through bringing together collective and privately available knowledge that risks can be perceived and assigned to certain production

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processes or products. Furthermore, as stated above, even if a pathway that initially appeared the most advantageous transpires in the course of time to be an error, the transition to other pathways is facilitated if at least in the early phase of pathway development alternatives were researched and tested for a temporary period. Institutions that block market access are just as harmful here as institutions that create targeted political-administrative incentives to use existing products and production processes.

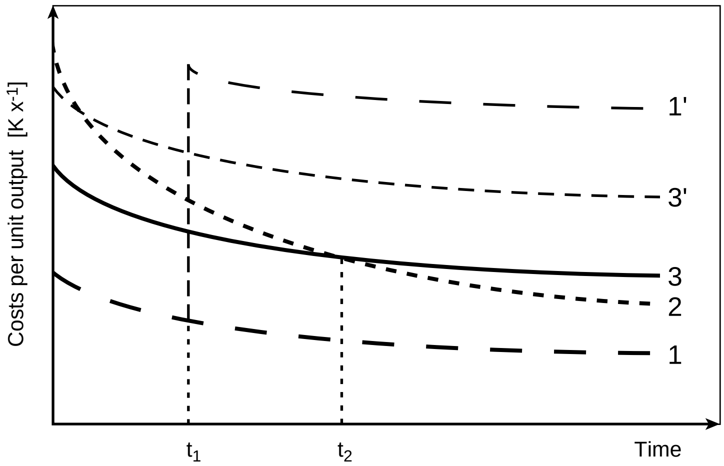

Figure E 1.4-1
Inefficient technology choice. The curves are explained in the text.
Source: modified after Klodt, 1995

the extent to which non-consideration of certain environmental standards can be interpreted as an inadmissible distortion of competition (WBGU, 1996). The stipulation of rules alone generally does not suffice here. It is above all important to implement them or to determine sanction mechanisms in the event of non-compliance.

Risks are certainly amplified by political instability, corruption, a lack of enforcement capacity on the part of the state and inflationary framework conditions. Among most economic actors, such factors cause short-term orientation of planning and thus an under-valuation of long-term risks. Here it becomes apparent how important it is to consider at the global level the constitutive principles of a market economy (i.e. clear allocation of property rights, enforcement of the liability principle, monetary stability and constancy of economic policy etc.). The recent events in Asia have shown particularly how free international liquidity can lay bare the weaknesses of individual national economies, and how speculative reactions can then exacerbate crises.

Severe poverty also amplifies risk. The Council pointed out in its first annual report (WBGU, 1994) that poverty alleviation is a first important step towards long-term orientation and thus towards improved environmental protection and risk reduction. Increased levels of development assistance are not always the solution to the problem. In many cases the prime concern must rather be to overcome corruption, tribalism, civil war and political instability.

Globalization

There is some controversy over the extent to which globalization and internationalization of the economy have a risk-amplifying effect. This is because these concepts allow very different interpretations. In a classic sense, the concept of globalization refers to the geographic expansion of sales and procurement markets. This generally increases competition, which is basically to be welcomed – as long as it does not cause a race to the bottom in environmental standards. However, in specific cases traditional sectors find it difficult to hold their ground in competition with the large companies of the industrialized nations, with the economies of scale and well developed distribution systems of the latter. What is more important from a risk perspective, however, is that through the geographic spread of markets global interpenetration is growing, and thus the danger of global risk bundling. This trend is heightened if globalization also leads to a homogenization of patterns of consumption and production. This deteriorates the resilience to crisis of economic systems, which is ultimately based upon heterogeneity and regionality, and effectively calls for a homogenization of the regulatory framework within which economic actors operate.

Internationalization

The process of internationalization is often equated with that of globalization. However, the two should be distinguished, as internationalization is rather defined in terms of property rights. Internationalization is then equated with an international spread of large companies, generally through the purchase of property rights to foreign production facilities or through own investment activity. This entails both opportunities and risks. Positive developments result if a transfer of capital and technology occurs, and if multinational corporations observe certain minimum environmental standards, be it for image reasons alone. Problems can arise if technology transfer leads to the selective dissemination of certain technology lines Box E 1.4-1). This can intensify a risk amplifying process resulting from the temporary dominance of certain technology pathways. Switching from one technology pathway to another often entails very high costs. Due to their capital intensity or the benefits of large-scale production that have in the meantime been exploited, decisions taken in the past determine the present and hamper a shift to technology pathways entailing lower risk. The problem also has political relevance insofar as it is exceedingly difficult to recognize in good time windows of opportunity (bifurcation points), i.e. points at which alternative pathways can or should be taken.

E 2 Specific vulnerabilities of regions and social groups

E 2.1
Factors influencing the probability and magnitude of damage

The probability of the risks of global change occurring and their possible magnitude of damage depend greatly upon which country and which social groups are affected.

1. *Magnitude of damage*. Climate risks, for example, are amplified considerably by the capabilities of the countries concerned and the vulnerabilities of the people affected. Droughts and floods (Cyclops-type risks) caused by climate change cost far more human lives in Africa than in the USA. Even within Europe, such disparities are distinct: the recent flooding of the Oder river caused less damage on the infrastructurally better equipped German side than it did in Poland (Section D 7). Around the same time, rivers flooded in China, too. Here there were almost 800 deaths, 50,000 houses were destroyed and 3,700 km^2 arable land inundated, with the consequence that some 30,000 t cereals were destroyed (Koschnick, 1997).
   For health risks (infectious diseases are a Pythia-type risk), too, the magnitude of damage depends upon the capabilities of states and the vulnerabilities of people. While hepatitis B, tuberculosis or malaria can be healed in many cases in industrialized countries, for people in developing countries the same diseases often mean a death sentence. Chemical risks such as accidents in chemical industry (Bhopal; a Damocles-type risk) can also have disparate impacts: in developing countries, the poor mostly live in densely populated favelas or other blighted urban settlements, which are often located close to industrial facilities and heavily trafficked roads, in particularly smog-polluted areas or along malaria-ridden and highly polluted river branches. Much the same can be said of the magnitude of damage associated with natural risks such as earthquakes (Damocles-type risks); in almost all cases, regionally specific capabilities and vulnerability specific to social groups determine the magnitude of damage and thus the effective risk.
2. *Probability of occurrence*. This, too, is determined substantially by factors specific to regions and social groups. This is particularly so for technological risks. Accidents in chemical industry such as in Bhopal or related to the use of nuclear energy such as in Chernobyl are not impossible in the comparatively wealthy industrialized countries, but do have a lower probability of occurrence than in India or in Ukraine due to the greater capabilities, such as a more effective regulatory system. The poorer capabilities and high vulnerability of people in developing countries also lead to an increased probability of occurrence for health risks (Section E 3.1).
   An examination of the capabilities and vulnerabilities of states and specific social groups is an indispensable part of every risk analysis. The risks of global change imply a North-South gradient of risk distribution that is an inverse function of risk responsibility. This poses a considerable challenge to the scientific analysis and evaluation of global risks. The goal of global risk minimization policy must be to reduce both magnitudes and probabilities with due regard to their regional and social group specific amplifiers. We focus here on poverty because the Council takes the view that prime importance attaches to this among all other factors of vulnerability.

E 2.2
Correlates of vulnerability to global change risks

E 2.2.1
Absolute poverty, growing global social disparities and environmental criticality

Absolute poverty

Absolute poverty is a crucial factor for the vulnerability of both societies and individuals. The German Ministry for Economic Cooperation and Development (BMZ, 1997) has termed poverty as one of the risks that is transboundary in nature and has emerged as a global hazard. But absolute poverty is not yet eliminated, despite the economic growth experienced by many developing countries (UNDP, 1997). Although for many people the changes that have happened over recent decades have indeed opened up new opportunities, these changes have often also produced hazards and risks that have nullified the successes made in the past in alleviating poverty. Thus the Human Development Index (HDI; Box E 2.2-1), by which the UN attempts to measure the quality of life and which has risen steadily since its introduction in 1990, dropped again for the first time in 1997 in 30 countries (UNDP, 1997).

Income-poverty also remains widespread. In developing countries, the number of people who command less than US-$ 1 per day and therefore live in 'income-poverty' according to the definition of the World Bank rose between 1987 and 1993 from 1.2 to 1.3 billion people. In the terms of this definition, poverty is most widespread in sub-Saharan Africa (266 out of 590 million people) and in South Asia (515 million out of a total of 1.3 billion people) with ratios of 45% and, respectively, 40% of the population. Overall, income-poverty is concentrated in rural areas. The famine riots in Indonesia that occurred in early 1998 during the Asian economic crisis highlight how suddenly poor segments of the population can become exposed to existential threats.

In other key fields of human development, too, the situation remains critical despite all progress. In the developing countries alone, more than 1 billion people live in inadequate housing. The United Nations Development Programme (UNDP) estimates that at least 600 million people live in housing that poses a hazard to health and life (a Pythia-type risk). Worldwide, some 100 million people are homeless, and the figure is rising. In industrialized countries, too, homelessness is on the increase. In New York almost 250,000 people live on the streets – this is more than 3% of that city's population (UNDP, 1997).

Although health services have improved considerably over the past decades, some 17 million people continue to die every year in the developing countries from curable infectious and parasitic diseases. Ninety percent of all HIV-infected people (out of a total of approximately 23 million) live in the developing countries. Poor people are more vulnerable to environmental changes: to sustain their livelihoods, they are particularly dependent upon the utilization of natural resources such as water or soils (WBGU, 1995a, 1998a).

Almost all empirical studies of the risks posed to the livelihoods of vulnerable groups in developing countries have shown that the position of women is particularly precarious. Women not only perform an increasing proportion of productive and reproductive work ('feminization of work'), but are in most contexts also responsible for utilizing common property, which has proven to be an important strategy in coping with crises. In this connection, the Council welcomes and confirms the concept for development policy of the German Ministry for Economic Cooperation and Development with regard to women in development (BMZ, 1997). Greater consideration needs to be given in development cooperation activities to the role of women in sustaining the livelihoods of vulnerable groups, but without thus placing new burdens of labor upon them. The same applies to the access of the poor to natural resources, which are traditionally common property.

Social disparities at the global scale

Heightening global disparities at the global scale are leading in many cases to an uneven distribution of the risks of global change, particularly in terms of magnitude of damage. This is illustrated by the regular differences in magnitudes of droughts, flooding or epidemics between industrialized and developing countries.

Regarding the development of global social disparities, recent UN reports show that progress in poverty alleviation has been substantial overall since the beginning of the 20th century, but that this has been distributed very unevenly. Moreover, income-related global disparities have continued to grow: the share of the poorest fifth of the world's population in global income has dropped to 1.1%, a figure that was still 1.4% in 1991 and 2.3% in 1960 (Table E 2.2-1). This trend appears to continue. The gap between the income share of the richest 20% and the poorest 20%

Box E 2.2-1

The Human Development Index

The Human Development Index (HDI) combines three categories of basic variables (for a critique: Nuscheler, 1997):

- Longevity, measured as average life expectancy at birth,
- Educational attainment, measured by the weighted combination of adult literacy (⅔) and the total school enrollment rate at the primary, secondary and tertiary levels (⅓), and
- Standard of living, measured as per capita GDP in real terms and expressed as purchasing power parity (PPP) in US-$.

of the world's population is ever widening: in 1960, its ratio was 30:1, in 1991 it was 61:1 and in 1994 it reached its highest recorded value of 78:1 (Table E 2.2-1).

While in 1965 the average income of the G-7 countries was 'only' 20 times higher than that of the seven poorest countries, by 1995 it was already 39 times higher. While the economies of a number of developing countries grew faster than those of the industrialized countries, this did not reduce absolute income disparities. Average per capita income in Latin America fell from ⅓ of that of industrialized countries in the 1970s to ¼ today. In Africa, average per capita income is now only 7% of that of industrialized countries. Only the growing economies in South-East Asia succeeded, at least until the Asian crisis of 1997, in reducing the income gradient to the industrialized countries, or at least in preventing it from growing (UNCTAD, 1997).

The average income of states or population groups is by no means the only indicator of their vulnerability to the risks of global change. In the opinion of the Council, the degree of 'human development' is more informative. This is viewed by the United Nations Development Programme (UNDP) as an expression of the opportunities for choice available to people in three fundamental dimensions, namely:

- Leading a long life,
- Attaining knowledge, and
- Having access to resources for a decent standard of living.

Taking such categories into consideration permits a more differentiated picture than the simple comparison of per-capita income (Table E 2.2-2). Thus the North-South gradient has indeed been reduced in relative terms in some areas, such as in health care, in food supply and in drinking water (Section E 3.2). At the same time, however, disparities between North and South have grown in communication, research and education. It is obvious that this greatly weakens the capacity of developing countries to manage and cope with the risks of global change. Even today, developing countries are endangered to a particular degree by growing environmental stresses such as deforestation, long periods of drought, soil degradation, soil erosion and dwindling surface water and groundwater resources (UNDP, 1997).

The Council is thus of the opinion that promoting the livelihood security of vulnerable groups and promoting their potentials for self-help must be a part of global risk prevention policy. Central areas of concern here are the informal and traditional livelihood systems (moral economy), which are increasingly losing influence under the most varied economic, social and political pressures. At the same time it is clear that formal security systems that might support the livelihood security of vulnerable groups are only being created to an inadequate extent.

Rather, it is becoming apparent that such security systems are being dismantled under the influence of global change. The recommendation of the Council is to carefully but perseveringly establish formal security systems for vulnerable groups, while at the same time ensuring that this does not jeopardize the still existing traditional or informal security systems. Such new livelihood security systems could consist of a mix of public and private-self-help oriented elements.

Social disparities within countries

In general, socio-economic disparities are far larger within developing countries than they are within industrialized countries. Numerous developing countries – notably in Africa – continue to be in economic and political crisis; here vulnerability to numerous risks of global change is particularly large. However, socio-economic disparities alone do not lead to higher susceptibility to environmental risks; what is decisive here is above all the proportion of people living in absolute poverty. If rising disparities are associated with rising rates of absolute poverty, then the number of vulnerable people grows. Income disparities, in contrast, only show how risk management potentials and risk exposure (for instance through differing levels of health care, differences in housing, food supply or safety nets through insurance systems) are distributed within a society. The growing socio-economic disparities among countries are accompanied by a growing intrastate polarization of income distribution and opportunities in life. UNCTAD's 1997 Trade and Development Report shows

Table E 2.2-1
Global income disparities, 1960–1994.
Source: UNDP, 1992, 1997

Year	Percent of global income			
	Poorest 20%	Richest 20%	Richest: Poorest	Gini coefficient
1960	2.3	70.2	30 : 1	0.69
1970	2.3	73.9	32 : 1	0.71
1980	1.7	76.3	45 : 1	0.79
1989	1.4	82.7	59 : 1	0.87
1994	1.1	86.0	78 : 1	–

Table E 2.2-2
North-South disparities of opportunities in life, 1960–1990.
Source: UNDP, 1992

	North		South		Absolute disparities	
	1960	1990	1960	1990	1960	1990
DECREASING DISPARITIES						
Life expectancy [years]	69.0	74.5	46.2	62.8	22.8	11.7
Adult literacy [%]	95	97	46	64	49	33
Food supply [daily calorie supply in % of requirement]	124	134	90	109	34	25
Infant mortality [per 1,000 live births]	37	13	150	74	123	61
Child mortality [per 1,000 live births]	46	18	233	112	187	94
Access to clean water [% of population]	100	100	40	68	60	32
RISING DISPARITIES						
Average duration of schooling [years]	9.1	10.0	3.5	3.7	5.6	6.3
University training, enrollments [%]	18	37	3	8	15	29
Scientists and technicians [per 1,000 people]	51	81	6	9	45	72
Expenditures for research and development [US-$ billion]	196	434	13	18	183	416
Telephones [per 1,000 people]	130	466	9	26	121	440
Radios [per 1,000 people]	449	1,008	32	173	417	835

that in almost all countries the income share of the richest fifth of the population has risen since the early 1980s, whereby in many cases a reversal of the post-war trend has occurred. In most developing countries, the upper fifth commands over more than half of the national income. The poorest fifth of the population, which is generally most vulnerable to risks, remains disadvantaged. In many countries the poorest 20% of the population earns on average ten times less than the richest 20%.

Another measure of income distribution expresses the shares in total income of three segments of the population: the richest 20%, the middle 40% and the poorest 40%. In most industrialized countries, income distribution follows a 40:40:20 pattern, i.e. the richest 20% of the population commands over about 40% of the total income, the middle 40% over a commensurate proportion of income and the poorest 40% over 20% of total national income. In an international perspective, societies with such a structure are considered countries with a relatively low degree of inequality (UNCTAD, 1997).

There are only few developing countries in which income is distributed according to the 40:40:20 pattern. These include Taiwan, South Korea and Nepal (UNCTAD, 1997). The other developing countries are rather characterized by an extremely uneven distribution of income. Some of these are still counted as belonging to an 'intermediate' category, in which the richest 20% commands over half of total income. In other developing countries, income is rather distributed according to a 60:30:10 pattern.

Environmental criticality as a risk amplifier

Regional risk vulnerability varies not only according to socio-economic disposition, but also according to ecological endowment, i.e. regions have a specific 'environmental criticality'. Environmental criticality refers to a situation in which the quality of life (income, GNP, health, food, freshwater supply etc.) is at risk due to environmental changes. Environmental criticality is a function of the speed and intensity of environmental changes, the vulnerability of people affected and their coping potentials. Kasperson et al. (1995) give an overview.

As a rule, regions with high criticality do not emerge from one day to the next. The environmental criticality of a region can therefore be described in stages. The two decisive attributes here are the regenerative capacity of the ecosystem and the buffering or adjustment costs incurred by the societies affected. Sustainable regions are characterized by high ecological regenerative capacity and low buffering or adjustment costs. In the cascade movement from an *impoverished* over an endangered and finally to a critical state, this is gradually reversed (Kasperson et al., 1995; Turner et al., 1995). In an impoverished region, the quality of life of the people living there is threatened over the medium or long term by environmental changes. A region is *endangered* if a stage of environmental degradation has been reached in which such a situation is expected in the near future (at the latest in the next generation). In the *critical* state, a deterioration of quality of life must already be tolerated due to environmental degradation. In such regions, the risks of global change can have particularly severe impacts due to the expected cumulative effects. Among regions with high environmental criticality, Kasperson et al. (1995) discuss Amazonia, the Aral Sea basin, the middle mountains of Nepal, Kenya's Ukambani region, the Mexico Basin, the Ordos Plateau of China, and the eastern Sundaland region of South-East Asia (Kalimantan, Sumatra, Java).

An IPCC special report (IPCC, 1998) has set out the expected region-specific impacts of climate change (Section D 6, Pythia-type risk) upon ecosystems and societies for all world regions. Here Africa is identified as the continent most vulnerable to climate change, due to its climatic and socio-economic disposition (e.g. dependence upon rain-fed farming and the general importance of agriculture). In terms of environmental criticality, possible amplification effects between drought risks and climate change play a decisive role (IPCC, 1995). Environmental criticality has a particularly severe risk-amplifying effect where environmental changes overlap, such as biodiversity loss, soil degradation and freshwater scarcity.

Despite work already done in this field, such as the development of a freshwater criticality index (WBGU, 1998a), a global overview of environmental criticality yet needs to be provided. This could proceed by superimposing world maps of soil degradation, freshwater contamination or scarcity, air pollution and UV-B radiation exposure, then further considering the potentially affected people, their specific vulnerability and socio-economic management potentials. The most frequent and most critical intersections could then be identified. Here the Council sees a need for further research, in particular to improve the knowledge of the resilience or adaptability of ecosystems and societies.

E 2.2.2 Forms and determinants of vulnerability

Which factors render people or certain regions particularly susceptible to the developments described above? What aggravates the vulnerability of certain social groups or regions and how does this intensify the risks of global change?

E 2.2.2.1 Determinants of rural vulnerability

Generally those people are most vulnerable to the risks of global change who are already among the poorest in a society. In developing countries, this applies particularly to those who live off marginal agricultural soils and who are confronted with continuing degradation of their environment and crop failures caused by drought and flood risks. The floods in Somalia (Cyclops-type risk) in November 1997 exemplify this. Even very conservative estimates suggest that half of the poorest people of the world live on such marginal agricultural soils – totaling more than 500 million people, located mainly in the Sahel zone of Africa, the mountain regions of the Andes or in the Himalayas. The livelihoods of all these people are directly and acutely threatened by the continuing degradation of natural resources (UNDP, 1997). The ecosystems of these areas are also highly vulnerable. Their soils are at risk of erosion, and rainfall has major seasonality and annual variability. These areas are often remote, without road connections to markets or infrastructure.

Worldwide, Chambers (1997) distinguishes between three types of agriculture. These types have different vulnerability to the risks of global change. In addition to the 'first agriculture' (with high technical inputs in the industrialized countries) and 'second agriculture' (in green revolution regions in developing countries) there is a 'third agriculture'. This is complex and diverse, and, due to its low degree of mechanization, crucially important to the rural poor, as it remains financeable and manageable. Nonetheless, it is particularly vulnerable to global risks. Estimates indicate that 1.9 to 2.2 billion people live off the produce of this third agriculture (Pretty, 1995). Despite this, its importance has been underestimated until now and little is known about its functional structure. The third agriculture is of particular importance for a global risk minimization strategy, for it currently provides the majority of the poorest and most vulnerable groups of the world with food. Furthermore, it is the only form of arable farming that still offers a potential for doubling and trebling productivity with little or no external inputs.

How can we identify those regions in which agriculture is particularly vulnerable to global risks but also particularly important to the livelihoods of poor people? There are five prime determinants:

1. *Low and stagnating production.* In most of the vulnerable agricultural regions of the world, agricultural productivity growth is equaled or outstripped by population growth. This applies particularly to sub-Saharan Africa, where between 1974 and 1990 food imports rose by 185%, food aid even by 295% (UNDP, 1997). In addition to population growth and environmental degradation, food insecurity is aggravated by the political instability of many countries, widespread corruption and ethnic conflicts. This is further exacerbated by historical misappropriations, such as the consequences of many decades of central planning in Mozambique. Insofar, low agricultural productivity in conjunction with population growth and political instability leads to a downward spiral of poverty and risk vulnerability.
2. *Growing claims upon common property resources (CPRs).* Particularly the poorest families in marginal agricultural areas such as arid regions or mountain zones depend greatly upon the use of natural resources that are common property. Many sustain their livelihoods through access to communal forests and pastures, where they not only collect fuelwood and graze their animals, but also harvest wild fruit and medicinal herbs. In India, studies have shown that the poorest families meet up to 25% of their needs through these resources (Beck, 1995). Population growth in conjunction with the above-mentioned problem of low and stagnating agricultural production is placing ever greater stresses upon these natural reserves. This further aggravates the insecurity of precisely the most vulnerable groups. Moreover, state policies (such as forestry legislation, nature conservation) often deny vulnerable groups their former access to such resources, thus further contributing to their vulnerability to global risks.
3. *Variability of natural processes and natural disasters.* Major and partly growing seasonal and interannual fluctuations in rainfall constitute severe risks for the poor. This variability increases stresses upon natural resources, e.g. through drought, which leads to increased erosion and diminished surface water and groundwater stocks. Global warming (the climate risk) will most probably lead to increased weather fluctuations and imponderabilities, thus aggravating the danger of famine, particularly in Africa.
4. *Weakening systems of livelihood security.* The dissolution of traditional systems of livelihood security, which are also discussed under the heading of 'moral economy' (Thompson quoted in Beck, 1995), is a particularly severe source of vulnerability for risk-prone groups. If networks of mutual support are weakened, new forms of risk emerge for vulnerable groups (women, children and the elderly) in the event of crop failures or disease. What makes this process so fatal is that traditional systems have generally not (yet) been replaced by new, modern forms of social security. It is particularly in times of crisis that traditional rights are often no longer maintained. Conflicts arise that are generally resolved in favor of the less vulnerable groups, and economic crises often lead households to abandon the principle of mutual support.
5. *Increasing market pressures upon resources.* Economic development is always also associated with the advance of markets. This is leading in many developing countries to natural resources that were previously common property being increasingly privatized and utilized by market forces. Groundwater is particularly important in this connection. This resource was formerly available to all village inhabitants through traditional wells. In many semiarid regions of the world, it is now increasingly being extracted through deep wells. These can generally only be used by means of motor-driven pumps, which only the wealthy farmers possess. Groundwater markets emerge that can greatly exacerbate the harvest and productivity risk for vulnerable groups – at least for the interim and as a side effect of an evolution that is probably positive over the long term.

This discussion shows that it is above all the small farmers and the landless in the marginal agricultural regions of the world whose livelihoods are exposed to particular existential risks. Geographically, these are the arid regions of the Earth, which are exposed to severe drought risks (Cyclops-type risks), the semiarid regions, in which seasonality presents particular problems for agricultural activities, and finally the high mountain regions of the Earth, where the great height differences, the tortuous terrain and the hazards of erosion, earth slides and seasonality lead to existential risks for small farmers and pastoralists. The conclusion to be drawn from this is that policies must focus more strongly on the problems of poverty in the marginal ecological zones of the world (UNDP, 1997). The yields of the traditional crops of these regions have risen only very slightly over the past 20 years, while the green revolution regions have been able to achieve spectacular rises in production. A 'second green revolution' is thus called for. This necessitates research on the sustainable development of marginal agricultural soils. This is an important recommendation of the Council with respect to agricultural research and rural development practice aimed at safeguarding the basis for livelihoods of marginal groups. However, the so-called second green revolution for poor farmers on marginal soils should by no means replicate the 'first green revolution'.

E 2.2.2.2
Determinants of urban vulnerability

While the proportion of the population living below the poverty line is generally lower in cities than it is in rural areas, it is nonetheless considerable. In Africa this proportion averages 29%, in Latin America 32% and in Asia (without China) 34% (UNCHS, 1996). Worldwide, some 330 million people in cities live in poverty. This group suffers above-average exposure to the risks of global change, both in terms of the magnitude of damage and, in some cases, the probability of occurrence. These people are generally completely exposed to the typical urban problems such as air pollution, noise or inadequate hygiene (Cyclops-type risks). The following factors contribute particularly to risk vulnerability in conurbations:

1. *High population density and population growth.* Conurbations and regions with high population densities and growth are always more susceptible to risk than sparsely populated areas. One and the same event, such as a Chernobyl-type disaster or the outbreak of an epidemic, will cause a quite different magnitude of damage, depending upon population density. Continuing urbanization and the emergence of 'megacities' is thus leading to rising local risk potentials.
2. *Urbanization rates in coastal zones.* The rate of urbanization is particularly high in coastal zones; about half of humanity now already lives in a coastal zone. Seventeen of the 25 cities with more than 10 million inhabitants are located on the coast. By the year 2010, some 320 million people will live in such coastal cities (Timmermann and White, 1997). Due to the anticipated sea-level rise, increasing weather extremes caused by climate change, rising salinization of groundwater caused by sea-water entry and changing groundwater levels (a rise endangers built structures, a drop endangers drinking water supply) urbanized coastal regions will emerge as the more risk-prone regions of the Earth. This applies particularly to developing countries and small island states.
3. *Lack of or inadequate social security systems.* Rural-to-urban migration is often associated with the loss of traditional social security systems, which are generally not replaced by other private or public systems. This weakens the capacity to mitigate the probabilities and magnitudes of damage associated with global risks such as natural disasters or chemical risks.
4. *Favela formation.* Unsolved development problems, particularly those in the rural areas of developing countries, are often reflected in the emergence of favelas and slums without adequate public infrastructure. This partitioning within cities also leads to a partitioning of risk potentials. Clustering of infectious diseases and high infant mortality are typical manifestations of this development.
5. *Deficiencies in urban planning and infrastructure.* In developing countries, urban planning, administration and infrastructure are mostly not able to provide basic services to all urban inhabitants. The supply of electricity, drinking water or wastewater disposal services is generally concentrated upon a few districts of the city. A substantial part of the urban inhabitants who gain their living in the informal sector is forced to be self-reliant. Due to these infrastructural and organizational deficits, urban inhabitants are more vulnerable to risk in developing countries than they are in industrialized countries.

E 2.3
Individual strategies for reducing social vulnerability

E 2.3.1
Individual assets for coping with the risks of global change

Against the background of the growing existential risks associated with global change and the particular role of social amplifiers, individuals, households and communities need to develop strategies by which to make themselves less vulnerable to these risks. The decisive aspect here is the capabilities of people to defend their livelihoods and to recognize and exploit opportunities to strengthen their resilience. In the social sciences, the concept of 'assets' has been developed in this connection (Swift, 1989; Chambers, 1997; UNDP, 1997). These assets are essential or helpful to an individual, a household or a group to master existential risks – i.e. to reduce the probability and magnitude of damage as far as possible – and thus to sustain their livelihoods. A variety of types of assets have been identified. Taken together, these are decisive factors in risk prevention (UNDP, 1997):

1. *Economic assets*. These include tangible assets such as arable land, livestock, housing, money and others. In developing countries, land has a key role, as it is in many ways the precondition to other economic assets. However, about ¼ of the rural poor are landless or have insecure tenure.
2. *Social and political assets*. These include the capability of people to utilize relationships to other people in order to buffer risks, for instance in the event of economic crisis or disease. In difficult times usually the support of relatives or other members of the community is sought first. But also the access to possible assistance by institutions and authorities is a part of social capital. Political assets further comprise what is known as 'empowerment'. This includes the possibilities of the poor to articulate politically their needs and problems, and the possibilities of political participation.
3. *Ecological assets*. To maintain their health and gain a living, people are dependent upon natural resources. These include common property resources, which function as a reserve, particularly in times of crisis.
4. *Infrastructural assets*. Access to clean drinking water, to schools, hospitals and other social services is an essential factor of livelihood security.
5. *Personal assets*. One of the most important assets is good health and thus the capacity to work and procure income. Personal assets also include skills and abilities. Time is a further important asset of vulnerable groups that should not be forgotten. If, for example, a large part of working time must be spent to collect fuelwood or for the procurement or marketing of agricultural produce, then little time remains for activities such as tending to children, the sick and the elderly.

E 2.3.2
Exposure and coping

Vulnerability can be described as the exposure of an individual or a household to sudden events or stress and the difficulties in coping with this. Vulnerability has two sides: the *external* side of shocks, stress and risk and the *internal* side of defenselessness, meaning a lack of means to cope without damaging loss (Chambers, 1989). This points to three fundamental dimensions of vulnerability: the risk of being exposed to a stress situation (probability of occurrence); the risk of not being able to respond to a stress event with suitable coping strategies (risk modulators); and the risk that the stress has severe consequences upon the population groups and regions affected (extent of damage). To gain a more precise understanding of social vulnerability, it is necessary to analyze carefully the structure of poverty (Swift, 1989). In addition to economic criteria, this means identifying the position of a person, a household or a group in the societal context, i.e. considering the social, cultural and political dimensions.

The concept of vulnerability has recently gained prominence in risk research in the social sciences (Kasperson et al., 1995) and specifically in hunger research (Downing, 1991; Watts and Bohle, 1993a). Various individual studies (Pryer, 1990; Downing, 1993; Bohle et al., 1994; Kasperson et al., 1995) have shown that vulnerability – as a complex ecological, sociocultural and political-economic concept – is very much better suited than, for instance, poverty or income criteria to identifying and explaining the specific life risk of individuals, households and social groups and their susceptibility to risks (Box E 1.2-3).

First approaches towards theoretically underpinning the vulnerability concept have been developed, focusing on issues of risk exposure, coping strategies and consequential damage. The causal mechanisms of vulnerability have been analyzed from three perspectives (Bohle et al., 1994): human ecology, entitlements and political economy (Fig. E 2.3-1).

The *human ecology* perspective concentrates on people-environment interactions. This is a matter of how, on the one hand, a society approaches its physical environment and experiences specific environmental risks (e.g. drought risks). On the other hand, the natural environment has considerable impacts upon the structure and reproduction of a society. Human ecology is thus an approach that addresses both the environmental risks faced by vulnerable groups

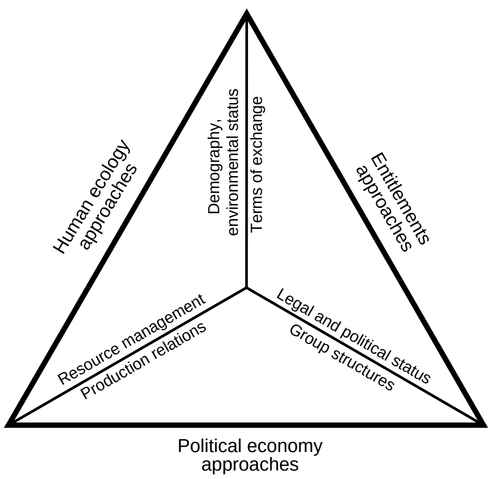

Figure E 2.3-1
An analytical model of vulnerability.
Source: modified after Watts and Bohle, 1993b

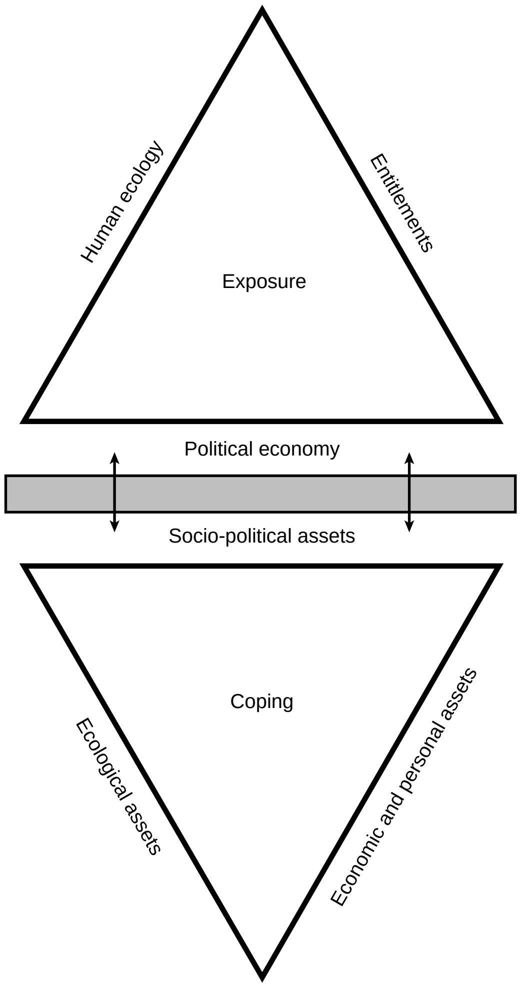

Figure E 2.3-2
The dual structure of vulnerability.
Source: Bohle et al., 1998

and the 'quality' of the resources available to them (Bohle, 1994).

In an *entitlements* perspective, a hunger crisis, for example, is not explained by a lack of food supply but above all by a lack of possibilities to express demand. Such entitlements go beyond the purely economic aspects such as the presence of mediums of exchange with which basic commodities can be purchased, including also socio-politically (e.g. enforceability of basic rights) and culturally mediated (e.g. mutual village support networks or caste membership) entitlements.

The *political economy* perspective asks how entitlements are determined by the political-economic macrostructure of a society. This is a matter both of the opportunities of vulnerable groups to participate, and of nation-state conflicts and crises or poor governance.

In the theoretical model of social vulnerability, the areas of overlap between the explanatory approaches highlight the interplay of individual determinants of social vulnerability, e.g. when population growth and environmental degradation on the one hand and a specific set of use rights on the other hand meet in a particular risk situation (e.g. drought; Fig. E 2.3-1).

However, if we look closer we find that this concept essentially only addresses the first dimension of vulnerability, namely exposure to risks, the 'external' side. It gives too little attention to the coping capabilities of those affected, the 'internal' side. This can be captured by using the concept of assets described above. We therefore depict the dual structure of vulnerability with two mirrored triangles, the one representing the external side of vulnerability as characterized by human ecology, entitlements and political economy, the other representing the internal side with the various dimensions of possible assets for coping with risks (Fig. E 2.3-2). Only the integrative consideration of the two realms of vulnerability delivers a comprehensive understanding of risk exposure and coping potentials.

E 2.3.3
Enhancing the coping capacities of vulnerable groups

With the question "Whose reality counts?", Chambers (1997) provoked a fundamental debate on the realities of life of vulnerable groups in ecologically susceptible regions. He pleads for a perspective from below, informed by the experiences of marginal groups in dealing with risks. Such a perspective concentrates on the local ecological and cultural context, the complexity of risk reduction strategies, the huge diversity of actions and reactions, the ever new dynamic adaptability and the unpredictability of the livelihoods of vulnerable groups. In this analysis, livelihoods and risk reduction are based on three pillars: tangible assets, intangible assets and specific risk reduction strategies. The prime characteristics of livelihood activities and risk prevention are complexity and diversity. There are above all three reasons (Chambers, 1997) for such complexity and diversity. The first reason is to safeguard the basis for livelihoods, by influencing gains of food, income and other resources in number, size and distribution such that making a living is sustained as a whole, no seasonal deficits occur and food and income are as diverse as possible. A second reason is the desire for security, using strategies that stabilize the livelihood and permit its sustainable security. This includes attempts to cushion livelihoods against external shocks and failures such as drought risks (Pilardeaux and Schulz-Baldes, 1998) or crop failures. A third reason is the desire for intangible values. Livelihood complexity and diversity can reduce dependence upon external forces, can strengthen the capabilities of the vulnerable household, can also have a liberating effect and confer self-respect, and serve in general to enhance well-being. This includes the diversity of available food, and of activities such as celebrations, visits and games, which are often very important for the social reality of vulnerable groups in marginal areas.

These risk reduction strategies suggest a reference framework for development assistance measures. Increasing the complexity and diversity of livelihoods and thus also of risk-reducing activities would appear to generally extend the leeway for action available to vulnerable groups. The prospects of success rise with the capacity of vulnerable groups to pursue their own preferences. This calls for a reorientation of relations between development experts and their clientele. Chambers (1997) summarizes this perspective under the catchwords of decentralization, democratization, diversity and dynamics. This new paradigm indubitably entails a reorientation of past development practices in many ways. These concepts offer numerous points at which development officials, politicians and academics should address the issues surrounding social group specific risk minimization.

There is a fundamental need to create a system of indicators for regional and social group specific risk exposure at various levels of analysis. The systematic analysis of the determinants of coping in the context of the livelihood strategies of vulnerable groups has led to the concept of assets with their various dimensions. On this basis, we might construct a mirror image identifying the main risk factors that jeopardize livelihoods. As these risk factors can vary depending upon the level of analysis, it is recommendable to structure such a system of indicators according to the individual, household and group dimensions.

The Council is further of the opinion that there is a need for renewed efforts to develop risk mapping at various scales. The development of such maps that visualize the risks to livelihoods on the basis of indicators has not yet moved beyond a rudimentary stage. Such maps exist as yet solely for the risk of famine. First attempts at risk mapping have been put forward at the global level and the country level. The first map indicating vulnerability to famines (Cyclops-type risk) at the global level was created by Downing (1992). For 172 countries, he constructed three indicators from World Bank statistics and linked them to form a food security index (Downing, 1992; Bohle, 1994). This index integrates the dimensions of food supply, purchasing power and health status. At the country level, three relief organizations have carried out pioneering work in the field of risk mapping: the UN World Food Programme (WFP), the non-governmental organization Save the Children and the Famine Early Warning System (FEWS) project funded by USAID. All three have undertaken extensive conceptual deliberations on the preparation of risk maps; however, at present only the FEWS project prepares such maps on a continuous basis. The Council views the refinement of such maps as an important research objective.

As a basis for this, there is a need for further analyses of the theoretical and conceptual fundamentals of criticality and vulnerability. This above all requires a more consistent linkage of the external and internal risk factors of livelihoods (Fig. E 2.3-2). In the opinion of the Council, such efforts must be concerned not only with identifying the fundamental determinants and dimensions of exposure and coping, but also with determining in the regional and social group specific context the specific relevance of individual risk sectors to the livelihoods of vulnerable groups.

The debate on the realities of vulnerable groups has shown that new methods of rural field research that are not only participatory but also integrate the affected people themselves can yield a new understanding of the actual problems, experiences and needs of vulnerable groups. Such methods have the potential to identify target groups and to recognize the prime hazards posed to the livelihoods of vulnerable groups. Such survey methods can make important contributions to the preparation of indicator systems and risk maps. Manuals, bibliographies and extensive survey material on these methods are now available. However, the greatest problem would seem to be that these methods require a great expenditure of time and emotional input by the researcher. Here the Council recommends that simpler and more practicable solutions be found.

E 3 Examples of complex risks

E 3.1
Global change and human health

Today, the world is inhabited by 5.5 billion people. In 1800, global population totaled only 1 billion. Average infant mortality has dropped from 129 per 1,000 live births in the year 1955 to a present rate of 58 (UNDP, 1997). Average life expectancy in Europe was 50% lower in 1850 than it is today (Deutsche Stiftung Weltbevölkerung, 1998).

This development is due primarily to advances in food production and infectious disease control, improvements in hygiene and the development of vaccines, antibiotics and chemotherapeutic agents. Despite impressive successes in reducing mortality, new human vulnerabilities are emerging and old ones are reappearing. This is caused, directly or indirectly, by global processes of change such as growing urban conurbations, ecosystem stress and degradation and global climate change. International institutions are increasingly concentrating on potential health threats caused by global environmental changes. For instance, WHO and UNEP have stressed their objective of improving the 'surveillance' of mortality and morbidity as a function of climate change (Haines and McMichael, 1998).

In a global perspective, climatic effects may be expected to have major health impacts in the future, too, and could lead to crises in various spheres. Climate-related food crises will above all affect the development of children. UNICEF and WHO have taken up the issue of child malnutrition in developing countries. Protein malnutrition affects every third child in these countries. In India, for instance, every second schoolchild suffers iron deficiency. Iodine deficiency with thyroid malfunctions is estimated to affect more than 1 billion people worldwide. Excessive lead intake has been found to affect 10–17% of English and American children, and up to 90% of children in some African cities (Williams, 1998a). All of the above factors affect brain development and learning ability in children and the intelligence of adults. It is mainly the poorer segments of the population who are exposed to them (Section E 2).

In 1990 the US Congress placed the focus of medical research on diseases of the central nervous system, and declared the 1990s the decade of the brain. While in the industrialized nations this means researching neurophysiological processes and genetic or neurodegenerative diseases, in developing countries it means addressing the neurotoxicological impacts of malnutrition upon brain development.

In 1996, WHO, WMO and UNEP published a joint study (WHO, 1996b) giving a comprehensive analysis of the direct and indirect health effects of climate change. This stresses the growing prevalence of so-called thermal stress and the spread of parasitic diseases, the latter partly being caused by changed biotopes of the vectors of a large number of pathogens. As discussed below, the problems are further compounded by the development of old and new forms of resistance in pathogens and vectors. The increased UV-B radiation levels reaching the Earth due to stratospheric ozone depletion are already having concrete effects upon certain diseases. Other factors such as the globalization of socio-cultural patterns of behavior, with their fundamental imponderabilities, may be assumed to be no less important. Inescapable uncertainties in assessing future global human health result from the interrelations between local and global environmental changes. These can form a web of causation with reciprocal amplification among its various strands, thus assuming considerable complexity. A good example of this is given by, for instance, regional deforestation driven by economic pressures. This can lead to a spread of insect species that transmit diseases, with the outcome of a local upsurge in vector-borne infectious diseases. At the same time, the loss of CO_2 sinks brought about by multiple events of this kind at the global level can lead to temperature changes with countless associated health consequences, such as the spread of further vector-borne infectious diseases caused by habitat shifts of the host organisms.

Another very concrete example of the complex risks of global change is given by the AIDS pandemic. Factors accelerating its relatively rapid spread included international migration, drug abuse and promiscuity. Further amplifying factors include the severe disparities between industrialized and developing countries, and latent infections such as tuberculosis. Although efficient measures by which to control this pandemic are known, many developing countries lack the resources and structures to enforce these. This draws a chain of consequences in its wake, which further restrict existing programs by overburdening their ability to compensate for adverse effects, and moreover further exacerbate the vulnerability of the already infected people.

E 3.1.1
Antimicrobial resistance of pathogens

Epidemics and food crises have always belonged to the main threats facing humanity. Their health effects are often synergistic. Since the introduction of antibiotics, many of the epidemic bacterial infections have been suppressed to a point at which they have been lost from sight. It is forgotten, however, that the interrelationships between host organisms and pathogens are labile and can be influenced by many factors. Completely eliminating pathogens from their host population only succeeds in the rarest cases, such as in the case of smallpox. A confluence of unfavorable factors leads to a resurgence of the pathogens. The increasing development of resistance to antimicrobial agents that has been observed worldwide over the past 10 years in important pathogens is a cause for concern. New forms of pathogen resistance are reported almost monthly in the leading medical journals.

Diarrheal illnesses caused by bacteria (e.g. *Vibrio cholerae*, *Escherichia coli*, salmonellae) and protozoa (e.g. *Giardia*) continue to be the main cause of fatal infections, which total 17 million annually. This class of lethal infectious disease causes some 3 million deaths annually and is the second most frequent cause of infant mortality worldwide. Some 120,000 cases are attributable to infection with *Vibrio cholerae* alone, which has caused epidemics in recent years in South and Central America, Africa, Asia and south-eastern Europe. High population density and poverty continue to be the main amplification factors for this disease (Favela Syndrome: WBGU, 1998a). However, it has recently become apparent that new, complex developments are giving new facets to the simple nexus between poverty, water contamination and dangerous diarrheal diseases, and can produce new vulnerabilities, primarily in the industrialized countries. This is exemplified by the development of resistance to antibiotics in salmonellae. These pathogens can also cause diarrheal diseases through contaminated water or food. Typhus-like epidemics triggered by salmonellae could re-emerge as a widespread threat, as they were in the pre-antibiotics era. In the USA, the typhimurium DT104 serotype of the *Salmonella enterica* strain has undergone a dramatic rise in antimicrobial resistance – from 0.6% in 1980 to 34% in 1996. As this strain has been identified in the samples sent to 36 out of 46 laboratories in the USA, it can at least be said that it is already widespread in that country. It is resistant to five different classes of antibiotics and thus constitutes a considerable threat (Levy, 1998). In the meantime, it has also been detected in a number of European countries, including Denmark. A clear causal connection is seen to the use of large quantities of antibiotics in intensive livestock farming. This development is thus emerging as a considerable human-induced health problem, primarily in the highly industrialized nations. The response to this development has been to establish a national surveillance program for antimicrobial resistance in salmonellae (MMWR, 1996). The EU has recently announced its intention to prohibit some of the eight antibiotics currently permitted as feed additives.

The spread of vector-borne diseases induced by climate change is also a real threat that is independent of disparities between developing and industrialized countries. Vectors (mosquitoes, stable flies, fleas and ticks) transmit e.g. rickettsiae, protozoa, viruses and borrelia to mammals. The main resultant diseases include malaria (e.g. *Plasmodium falciforme*), yellow fever (YF), dengue fever and sleeping sickness (Chagas). Temperature and humidity play a major role in the habitat of the vectors, and it is expected that global warming will lead to areas that currently still have a low prevalence experiencing a distinct increase in the spread of some vector-borne pathogens (Haines and McMichael, 1998). For instance, a climate-related spread of ticks is suspected to be a possible cause of the increasing incidence of tick-borne borreliosis (Brown, 1993).

For vector-borne diseases, resistance can develop in two directions – that of the vectors and of the pathogens that they transmit. This complicates combating such infections compared with infections that require no vector for their transmission. Malaria is a classic example, its history reflecting the complex interrelations among a variety of factors. The introduction of effective pesticides such as DDT was able to suppress the devastating impacts exerted by this disease worldwide. However, in the face of increasing development of resistance, the WHO program for eradicating malaria was abandoned again in 1969 due to lack of success. In some parts of the world, the prevalence of this disease is even rising again. In

1997, malaria claimed approximately 2.1 million lives. Anthropogenic interventions and climatic change leading to expanded pathogen biotopes play a causal role. However, the main causes are at present thought to be resistance of both the transmitting mosquito species (*Anopheles* spec.) to pesticides and of the pathogens themselves (in particular *Plasmodium falciforme*) to chemotherapeutic agents (Diesfeld, 1997).

Mycobacterium tuberculosis, which causes tuberculosis, is a further example of a possibly emerging crisis caused by the development of resistance in 'old' pathogens. At least 35% of the world population is infected with tuberculosis. More than 8 million new cases and 3 million deaths are recorded annually (WHO, 1996b). Upon the initiative of the WHO, epidemiological data on the incidence of antituberculotic resistance were recently surveyed in 35 countries (Snider and Castro, 1998). This survey confirmed the suspicion already expressed in recent years by the Centers for Disease Control and Prevention that the resistance of tuberculosis bacteria to drugs is rising. Worldwide, an average of 10% of tuberculosis strains exhibit primary resistance. The resistance rate of bacteria isolates in treated patients averages 36%, 13% exhibiting multidrug resistance (resistance to more than two antituberculotics). This is an alarming development, considering that the number of drugs effective against tuberculosis is limited. The following prime causal and synergistic factors can be identified:

- Synergism with the human immune deficiency virus HIV is contributing to the spread of tuberculosis, particularly in those regions of the world where HIV infection levels are high. Many of the tuberculosis outbreaks reported with resistant pathogens took place in groups of HIV-positive individuals. Tuberculosis is the best example of the fact that the condition of host organisms (e.g. depressed immune systems or genetic disposition) can massively influence the epidemiology of a disease.
- In countries with poorly structured and underfunded health systems, resistance is created by the inappropriate use of cheap monotherapies instead of the necessary multiple drug therapy. The countries of the former Soviet Union are representative of this, where antimicrobial resistance of tuberculosis pathogens has reached a level of 38%.
- The permanent interaction between *Mycobacterium tuberculosis* and the immune system of the host organism leads to the constant creation of new strains with differing degrees of virulence, and thus constantly new challenges to the public health system and research. For instance, only recently a particularly virulent strain was identified as being responsible for a minor epidemic in the USA (Bloom and Small, 1998). Fortunately, this pathogen reacted sensitively to classic antituberculotics.

E 3.1.2
Health effects of stratospheric ozone depletion

Section D 5 discusses the development of stratospheric ozone and the global impacts of its depletion. The health effects of rising levels of UV-B radiation near the Earth's surface include a rising incidence of various types of skin cancer, cataracts and changes in the immune system detrimental to the course of cancers and infectious diseases. Of these, a particularly notable effect worldwide is the development of skin cancer in people with lightly pigmented skins.

The occurrence of squamous cell carcinoma (SCC) and of basal cell carcinoma (BCC) of the skin, which are in fact the most frequent tumors in humans, is controlled by the lifelong cumulative UV dose and the pigment protection of the skin of affected individuals. Consequently, the highest rates of new cases, which come to approximately 200 per 100,000 inhabitants and year, occur in the fair-skinned population of places with high levels of solar irradiance (such as Texas and Australia). To assess the risk of UV exposure triggering SCC and BCC, it is necessary to know the relative differences in carcinogenic effectiveness and the dose-effect relationships of various UV wavelengths (Diffey, 1998). Extensive data is available for the two types of tumors, so that the following statements can be made: 1% ozone depletion leads to an 1.2–1.4% increase of the carcinogenic effect by UV-B and a rise in SCC incidence of 3.5%. In the event of a persistent ozone depletion of 10%, a roughly 20–35% rise in the incidence of the two skin tumors must be expected, although for the individual adult only a small total extra lifetime risk arises of less than 5%. However, in such a case the lifetime risk of children living today would be 10–16% higher. If the production and consumption of ozone-depleting substances continues to be reduced pursuant to the Montreal Protocol, the lifetime risk of these children of developing one of the two skin tumors is probably less than 10% (Slaper et al., 1996). It is to be hoped that the public perception of these risks will lead to modified patterns of behavior with regard to sunlight exposure, thus attenuating the predicted rise.

For malignant melanoma skin cancer, too, decades of research efforts have yielded convincing evidence that UV radiation is the prime causal factor in its occurrence. This tumor very often already forms metastases from a thickness of 1.5 mm, and can then generally no longer be healed. As opposed to SCC and

BCC, the additive UV dose received is only decisive for the formation of one of the known types of malignant melanomas. For the most common type, the superficial spreading melanoma (SSM), there is no linear connection to UV exposure. Here the number of sunburns in childhood and adolescence plays a much larger role. The latent period between frequent sunburns and the occurrence of the tumors comes to 20–30 years. The sensitivity of the young skin explains the predominant prevalence of SSM in younger and middle-aged persons. The incidence of this dangerous tumor has risen greatly worldwide over the past 30 years (from <5 to approximately 40 new cases per 100,000 inhabitants and year in some countries such as Australia). This has been particularly so in the industrialized countries, and has been amplified by globally changed patterns of behavior (clothing, holiday habits). By the year 2000 the risk in the American population of contracting a melanoma is expected to be 1:75 (WHO, 1996a). In some countries, such as Australia and Scotland, the steep rise in the incidence of this highly malignant tumor affecting younger people has led to extensive educational campaigns, training programs and the marketing of highly effective protective lotions and clothing. However, only these two countries have yet succeeded in slowing down the growth of melanoma incidence. In Australia, a drop in death rates was recently recorded for the first time (Giles et al., 1996). Education programs aimed at modifying behavior are presently the only effective measures. They need to be complemented by targeted research on therapeutic options.

E 3.1.3
Are allergic diseases increasing due to global environmental changes?

A series of epidemiological studies have pointed to the conclusion that allergic diseases, such as allergic asthma, hay fever and so-called atopic eczema (a severe chronic inflammation of the skin) are on the rise (Wüthrich, 1989). A worldwide survey carried out using questionnaire and video association techniques has shown that asthma, with a prevalence of approximately 25% in 13-year-olds in e.g. England, is currently one of the largest morbidity and mortality factors in childhood (ISAAC, 1998). A further survey carried out in England has shown that atopic eczema affects 1.4 million people there and causes annual costs of about £ 450 million (Herd et al., 1996). Similar figures have been reported for some areas of the USA. Atopic diseases are caused by a complex interplay among individual genetic and various environmental factors. Studies in China and Africa have shown that with the same atopic sensitization rates the prevalence of allergic asthma can vary greatly from region to region (Leung, 1997; Yemaneberhan et al., 1997). Allergens (allergy-triggering substances) in the outdoor (e.g. pollen) and indoor (e.g. mite feces and mite body antigens, or antigens associated with animal hairs) environment are sensitizers and triggers, depending upon their quantity. Although much scientific attention has been devoted to these diseases over the past 10 years, many questions still remain unsolved.

The findings made to date indicate that in addition to quantitative differences in allergen exposure a series of further environmental factors are important for the formation of atopic diseases. Anthropogenic forms of air pollution have repeatedly been thought to be the culprit in recent years. Animal experiments have indeed yielded indications that the rate of sensitization to pollen allergens may be influenced by certain substances such as formaldehyde and sulfuric acid (Osebold et al., 1980; van Loveren et al., 1996; Riedel et al, 1996). In humans, however, the connections are still unclear. A proof of enhanced sensitizing properties of pollutant-modified allergens has yet to be delivered. Epidemiological studies have noted that the prevalence of atopic diseases is highest in anglophone countries. In a simplistic manner, this has repeatedly been viewed as a proof of the causal role of transportation and industrial emissions. Two recently published major epidemiological studies have now both shown that the extent of anthropogenic air pollution cannot by itself be evaluated generally as an amplifying factor. These studies come to the conclusion that asthma has the highest prevalence in some regions of the world where air pollution levels are very low, such as New Zealand (ECRHS, 1996; ISAAC, 1998). China and eastern Europe, with their partially very high levels of air pollution by particulates and sulfur dioxide, have low asthma prevalence throughout, while western Europe and the USA, with differently composed air pollution and high ground based ozone concentrations, exhibit an intermediate prevalence of asthma. German studies comparing the situation in eastern and western Germany have similarly underscored the importance of the quality over the quantity of emissions (von Mutius et al., 1992; Schäfer et al., 1995).

In addition to the quantities and qualities of allergens in the environment, recent findings suggest that social factors such as vaccination behavior and family size also influence the prevalence of atopic diseases (Shirakawa et al., 1997). It has at least become amply clear that the interplay among triggering environmental factors as contributory causes of atopic diseases - the prevalence of which may well have risen as much as tenfold over the past 50 years – is complex and differs greatly from region to region.

Substances emitted to the environment must be examined separately, and their relevance can only be assessed properly if the other, already known individual disposition and risk factors are taken into consideration at the same time. Intensified epidemiological research that considers both the environmental exposition and genetic disposition of individuals studied is necessary, as is further research on the immunological connections.

E 3.2 Global change and food security

E 3.2.1 Introduction

Global food security continues to count among the prime challenges to research and public policy. In total, some 800 million people suffer hunger and undernutrition, about 200 million children suffer protein deficiency. This situation would be far more dramatic if the Green Revolution had not delivered an unprecedented increase in food production (WBGU, 1998a). Over the past 25 years, it has been possible to raise per-capita food availability from 2,440 kcal day^{-1} to 2,710 kcal day^{-1} – despite the world's population having grown over the same period by approximately 1.6 billion people. However, this positive development is compromised by severe regional disparities in food availability. While per-capita availability figures 2,520 kcal day^{-1} in the developing countries, a value of 3,330 kcal day^{-1} is reached in the industrialized countries. This means that in sub-Saharan Africa, for instance, per-capita availability is some 20% below the global average.

The presently available dietary energy suffices to feed the world's present population. However, it is distributed very unevenly across the globe, and in some cases also across regions. Poverty remains the main reason for this disparity. Demographic developments will change the situation by the year 2020. The latest FAO forecasts assume that food production needs to be increased by 75% in order to provide an adequate food supply for the world's population in the year 2020. This figure illustrates the huge challenge posed by global food security. It needs to be kept in mind here that food security is not only a matter of producing and distributing food in order to satisfy basic needs, but also includes the institutional framework that allows people to gain access to food in sufficient quantity and quality.

E 3.2.2 Structural changes in food production

The production of food, particularly of cereals, has undergone enormous change in the 20th century. It is this that has made it possible to feed the growing human population. At the same time, however, a series of new risks have emerged in conjunction with this positive development in agricultural production (Green Revolution Syndrome: WBGU, 1998a), which, in conjunction with factors extraneous to agriculture itself, have the potential to endanger global food security. In the industrialized countries, what was once a subsistence-oriented agricultural system has evolved into a highly modernized production system. In the developing countries, too, the Green Revolution has brought about fundamental changes in traditional farming practices. Both systems are greatly dependent upon the input of nonrenewable energy and materials (mineral fertilizers).

Intensive farming practices are typically characterized by their relatively low biological diversity of crop species, crop rotations and types of seed utilized. Monocultures, in particular, are highly vulnerable to excessive insect multiplication or to fungal attack. Resultant crop losses count among the risks that can very rapidly develop catastrophic effects in a region. Future forms of agricultural production need to give greater attention to the value of biological diversity. This implies soil-conserving tillage, diverse crop rotations, avoiding nutrient surpluses, preserving or restoring diverse landscape structures and keeping numbers of livestock appropriate to the available area.

The greater amount of care required by high-yielding crop varieties, such as the precise control of the quantity and timing of inputs of water, fertilizers or plant protectants, in conjunction with dependence upon external inputs such as fertilizers, seed, loans or advice amplify the vulnerability of the food production system to human failure, market failure (such as the failure of fertilizer or seed supplies) and environmental degradation. At the same time, however, such agricultural systems are highly productive. Research has shown that in addition to the above systemic factors, the risks of food production can be further amplified by the susceptibility to crisis of distribution networks for agricultural inputs (Pilardeaux, 1995). For example, food production crises can already be triggered by a loss of rural finance systems or of secure subsidies, such as for fertilizers. A further risk can stem from the unconsidered adoption of cultivation strategies that were successful in different ecological and social settings.

Inappropriate agricultural systems are not only unstable, but also have negative impacts upon their natural environment. In its 1997 annual report, the Council has discussed in detail how inappropriate irrigation can lead to soil waterlogging and salinization. Soil degradation can also result from the creation of the very large plots required by mechanization, if no space is provided any more for the bushes and trees that previously contained wind erosion. Declining biological diversity has repercussions upon the future prospects of food production, as it diminishes the genetic resource basis which is essential for plant breeding. At the 1996 International Conference on Plant Genetic Resources organized by FAO, debate centered on this aspect and the resulting risks to world food supply.

Intensive, high-yielding agricultural production systems generally have a higher water requirement than traditional forms of arable farming and thus exacerbate the utilization pressure upon local resources, such as through the use of deep wells and the exploitation of fossil groundwater reserves. They are generally also more dependent upon regular water supply, meaning that they are less drought resistant. Much the same can be said of their fertilizer requirements. Some high-yielding varieties are highly sensitive to parasites and pests, some also to frost or salt. It depends greatly upon the local conditions whether one or the other characteristic of an agricultural system emerges as a risk factor or not. This general weakness of agro-ecosystems has to be compensated for by means of corresponding cultivation effort and countermeasures. The further development of site-appropriate, adapted utilization strategies is an urgent task. It can only be mastered successfully if the requisite ecological, economic and social information is generated and disseminated.

The task of securing food supplies for a growing population is faced by a fundamental dilemma. If the people suffering malnutrition and hunger are to be fed by conventional methods, production would need to almost double over the coming 30 years. If levels of productivity remain where they are today, this surge in production would only be possible at the cost of the still remaining forest and grassland areas, which would then further decline. The higher levels of food production necessary to meet the demands of a growing world population increases utilization pressures upon natural resources. This is compounded by the circumstance that in many areas the performance of agricultural systems is jeopardized by increasing environmental degradation.

E 3.2.3
Impacts of global environmental change upon food production

Soil degradation

Worsening soil degradation (WBGU, 1995a) is one of the insidious risks that jeopardize global food security. Year for year, the basis of food production dwindles due to the partially irreversible loss of valuable arable soil, and due to its degradation. Arid regions are particularly vulnerable. Some 250 million people are directly affected by desertification, about 1 billion are at risk. In the arid, semiarid and subhumid regions of the world, about 20% of the land surface is affected by desertification. In response to this, a UN Convention to Combat Desertification (CCD) has been adopted (Pilardeaux, 1997).

As set out above, the present cropland area will only suffice for food production if it proves possible to double or quadruple yields. To achieve this goal, it would be essential to halt soil degradation and to restore as far as possible the damage already inflicted. Even today, cropland is exhibiting severe damage, thus underscoring that previous soil utilization strategies – including traditional ones – are by no means sustainable. It further illustrates that the partially spectacular yield improvements brought about by irrigation, fertilizer application, plant protectants and agricultural machinery, and by the use of new, high-yielding plant varieties, have come at the price of intolerable degradation of soils. Twenty million km^2 of the land surface now exhibit visible human-induced damage. Of these, 39% are located in Asia, 25% in Africa, 12% in South America, 8% in North America, 11% in Europe and 5% in Oceania. Water erosion is the dominant cause with 56% of the area, followed by wind erosion (28%), chemical degradation (12%) and physical degradation (4%; Oldeman, 1992).

It is due to the diversity of soils and their often very slow processes of change that their advancing human-induced jeopardy has as yet scarcely attracted public attention, still less as a worldwide crisis. A further cause of the lack of awareness is that a growing part of the world population lives in cities, which leads to an increasing alienation from the natural bases of human existence. With this is associated a decline in general willingness to take the steps necessary to preserve these bases and to bear the concomitant costs. Combating soil degradation and raising awareness of the associated risks are important tasks in efforts to overcome the food crisis. Extending the Desertification Convention to a global soil convention, as the Council proposed in 1994, could be an important step towards solving these problems.

Global climatic changes

The new special report of the IPCC on the regional impacts of anticipated climate change shows clearly that the impacts of climatic changes upon food production are still subject to major uncertainty. Africa has been identified as the world region most susceptible to the risks of climate change (IPCC, 1998).

It is not known whether global food production will profit from the anticipated climatic changes or not. For instance, one question is whether a drop in yields in Latin America could be balanced quantitatively by the possible utilization of Siberian permafrost soils, and if so whether the resultant social and ecological problems can be managed at all.

Altered precipitation patterns will above all harm agricultural production in rain-fed cultivation areas, while drops in groundwater levels or the intrusion of sea water into coastal groundwater will above all harm the large irrigated regions. If precipitation regimes shift, it must be expected that agro-ecological zones also shift. If these processes evolve slowly, an adaptation of societies is at least conceivable, but the effects that may result from sudden changes are still largely unresearched.

Weather extremes have always presented unpredictable risks to agriculture and have repeatedly triggered famines. It is clear that an increasing incidence of weather extremes harbors a high risk to global food security. This was amply illustrated by the El Niño event of 1997/98. The magnitude of such risks depends upon global grain stocks and further upon smooth distribution in the event of a disaster. With its monitoring systems, FAO is making a valuable and increasingly important contribution to provisioning against such risks. However, without a sufficiently large buffer in the form of grain stocks it will not be possible to react swiftly.

Freshwater scarcity and pollution

Utilization pressures upon water resources are rising worldwide (WBGU, 1998a). It is clear that water availability will have direct impacts upon agricultural production. Even today, 70% of the water utilized by human society is deployed in agriculture to produce food. Forty percent of global food supply is produced in irrigated cultivation. In future, more food will need to be produced with less water, meaning that the efficiency of water usage must be improved substantially. The Council has already pointed out the necessary reduction of losses in irrigation (WBGU, 1998a). In some regions, acute water shortages will arise that can no longer be compensated solely by seasonal rationing of water supply. As food is not a substitutable good, bottlenecks or necessary imports will impact directly upon prices, with the possible consequence of purchasing power related food crises. It is thus essential that in regions where soils have poor carrying capacity non-farming employment alternatives are created for the population.

The greatest risks to food supply arise in the arid and semiarid regions, where drought events have shown in the past how narrow the regional food leeway already is, and where competition for limited freshwater resources will be at the cost of agriculture. Famine early warning systems have already been established for Africa, in order to be able to provide timely relief in collaboration with the World Food Programme (WFP) and other organizations in the event of an emergency. A global risk would arise if such events cumulate and occur simultaneously in many areas of the world.

E 3.2.4
Impacts of globally relevant societal developments upon food production

Population growth

World population is continuing to grow, if at slightly lower rates. The still high growth rates in Africa (about 3%) and in Asia and Latin America (almost 2%) make it appear probable that the population will grow from a present level of 5.7 to over 6 billion in the year 2000 and 7 billion in the year 2010. It is expected that by the year 2010 more than 80% of the world population will live in Asia, Africa and Latin America. If FAO forecasts for population development and food production prove true, the number of chronically undernourished could drop slightly in almost all developing countries – from a total of 809 million (1990–92) to 730 million in the year 2010. The undernourished proportion of the world population would drop from 20% to about 13% according to FAO figures, with the exception of sub-Saharan Africa, where an absolute increase by 302 million people is forecast. This means that by the year 2010 one third of the population of Africa would be undernourished if no countermeasures are taken. Africa remains the focus of efforts to combat hunger, as was stressed at the 1996 UN World Food Summit. However, the FAO forecasts do not give adequate consideration to the dynamics of global change; for instance, it cannot be estimated with certainty what role climatic changes and soil degradation will play.

Urbanization

Through continuing urbanization, global food security will become more and more a logistic problem and a question of food distribution. In the year 2000, half of the world's population will live in cities. This figure is in the order of the entire world population in 1960. The consequence is that for more and more people, food security depends upon their purchasing power. Food crises thus have both a production component and a supply component. The world cereal markets already react extremely sensitively today. Even the announcement of an El Niño suffices to generate substantial price rises.

This is compounded by the circumstance that worldwide agricultural production is increasingly concentrated upon a few core regions. Food is distributed from these surplus regions throughout the world. Food security is thus becoming more and more dependent upon the dynamics of the global markets. Within individual countries, too, a substantial part of food production is increasingly concentrated upon a few regions ('granaries'). This is a development that has been intensified by the Green Revolution, which overproportionately profited traditional irrigation regions. Such systemic changes constitute a risk-amplifying factor.

Development disparities

The risks of food security are distributed unevenly, both spatially and across social groups (Section E 2). It is mainly the developing countries that are exposed to the risk of famine. In these countries, four segments of the population can be distinguished that are particularly vulnerable to food crises:

- The poor in rural areas who do not have sufficient means of their own to produce enough food. These include small farmers and fishers, and nomads.
- The poor in urban conurbations, who do not have sufficient income to purchase enough food.
- Refugees and displaced people who are the victims of natural and man-made disasters or wars.
- Women, children, the elderly and in some cases also ethnic minorities, who are generally vulnerable to food crises due to the disadvantaged position that they have in many societies.

E 3.2.5
Intersections between the problems of global change and food risks

As the analysis has shown, hazards to food security result from an array of risks associated with the problems of global change. The core problems of global change – such as soil degradation, freshwater scarcity, climate change, increasing incidence of weather extremes, loss of biological diversity, population growth and rising development disparities – combine with the intrinsic risk aspects of intensive modern and in some instances also traditional agricultural systems to produce a quality of risk that is new and unknown.

Forecasts of population growth and of the potentials to increase food production underscore that the phase of cropland expansion in favorable areas is largely concluded and that increasingly less suitable soils must be utilized. Humankind has already entered the next 'stage of escalation', in which production improvements can essentially only be expected through improving per-hectare yields. This is why all opportunities to promote an appropriate, sustainable and environmentally sound utilization of soils must be exploited. This includes utilizing the opportunities held out by biotechnology and genetic engineering (Section D 4).

The modern agricultural systems have themselves experienced changes that make them increasingly susceptible to the dynamics of the world market. Here particular attention needs to be given to possible deformation or collapse of distribution networks for agricultural inputs caused e.g. by price rises and production or transport bottlenecks.

In sum, the Council is of the opinion that global food security is one of the prime challenges faced by the academic and political communities and by society at large, as in this domain the imponderabilities and potential magnitudes of damage are particularly large. Global food security risks count among the risks of global change that need to be addressed by society in an iterative manner, i.e. through step-wise scientific analysis and continuous political re-evaluation of changing situations. Moreover, there is a major and presumably long-term need for further research in order to gain an improved understanding of the dynamics of global food security and global change. Both production- and distribution-related aspects need to be considered. In its previous reports, the Council has already submitted proposals on individual aspects of this complex (WBGU, 1995a–1998a).

E 4 Risk potentials of complex environmental systems

Nature, human civilization and the diverse interconnections between the two form a complex, dynamic system. It is an essential characteristic of such systems that they cannot be fully represented by the analysis of their various subsystems.

At the interfaces between these subsystems, we generally find high rates of material and energy exchange, often controlled by feedback mechanisms, with internal dynamics that vary over time. The overall character of the system, particularly with regard to its response to internal or external perturbations, thus differs greatly from the simple sum of its subsystems. It is further characteristic of complex environmental systems that they are usually in a state of disequilibrium influenced or controlled by external factors. This is exemplified by agricultural landscapes or managed coastal zones with high material and energy inputs.

The syndromes of global change are the outcome of anthropogenic interventions in the environment (Section E 4.2). Their characteristic patterns of damage to humans and ecosystems form complex, multicausal webs of effects that cannot be represented as linear cause-effect chains. These patterns can be identified in similar forms in different regions of the world (WBGU, 1997a). In the language of systems theory, they represent an array of apparently stable but risk-prone patterns of the complex 'system of global change'.

E 4.1
A systems analysis perspective on complexity and risk

Particular risks reside in the circumstance that environmental systems are not structurally simple, linear systems. The theory of nonlinear dynamics and the theory of complex systems offer tools by which to understand these complex risks. The following section briefly presents these tools. They can be used to analyze, structure and classify the special features of such risks; in certain cases they can also be used to develop appropriate strategies for mitigation.

E 4.1.1
Characteristics of complex systems

In order to evaluate the susceptibility of complex environmental systems to perturbations, we must first examine the forms of system reaction, behavior and transition and regime shifts. These shifts can bring about lasting changes in the character of a system. Thus not only the mean values and variabilities of observable quantities may change, but completely new structures or interconnections may emerge (system topology or dimensionality).

The special character of complex environmental risks is based above all upon two fundamental characteristics of dynamic systems: nonlinearity and complexity. Nonlinearity means that the cause-effect relationships in a system are not proportional. Thus a continuously growing disturbance may remain without effect over a lengthier period, but then suddenly trigger a system flip. Complexity refers to the intermeshing of individual subsystems with the result that essential aspects of the overall system cannot be understood by analysis of its parts. Such complex systems exhibit a series of new phenomena (emergent properties) which cannot occur even in intricate linear systems. Nonlinear effects that only become dominant when forces, perturbations or excitations are large can in fact determine the structure of the overall system. In linear theories, these effects are viewed as negligible 'minor perturbations' because when forces are low their relative magnitude is negligible.

This results in an essential characteristic of complex environmental risks: the behavior of such systems generally cannot be predicted over the long term. This phenomenon, known as *chaotic dynamics*, can occur even in apparently simple systems whose changes follow deterministic rules (e.g. the nonlinear pendulum; Duffing, 1918). Although the mechanisms of weather events, for instance, are well known, they cannot be forecast over the longer term. In fact, it has been shown here that even an exceedingly simplified model of weather exhibits a highly complicated behavior (Lorenz, 1964). Moreover, complex systems can undergo sudden behavioral swings that change their structure, triggered by only slight quantitative changes in external influences. Such situations are termed 'bifurcations' and can be classified in terms of their patterns of behavior and transitions (Guckenheimer, 1990). For instance, in limnetic ecosystems population explosions of algae (algal blooms) can occur through only slight rises in pollutant discharges. A further everyday example is the conversion of water to ice caused by an only slight change in temperature close to the freezing point, with the result that the water runoff regime of a region is suddenly and critically changed. A further critical aspect in complex environmental systems is that they are generally only incompletely understood. Stable long-term behavior can be confused with slow transition (transients; Braun and Feudel, 1996). A possibly inappropriate extrapolation of the behavior of environmental systems can then lead to misjudgment of their long-term behavior, with severe consequences.

In addition to the above characteristics of nonlinear systems, there are a number of related phenomena that can be grouped under the heading of *structure formation*: these include pattern formation in space or time (Kai, 1992; Grebogi and Kurths, 1995), self-organization and synchronization (Rosenblum et al., 1996), self-organized criticality (Bak et al., 1987), self-similarity, intermittency (Daviaud et al., 1992), turbulence, strange attractors (Lorenz, 1964) and bi- and multistability (Feinberg, 1980).

To illustrate the phenomenon of multistability, we may consider a hypothetical planet. The global climate of this planet can have one of two very different states, each of which is stable; either it is an 'ice planet' or a 'desert planet' (Budyko, 1969). One avenue by which the planet can flip between these two states is the occurrence of a major external disturbance (e.g. a meteorite impact). Here there is not necessarily any form of corresponding 'inverse disturbance' that might reverse the transition back to the other state.

The other avenue is much more dangerous, namely a transition in the form of a *bifurcation*, i.e. a sudden swing in the system perhaps triggered by only a slight change in external influences (e.g. the absorptive behavior of the atmosphere). The danger inherent in this scenario is that even if the external influence ceases immediately the system will only return gradually and perhaps by circuitous paths to the former state (hysteresis). Similar hazards can arise from the metastability of a system, in which the present state is only apparently stable but can in fact switch to another, more stable state without external triggers.

Conversely, nonlinearities can also attenuate runaway processes, thus preventing extreme system evolutions. In such cases, they become guarantors of the stability of the overall system.

In order to gain a first overview of the possible risks associated with an environmental system, all structure formation phenomena of the system are entered in diagrams (known as bifurcation or phase diagrams). These diagrams are created by entering on a pattern chart those domains in which the system exhibits uniform behavior (Guckenheimer and Holmes, 1990). The theory of nonlinear dynamics provides mathematical methods and numeric algorithms for this (Jansen, 1995; Seydel, 1988). The systemic properties of individual domains differ not only in degrees but also in qualities (e.g. stable ↔ unstable, oscillatory ↔ chaotic ↔ turbulent, liquid ↔ solid ↔ gaseous). Bifurcations generally occur at the domain boundaries. In view of the circumstance that these bifurcations can have dramatic consequences, this discipline is known in mathematics as catastrophe theory (Arnold, 1992).

If we know the bifurcation diagram of a system and further know the external influences or parameters (e.g. climate, elemental loading) to which it is subject, then we can chart the regime in which it is situated. We can state how far removed it is from a possible 'catastrophe', i. e. a bifurcation. We can further identify the direction in which the parameters must be influenced in order to stabilize the system and prevent a bifurcation. This of course presupposes that these parameters can be influenced at all or are technically accessible.

In most cases, the question of the future development of a system cannot be resolved on the basis of the bifurcation diagram alone. Here the extreme sensitivity of many systems to minor perturbations plays a pivotal role. Under certain preconditions, the interplay between complexity and nonlinearity leads both to an exponential spread of small perturbations and to an exponential growth of uncertainty attaching to small measurement errors, without the entire system collapsing straight away (chaos regime). The perturbation or uncertainty then spreads throughout the system in the shortest time, meaning that predictive uncertainty comes to 100%. This effect is frequently rendered in a simplified form in the popular sciences as the 'butterfly's wing effect' (while usually failing to mention that certain preconditions must be given for this). In the case of linear error propagation, in contrast, a 5% initial error leads to a 5% deviation throughout. Due to the exponential growth of the error in the chaos regime, it is generally impossible to predict the behavior of such a system beyond short intervals, nor can this be compensated by increased computational effort. This fundamental impossibility of long-term prediction of the behavior of many environmental systems makes it all the more necessary to gain a qualitative understanding of general system characteristics, such as stability. This is precisely what bifurcation analysis can provide and can depict in the diagrams described above. However, it remains to be noted that transitional (transient) behavior is sometimes hard to distinguish from 'real' chaos.

E 4.1.2
Risk potentials of complex systems

In the following, we shall discuss three representative systems that exhibit a high risk potential due to their structural complexity – the complex behavior of ecological, economic and social systems. Many of these phenomena can be explained at least qualitatively. However, a comprehensive analysis of ways in which to exert a targeted influence on such systems yet remains to be delivered (Section E 4.2). Here the Council sees a major need for research.

At first sight, it may appear hopeless to represent and explain social systems in mathematical terms by reducing them to a small number of parameters. That this is nonetheless feasible is mainly attributable to two reasons. One reason is that statistical methods can be applied at the population level. Thus while we cannot forecast which couples will marry when, the average number of marriages per year can indeed be predicted. Such statistics disregard the individual fate but are nonetheless able in many cases to model overall behavior. The second reason is that individuals do not act independently. This is exemplified by the collective phenomenon of panic selling when share prices drop below a certain level. As discussed in the previous section, it is precisely these types of coupling effects that lead to complexity-related risk potentials that can be analyzed using the theory of nonlinear dynamics.

Ecosystems: Arrangements among the species
The hierarchy of resource utilization in an ecosystem, frequently termed a food chain, is revealed upon closer scrutiny to be a complex of fine-meshed 'food webs'. The diverse biotic interactions of the species involved (predator-prey relationships, competition, symbiosis etc.) can contribute to stabilizing the overall system. All members have several functions (production, consumption, destruction) at the same time within the energy and nutrient flows of the system. It is this multilayered characteristic that permits the ecological system to react to external influences, thus maintaining its present equilibrium or establishing a new one. It is characteristic of networks of interrelations that have evolved over long periods that consumers exist which recycle and further convert many ('waste') products of the individual processes. The system is in a self-stabilizing flux equilibrium (steady state), in which the main material fluxes are linked with each other by negative feedback loops through the species involved. The overall behavior of the system is thus fairly resilient to disturbances.

This is contrasted by the artificial ecosystems of our human civilization. Changes take place on short time scales in terms of evolution history, and individual products generally exhibit high input or output rates (pollutant discharges, monoculture harvests). The new system state that emerges is not in material equilibrium; individual substances accumulate (e.g. soil acidification) or nutrient deficiencies arise. Flora and fauna are exposed to major short-term adjustments – the system can undergo structural change or may 'flip'. At the very least, the internal self-stabilization potential of the ecological system is massively impaired and is no longer able to withstand additional disturbances that may also be of natural origin.

This risk characteristic is exemplified by disturbances of the ecological equilibrium between fire events and biomass stocks (Holling et al., 1996). Until recently, the structure of this equilibrium in ecosystems was not fully understood. In many ecosystems, a self-stabilizing control capacity has evolved over long periods, so that disturbances caused by fire or insect pests do not endanger the long-term viability of the system; on the contrary, they may even be necessary for its continued existence. This equilibrium can be rendered unstable by misconceived forest fire protection strategies aimed at immediately extinguishing smaller fires. Over the medium to longer term, large quantities of combustible biomass then accumulate, with the result that small fires can precipitate large-scale destruction.

Economies: Synergistic effects
Economic systems, particularly those geared strongly to market principles, exhibit certain similarities to ecological systems. A large number of actors (producers, consumers, state actors) are connected with each other through markets, integrate their own expectations of the future (e.g. trends, but also the risks and opportunities of innovations) in their individual planning and are thus obliged to continuously adjust their plans. Prices represent crystallized information, e.g. on the willingness to pay of demanders. Driven by the quest for economic benefits or individual utility maximization, producers strive to attract demand and cut costs. Strategies to do so include developing new products and production processes, or improving the organization of procurement and marketing channels.

Via relative prices, demand is modified by quantity effects and substitution effects, whereby new styles of consumption can also emerge. Competition, which continuously leads to the devaluation of conventional products or production schemes, generates high adaptive flexibility and efficiency among producers through adaptation to demand and the continuous production of new knowledge. Given constancy or calculability of political framework conditions and validity of the liability principle, a long-term orientation with risk-reducing effect will emerge (Section F 2). This is particularly so if as many of the costs and benefits of production as possible are integrated in individual profit and loss planning. These systems may be viewed as a searching process that can guarantee a high degree of self-regulating societal sustainability. Where there is high price flexibility and mobility, these systems are well able to withstand shocks and disturbances. However, this robustness does have its limits. If these limits, which are difficult to define a priori, are overstepped, a collapse in the performance of economic systems can occur, with a corresponding loss of wealth.

Problems arise if discontinuous political signals or inflationary framework conditions lead to short-term orientation and over-reactions. Similar effects can occur if economic systems are overburdened by state activities, or if an absence of competition leads to a homogenization of the planning decisions of individual economic units. If technological lines or specific forms of behavior (such as consumption habits) then become dominant in a one-sided fashion, development tendencies with higher risk potentials can set in. To the degree in which globalization and internationalization lead to the emergence of powerful global corporate networks, the capability of nation states to control economic systems, which has already been low enough in the past, drops further. International efforts must then create incentive systems that ensure greater long-term orientation and a risk-reducing evolution of knowledge. Such efforts include securing worldwide competition, enforcing the liability principle, creating stable political framework conditions and reducing inflation risks.

Societies: Are revolutions predictable?

To make it clear from the start: no, they are not. Nonetheless, there are indeed recurrent regularities that are quite typical of complex nonlinear systems. From these, in turn, we may derive indicators of susceptibility to upheaval.

Individuals, being integrated in a social system, do not act independently of each other. Prevailing public opinion thus becomes a collective phenomenon. This exhibits aspects of nonlinear dynamics, such as feedback effects through communication and mass media, sensitivity to small perturbances (popularity swings caused by single statements of politicians) or critical states (such as the major predictive uncertainties attaching to election outcomes in situations of crisis, with the possibility of political upheaval).

The dynamics are exemplified by the outburst and extinction of fashionable trends. At first, the time must be ripe for the trend (critical state). This is often brought about by novel technical possibilities (such as cellular phones) or by an image loss of previous products. To precipitate the wave, it then suffices for a small group to initiate a self-amplification process. Beyond a certain degree of product awareness, the product rapidly becomes standard in the media and among the public. As the mass media in particular depend upon their clients, more specifically their interests and preferences, a further amplifying feedback effect occurs.

This can be transferred to political propaganda, following similar regularities that are often exploited in practical politics – destabilizing the system while at the same time forming a new leadership elite that can function as agent provocateur. Similarly, but with an opposite sign, dictatorships strive to control and suppress communication – and thus coupling and feedback – precisely in order to prevent such critical states arising.

E 4.1.3
Controlling complex systems: Prospects and limits

Opportunities are in principle available to apply controlling interventions to nonlinear systems before accumulated errors have become uncontrollable (Shinbrot et al., 1992; Pyragas, 1992). Permanent control, even of chaotic behavior, can thus be achieved in principle. A variety of approaches have been developed, the best known of which is the OGY method named after its developers Ott, Grebogi and Yorke (Ott et al., 1990). Apart from such methods, 'conventional' control engineering techniques can often be applied to influence nonlinear systems (Slotine and Li, 1991).

Despite many advances and successes in the understanding and modeling of complex systems, there are limits. Environmental systems in particular are very high-, often even infinite-dimensional (continuum systems), thus transcending the analytic and numeric capabilities of present science and computer technology. Conventional control strategies similarly only function in finite (in particular low-dimensional) systems.

Moreover, most environmental systems are only incompletely known or measurable. The phenomenon of error amplification discussed above means that neglected influences may jeopardize the whole analytical enterprise. Moreover, even if a perfect control strategy is available, the selection of the 'desired' state may depend upon non-systemic interests. Finally, it needs to be kept in mind that a controlled system is a new and possibly more complicated system that may behave differently due to interventions and possible feedbacks.

A new and promising approach by which to take into consideration incomplete system knowledge and the impossibility of long-term prediction is known as *fuzzy logic* (Böhme, 1993). With this technique, soft – 'fuzzy' – criteria are used to take decisions only for the immediate next step in order to achieve a global goal or to prevent a hazardous situation (Schellnhuber and Wenzel, 1998b). Fuzzy logic has proven its usefulness particularly in such situations where the system is not described completely or functional relationships between system components are only known qualitatively. In such situations, fuzzy control also offers an opportunity to utilize qualitative expert knowledge for control strategies. This method is not only suited to control simple technical systems, but also to manage exceedingly complex systems.

Thus for instance the Bundesbank (the German Central Bank) strives to avoid economic instability caused by high inflation rates mainly by means of evaluating, on the basis of expert knowledge, macroeconomic data and certain actor expectations and then adjusting interest rates accordingly. This is done without any completely described model of the overall macroeconomic system being available, and without certain knowledge of the long-term behavior of the system.

All control strategies need a goal formulation from which at least a short-term target can be defined. This can be, for instance, *optimization* of a selected target parameter, *pessimization* in the form of avoiding high-risk situations or – more in terms of bifurcation theory – the unconditional *prevention of undesirable scenarios*. A different type of goal would be to maintain maximum leeway, meaning to aim only at such states that maintain later options to move to as many alternatives as possible. The guiding principle would then be to preserve as many *options for action* as possible (Schellnhuber and Kropp, 1998a).

For instance, in the concrete case of climate risks the costs of risk prevention would have to be balanced against the costs of damage compensation, with the restriction that the new climate must under no circumstances transgress intolerable limits. The goal parameter for optimization would thus be total costs incurred, which are to be kept as low as possible. Here, however, we encounter the inaction dilemma that is typical for nonlinear systems, too: through inaction, which costs the actors nothing, total costs can be held at zero until the system reaches a discontinuity point, collapses suddenly and suffers very large damage over a short time – associated with correspondingly large total costs. From a systems perspective, a strategy of continuously weighing alternatives and adapting control parameters accordingly is thus preferable.

At this point, however, it needs to be noted once more that even with good knowledge of the system a complex system such as the Earth's climate can only be controlled 'softly', because, as set out above, long-term predictions are impossible for complex nonlinear systems. Not only are nonlinearities omnipresent in systems, but also it is frequently the purportedly negligibly small effects that lead to the structural diversity observed. The progress made in systems modeling has shown that there are common basic types in the models that transcend the disciplines. Mathematics and computer simulation have developed suitable tools for dealing with complex systems. Further, advanced techniques are being developed and tested. In the realm of social systems, however, the science is still nascent – here there is a major need for research.

The theory of complex systems yields, on the one hand, technological and scientific advances (e.g. high-performance lasers, turbulence phenomena, granular materials). On the other hand, it yields the epistemological realization that, even in the 'computer age', computability and predictability meet natural limits. The risks associated with global environmental changes cannot be eliminated by means of advance computation. This does not render such computations valueless, but demands the statement of an error corridor in order to evaluate their quality. Awareness of the unpredictable self-amplification effects that can be brought about by the most minute disturbances or interventions in a system suggests three responses: cautious action, continuous monitoring of system states, and maintaining a healthy skepticism about all long-term forecasts of complex systems.

E 4.2 Syndromes: The risk potential of global change

E 4.2.1 Syndromes as risk generators and amplifiers

It is the opinion of the Council that, as a consequence of global change, the impacts of environmental risks will continue to intensify in many regions of the world. In future, hazard potentials may rise due to new or intensified hazards. These include extreme weather events, shifting climate zones (IPCC, 1998), global population development and worsening soil degradation. At the same time, the vulnerability of many regions is rising, due to worldwide social and economic changes and the resultant pressures exerted upon societies and ecosystems. The magnitude of damage caused by natural risks does not depend solely upon the intensity of geophysical processes, but also upon the stresses and changes to which the regional environment is exposed, and upon regional and social vulnerability to crisis (Sections D 7 and E 2).

To assess these risks, we must consider not only the present state of a region or society, but also the question of which additional changes and threats are emerging from global change. For countries that are densely populated, poor or already severely stressed by environmental degradation, even slight impacts can have fatal consequences, while regions that are sparsely populated, wealthy or still ecologically intact are much less vulnerable (Section E 2).

This makes it clear that an assessment of future global risks must concern itself not only with the dimension of the event component (e.g. probability of occurrence, certainty of assessment), but must also address possible damage potentials and response capabilities 'on site'. The integrated assessment of regional vulnerabilities that this requires is still a nascent discipline and needs to be improved (Kasperson et al., 1995).

In the opinion of the Council, the prime problems of global change that exacerbate worldwide vulnerability to the consequences of man-made and natural disasters include climate change, the loss of fertile soils, the decline in biological diversity, the increasing scarcity of freshwater and the overexploitation of the oceans (WBGU, 1997a). The rise in (partially human-induced) natural disasters is also an important manifestation of global change – this can be an indirect consequence of population growth leading to higher levels of resource consumption, and of increasing migration or urbanization.

In its previous annual reports, the Council has repeatedly noted the difficulties presented to scientific analysis by the diverse phenomenology of global change and its complex causal webs. It is urgently necessary to establish a transdisciplinary research enterprise oriented to the core problems of global change, using best available knowledge to identify and analyze these cross-sectoral problem s (WBGU, 1997a). In this endeavor, the Council has proposed the *syndrome approach* as a new strategy and has successfully utilized it for a variety of research tasks (WBGU, 1995a, 1997a, 1998a).

Syndromes are typical patterns of problematic people-environment interactions that can be found worldwide and can be identified as regional profiles of damage to human society and ecosystems. They describe the patterns of damage to global environmental assets, regional ecosystems, social systems and human health at the level of causative trends (e.g. rising consumption of raw materials and energy, increasing traffic volumes or human impoverishment) and their linkages (in the form of amplification, attenuation, synergism etc.). From this systems analysis perspective, it makes a great difference whether, for instance, the forests of the world are cut down by small farmers and the landless in order to sustain their livelihoods (Sahel Syndrome) or by multinational corporations for reasons of profit maximization (Overexploitation Syndrome). For the forest, the consequences are identical, regardless of who logs it for what reasons. But for a scientific research enterprise seeking to identify cause-effect chains – and for effective policies to conserve the forests – the difference is very relevant indeed.

The Council has identified 16 main global change syndromes, and has already analyzed some of these in depth (WBGU, 1997a, 1998a). We shall now examine to what extent the syndromes generate or amplify global environmental risks, or exacerbate regional vulnerability to risk. In a first step, we shall briefly outline the general links between environmental risks and syndromes. This is followed by a discussion of the contribution of the syndromes to the generation of global risks, and their contribution to exacerbating regional or global vulnerability to risks. In order to flesh out these deliberations for a concrete example and thus to illustrate the suitability of the syndrome approach for risk research, we then analyze climate risks in terms of the syndromes that drive them or exacerbate regional vulnerability (Section E 4.2.2). We then shift the perspective to focus on a specific syndrome (the Dust Bowl Syndrome). Here we discuss which global risks are driven by the pattern of industrial agriculture, or which vulnerabilities are exacerbated or created thereby (Section E 4.2.3). All in all, the purpose of this discussion is to highlight how the system of classification and evaluation of risks proposed by the Council (Section C) can be supported by use of the syndrome analysis tool that has now been evolving for some time (Table E 4.2-1).

Syndrome approach and risk analysis

The syndrome approach and risk analysis are complementary scientific tools. We shall use both here to depict global change and the potentially associated hazards. A common feature of the two approaches is that they integrate issues of scientific analysis, evaluation and political decision-making. Both tools are scientifically founded, value-based and decision-oriented procedures for assessing critical developments at the interface where society, environment and technology meet.

Table E 4.2-1
Syndromes of global change.
Source: WBGU

Syndrome (groups)	Characterization
'UTILIZATION' SYNDROMES	
Sahel Syndrome	Excessive claims upon a marginal resource basis that is essential to reproduction
Overexploitation Syndrome	Conversion to other uses or overexploitation of forests and other ecosystems
Rural Exodus Syndrome	Environmental degradation caused by abandonment of traditional forms of land use
Dust Bowl Syndrome	Non-sustainable industrial management of soil and water resources
Katanga Syndrome	Environmental degradation caused by extraction of non-renewable resources
Mass Tourism Syndrome	Development of and damage to near-natural areas for recreational and adventure purposes
Scorched Earth Syndrome	Environmental degradation through military activities
'DEVELOPMENT' SYNDROMES	
Aral Sea Syndrome	Environmental damage caused by large-scale projects aimed at restructuring natural landscapes
Green Revolution Syndrome	Environmental degradation caused by the introduction of site-inappropriate farming methods
Asian Tigers Syndrome	Neglect of environmental standards in the course of highly dynamic economic growth
Favela Syndrome	Environmental degradation caused by uncontrolled urbanization
Urban Sprawl Syndrome	Landscape degradation caused by planned urban and infrastructure expansion
Major Accident Syndrome	Singular anthropogenic environmental disasters with longer-term impacts
'SINK' SYNDROMES	
Smokestack Syndrome	Environmental pollution caused by long-range, diffuse dispersal of mostly persistent substances
Waste Dumping Syndrome	Appropriation of environmental space through the controlled and uncontrolled dumping of wastes
Contaminated Land Syndrome	Local contamination of environmental media, mainly at industrial locations

The differences between the approaches are due to their different origins and the different uses to which they have been put. Risk analysis, the older concept, is applied to technical plants, project types, technologies or technological-organizational systems. It is used to conduct an assessment of the risk (expressed as probability of occurrence and magnitude of damage) posed by their hazard potential, and to assist in developing and implementing the necessary risk-reducing measures. The focus lies on technologies and their potential consequences.

Syndrome analysis, the more recent concept, is concerned with globally relevant people-environment interactions that constitute a high risk potential. These interactions ultimately jeopardize humanity's prospects for sustainable development in the ecological, economic and social realms. Syndromes are descriptions of global damage in the form of prototypical damage patterns. Due to the quantity of individual types of damage involved and the diversity of driving forces (trends) aggregated in a syndrome, the syndrome approach operates with a far more complex concept of risk than technical risk analysis does.

- There are global trends that increase the probability of occurrence of global risks; these include the growing number of large-scale technical projects, growing traffic volumes or industrialization.
- Other trends suggest an increased worldwide damage potential; these include the growth of physical assets, urbanization or population.
- Some trends point towards a simultaneous rise in the probability and potential magnitude of damage; these include the application of technological knowledge.
- Syndromes frequently operate with trends that involve mounting damage, e.g. increasing air pollution, soil erosion or mounting damage to human health.
- Syndromes also include individual trends that have a risk-attenuating effect; these include the growth of environmentally sound patterns of pro-

duction and consumption, or the improvement of pollution control.
- In some instances, it is not clear whether a trend will have a risk amplifying or attenuating effect; these ambivalent trends include medical progress, the increased application of biotechnology and genetic engineering, or automation/mechanization.
- The syndrome approach also embraces the dimension of subjective risk perception, e.g. growing environmental awareness or sensitization to global problems.

Syndromes as generators of global environmental risks: The example of nuclear energy

Classic risk analysis speaks out loud and clear where it is a matter of assessing individual probabilities of occurrence and magnitudes of damage. It is silent, however, where the issue is one of root causes, framework conditions and linkages of risks among each other. This is where syndrome analysis comes to the fore. It is particularly useful where it is a matter of qualifying damage dynamics and ascertaining causal pathways.

In the following, we outline the application of this tool to the risks presented by the utilization of nuclear energy (a Damocles-type risk), which are characterized by a very low probability in conjunction with a high catastrophic potential. Classic risk analysis already ends at the question of the socio-technical genesis of the nuclear energy risk. Risk analysis also says little about the systemic characteristics of a region that does not utilize nuclear energy itself but, due to its high vulnerability, is particularly severely affected if damage occurs. Here syndrome analysis can extend the field of inquiry. The causal complexes of the nuclear energy risk involve a series of syndromes:

- *Katanga Syndrome*. Uranium mining can lead to local radioactive contamination; this syndrome thus contributes to increasing the global nuclear energy risk (on the resource extraction side).
- *Scorched Earth Syndrome*. This helps to identify, in connection with other risk factors, the hazards of radioactive contamination resulting from conflicts escalating to the point at which military force is used, or terrorist attacks.
- *Asian Tigers Syndrome*. An important characteristic of this syndrome is the rapidly growing energy demand that it entails. This is frequently met by expanding nuclear energy. If, however, this is developed all too hectically and attention is focused all too narrowly upon energy growth, it may often happen that too little attention is given to safety requirements. This is particularly so if power plants have low technical standards.
- *Urban Sprawl Syndrome*. Modern urban lifestyles lead not only to the functional and spatial separation of work, housing and shopping (and thus to urban sprawl and rising traffic volumes), but also – in conjunction with high material and energy throughputs and rising human aspirations – to rising energy demand. Unless behavior changes (energy conservation) or technical alternatives are implemented (renewable sources of energy), this syndrome, which prevails above all in the industrialized countries, promotes the use of energy generation facilities with high energy densities. Nuclear power plants are prototypical of such facilities.
- *Major Accident Syndrome*. A central trend of this syndrome is the mounting technological risk that resides in the use of technologies that are complex and potentially hard to control. This is above all the case where technical and organizational standards are lowered or are no longer applied appropriately.
- *Waste Dumping Syndrome*. The final storage of highly radioactive process wastes is a particularly hazardous aspect of the utilization of nuclear energy. After the disposal of radioactive wastes, a persistent risk of the release of radioactivity will remain that depends upon the safety standards applied.
- *Contaminated Land Syndrome*. Decommissioned nuclear power facilities present a further risk component. This syndrome covers the environmental hazards engendered by situations in which the products of the anthropospheric metabolism of past development phases emerge as a problem for present societies.

Syndromes, being global patterns, cannot explain in concrete terms why an accident in reactor x of type y at location z occurred. What syndromes can do is to make an important contribution to explaining why the global risk of nuclear energy has arisen, why it has spread, which cause-effect relationships prevail and which further risks may result in connection with the utilization of nuclear energy.

Syndromes as generators of global environmental risks: The example of infectious diseases

Infectious diseases (a Cyclops-type risk) have causal links with the following syndromes:

- *Mass Tourism Syndrome*. Due to growing volumes of mass tourism worldwide, pathogens are able to spread rapidly and over long distances. Many people in the tourism countries of origin are not vaccinated against these pathogens, which are unknown to their immune system.
- *Scorched Earth Syndrome*. This refers to the dan-

ger of epidemics being caused by the deliberate spread of pathogens (bacteriological weapons) in military conflicts (e.g. Iraq in the first and possibly also in the second Gulf War).

- *Aral Sea Syndrome*. The construction of large dams exacerbates the risk of infectious disease because, depending upon geographic location and ecological conditions, large bodies of stagnant water promote the spread of water-related diseases (e.g. schistosomiasis; WBGU, 1998a).
- *Favela Syndrome*. High population density, poor infrastructure (in particular water supply and wastewater disposal), high levels of poverty and political failure are the main characteristics of this syndrome, which is prevalent above all in the urbanization of Africa, Asia and Latin America (WBGU, 1998a).
- *Waste Dumping Syndrome*. Everywhere in the world, there are deposits for wastes of all kinds, from which infectious diseases can spread rapidly.

Here, again, syndrome analysis is not intended to substitute concrete case analysis. Rather – by covering the ground left open by isolated case studies and abstract world models bare of cultural differentiation – it aims to identify globally relevant patterns that increase probabilities, damage potentials or vulnerabilities to worldwide risks.

Vulnerabilities resulting from global change

The amplification of global environmental risks can also result from higher vulnerability to one and the same hazard. The concept of vulnerability refers to modified damage potentials, above all at the regional level, that result from greater susceptibility or diminished preventive or reactive capabilities due to inadequate risk or disaster management (Section E 2). Vulnerability is a regional complex embracing both biogeographical endowments and economic, social or other anthropogenic structures. The concept centers on the people directly affected in the region (Table E 4.2-2).

The *Scorched Earth Syndrome* intensifies vulnerability to all types of risk. Infectious diseases, the release of contaminants, the legacy of mines in fields and roads, and floods caused by broken dams are all typical manifestations of war. In addition to this generic syndrome, other syndromes of global change impact upon vulnerability in the specific types of area listed in Table E 4.2-2.

The examples of the hazards posed by the utilization of nuclear energy or the failure of large dams illustrate that Damocles-type environmental risks are present worldwide in 'marginal' urban areas, too. 'Marginal' does not mean remote, but socio-economically disadvantaged and often overburdened by urbanization processes. The *Favela Syndrome* is a typical correlate of urbanization. This syndrome involves unplanned urbanization with a high proportion of informal settlements, poverty and characteristic environmental and health hazards. Not even minimum infrastructural standards are achieved for reactive, not to mention proactive disaster management. This is compounded by the circumstance that risk-prone industries often locate at these sites, moreover exerting a further pull upon the rural, mostly underprivileged population.

Rural 'marginal' areas are characterized by low socio-economic – and also natural physical-geographical – tolerance to stress. The *Sahel Syndrome* that typically appears here relates to marginal sites where the rural poor and segments of the population at risk of marginalization jeopardize the natural bases of reproduction due to a lack of alternatives. The problems to which the population is exposed include mounting poverty, rural exodus, rising susceptibility to food crises and increasing frequency of political and social conflicts over scarce resources. The consequences can extend to the desertification and destruction of the marginal areas, entailing great risks to society and ecosystems. Through these processes, the Sahel Syndrome exacerbates vulnerability.

The specific vulnerability of 'developed' urban areas differs greatly from that of the two previous examples. Nonetheless, here, too, high vulnerability prevails due to high population density, settlement and production structures and highly developed transport infrastructure. High mobility can greatly raise the speed at which infectious diseases spread. The high concentration of man-made assets entails a very large damage potential for risks of the Damocles (e.g. the Kobe earthquake in January 1995) or Cyclops class.

Geographic typology	Syndromes that heighten vulnerability
Marginal urban areas	Favela Syndrome, Scorched Earth Syndrome
Developed urban areas	Urban Sprawl Syndrome, Aral Sea Syndrome
Marginal rural areas	Sahel Syndrome, Scorched Earth Syndrome
Developed rural areas	Dust Bowl Syndrome, Rural Exodus Syndrome, Scorched Earth Syndrome

Table E 4.2-2
A typology of syndrome vulnerability. Terms are explained in the text.
Source: WBGU

The vulnerability of 'developed' rural areas, which are mainly in agriculturally favorable locations, is influenced particularly by the *Dust Bowl Syndrome*. This relates to environmental damage caused by non-sustainable use of soil or water resources as factors of biomass production with high inputs of energy, capital and technology. The short-term aim of such production systems is to harvest the maximum possible yields on the available area. In many instances, essential long-term environmental aspects are subordinated to this aim. The Dust Bowl Syndrome also refers to similarly motivated forms of forestry (e.g. clear-cutting with subsequent planting of rapidly growing monocultures, without regard to soil quality or biodiversity loss) or aquaculture (eutrophication and destruction of coastal ecosystems). The characteristic inputs, such as high-yielding varieties, agrochemicals and mechanization, while forming the basis for modern industrial biomass production, generate great vulnerability to Cyclops- or Pandora-type risks. Due to the high damage potential and the lack of available or realizable preventive measures, the risk can scarcely be controlled. The emergence of the Dust Bowl Syndrome is often accompanied by the Aral Sea Syndrome. High irrigation requirements, particularly in climatically less favorable regions, have led to many dams being built worldwide, which increase vulnerability in productive rural regions in particular (WBGU, 1998a).

E 4.2.2
Climate risks and global change syndromes

In the following, we discuss the interactions between the syndromes of global change and the risks posed by climate change. In particular, we examine the extent to which the presence of the syndromes might modify the probability of occurrence or the damage potential of the climate risks.

Linkages between climate change and syndromes

The Council's 1996 annual report provided first indications of the connection between global change syndromes and climate change (WBGU, 1997a). This identified a link for seven syndromes, namely

- In the 'utilization' group the Overexploitation and Dust Bowl Syndromes,
- In the 'development' group the Aral Sea, Asian Tigers, Favela and Urban Sprawl Syndromes, and
- In the 'sink' group the Smokestack Syndrome (WBGU, 1997a).

This spread across the three syndrome groups is illustrative of the complex way in which climate change intermeshes with other problems of global change. Climate change is thus the outcome of many developments – the inappropriate utilization of natural resources, non-sustainable development processes and inappropriate ways of disposing of the effluents of human society. While climate change is on the one hand a consequence of human-induced environmental changes, it also generates impulses that can attenuate or amplify regional disposition and exposure to syndromes. If, as in the case of the Sahel Syndrome, vegetation cover recedes due to overexploitation, this not only increases the desertification risk in semiarid regions, but the altered albedo also changes the regional climate. The Sahel Syndrome can thus intensify human-induced climate change. Conversely, global climatic changes can influence regional precipitation regimes such that previously favorable locations become marginal. Increasing drought frequency can then bring on the Sahel Syndrome.

It follows that the global change syndromes identified by the Council can be viewed from two perspectives: their contribution to climate change and their sensitivity to climate change. The Sahel and Rural Exodus Syndromes count among the people-environment interactions that are sensitive to climate change (Fig. E 4.2-1). On the other hand, the Smokestack and Asian Tigers Syndromes are mechanisms that exert a particularly strong influence upon climate change. The Green Revolution and Dust Bowl Syndromes, in turn, both contribute to and are affected by climate change.

The contribution of syndromes to the probability of occurrence of climate risks

The assessment of the influence of the syndromes upon the risks of climate change is hampered by the wide range of intersecting causal relationships in space and time. Human-induced climate change (Smokestack Syndrome) amplifies the risk of extreme events, such as storms, sea surges, flooding, drought or large-scale fires. Moreover, it is to be expected that climatic zones shift over the long term. This entails the further risk of spreading ranges of diseases and pests, and can jeopardize global food security (Section E 3.2). Direct and indirect inputs of substances to the environmental media can further imply existential hazards to coastal and forest ecosystems.

As the Smokestack Syndrome not only accelerates global warming but is also responsible for the more regional impacts of trace gases and the local contamination of soils, water and air, it is a pattern of people-environment interactions that exerts a major influence upon the probability of occurrence of the damaging events associated with the risks of climate change.

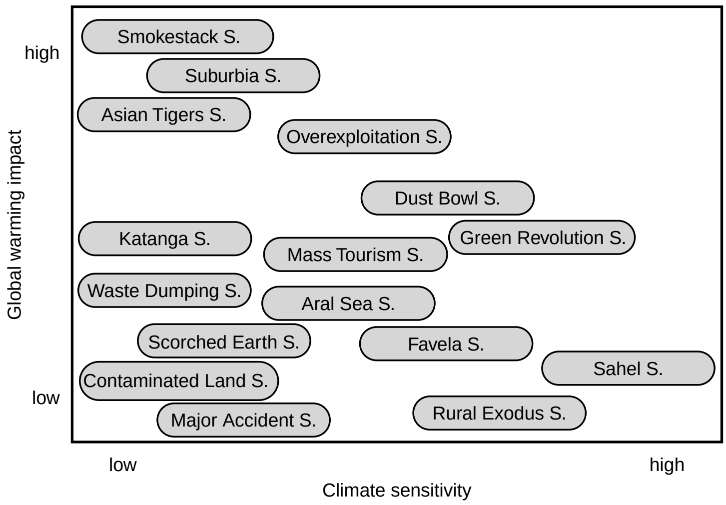

Figure E 4.2-1
Climate sensitivity and global warming impact of the syndromes of global change.
Source: after Petschel-Held and Reusswig, 1998

The Asian Tigers, Urban Sprawl, Green Revolution, Overexploitation, Dust Bowl and Mass Tourism Syndromes also contribute to rising levels of greenhouse gases in the atmosphere. Thus, they, too, heighten the probability of occurrence of the climate risks set out above.

In addition to their global effects, the Overexploitation, Green Revolution, Dust Bowl, Urban Sprawl and Aral Sea Syndromes can also heighten regional and local climate risks. Large-scale morphological changes caused for instance by clear-cutting, desertification, groundwater drawdown or land-use changes can exert strong influences upon regional climate and thus upon the probability of occurrence of climatic risks.

However, it is scarcely possible to quantify this form of risk amplification. Precise statements on the probability of occurrence of climatically hazardous constellations would require a considerably better knowledge of climate change and its coupling with global change syndromes than is available at present. Section E 4.1 has already discussed the effects, in complex interconnected systems, of systemic coincidences which can already be identified but not yet sufficiently explained.

Moreover, the effects of the syndromes and of natural climate variability upon the risks of climate change frequently operate in parallel, so that it is scarcely possible to assign probabilities to one or the other. While it can be said of the above syndromes that they exert a risk-amplifying effect in the stated fashion, this effect remains unquantifiable.

The contribution of syndromes to the damage potential of climate risks

Global change syndromes not only amplify probabilities of occurrence, but they can also intensify the damage potential of climate risks. This is exemplified by the Sahel, Waste Dumping and Favela Syndromes. If marginal areas are managed non-sustainably and the limits to carrying capacity are approached, the Sahel Syndrome intensifies the damage potential associated with climate risks because of the absence of natural resilience to suddenly occurring extreme weather events. Brief bouts of extreme rainfall can then devastate the livelihoods of many people at one blow.

The particular problem of the Waste Dumping Syndrome is the localization, concentration and accumulation of contaminants. This results in contaminant combinations that can be blown through the air to nearby settlements or flushed out of the immediate landfill area by extreme weather events. This can damage soils and potable water resources to such a degree that parts of such settlements are rendered uninhabitable and considerable health hazards are generated.

The Favela Syndrome is typified by high population density in conjunction with poor infrastructure. Climatically conditioned damaging events (e.g. landslides after heavy rainfall, or earthquakes) can generate very large damage. It is a prominent feature of the Favela Syndrome that it not only amplifies the damage potential, but also the probability of occurrence of climate risks (urban heat islands).

E 4.2.3
The risks of the Dust Bowl Syndrome

Syndrome analysis distinguishes three clinical pictures or syndromes associated with agriculture: the Sahel Syndrome, stemming from the poverty-driven overexploitation of marginal sites (WBGU, 1997a), the Green Revolution Syndrome that can result from the introduction of inappropriate agricultural technologies in developing countries (WBGU, 1998a) and the Dust Bowl Syndrome (Plöchl, 1997). The latter refers to the natural physical-geographical consequences of the industrialized farming practices that have emerged in the context of the evolution of national and international markets.

These non-sustainable farming practices can lead to substantial environmental damage. Types of damage include changes in the hydrological regime, eutrophication and contamination of surface water and groundwater reservoirs, the loss of biological diversity, the accumulation of pesticides in the food chain with resultant health impacts and the emission of greenhouse gases.

The Dust Bowl Syndrome occurs not only in developing and newly industrializing countries, but also in industrialized nations, where the displacement of labor from agriculture through rising labor productivity plays a major role.

The central trend of the Dust Bowl Syndrome is the intensification of agriculture, which, via interactions with various spheres, leads to the degradation of the natural bases of production (Fig. E 4.2-2). Agricultural intensification is driven by economic developments in conjunction with technological advances. This is underlain by rising aspirations and the spread of western lifestyle and consumption patterns. A number of the trends involved contribute significantly to amplifying a variety of central risks:

- The use of high-yielding crop varieties is typical of agricultural intensification in the Dust Bowl Syndrome. Recently, these varieties have been developed by genetic modification.
- The syndrome heightens the climate risk, notably through methane emissions in animal husbandry and wet rice cultivation, and through N_2O emissions from the intensive application of mineral fertilizers and organic manure. In addition to intensification, expansion of agriculturally utilized areas, with the associated conversion of forest ecosystems to agricultural uses, plays an important role. Taken together, agriculturally related emissions presently account for about 30% of the total annual growth in human-induced radiative forcing. Of this, a considerable proportion is attributable to the Dust Bowl Syndrome.
- The Dust Bowl Syndrome is frequently associated with intensified irrigation. In the USA, for instance, the area of irrigated cropland doubled between 1940 and 1970. In order to supply this water, major dam projects were constructed in the western USA (e.g. regulation of the Colorado river). The syndrome thus contributes to the risks entailed by the construction of dams (Aral Sea Syndrome, cf. Section D 2 of the Council's previous annual report: WBGU, 1998a).
- Mechanization and the use of high-yielding varieties necessitate the application of large quantities of pesticides, which contribute substantially to the risk posed by persistent organic pollutants (POPs).

An amplification of the above risks must be expected in regions where the Dust Bowl Syndrome occurs. Fig. E 4.2-3 gives a global overview of the present intensity of the syndrome. Syndrome intensity is a function of the following basic indicators:

- Degree of degradation caused by arable farming,
- Degree of degradation caused by cattle breeding,
- Degree of agricultural labor productivity and of world market orientation.

With syndrome analysis, we can identify not only the areas in which the Dust Bowl Syndrome is already prevalent, but also those regions that are at risk. For this purpose, a preliminary analysis of regional disposition to the Dust Bowl Syndrome has been performed. This is based on a global survey of agriculturally favorable sites and of the essential factor of accessibility for agricultural use. Comparison of the findings of this survey with the intensity map permits identification of the regions at risk of contracting the Dust Bowl Syndrome. These include the rainforest areas of Brazil, Venezuela, Central America, Mexico and Papua New Guinea. In Africa, the southern parts of Nigeria, Ghana and Côte d'Ivoire are at risk, as are parts of Congo. In some countries currently afflicted by the Green Revolution Syndrome, a transition to the Dust Bowl Syndrome appears possible (Indonesia, Bangladesh, Sri Lanka, Vietnam and Myanmar).

E 4.2.3.1
Quantitative assessment of the risks generated by the Dust Bowl Syndrome

The damage potential of the Dust Bowl Syndrome can be disaggregated into different components. One of these is the damage potential that results within 'Dust Bowl regions' themselves due to already operating mechanisms. This potential comprises effective, contingent and compensation damage to the agricultural sector (Section C 2). A further component is the damage potential that may be amplified in other regions by the Dust Bowl Syndrome. Finally, those forms of secondary damage need to be assessed that can arise through the conversion of natural ecosystems to 'Dust Bowl agriculture'.

The risk of damage to the agricultural sector due to the Dust Bowl Syndrome

The intensity map of the Dust Bowl Syndrome (Fig. E 4.2-3) is based in part upon the assessment of the

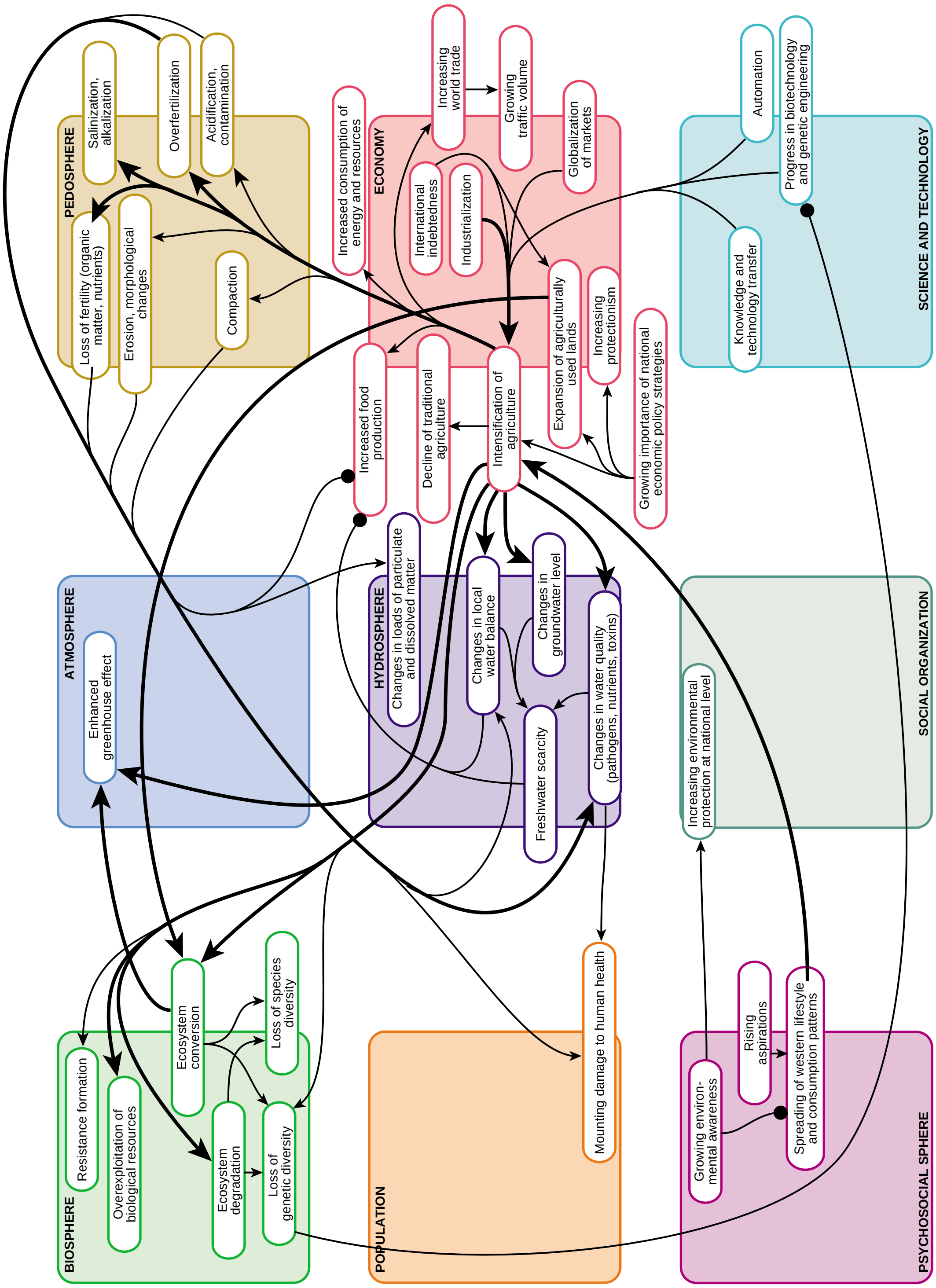

Figure E 4.2-2
Network of interrelations for the Dust Bowl Syndrome.
Source: QUESTIONS project

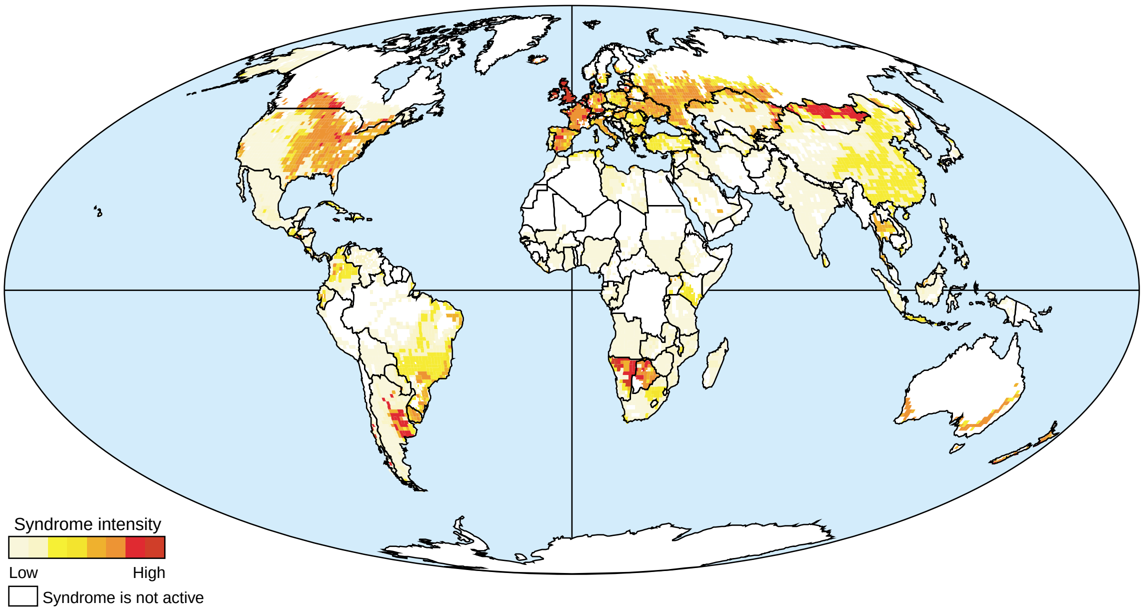

Figure E 4.2-3
Intensity of the Dust Bowl Syndrome.
Source: QUESTIONS project; Plöchl, 1997

hazardousness of agricultural management practices expressed in the syndrome-specific network of interrelations by the trends of soil compaction, erosion, groundwater drawdown, contamination and salinization. The intensity determined on this basis can thus be interpreted as a *probability* that, if present production methods are retained, the natural bases of agricultural production will be severely impaired by the Dust Bowl Syndrome in the future (over a long-term horizon). Quantifying the effective damage potential requires precise knowledge of the value of the endangered natural and man-made assets. In addition to the fact that favorable agricultural soils have substantial qualitative differences, assessment of the effective damage potential is hampered by the circumstance that even if the agricultural 'medium of production' is completely lost other uses remain possible (e.g. as settlement area). The natural physical asset value (natural capital) of the soil, as has been identified e.g. by Costanza et al. (1997) must thus be distinguished from the anthropogenic physical asset value (cultivated and infrastructurally developed soils). Its quantification presents major difficulties. However, physical asset value is in any case of only minor significance as a measure of the damage potential of the Dust Bowl Syndrome; the main damage potential results from the utility value of favorable soils.

This potential is a function of the lost utility of the soil (contingent damage). The Dust Bowl Syndrome can lead to farming being hampered or productivity declining. In the worst case, the soil will not be able to be cultivated at all, so that the lost utility corresponds to the market value of all agricultural produce that could have been harvested without the harmful effects of the Dust Bowl Syndrome. The contingent damage potential is also an indirect measure of the effective damage potential, as it can be assumed that comparatively high yields can be produced on very fertile soils.

The compensation damage associated with the Dust Bowl Syndrome, which is a function of the *consequences* of lost utility caused by the syndrome, is very hard to assess (as it depends greatly upon the appraisal of the substitutability of natural bases of production). We therefore take contingent damage as the basis for the following risk assessment. The damage potential of the Dust Bowl Syndrome is expressed as lost utility, i.e. as yield loss. On the basis of FAO and WRI (World Resources Institute) figures, the shares of industrial agriculture in the gross national product of 159 countries were determined for the year 1993. In order to be able to distinguish the damage potential of the Dust Bowl Syndrome from that of the Green Revolution Syndrome, the share of grain production in agricultural value added was deducted for those 18 of the 159 countries whose indus-

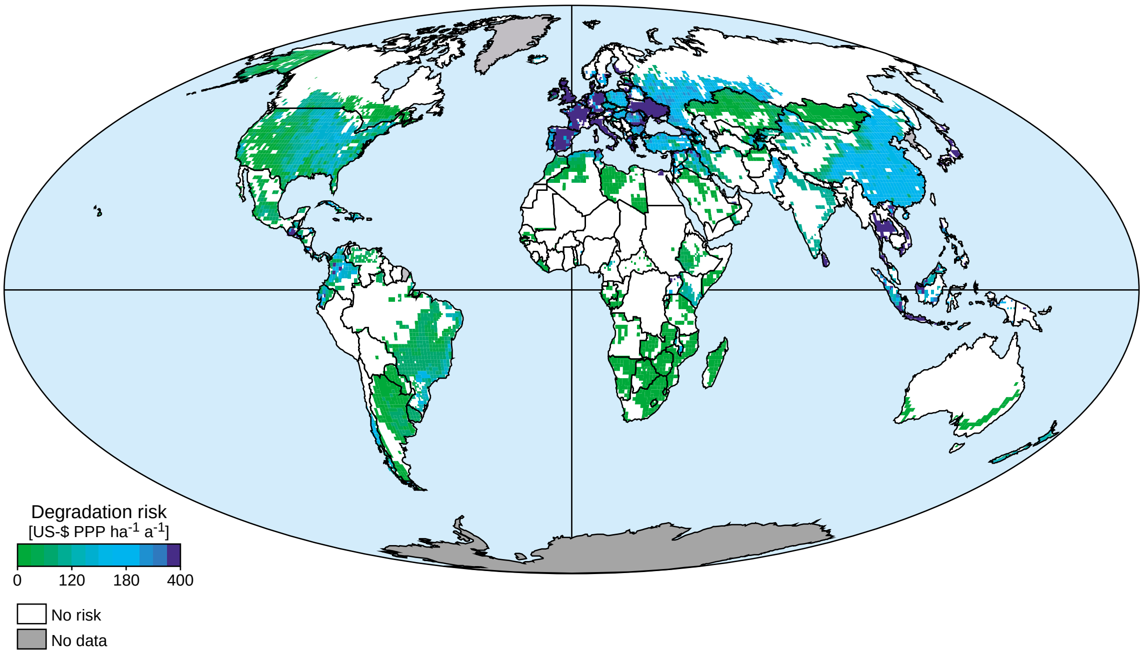

Figure E 4.2-4
The risk posed to the agricultural sector by the Dust Bowl Syndrome.
Source: QUESTIONS project

trial agriculture is of the Green Revolution type (WBGU, 1998a). The grain production of these countries mainly serves the domestic supply and is thus generally not available to the market for agricultural produce.

The damage potential calculated in this fashion was then multiplied by the intensity values of the Dust Bowl Syndrome (whereby, in a first approximation, the specific national damage potential was distributed evenly across the agriculturally utilized area of each nation).

This analysis shows that the largest absolute risks per hectare arise in the EU, Japan, Thailand, Sri Lanka and Ukraine, and in parts of Indonesia, Malaysia and Guatemala (Fig. E 4.2-4). If we place the national Dust Bowl risk in relation to national gross domestic product, we receive a country ranking as shown in Table E 4.2-3. This provides an indication of the relevance of this risk to the respective national economies.

It is striking that the ten most critical countries include five of the former Eastern Bloc. In these transition economies, the combination of environmentally hazardous agricultural practices and the present collapse of the industrial sector generates a significant hazard. We find a similar picture in a number of developing economies that are dependent to a significant degree upon cash crops. If agricultural practices are not modified soon, these countries will run a particularly high risk of devastation to their economies caused by the destruction of their natural bases of production (Box E 4.2-1).

The risk of damage to natural ecosystems due to the spread of the Dust Bowl Syndrome

In the Dust Bowl Syndrome, 'problematic' land uses pass through two phases: starting with an almost entirely natural state of a region that is assumed to be

Table E 4.2-3
Countries particularly endangered by the Dust Bowl risk in terms of potential damage to the agricultural sector.
Source: QUESTIONS project

Country	Dust Bowl risk as a percentage of gross domestic product [% GDP]
Georgia	28.5
Moldova	11.3
Sri Lanka	11.3
Guatemala	9.9
Romania	9.0
Bulgaria	8.2
Thailand	8.0
Armenia	7.2
Vietnam	7.1
Ecuador	6.2

Box E 4.2-1

Environmental degradation as a risk to international security?

One of the frequently cited risks of global change is that of ‘environmental wars’, meaning violent conflicts between or within states caused at least in part by environmental degradation and natural resource scarcities (Bächler et al., 1996; Calließ, 1995; Carius et al., 1998). In collaboration with the Potsdam Institute for Climate Impact Research (PIK), the Heidelberg Institute for International Conflict Research (HIIK) and the Ecologic institute in Berlin, an effort has now been made to apply the syndrome approach to empirical peace and conflict research (Biermann et al., 1998a, b). Findings of syndrome analysis were linked with data records of the Heidelberg KOSIMO database in order to test to what extent individual syndromes of global change correlate with violent and non-violent interstate and intrastate conflicts. KOSIMO, a conflict simulation model, is an approach to conflict analysis developed in 1988–1991 at the Heidelberg Institute for Political Sciences (Pfetsch, 1991, Pfetsch and Rohloff, 1998; Rohloff, 1998); since 1991, the data records have been continuously updated and evaluated by the institute in cooperation with HIIK.

With this approach, linking syndrome analysis and conflict theory, a first step is to identify 'critical environmental constellations'. This is done independently of empirically observed conflicts. In a second step, these constellations are matched with real cases of conflict. While, due to its global perspective, the approach is neither able to fully explain nor forecast individual conflicts, it is able to identify significant global correlations between individual symptoms of global change and conflicts. This has been undertaken in detail for the Aral Sea Syndrome and the Sahel Syndrome (Biermann et al., 1998a, b).

In the context of research on the Aral Sea Syndrome, the analysis of critical upstream-downstream riparian situations worldwide revealed that there is indeed a statistically significant connection between natural physical-geographical interdependencies, relatively constrained per capita water resources and international conflicts. However, due to the low total number of conflicts over water and an array of special conditions, this finding needs to be interpreted cautiously (Table E 4.2-5). While in some of the cases analyzed, water conflicts can indeed be identified, this is often explainable by other influencing factors (notably the cases of the wars between India and Pakistan, and those between Israel and the Arab states), not by the critical water constellation as such. It is above all these other influencing factors that have led to or have precipitated the outbreak of conflict over the relatively scarce water resource. Such factors include regional policies motivated by security interests (Turkey/Kurdistan), an isolated regime willing to engage in conflict such as Sudan or an ongoing interstate conflict (Israel/Jordan, India/Pakistan). Where such special influencing factors do not prevail, it can be found, at least at present, that comparably critical constellations are usually resolved cooperatively.

The analysis of the Sahel Syndrome shows that the emergence of the syndrome correlates strikingly with violent intrastate conflict. Of course this correlation provides no causal explanation, as an existing intrastate conflict may well have influenced the outbreak of the syndrome. Nonetheless, global analysis using a syndrome-analysis-cum-conflict-theory approach is able to identify a distinct connection between the emergence of the Sahel Syndrome and violent intrastate conflicts.

Interdisciplinary refinement of the approach promises a more detailed and differentiated analysis. This will be valuable to highlight more clearly the most strongly correlating variables at the interface between environment and security, and thus to make an improved methodological and empirical contribution to the debate.

Table E 4.2-5
The 15 most critical upstream-downstream constellations worldwide.
$x_{(u)}$: criticality of the dependence of the upstream state upon the water flowing to the downstream state.
$x_{(d)}$: criticality of the dependence of the downstream state upon the incoming water.
$x_{(total)}$: total criticality.
‘Water conflicts’ are identified on the basis of quantitative and qualitative KOSIMO data.
Source: Biermann et al., 1998a, b

Upstream	Downstream	x_o	x_u	x_{total}	Water conflict
Israel	Jordan	1.000	1.000	1.000	Water conflict
Ukraine	Moldova	0.335	1.000	0.655	
Algeria	Tunisia	0.742	1.000	0.637	
India	Pakistan	0.000	1.000	0.500	Water conflict
Afghanistan	Pakistan	0.000	1.000	0.500	
Iraq	Kuwait	0.000	1.000	0.500	
Sudan	Egypt	0.000	1.000	0.500	Water conflict
Turkey	Syria	0.000	0.946	0.473	Water conflict
Afghanistan	Uzbekistan	0.874	0.393	0.368	
Oman	United Arab Emirates	0.335	1.000	0.353	
India	Bangladesh	0.698	0.367	0.312	Water conflict
Belarus	Ukraine	0.000	0.616	0.308	
North Korea	South Korea	0.000	0.971	0.269	
Austria	Czech Republic	0.000	0.477	0.238	
Syria	Iraq	1.000	0.236	0.236	Water conflict

disposed to the syndrome (WBGU, 1997a), causal factors can initially bring on the syndrome-specific development (exposition). Both syndrome initialization and the ensuring syndrome dynamics are associated with damage to natural ecosystems. In the following, we assess the damage and its risk character generated by land-use change at the onset of the Dust Bowl Syndrome.

The damage caused by the use of natural areas for arable or livestock farming can be characterized as a loss of functions of the natural ecosystem concerned. In the broadest sense, such functions include

- Contributions to biogeochemical cycles,
- Functions of biological diversity,
- Stabilizing effects upon regional morphology,
- Climate regulation,
- Cultural functions, and
- Recreational functions.

In principle, agriculturally utilized areas can fulfill similar functions, although in a manner that is greatly modified (e.g. climate and gas regulation) or reduced (e.g. biodiversity, recreational value). It appears expedient here to view the functional losses arising from conversion as non-compensable. This appears particularly suitable for the Dust Bowl Syndrome as an expression of capital-intensive agricultural use, which is associated with a most far-reaching loss of ecosystem functions.

To assess the value of the ecosystem functions lost due to conversion, we take recourse here to the work of Costanza et al. (1997), who, on the basis of a comprehensive desk review of the literature, have undertaken a monetarization of these functions. Specific monetary values are assigned to the tropical and boreal forests, grassland/rangeland and wetlands. Seventeen categories of ecosystem functions are considered. Although the work of Costanza et al. has been hotly debated and the Council has previously voiced its reservations concerning attempts to completely monetarize the utility of nature (WBGU, 1994), the valuations made here are considered to be adequately founded and thus sufficient for the purposes of the present discussion, at least as regards their distribution and magnitude. One problematic point is the statement of global average figures, as this makes it impossible to distinguish between local and global ecosystem services (water filtration by wetlands being an example of the former, climate regulation of the latter). Nor are these ecosystem services placed in relation to contingent or effective demand, although this is important in the context of the willingness-to-pay approach taken by Costanza et al. The results of the valuation exercise must therefore be viewed as a first and fairly rough approximation. According to Costanza et al. (1997) the ecosystem function value of a tropical forest amounts to US-$ 2,007 ha^{-1} $year^{-1}$, that of a boreal or temperate forest is US-$ 302 ha^{-1} $year^{-1}$, that of marshland or mangroves is US-$ 9,900 ha^{-1} $year^{-1}$, that of swamps or flats is US-$ 19,580 ha^{-1} $year^{-1}$ and that of grassland or rangeland is US-$ 232 ha^{-1} $year^{-1}$ (all figures are for 1994).

It is striking that beside tropical forests, it is in particular the wetlands to which a high value is assigned. While tropical forests are important for global nutrient metabolism and climate regulation, the high value of wetlands is due to their filter and regulation

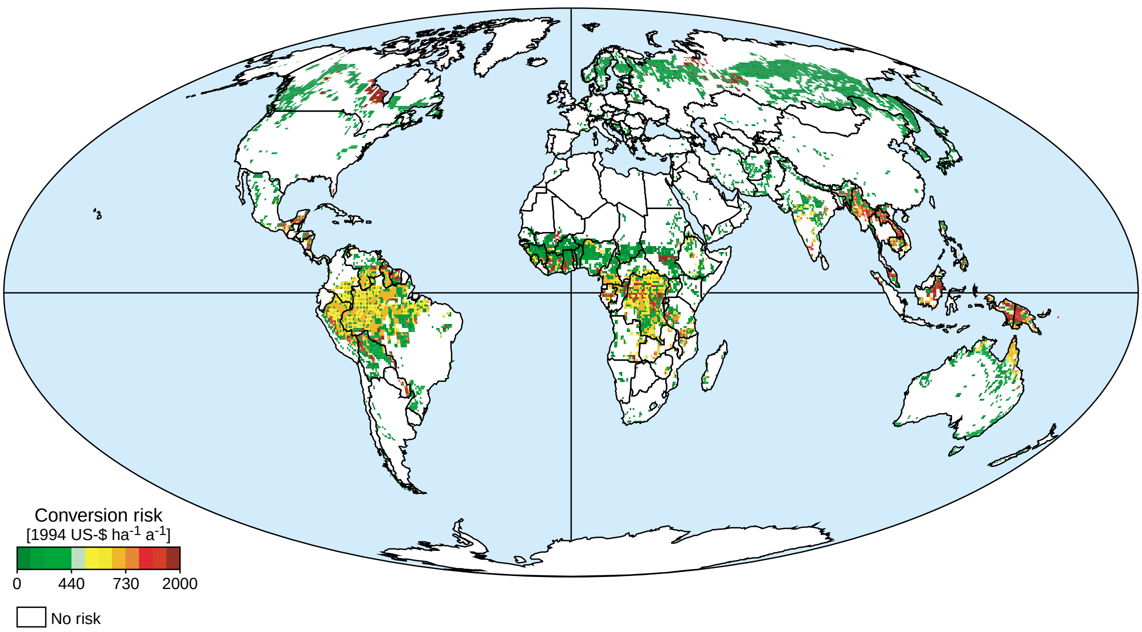

Figure E 4.2-5
The risk of the spread of the Dust Bowl Syndrome in regions that have a disposition to the syndrome. The figure gives a logarithmic presentation of the indicator, i.e. with greater differentiation of the small and medium values. Risks larger than US-$ 2,000 ha^{-1} $year^{-1}$ are not specifically color-coded – in some regions of South-East Asia, a maximum value of US-$ 19,580 ha^{-1} $year^{-1}$ is reached.
Source: QUESTIONS project

Table E 4.2-4
Monetary valuation of the services of different ecosystem complexes.
Source: Costanza et al., 1997

Ecosystem	Function value for 1994 [US-$ ha^{-1} $year^{-1}$]				
	Tropical forest	Boreal/ temperate forest	Marshland/ mangroves	Swamps/ flats	Grassland/ rangeland
	2,007	302	9,900	19,580	232

function. These data for biogeographical units are used in the following together with a global ecosystem classification (Olsen et al., 1985) to map the value of ecosystem functions. This is the value that is lost when an area is converted to agricultural use, and is thus the potential damage of a 'Dust Bowl use'.

To assess the probability with which a largely natural ecosystem is converted into an agriculturally utilized area, we must determine the syndrome disposition. Disposition is an expression of the probability of a syndrome occurring at any point in time. The disposition index is a function of the assessment of favorable agricultural sites (Cassel-Gintz et al., 1997) and of accessibility (Cassel-Gintz, 1997) as an indicator of market proximity. However, we must keep in mind here that this approach also includes such regions that are in fact already afflicted by the syndrome. We must therefore exclude from the global distribution of disposition those regions in which the syndrome is already prevalent. We thus gain a first assessment of the global distribution of the probability of a transition from a largely natural ecosystem to 'Dust Bowl Syndrome agriculture'. By multiplying the two indexes we receive an initial global assessment of the conversion risk of the Dust Bowl Syndrome, and thus also of the loss of ecosystem functions.

The risk of ecosystem function loss is high for the remaining wetlands (Table E 4.2-4). With damage potentials of US-$ 500–900 ha^{-1} $year^{-1}$, a number of boreal regions around Hudson Bay and in western Siberia are also exposed to considerable risk. Due to their low agricultural potential and thus low disposition, these regions correspond to the classic type of risk: a high damage potential in conjunction with a relatively low probability of conversion.

It not being purposeful to aggregate the conversion risk at the national level, as damage cannot be separated between the 'local' and 'global' levels, a comparison of global conversion and degradation risks suggests itself. Here we find that the global conversion risk entailed by the spread of the Dust Bowl Syndrome (US-$ 1,920 billion $year^{-1}$) is about 80 times larger than the degradation risk (US-$ 22.6 billion $year^{-1}$). In the quantification of the degradation risk, the possibility of compensating for damage was neglected so that the assessment is on the conservative side, and only applies for complete substitutability. Nonetheless, an expansion of industrial agricultural practices to previously uncultivated regions is extremely risky. This applies particularly for tropical rainforests and wetlands (Fig. E 4.2-5), in which e.g. population growth, food scarcity, cash cropping or the destructive exploitation of timber resources place stresses upon the land resources still uncultivated. An expansion of forms of agricultural use that at least partially preserve natural ecosystem services (e.g. agroforestry) would reduce this risk, as would policy reorientation in accordance with the recent poverty debate (empowerment of the poor).

Risk policy

F

Risk evaluation and the choice of tools F 1

F 1.1
Elements of risk evaluation

By 'risk evaluation', the Council means a group of techniques for making judgments, in a rational manner, about a risk in terms of its acceptability for society as a whole or for certain groups and individuals (Berg et al., 1995). This turns on three issues:
- Should a certain risk be accepted by a society at all?
- What amount of resources should be expended to reduce or control the risk?
- Which tools should be applied to control the risk?

F 1.2
Determining the acceptability of a risk

Notwithstanding the use of formal decision-making procedures, it always depends upon subjective values whether a risk is to be rated as acceptable or unacceptable from a normative perspective. Formal risk evaluation techniques can help to make coherent decisions within a given matrix of values. They guide decision-making, but can never be a substitute for the decision itself (Fischhoff et al., 1981).

Cross-risk comparisons

Among formal comparative evaluation techniques, the special characteristic of cross-risk comparisons is that they use observed behavior as the standard for the acceptability of risks. If a society has already rated certain risks as being acceptable, then it is logical to demand that options for action which are associated with lower risks are also accepted (Wilson and Crouch, 1987; Merkhofer, 1987; Fritzsche, 1986).

However, the use of risk comparisons to determine risk acceptability presents a number of problems. Conventional risk comparisons neglect the dimension of the benefit of the risky action, treating benefit as a *ceteris paribus* condition (Crouch and Wilson, 1982). For instance, when comparing coal-fired with nuclear power generation, it is assumed that in both cases the benefit of the unit of electric energy is equal for the consumer. This may be plausible for electric power supply; however, if we include energy efficiency as a further alternative, then consumers may quite well have different preferences for the same level of utility, i.e. they are not indifferent to the various means of providing an identical energy service.

Where a risk comparison is undertaken with the purpose of examining risk reduction options, the *costs* of reduction associated with the action in question must also be considered. Moreover, risk comparisons frequently only refer to the expected value of the risks compared. Such a restriction to the expected average damage is problematic if the confidence intervals of the risk assessments and the remaining uncertainties (Section C) vary across the risks being compared, or if the temporal sequence of occurrence of damage (meaning different hazard potentials for the same expected value) plays a role in evaluation.

It follows that risk comparisons are mainly appropriate for risks situated in the normal area defined by the Council, and possibly also for those classes of risk that have a high certainty of assessment (Damocles or Medusa), but not for risks characterized by high uncertainty or statistical uncertainties (Cyclops, Pythia, Pandora). In the latter case, expected values and distributional parameters need to be integrated in the decision as multidimensional evaluations (Merkhofer, 1987; Femers and Jungermann, 1991; Akademie der Wissenschaften, 1992).

Due to these analytical limits of cross-risk comparisons, they cannot serve as the sole standard by which to evaluate new risks, particularly not if high uncertainties attach to the consequences of damage (Fritzsche, 1986; Wilson and Crouch, 1987; Merkhofer, 1987). The decision-making process must also always integrate further dimensions, such as benefit, distributional effects, the cost-effectiveness of risk reduction and other relevant criteria. Nonetheless, risk comparisons do have an important *orientation function*. It is often difficult to communicate risk assessments to decision-makers and to the general public

(Section F 7). A comparison with known risks can serve to illustrate the degree of hazard posed by a novel source of risk, without answering the normative question of acceptability (Covello, 1991; Fermers and Jungermann, 1991).

Cost-benefit analysis

Cost-benefit analysis means to balance explicitly the costs and benefits of a variety of options for action by comparing and quantifying opportunities and risks. This comparison is made on the basis of a full monetarization of all benefit and cost categories (Fischhoff et al., 1985). A variety of methods (shadow prices, willingness to pay, price standard) are used to convert into monetary units the benefits and expenditures (costs, organizational effort, costs of conflict, costs for decision-making etc.) of the different options for action. Risks can then be evaluated by a simple calculation. If the risk can be reduced continuously, then *that* level of reduction is to be chosen at which the total cost function (the sum of costs expended and of costs incurred by the residual risk) is at a minimum. If such continuous reduction is not possible, then that option is to be chosen at which the difference between benefits and costs is largest (Fischer, 1973; Hansmeyer and Rürup, 1975).

What makes cost-benefit analysis so attractive is that it offers a tool by which to orient risk evaluation to market prices that can directly reflect societal benefits. Thus costs for risks can be integrated in insurance premiums, while expected gains from opportunities can be integrated in share prices or in the provision of venture capital. However, the integration of external effects and the valuation of public goods present difficulties. Here shadow prices that simulate market value must be ascertained indirectly. While scientific approaches have been developed by which to perform this, these approaches vary substantially, so that in many cases their results remain ambiguous (Harvey, 1985; Fischhoff et al., 1985). A further difficulty is presented by the question of how to discount such prices over time (Hansmeyer and Rürup, 1975; Smith, 1986). While for market prices the usual interest rate on the market is adopted, it is difficult to justify the choice of discount rate for the monetarization of external effects, particularly those of non-material nature. While it makes sense to discount with a negative interest rate such gains that are only expected in the distant future, it is scarcely plausible to appraise the victim of a future damaging event as being less 'valuable' than the victim of a present exposure.

The above problems are particularly striking when dealing with risks to human health and ecosystems. Which money value corresponds to an x% rise in the risk of dying from cancer? How does this money value change if the damaging event only occurs in 20 years from now? (Baram, 1980; Kelman, 1981). Despite these problems, cost-benefit analysis has an important function in industry, public policy and the courts. This is particularly so where it is necessary to compare, in a manner independent of the subjective preferences of the individual members of a society, the costs incurred by and the benefits accruing to a national economy. Indirect indicators such as prices for buying additional insurance cover or costs for restoring health can provide useful approximations to the monetary expenditures and gains that are to be expected in the real world (Fischer, 1973). For instance, the damage caused by acid rain can be operationalized in terms of the losses incurred by the timber trade and the tourism sector (Wicke, 1990). However, such an analysis captures neither esthetic nor ecological damage.

Decision analysis

In public policy and industry, the tools of formal decision analysis (the 'logic of decision') are applied to many problems of collective evaluation; notably in economics, sociology and philosophical ethics, these tools have been extended and refined in recent years for application to the various requirements posed by these scientific disciplines (Edwards, 1954; Gäfgen, 1963; Raiffa, 1973; von Winterfeldt and Edwards, 1986; Jungermann et al., 1998).

Formal decision analysis is based on the subjective individual evaluation of expected consequences of an action. The consequences and their probabilities of occurrence are determined, and are then converted into subjective utility values. Overall utility is determined by integrating the weighted individual utilities. The particular advantage of decision analysis is that, for given goals and knowledge, a choice doing optimum justice to subjective preferences can be made across a variety of options for action. Moreover, by making explicit the goal dimensions, goal evaluations and weightings, the transparency of the decision-making process to the public is improved, thus providing an important contribution to justifying risk policy measures.

Decision analysis has its limits, too. As it is necessary to integrate subjective preferences, the choice of weightings assigned to the various dimensions must be argued plausibly and legitimated politically. Decision analysis provides no justification for the values that are integrated in the analysis as preference judgments. Breaking down complex situations into manageable individual problems can lead to certain interactive influences being neglected or holistic impressions excluded.

Decision analysis can only yield coherent conclusions from the information provided by decision-makers through their preferences and their level of knowledge. It thus offers a formal framework that is only effective if new information, goal corrections and – particularly in group decision-making processes – negotiations and consultations are integrated in the analysis (Raiffa, 1973; Edwards, 1977). The possibility of revising e.g. goals or assessment standards, i.e. the freedom of decision-makers or of those affected by the decision to raise objections, is facilitated by the transparent presentation of the decision-making process. It is this that gives the method its superiority over holistic judgments and mere aggregations of individual decisions.

Decision analysis techniques are particularly suited to evaluating risks because they compare explicitly the risks and benefits and use the preferences of the decision-maker as the value standard by which to evaluate the relative weights assigned to each category of benefit and damage (Fischhoff et al., 1981). Moreover, the Bayesian concept of probability favored in decision analysis makes it possible to assign numeric probabilities to all conceivable consequences and thus to render them comparable.

Risk evaluation on the basis of the precautionary principle

The three evaluation techniques discussed above proceed from the assumption that the effects of actions are known, so that both the magnitude and the relative frequency of damage can be specified. The resultant consequences of an action are then taken as the basis on which to evaluate its desirability. Such an approach is no longer possible if nothing is known or there is high uncertainty about the consequences of the action under consideration. This situation is given above all in the Pythia, Cyclops and Pandora classes of risk.

Generic minimization of the consequences of actions would appear to offer a solution to the problem of incertitude or high uncertainty. It is to this approach that Germany has given particular priority in its body of environmental law, in the shape of the precautionary principle (Rehbinder, 1976; Hartkopf and Boehme, 1983). According to this principle, emissions are to be prevented or reduced even if a lack of scientific knowledge means that negative effects are not known but such effects cannot be excluded. Within the typology of risk proposed by the Council, this principle applies primarily to Pandora-type risks, because these combine high levels of ubiquity (global dispersion) and persistency (long duration of effectiveness). Two formulas are applied to implement the requirement of precautionary action against unknown effects of emissions:

- The principle of reducing emissions to a level that is *as low as reasonably achievable (ALARA)*. This requires that every emission is reduced as far as possible, the limit being the reduction effort that is still economically and socially reasonable. The definition of where this reduction level lies is a matter of discretion from case to case. In Germany, as in many other countries, the ALARA requirement is applied e.g. in radiation protection. Every exposure to ionizing radiation should be reduced – if at all technically and economically reasonable – to a minimum level that is far below the permitted limit value.
- The principle of *best available control technology (BACT)*. This requirement prohibits every emission that could be prevented with a control technology that is available on the market and has proven itself in practice. A variant of this statutory formula is the ‘state of the art and science’ (Stand der Wissenschaft und Technik) established by the German Nuclear Energy Act (Atomgesetz), under which concepts for controlling contaminants or improving technical safety that have been newly developed by science must also be realized, even if they have not yet been demonstrated at industrial scale.

The implementation of both standards can easily lead to suboptimal solutions, as they do not require a systematic comparison of costs and benefits (Rowe, 1979; Akademie der Wissenschaften, 1992). Theoretically, under the BACT standard a potentially hazardous pollutant can still be released in large quantities if no appropriate control technology is available on the market. The converse case is also possible in which valuable economic resources are expended to control a completely harmless substance or to reduce a contaminant far below the threshold value, for the only reason that sufficient technologies are available to bring about substantial reduction. A further aspect is that when new technologies emerge and disseminate, risks are frequently larger in the initial stage of development than in the later stage when the technology has evolved to maturity. A situation can thus arise in which new technologies promise a long-term risk reduction, but cannot be introduced under the BACT requirement because the old, already mature technologies present lower risks than the new technologies in their initial stage.

Much the same can be said of the ALARA requirement. The determination of when a reduction is no longer reasonable (which is an indeterminate legal concept) results either from a formal analysis involving the systematic balancing of benefits and risks, or from a balancing judgment. The main problem is that the minimization requirement can be associated with costs that are out of proportion to the risk reduction achieved. If application of the ALARA standard prevents technological options that can only develop their risk-minimizing function in the future, then this is an infringement of the principle of distributional equity over time. In certain cases this may be purposeful and justified, but the application of the ALARA standard does not explicitly identify such an infringement – indeed, it prevents a systematic balancing of this infringement with the benefit gained in the other goal dimension of short-term risk reduction.

These difficulties illustrate that it is only then purposeful to apply the precautionary principle if one of the three following preconditions is given (Fritzsche, 1986):

1. Little or nothing is known of the effects of the pollutants in question, but it is to be expected that adverse effects will arise over the long term (such cases belong to the Pythia, Pandora or Cyclops classes of risk).
2. The effort required to control pollutants varies substantially from situation to situation, so that the ALARA standard permits a flexible reaction that can take into consideration the cost of reduction. Here it is essential that the determination of what is reasonable is the outcome of a systematic balancing process (such cases belong to the Damocles or Cassandra classes of risk).
3. The BACT requirement can be imposed in addition to the stipulation of rational standards, in order to reduce pollutants in cases where their effects do not make this indispensable, but such reduction is technically and financially viable (such cases belong to the Damocles or Medusa classes of risk).

We may conclude that the requirements of precautionary action should apply above all in cases where there is a severe lack of knowledge of the possible consequences of an action. If this condition is not given, the requirements can serve as an additional incentive for risk reduction, but lead necessarily to the suboptimal allocation of societal resources. Such a deviation from the optimum model can be quite well justified if impact-related criteria are not a part of the catalog of goals.

Risk evaluation on the basis of classes of risk

None of the risk evaluation techniques discussed above is fully convincing. Each requires political judgments on the acceptability of risks. This becomes particularly problematic in cases where risks have effects transcending national boundaries and disparate strategies are pursued in individual countries to manage these. The Council is therefore of the opinion that it is not expedient to recommend any single form of risk evaluation for global risks. The Council rather envisages, based on the discussion expounded in Section C, the following structure of the evaluation process:

In a first screening step, it must be clarified whether enough knowledge about a risk is available to be able to evaluate it. If the knowledge base is narrow, then the strategies discussed in detail in Section G (precautionary and resilience strategies) should be pursued. If the knowledge basis is broad enough to classify the risks, then the following steps should be taken.

- The location of a risk in the three risk areas (normal, transition and prohibited) is ascertained. The criteria for this positioning are explained in detail in Sections B and C.
- If a risk is situated in the normal area, then a cost-benefit analysis should be carried out on the basis of the microeconomic costs and benefits – and including macroeconomic costs and benefits if there are relevant external effects. If options have equal benefit, evaluation can further use a simple cross-risk comparison. In addition, market-based instruments (liability, insurance etc.) should be brought into play in order to provide motivational incentives for a comprehensive and efficient balancing of benefits and risks, and to give further financial incentives for risk reduction.
- If a risk falls in the prohibited area, then unconditional reduction is generally called for. If necessary, the activity must be banned. Such a risk can only be accepted in exceptional cases, namely if such a high future growth in benefit is to be expected that this can make even a normally intolerable risk acceptable. In this case, a political clarification process with discursive elements is recommendable.
- If a risk falls in the transitional area, then it must first be determined to which class of risk it belongs. Risks in the transition area are acceptable in cases where it proves possible to overcome or contain the critical elements of the specific type by means of type-specific measures. For this, concrete proposals have been elaborated in Sections A and C.
- If type-specific measures succeed in moving a risk from the transition area to the normal area, the conventional balancing techniques (cost-benefit analysis, risk comparisons, decision analyses) can again be applied. If this does not succeed, a political decision must be taken as to whether the benefit justifies an exception. The process by which this decision is made must be plausible and reproducible.

The central advantage of the approach developed by the Council is that it does not rely on a fixed set of evaluation techniques but instead permits an evaluation of risks appropriate to the specific circumstances by applying approaches appropriate to the specific type of risk.

F 1.3
Allocating risk reduction resources

The next step after risk evaluation is to analyze the acceptable level of costs for further risk reduction. This step generally uses cost-effectiveness analysis, under which measures aimed at improving safety are assessed as to the volume of scarce resources that must be allocated to reduce a given risk. This can follow a rule such as that for every dollar spent to reduce a risk the reduction potential must be exploited optimally (Merkhofer, 1984; Fritzsche, 1986). In this optimization approach, the marginal costs per unit utility (e.g. human life saved, cancer prevented, biotope preserved) are identified for all risks under consideration. The budget available for risk reduction is then distributed among the sources of risk in such a fashion that overall utility is maximized (Smith, 1986). This approach is based on the assumption that the risks that remain after optimization in this manner are acceptable. However, this acceptability requirement cannot be met by the cost-effectiveness approach itself. The acceptability of residual risk must rather be determined by one of the formal techniques described in Section E 1, or by political consultation.

The cost-effectiveness approach renders amenable to analysis a series of difficulties that typically arise when evaluating risks (Shrader-Frechette, 1984):

- The approach can calculate with the value of a human life, without a human life having to be substituted by another, e.g. monetary value.
- All values are weighted equally; human life equals human life. The approach thus does justice to egalitarian notions such as the equal distribution of risks.
- Every departure from the cost-effective solution would imply an overall increase in damage. Decision-makers are thus under pressure to legitimate their decisions if they do not opt for the cost-effective solution, as this would then mean, for instance, that they were willing to sacrifice more human lives than would have to be accepted under the optimal solution.

However, the cost-effectiveness approach depends upon assumptions and suppositions that restrict its use to certain classes of problems (Morgan, 1990). Firstly, it is supposed that the budget available for risk reduction is a constant. In actual fact, a society can decide on a broad range of sums that it is willing to make available for risk reduction. The volume of the safety budget cannot be decided using the cost-effectiveness approach, as this would lead to infinite regress. Secondly, the cost-effectiveness approach only functions without further ado when carried out within one damage or cost dimension. If there are several dimensions of costs or damages, which is usually the case in reality, the individual dimensions must first be amalgamated to one metric, i.e. weighted among each other. Thirdly, the approach can produce counterintuitive results if moral evaluations of the various risk-causing actions diverge (Shrader-Frechette, 1984; Akademie der Wissenschaften, 1992). In a moral perspective, it thus makes a considerable difference whether, to name three examples, a toxic substance is emitted to the air without the consent of those affected and without utility for those who are exposed to the risk, whether exposure to the same substance occurs in connection with a mutually agreed employment contract or whether it is used as a means of suicide.

F 1.4
Risk control

Once the question of the acceptability of a risk has been answered in a satisfactory manner and the costs of risk reduction have been distributed effectively, the question of risk management arises, notably the question of which means shall be used to achieve the level of risk reduction required. The main risk control tools applied or debated can be classified as follows (Renn, 1996):

- Command-and-control bans, limit values, technical instructions and process standards are regulatory instruments. These are issued by governmental agencies and prescribe certain mandatory forms of behavior. In the event of non-compliance, sanctions are available. Liability law also belongs in this group of tools.
- Environmental planning seeks to guide activities and actions in a systematic and targeted manner such that certain objectives can be achieved. Planning tools can refer to certain, clearly demarcated areas and landscapes, or can have a supra-spatial focus, referring to specific tasks and concerns. Here both state and non-state organizations seek to enforce the objectives of risk policy within their respective fields of competence. Landscape planning, ambient air quality planning, water resources planning and waste management planning are important types of risk-related planning. Risk prevention concerns are also a part of transport planning, energy and resource planning, plot realignment planning and forestry master planning (Brösse, 1995).

- Market-based instruments such as insurance premiums and industrial funds are decentralized incentive systems which serve to reduce or even prevent risks. If the conditions for their efficacy are given, they promise an effective reduction and efficient management of risks.
  Environmental taxes and levies, certificates, subsidies and other forms of financial assistance aim at creating economic incentives such that risks are reduced or are at least regulated efficiently. These incentive-based instruments depend on the modification of prices for risk-causing or innovative actions.
- Participatory and cooperative tools bring together state and non-state actors in consensual decision-making processes. Communicative approaches are exemplified by round tables, mediation techniques and cooperative discourse (Renn and Oppermann, 1995). The outcomes are supported and implemented by participants in a voluntary manner. Environmental cooperation takes place in the context of voluntary agreements and initiatives of industry.
- Environmental education and awareness-raising are tools aiming at information and education. They enhance risk awareness and exert an indirect effect upon the behavior of both those who generate and those who are exposed to risks (WBGU, 1994).

For the concern of the present report, namely the management of global risks, these tools can be further specified. Table F 1.4-1 gives a systematic overview of the tools discussed in detail in the following sections of Part F of this report. The Table further lists the target groups to which the various tools are primarily directed. Each type of tool is described and evaluated in depth in Sections F 2 to F 7. Section H 2.1 finally links the individual tools to the Council's typology of risk.

Table F 1.4-1
Overview of risk policy tools.
Source: WBGU

Tool	Target group		
	Individuals/ households	Organizations NGOs, companies	International level
Liability	Compulsory insurance, probabilistic causal liability	Non-fault (strict) liability (with innovation proviso), fault liability	Liability consensus
Funds		Funds	International funds
Regulatory law	Bans, consumption standards	Standards (emissions etc.)	International standards
Permitting		Prototypical permitting procedures	International procedural standards
Incentives	Consumption levies	Taxes and charges	International harmonization of policies on fiscal charges
		Tradeable permits	Tradeable permits, Joint Implementation
Institutional measures	Public welfare services (drugs, etc.)	Capacity building, emergency planning, risk management in development assistance, technology and management transfer	International emergency groups, (UN) Risk Assessment Panel
Information and communication	Awareness-raising, participation, empowerment	Education, training, mediation, codes of conduct, voluntary commitments	Prior informed consent, networking
Research	Risk identification (registers)	Networking, substitute substances	Early warning systems
Technical measures	Indirect protection (iodine tablets)	Resilience strategies, substitution	Resilience strategies, substitution

Liability

F 2

If the damage potentially associated with a risk manifests itself, liability rules place the injured party in a position to claim compensation from the party responsible for the damage suffered (post-event compensation function). Moreover, the person undertaking the risky activity is thus made responsible for the potential negative consequences of that activity. By internalizing the damage at the party responsible, prevention and safety measures are thus in that party's own best financial interest (damage prevention function). The prevention function has two aspects: for one thing, liability – be it based on or regardless of fault – creates incentives for a responsible party to make use of available knowledge about prevention options and possible damaging effects. The second aspect is that liability – particularly strict liability, i.e. regardless of fault – creates incentives to generate new knowledge about prevention options and previously unknown damaging effects, as this knowledge can be used to reduce the responsible party's costs. If this knowledge is passed on to third parties, be it through targeted dissemination or through gradual diffusion, the whole of society ultimately profits. From an efficiency perspective, the prevention function of liability is key, as it reduces the probability of damage occurring and limits expected losses. In the ideal case, prevention measures are implemented until extra prevention costs at the margin equal expected extra loss reduction.

A distinction is made between the liability of the sovereign state under state liability law and responsibilities under international law on the one hand, and the liability of the individual under national and international liability rules on the other. These forms are joined by the claims that the state can make against private entities (e.g. by way of cost recovery). Risks are generated mainly by the activities of private entities. This is why, with respect to damage prevention, private-law liability is the prime instrument. State liability for sovereign actions is in comparison secondary, as here it is impossible to bring generator-focused financial tools to bear (Rehbinder, 1992a).

F 2.1
Structures of liability under private law

Not least under the impression of spectacular industrial accidents such as Sandoz (1986), Exxon Valdez (1989) and Bhopal (1984) private-law liability has been integrated in the instruments of national and international environmental law. The extent to which liability can create incentives to prevent damage depends crucially upon its design, which needs to be as appropriate to the issue at hand as possible, and also upon the risks that it is intended to cover (Section F 1). The compensation and prevention functions need not necessarily be in competition (Endres, 1992). However, useful prevention may be perverted to the point of deterrence if, with the aim of protecting the victim, potentially responsible parties are exposed to disproportionate liability. The effectiveness of a liability regime depends upon whether it is able to cover damage appropriately while at the same time being designed in an implementation-friendly manner.

F 2.1.1
'Ecological damage' as a redressable loss

Civil liability is tailored to protecting the legal interests of individuals. In cases where an environmental impairment cannot be disaggregated completely into infringements of individual legal interests, liability gaps arise, as the environment is not an object of individual legal protection. But even where a case of environmental destruction can be presented completely as an infringement of individual legal interests, ecological damage is only covered incompletely by liability law (Friehe, 1992). A typical case would be the pollution of a plot of land which, in addition to its (covered) relevance to the owner, further has a (not covered) function for the wider ecosystem balance beyond that plot of land. Here a need for regulation and definition remains (Brüggemeier, 1989).

This issue has recently become the focus of intensive research. Legal policy proposals (Godt, 1997) aiming at covering the environment as an object of legal protection range from proposals for a generous construction of property law, over the proposition that certain forms of environmental damage constitute an infringement of the general right of personality as an 'other right' within the meaning of Article 823 para 1 of the German Civil Code ('sonstiges Recht', Bürgerliches Gesetzbuch, BGB), through to the far-reaching call for legal standing for nature as such.

Statutory provisions such as Article 22 of the German Water Resources Management Act (Wasserhaushaltsgesetz, WHG) illustrate that it has been possible to partially close previous liability gaps such as, in this case, for surface waters and groundwater which cannot be individually owned. As distinct from such individual provisions, there are also approaches towards comprehensive coverage of environmental damage. In the USA, environmental damage is covered as 'natural resources damages' regardless of individual rights, and in Italy the Environment Act of 1986 has elevated the environment to an object of legal protection (Seibt, 1994; Kadner, 1995). In both cases it is the state that is entitled to assert claims, in the absence of individual assignability of entitlement. It would in principle also be possible to entitle associations to assert claims (Kadner, 1995). In Germany, the possibility of public sector trusteeship for nature has already been debated for some time (Rehbinder, 1988). Article 3 of the draft Genetic Engineering Liability Act (Gentechnikhaftungsgesetz) proposed on 12.6.1997 by the Austrian Federal Minister of Justice provides for compensation for environmental impairments. According to Kletecka (1997) the intention of this is to cover purely ecological damages. Consequently the issue of liability for ecological damage has established itself in the legal policy debate in Austria. Those who have borne the costs of restoring damage are to be entitled to assert claims (Kletecka, 1997).

With respect to utilizing the preventive function of liability, the problems attached to the coverage of ecological damage should not be over-evaluated. Even the coverage of individual rights already makes liability a sharp sword that can give incentives to parties responsible for environmental pollution to mobilize their knowledge and capital in order to minimize risks. Nor does it detract from the preventive function of liability that the injured party is essentially free to convert the damage into cash. A fruit farmer who has received compensation for the damaged orchard may thus quite well use the money received to convert the orchard into a motorcycle racing track. In terms of the compensation function of liability, this is obviously an undesirable outcome. Here we see that the compensation and prevention functions need not always meet.

F 2.1.2
Cases in which proof of causation is difficult or impossible

Assigning responsibility for environmental damage commensurate with causation is an issue that can present more serious difficulties. The proof of causation of those forms of environmental damage that present themselves as gradual, cumulative or long-distance is in fact the cardinal problem in applying liability (Herbst, 1996; Salje, 1993). This can for instance be because a no longer identifiable plurality or even the general public has caused a damage (as exemplified by forest damages by acid rain). Liability assignment under private law, with its focus on the individual, then meets insurmountable barriers. Here it may be appropriate to consider fund schemes or compensation systems involving statutory environmental insurance agencies, insofar as a specific group of responsible parties can still be identified.

In some cases, liability can be applied despite difficulties in causation by means of easements of proof (e.g. by dispensing with the requirement of full proof and applying instead a 'balance of evidence' standard) or by presumption of causation (as established e.g. by Article 6 of the German Environmental Liability Act – Umwelthaftungsgesetz, UmweltHG) with an associated reversal of the burden of proof (Brüggemeier, 1989). Introducing probability liability is a more radical solution. Here the conventional, deterministic understanding of causation is largely replaced by a probabilistic approach. The transition is fluid between easements of proof and the introduction of probability liability, notwithstanding that the first is a procedural tool while the latter is a new type of liability based on a different standard of substantive causality.

It is essential that liability does not degenerate to mere liability on suspicion. In cases where proof of causation cannot be provided, even under eased requirements, factual limits are set to the enforcement of the law (Kinkel, 1989). The danger of overstepping the limits of a proper assignment of damages doing justice to true causation is greater if probability liability is applied than if easements of proof are used. Options for expediently applying easements of proof should therefore be fully exploited before considering probability liability. Accordingly, the independent commission of experts on a German Environmental Code (Umweltgesetzbuch, UGB-KomE) made exclusive provision for easements of proof in its proposed Code. Article 176 para 1 of the draft Code introduces a more general presumption of causation that applies to all elements of environmental liability in the draft (BMU, 1998). This goes beyond the presumption of causation already established by the German Environmental Liability Act (Article 6 UmweltHG, or Article 176 para 2 UGB-KomE). The presumption of causation implies an easement of proof: causation is presumed if, under the circumstances of the specific case, the balance of evidence definitely suggests that the damage has been caused by an action pertinent to the case. The commission intends to thereby preclude the danger of responsible parties becoming subject to liability on suspicion (BMU, 1998).

A different line of development is to be seen in the debate on whether to completely take recourse on the substantive side to a probabilistic concept of causation. This debate has been under way for some time, particularly in the USA. Liability based on probability would need to be complemented by arrangements for proportional assignment of overall damage. The probability of causation would determine the level of the claim for compensation (Wiese, 1998). If only a few of the main responsible parties can be identified, there would be a danger of excessive liability if proportional assignment were not implemented, as the responsible parties who are known would bear the responsibility of those who are unknown, too.

An issue that follows on from the above, but at a different level, is whether, where there is a plurality of responsible parties, each should be liable individually to the injured party according to each responsible party's proportion in causation, or whether all responsible parties should be jointly and severally liable for the entire damage. In the latter case, the injured party can choose to whom he shall direct his claim. The party held liable by the plaintiff can then seek compensation from the other responsible parties, but bears the risk of insolvency. Victim protection speaks in favor of joint and several liability. However, as the injured party will generally take recourse to the responsible party with the greatest financial capability, but the latter need not necessarily bear prime responsibility or may indeed only have a small part in causation, joint and several liability can lead to inequitable outcomes (the so-called 'deep pocket' effect).

In Germany, when arguing for the application of a statistical (probabilistic or epidemiological) standard, reference is usually made to the case law of other countries. However, as far as we can see, liability law has not been based by statute on stochastic causality in any other country, either. As we shall set out below, the Sindell ruling of the Californian Supreme Court (Bodewig, 1985), which is much cited in this connection and from which the instrument of market share liability (Elliott, 1988) was developed, can quite well be construed differently.

The mother of the plaintiff had taken the drug DES during pregnancy in order to prevent a miscarriage. Years later, the plaintiff contracted a rare form of cancer due to this drug. It could no longer be ascertained which DES manufacturer had made the specific drug that the mother of the plaintiff had taken. Under the market share liability standard developed in the ruling, the market share at the point in time of causation is taken as an indication of the probability that a manufacturer has caused the damage, and all manufacturers are liable according to their market shares (Marburger, 1986).

It needs to be kept in mind, however, that the Sindell action was a so-called class action, i.e. one in which the plaintiff also represented all the other persons injured by DES (Elliott, 1988). Following the statistical law of large numbers, the assumption that the market shares of each manufacturer will correspond to their share in causation of the overall damage (namely the health impairments suffered by all DES victims) will be more justifiable than the probability in each individual case (Elliott, 1988). Viewed thus, the assumption that the Sindell ruling was based on a probabilistic concept of causation needs to be relativized. Nor is market share liability uncontroversial in the USA. The Supreme Court of Iowa, for instance, has qualified market share liability as a 'court-constructed insurance plan'. It was easier for the Supreme Court of Iowa to reject the action brought, as in the specific case it did not have to adjudicate on a class action (Posch, 1988).

Under pollution share liability (Müller-Chen, 1997; Marburger, 1986), which is modeled on market share liability, the emitter is liable according to his share in pollution. In extension of Sindell, where only the five largest manufacturers with a joint market share of 80% were sued, it suffices under pollution share liability for the plaintiff to sue the main emitters of a region, and not all of them. This appears appropriate with respect to the associated costs of investigation and litigation. Excessive liability can be avoided by means of proportionate liability of the defendants – in Sindell, for instance, up to 80% of the total damage. However, it is doubted by some whether the analogy between market shares and pollution contributions is appropriate. Other than in the DES cases, where each manufacturer sued had certainly caused individual cases of damage by manufacturing a certain drug that brings on a specific rare form of cancer, this cannot be said of pollutant emissions, particularly in view of their spatially and temporally varying distributions (Assmann, 1988).

Japanese case law has four rulings from the period from 1967 to 1973 in which a statistical correlation between certain pollutant exposures and disease frequencies were viewed as establishing liability (Holzheu, 1994; Brüggemeier, 1989). The Japanese legislator subsequently solved the problem by establishing a statutory fund (Rehbinder, 1989), so that liability was no longer claimed.

In summary, we may state that a probabilistic proof of causation generally does not lead to unacceptable liability on suspicion if it is limited to easing the burden of proof by reducing it to a '(clear) balance of evidence' standard. In special cases a market share or pollution contribution may also be used as a standard for generator-appropriate assignment of damage, but this cannot be generalized.

So-called mass damage presents further problems in proving causation. This type of damage includes large-scale accidents – such as the recent high-speed railway accident at Eschede, Germany – which may under certain circumstances also entail environmental impairments through emissions. This issue was debated by the civil law section of the 62nd German conference of jurists (Deutscher Juristentag) in September 1998. The introduction of class action in Germany was also debated. However, in contrast to the US class action suit, this should not establish a compulsory cooperative of injured parties. The conference also stressed the importance of liability funds, which can help to close gaps in insurance cover in the event of mass damage.

F 2.1.3
Liability based on fault versus strict liability

The traditional view of German jurisprudence (Steffen, 1990) is that liability based on fault has a preventive effect, while strict (no-fault) liability does not. Liability based on fault depends upon the care taken, while strict liability is precisely a 'consideration' for the circumstance that hazardous activities whose consequences are difficult to predict but which are in principle desired by society are permitted. In this understanding, strict liability has the function of balancing the burden placed by 'permitted risks' on society. If this conventional understanding of strict liability is thought through to its logical conclusion, then it is nonsensical to ascribe a preventive function to strict liability as this would mean preventing what has been just permitted.

In the meantime, legal theory is increasingly stressing the preventive side of strict liability, too. This has been influenced by the findings of economic theorists in this field. A fine jurisprudential distinction is drawn between the purpose and the effect of strict liability (Rehbinder, 1992a). A further point put forward in favor of a preventive interpretation of strict liability is that the threat of liability imposition implied by liability based on fault is an integral component of strict liability, and that strict liability pursues the preventive purpose at least as much as liability based on fault does (Blaschczock, 1993). The assumption that strict liability cannot exert a preventive effect is based on a static understanding of 'permitted risk'. Strict liability can also be interpreted as a means of forcing the actor to explore the (safer) alternatives for action (himself) (Ladeur, 1993).

The opposite opinion, which negates the preventive function of strict liability, is useful inasmuch as it points to the limits of the purposeful preventive effect of strict liability. The threat of liability must not lead to a factual ban, in the sense that certain economic activities are dispensed with completely for fear of incurring liability. In that case, the argumentation of the opposite opinion would indeed be correct. Moreover, apart from this extreme case, it must always be kept in mind that liability can exert constraints upon innovation.

Dispensing with such an activity does not necessarily mean improved safety. In the most unfavorable case, liability can lead to a situation in which a certain activity with known and thus calculable risks is retained, while an alternative activity with (still) unknown – but, as would transpire, substantially lower – risks is abandoned. When instrumentalizing strict liability in environmental law, this point needs to be kept in mind. The severity of a liability rule is not a sufficient criterion for its effectiveness.

There is a crucial difference in the way that liability based on fault and strict liability cover development damage or gradual damage. Under strict liability, a responsible party can in principle be held liable even if the damage results from a continuous and lawful activity, such as fertilization practices over lengthy periods (Brüggemeier, 1989). 'Development damage' refers to such types of damage whose occurrence was not predictable at the point in time of the causative action. Strict liability creates an incentive for industries to continuously review the effects of permitted activities, possibly even to carry out research (Herbst, 1996). Liability based on fault, which depends upon subjective blameworthiness, creates no such incentive (Panther, 1992). However, it may be noted that due to the objectification of duties of care, liability based on fault is in fact becoming increasingly similar to strict liability (Godt, 1997).

The question arises for strict liability as to how the assignment of development risks to industry, which is in theory complete but in practice regularly restricted, can be designed purposefully in the interests of risk management. This can be done by setting liability ceilings, or by means of exclusion of liability for such damage resulting from development risks that could not be anticipated at the time when a product was put on the market (cf. Article 1 para 2 No. 5 of the German Product Liability Act – Produkthaftungsgesetz, ProdHG). Such approaches further prevent excessive burdens upon industry which might otherwise lead to industry dispensing entirely with economic activity and research in certain spheres.

F 2.1.4
The role of insurance

We have discussed liability as a two-person relationship between the responsible party and the injured party. In practice, however, a third person generally enters the relationship, namely the insurer. If a potentially responsible party bears the costs of damage alone, he will, if he has a risk-averse attitude, take excessive precautions to prevent damage from happening. He does not orient his actions to the expected damage, but assigns greater importance to the reduction of earnings caused by compensation payments in the event of damage than he does to the absence of a reduction of earnings in the event that the damage does not materialize. In the extreme case, this can lead to precaution by abandonment, so that a society forgoes positive developments. Insurance offers a solution to this problem. The potentially responsible party can, by paying an insurance premium, transform into security his uncertainty or incertitude concerning future payment of damages (Karl, 1992).

The insurance premium is oriented to the expected value of the damage, so that precautionary measures will tend to be reduced to an optimum level. In this way, insurance options can be evaluated positively: they serve to contain macroeconomic costs incurred by excessive precautionary expenditure. On the other hand, new costs can be incurred if insurers have only a limited ability to correctly assess the individual precautionary behavior and the individual risk. If the policyholder can assume that reducing precautionary measures and thus costs and/or expanding risk-prone activities will not lead to rising insurance premiums, he will tend to limit his precautions and/or extend his risk-prone actions. This entails additional costs for the economy. However, competition among insurers forces these to levy risk-oriented premiums, e.g. through deductibles or bonus-penalty systems. Insurers thus create incentives to produce new knowledge of damaging effects and technological or organizational prevention options. They further function as multipliers for empirical knowledge by integrating experience made with earlier losses in the rating elements that determine the levels of premiums.

Whether certain risk-prone activities are beneficial for a society and are rendered more manageable in the course of time thus also depends upon the efficiency of insurance systems. In situations where risk-prone activities are only undertaken because the responsible party, due to limited financial means, is not able to provide compensation at all in the event of damage, compulsory insurance arrangements are needed. Compulsion is justified because pollution regularly endangers and damages third parties without their consent (Karl, 1992). Here, however, care needs to be taken that the compulsory system does not undermine the assignment of individual responsibility created by liability in that the insurer is exploited as an anonymous ‘reimbursement agency’, the insurer forgoing his possibilities to take recourse to the individual polluters.

A final critical issue in the context of insurance systems is that of ‘moral hazard’. This term was coined by the insurance industry to refer to cases in which a policyholder reports too high or even entirely fictitious losses. The problem for the insurer is the lack of verifiability. The problem for the insurance system as a whole is that premium payments are higher than they would need to be on the basis of the insured loss. In the environmental liability context, there are various forms of moral hazard for the insurer. If the insurer has insufficient information about the risk posed by an individual policyholder, it can only apply some form of average rating. This, however, attenuates the incentive of the individual to take damage-preventing measures (Holzheu, 1994). Due to the coverage provided by the insurer, the responsible party has no direct interest in asserting contributory negligence on the part of the injured party and thus reducing the level of insured loss. We may also note a phenomenon termed by Priest as ‘victim moral hazard’, which precipitated a crisis in the insurance industry of the USA in the 1980s (Herbst, 1996). This phenomenon arose in the field of product liability, where manufacturers and thus their insurers were increasingly held liable in cases in which damage would previously have been borne by the injured parties themselves or their own insurers. This shift came about through the application by the courts of increasingly strict diligence standards, in conjunction with astronomic compensation payments. This led to drastic premium rises and to the complete suspension of insurance cover for some products. Due to differing legal systems, the USA experience is not directly transferable to other countries such as Germany. In particular, the German system does not provide for juries ‘sympathizing’ with the victim and thus driving compensation claims to irrational levels. The US experience does show, however, that the insurability of risks depends crucially upon a careful and balanced adjudication that applies strict standards to the behavior of the injured party, too (Herbst, 1996). The general risks of life or the risk to which the individual exposes himself must not be passed through to presumed responsible parties under the guise of victim protection or compensation notions.

F 2.1.5 Realization of liability claims and its preventive function

For both individual responsible parties and their insurers, it is not the expected level of damage which is relevant, but rather the expected effective payments for damages. The lower the anticipated probability of liability for damages, the lower are the expected payments or premiums and thus the precautionary incentives. Low probability of liability can be due to:

- Actions not being enforceable, because there is a lack of a basis for a claim, there are problems in proving causation or a replacement or compensation is not feasible.
- Actions not being economically worthwhile.

These factors lead to too many risks being incurred, whereby third parties bear the costs of damage. The underlying causes are diverse. On the one hand, design of institutions plays an important role. The legal provisions necessary for successful liability (such as access to justice) can be absent or can be designed such that furnishing the necessary proof is very costly. Here, institutional alternatives need to be examined that provide more scope for liability. On the other hand, institutions establishing liability, regardless of how they are designed, can be structurally associated with such high costs that their effectiveness is severely restricted. Thus, in cases involving a plurality of emitters it will frequently be impossible to prove 'in accordance with the truth' that one of these emitters has caused the damage, regardless of how the legal rules are designed. Similarly, in cases that occur with great time lags or through synergisms it will frequently be impossible to ascertain the 'actual' responsible party. If easing the burden of proof does not help, then civil liability remedies must be dispensed with in such cases. Other risk control tools then need to be considered, for victim protection must not lead to liability upon suspicion.

F 2.2 Liability under private international environmental law

The efficiency of private-law liability is reduced in cases of transboundary environmental impairment where the polluter and the damage are localized in different states. The risk of becoming liable to claims for compensation is *de facto* very much reduced in such cases. In contrast, the legal policy objective must be to provide judicial remedies to the injured party in a forum to which that party has access; the judgments made in that forum must have prospects of enforcement in the state in which the polluting facility or the property of the polluter is located.

The conditions under which liability may apply are determined by the law of the nation states, and thus differ from country to country. It therefore needs to be ensured that the polluter cannot withdraw to the lowest level of protection through his choice of location ('liability havens'). One way of countering this would be to introduce a – globally or regionally – uniform body of environmental liability law. However, this presupposes that the states concerned agree to such a liability regime. This has as yet only been the case in a few specialized areas. Nonetheless, the effectiveness of international environmental liability could be enhanced considerably, regardless of whether uniform liability standards are introduced, by means of harmonizing the national rules governing private international law (conflict of laws). Private international law does not itself contain any liability rules; rather, it is the body of principles for deciding which of two or more competing or conflicting bodies of national law shall apply.

F 2.2.1 Agreements on international environmental liability law

On international environmental liability, agreements have as yet only been concluded in individual areas such as oil and nuclear liability (Section F 2.2.1.1); however, a number of organizations have indeed elaborated draft codifications (Section F 2.2.3). Two basic types of international agreement can be distinguished here. Firstly, there are agreements concerned purely with conflict of law rules. These do not formulate any specific liability provisions, but merely determine which national liability regime applies if a matter has links with different bodies of law. There is a second group of agreements that make separate substantive provisions, and thus create truly uniform international law.

F 2.2.1.1
International agreements in special areas

Pollution damage arising in sea transport

Today's liability regime applying to sea transport was pioneered by the 1969 International Convention on Civil Liability for Oil Pollution Damage (or Civil Liability Convention, CLC) negotiated under the auspices of the International Maritime Organization (IMO) (Ganten, 1997; Rinio, 1997; von Hoffmann, 1998). Germany and 90 other states joined the original convention, but not the USA, which continues to insist on its special course. Since 15 May 1998, accidents have been regulated on the basis of an improved Protocol of 27 November 1992, which was designed as a convention in its own right. This regime applies to pollution damage occurring within the exclusive economic zone (EEZ) of a Party (i.e. within 200 nautical miles from the coast). It applies to all vessels built to carry oil in bulk. It is irrelevant whether the ship sails under the flag of a contracting party. The CLC regulates conclusively the strict liability imposed upon the owner of a ship. The liability caps were raised substantially in 1992; these do not apply if negligence or intent can be proven. Owners are obliged to take out third-party liability insurance, with coverage depending upon the size of the ship. Claims for compensation can only be made in the courts of the contracting parties within whose territories the damage has occurred or protective measures have been taken.

The CLC was supplemented by the 1971 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (the Fund Convention). This affords further protection to the injured party in cases where oil pollution damage is not recoverable under the CLC or is not fully recoverable due to the liability caps. The fund is being supplemented by contributions of the mineral oil industry. In parallel with the CLC, the Fund Convention was also subjected to thoroughgoing revision by the 1992 Protocol.

In 1996, IMO proposed an International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS Convention). This excludes from its scope oil and nuclear accidents at sea, which are regulated by specialized agreements. The proposed convention provides for the establishment of an HNS fund modeled on the oil liability fund, which is subsidiary to the strict liability of the carrier. It is not yet clear whether the proposed convention will enter into force; by the expiry of the deadline for signature at the end of September 1997, only 6 further European states and Canada had signed in addition to Germany. In view of the importance of the matter – more than half of all goods transported by sea are classified as hazardous or toxic (Puttfarken, 1997) – a uniform liability regime appears extremely desirable. The reticence displayed by many states is evidently because, as opposed to oil transport, no severe accident involving hazardous and noxious substances has yet occurred.

Nuclear accidents

For Western Europe, nuclear liability law was largely harmonized by the Paris Convention on Third Party Liability in the Field of Nuclear Energy adopted on 29 July 1960 under the auspices of the OECD, and the Brussels Convention Supplementary to the Paris Convention of 31 January 1963. The Paris Convention regulates civil liability arising from a nuclear incident, while the Brussels Convention clarifies the modalities of financial coverage in the relationship among the party States under international law. This regime covers not only accidents, but also harmful continuous impacts. The recovery of damages is regulated primarily by the provisions of the Paris Convention. This is supplemented by reference to the national law of the forum state, being the state in which the incident took place, for instance with regard to claims for compensation for non-pecuniary damage. Under the Paris Convention the operator of the nuclear installation is held liable irrespective of fault. In departure from the Paris Convention, since 1985 there has no longer been any maximum liability for incidents occurring in Germany. Geographically, the Paris Convention covers neither nuclear incidents proceeding from installations in non-party States, nor damage suffered there. Notably, the Chernobyl reactor disaster thus did not fall under the scope of the convention. Here the victims received compensation from the states affected, if at all. In Germany, the German taxpayer thus had to pay, not the operator of the power plant.

The Vienna Convention on Civil Liability for Nuclear Damage adopted on 21 May 1963 under the auspices of the International Atomic Energy Agency (IAEA) has only had very limited success to date. This was originally conceived as a worldwide agreement. However, as a result of its intended worldwide scope, in many fields it only contains minimum requirements which are considered to be inadequate by most states.

In September 1997, the Vienna Convention was amended by a Protocol. It remains to be seen whether the Protocol, which has not yet entered into force, will enhance the acceptance of the Vienna Convention. At the same time, a Convention on Supplementary Compensation for Nuclear Damage has been opened for signature. Both conventions now explicitly include in their definition of 'damage' the costs for restoring environmental impairment.

Sea transport of nuclear materials is regulated by the Brussels Convention of 17 December 1971 Relating to Civil Liability in the Field of Maritime Carriage of Nuclear Materials. This channels liability to the operators of nuclear installations. The convention of 25 May 1962 on the liability of operators of nuclear ships has not yet entered into force. The reticence of many states is probably because the wording of the convention also includes warships.

F 2.2.1.2
General environmental liability agreements

If we look at their ratification status, the situation regarding general agreements on liability for transboundary environmental damage is far less encouraging than it is for the specialized agreements discussed above.

Council of Europe

The Convention on Civil Liability for Damage Resulting from Activities Dangerous to the Environment (the Lugano Convention) concluded on 21 June 1993 under the Council of Europe's auspices (Pipers, 1995; Friehe, 1995; Seibt, 1994) has a substantive scope going far beyond liability as such (including compulsory third-party liability insurance). This is exemplified by supporting provisions relating to procedural and administrative law. The Convention provides for strict non-fault liability for dangerous activities. The Convention contains a non-conclusive list of such activities. Only a few states have signed the convention so far, and none have yet ratified it.

The prospects for entry into force – which would require three ratifications – are not favorable. This is presumably partly because the party States have not been given the option to set liability ceilings. Other states such as Germany, which adopted its own Environmental Liability Act in 1991, presently see no need for such a detailed regulation at the international level. However, such reticence on the part of the legislator is not justified as long as the national solution is not markedly superior to the international one.

European Union

In the European Union (EU) arena, the most important recent development is the European Commission's 1993 Green Paper on Remedying Environmental Damage [COM 93 (47); Müller-Chen, 1997; Hager, 1997]. The declared purpose is to reduce distortions of competition that result from differing liability systems. The Green Paper centers on the concept of reinstatement of the natural environment, compensation being secondary. Collective compensation models are discussed as backstop mechanisms. Due to the highly controversial debate that it has triggered, a transposition of the Green Paper into concrete legislative projects is not in sight. In the meantime, the Commission is working towards a White Paper, which shall serve as a basis for further deliberations. The extreme positions in this debate are a comprehensive harmonization of environmental liability law by an EC directive on the one hand, and retaining the present situation, i.e. the regulatory competence of the member states, on the other. An intermediate solution also debated is for the Community and its member states to join the Lugano Convention of the Council of Europe. The literature calls into question the justification of a separate regulation at the EU level with reference to the subsidiarity principle and the Lugano Convention (Klass, 1997).

As a true substantive harmonization of environmental private law at EU level is not to be expected in the near future, attention turns to approaches towards harmonizing at the European level the body of principles for deciding which of two or more competing or conflicting rules shall apply (conflict of laws). In connection with pertinent resolutions adopted at the European intergovernmental conference in Amsterdam in June 1997, the preliminary work for a convention on the law applicable to non-contractual obligations is currently assuming concrete form. Such a convention should also address the issue of the applicable environmental liability law in cases of transfrontier impairment. Here the 'favorability principle' ('Günstigkeitsprinzip') suggests itself as a conflict-of-laws approach.

Hague Conference

We may further note deliberations of the Hague Conference on Private International Law, which has addressed the issue of regulating problems of environmental liability law in an international agreement (von Bar, 1995). In keeping with the tradition of the Hague Conference, these efforts concentrate on issues relating specifically to conflict of laws and international procedural law. No schedule has yet been set. Such a convention will not yet be a part of the 19th conference due for the year 2000.

Scandinavia

The Nordic Environmental Protection Convention adopted on 19 February 1974 by the Scandinavian states could serve as a model for a multilateral agreement. This covers all emissions proceeding from the real estate of a contracting party (Lappe, 1993). The particular advantages of this convention include the equal treatment that it accords to nationals and non-nationals in environmental proceedings, and the right to bring actions in the state from whose territory the environmental impairment proceeds. The rules contained in the convention on conflict of laws also appear convincing; under these the injured party can effectively choose whether the law of the state in which the damage was generated or that of the state in which the damage occurred shall be applied. To support protection against environmentally harmful actions emanating from other parties, a monitoring body is established in each party to the convention that must be heard in the other party States. In order for these bodies to be able to operate effectively, it is agreed that they shall have free access to information.

F 2.2.3 Procedural problems

The control function of international environmental liability law cannot be improved as long as the procedural issues pertaining to transfrontier actions have not been adequately considered (Schack, 1992). The question of the country in which an action can be brought (international jurisdiction) can thus considerably hamper transfrontier actions. The recognition and enforcement of foreign court rulings is also an important issue.

The international agreements on specialized areas discussed above expressly contain provisions regulating jurisdiction. However, specific provisions can be problematic. This is exemplified in the area of nuclear liability by Article 13 of the Paris Convention (Section F 2.2.1.1), under which jurisdiction over actions lies exclusively with the courts of the contracting party in whose territory a nuclear incident occurred. Here the procedural channeling to the courts of the installation State makes it difficult for the injured party to bring actions, and is in contradiction to the more reasonable general rule established by the Brussels (EEC) Convention on Jurisdiction and the Enforcement of Judgements in Civil and Commercial Matters, under which the courts at the places of the causative act and of the harmful outcome have concurrent jurisdiction. The Brussels Convention is of prime importance to European legal relations, but is not applicable in matters falling within the scope of the more specialized provisions of Article 13 of the Paris Convention.

Furthermore, effective legal protection is only ensured if a successful action by the injured party for compensation or injunction can be enforced against the responsible party. In the case of transfrontier emissions, the question frequently arises as to whether a judgment given in the country where pollution takes place will also be recognized and enforced in the country where the polluting installation is located. For European legal proceedings, the Brussels Convention already guarantees maximum freedom of applicability of judgments within the member States. The Lugano Convention of the Council of Europe (Section F 2.2.1.2) contains corresponding provisions. A noteworthy project in this context is that of the Hague Conference on Private International Law to create a worldwide convention on recognition and enforcement, which would in particular cover legal relations with the USA. This convention will be a topic of the 19th Hague Conference in the year 2000 (on the preliminary work cf. von Mehren, 1997 and Walter, 1997).

All conventions contain conclusive catalogs of reasons for which recognition and enforcement may be refused. It is to be noted that these reasons do not expressly include the circumstance that a ruling in the country in which the judgment was given is incompatible with an operating permit under private law that was granted to the polluter in the country of the court applied to. Many authors nonetheless assume, with reference to the provison of the *ordre public*, that such a permit must stand in the way of recognition and enforcement (Schack, 1992). This curtailment of freedom is regrettable and underscores the need for an international harmonization of the public law of permits.

Where no international agreements apply directly, many states are willing to recognize and enforce foreign court judgments. Concerning German practices, we must draw attention here to Article 32a of the German Code of Civil Procedure (Zivilprozeßordnung, ZPO). By providing for exclusive jurisdiction of German courts for domestic installations within the meaning of the German Environmental Liability Act, the Code stands in the way of the recognition of judgments given at the foreign place of occurrence of environmental impairment. As opposed to this, the Federal Republic of Germany claims, in the converse case, international jurisdiction for its courts from the aspect of the domestic place of occurrence when the emitting installation is abroad. Article 32a ZPO is thus not only an expression of unjustified inequality of jurisdictional treatment of domestic and foreign courts, but also impedes the free applicability of judgments and thus greatly disturbs the international harmony of adjudication (Pfeiffer, 1993).

F 2.2.4
Recommendations concerning liability under private international environmental law

It is only at the international level that an effective liability regime for transfrontier environmental impairment can be developed that does justice to competing interests and the matter at hand. The superiority in this respect of international agreements that harmonize substantive law and can provide comprehensive, coordinated provisions is clear. Moreover, these can provide a context within which to address issues such as third-party liability insurance or the establishment and financing of liability funds. On the other hand, historical experience teaches us that it is only rarely possible in the negotiating process to achieve a final regulation of the problems at hand. National legislators do not expect innovations of private international law to be viewed positively by the electorate – this applies particularly to environmental liability, with its possible repercussions upon national competitiveness. Frequently, it is only the public pressure after disasters have happened that brings about an increased willingness to negotiate. For instance, the 1969 Agreement on Liability for Oil Pollution Damage can be seen in connection with the oil pollution disaster caused in 1967 on the coast of Cornwall by the Liberian tanker Torrey Canyon. The recommendation of the conference of ministers of justice of 1986 that led to the Lugano Convention of the Council of Europe was adopted only a few weeks after the Chernobyl reactor accident (and only shortly before the Sandoz accident in Basel).

On the other hand, proposals for international agreements have also failed because the envisaged liability ceilings were considered to be too low. Moreover, many, particularly European, states which have recently invested great effort in creating modern environmental liability legislation are most reluctant to accept the necessity of uniform international law if this would render redundant the effort invested or would mean a material step backwards. We thus find that creating a body of uniform international law only has prospects of success in either clearly defined specialized areas (nuclear and oil damage liability; genetic engineering in the future) or for a limited circle of contracting parties (Scandinavia; possibly the EU). In contrast, agreements concerned purely with conflict of laws only promise a limited harmonizing effect, but are more realistic in practice due to their greater propensity for consensus.

It appears recommendable and practicable to proceed in several stages:

- Over the short term, work should press ahead on an EU agreement on conflict of laws, in order to thus guarantee international consistency of judgments in cases involving transboundary environmental impairment. For the reasons set out above, the forum should be chosen under such an agreement according to the 'favorability principle' ('Günstigkeitsprinzip'). Such a harmonization of conflict of laws provisions, for which we already have a successful model in the international law of obligations, would provide the desirable complement to the procedural harmonization already achieved through the Brussels Convention on Jurisdiction and the Enforcement of Judgements.
- Over the medium term, approximating substantive environmental liability law within the European Union is expedient, for the simple reason of the associated harmonization of conditions of competition. This approximation of private law should be joined by a harmonization of public permitting law. In the shape of the European Court of Justice, the EU has a body capable of ensuring the requisite uniform construction in the member states of the rules created by these harmonization efforts.
- In parallel, the Lugano Convention of the Council of Europe should be promoted, not least because this offers the possibility of integrating the eastern European countries. For those states that cannot resolve to accept such far-reaching harmonization of substantive law, all efforts must be made to at least ensure that these states recognize and enforce judgments handed down to injured parties by courts in the place of occurrence. Recognition agreements offering structures for non-members of the EU in particular are presently available in the shape of the Lugano Convention and, in future, in the shape of the anticipated Hague recognition and enforcement agreement.
- Finally, support should be given to the objective now pursued by the Hague Conference of developing an internationally acceptable agreement on conflict of laws rules in the field of environmental liability. At present, the prospects of such an ambitious project cannot be assessed with any certainty, although the work on such a project is – regardless of the finally achieved number of ratifications – a pioneering effort towards promoting an understanding of private law as a means of global risk management through environmental liability law.

Environmental liability funds F 3

Environmental liability funds have the potential to solve a number of the problems associated with individual liability. Their purpose can be to provide funding for the remediation and compensation of damage that has already occurred, or to pool funds with which to compensate for future damage. In the first case the financing function is dominant, as exemplified by the CERCLA/Superfund for remediating contaminated sites in the USA (Hohloch, 1994; Karl, 1994). If a fund has the second purpose, the financing function is joined by a preventive function if future damage or payments can be reduced by means of precautionary measures. Funds attempt to compensate for damage resulting from environmental pollution caused by products, waste disposal and emissions to air, soil and water in cases where there is a lack of access to individual polluters, and to create specific incentives for potential polluters to take precautionary action. They are worth considering if delivering proof of individual causation is associated with high costs, or if damages cannot be recovered from individual polluters. Problems in proving causation arise in the event of or in relation to (Karl, 1994)

- Many potentially responsible parties,
- Unknown sources of emissions,
- Long periods between emission and manifestation of damage,
- Synergistic damage, and
- The unequivocal identification of the cause of damage.

The more difficult it is to establish a link between polluter and damage, the more dominant the compensation function of a fund becomes. From an efficiency perspective, funds are most effective if there is a definable circle of potentially responsible parties that is integrated completely in the fund scheme and makes contributions to the fund proportional to the risk emanating from each party, and, moreover, this circle is connected to a group of parties whose damage suffered can be attributed relatively clearly to certain effects. Here differentiated incentives to take precautionary action can be given if the criteria for assessing fund contributions are designed accordingly. Contributions must be linked to the circumstances to which the damage is causally attributable, and not to proxy measures (e.g. to emission levels, not to products or inputs; Karl, 1994; Rehbinder, 1992b). It is at this point that problems associated with balancing efficiency gains and practicability arise. The less differentiated the assessment of fund contributions is, the more likely it becomes that individual emitters adopt a free-rider position because precautionary action is not rewarded and the costs of damage are borne by all fund members. The precondition to differentiation is that the fund operator has an interest in giving such incentives. In contrast to insurance companies, who do indeed have such an incentive because they must maintain their position in competition with other companies and efficient precautionary incentives provide cost reductions, fund operators may lack this incentive (Ladeur, 1993). The weaker this incentive is for the operator, the more the compensation function of the fund gains importance to the detriment of the preventive function. A further problem is that, compared with individual strict liability, funds generate inadequate incentives to carry out research in order to discover possible negative consequences of emissions that are not yet known. This would be only worthwhile if contributions could be thereby reduced, for instance if these are assessed (in part) on the basis of the research effort undertaken by an emitter.

These efficiency-related problems of funds restrict their usefulness. However, these problems should not be overstated, as they must always be seen in relation to available alternatives and the critical points of such alternatives. The initial argument in favor of a fund solution in a given situation is the lack of incentive effect emanating from individual liability claims against concrete polluters. Without a fund – or other measures – excessive damage will remain without compensation for the injured party, and precautionary incentives will also be too weak. Funds can improve this situation both in terms of cost distribution and in terms of precautionary efforts. The question nonetheless remains as to whether:

- The efficiency goal could not be attained more cost-effectively by other measures, and whether

- Compensation could be provided more cost-effectively by other avenues.

Expected damages resulting from continuous emissions can also be reduced by means of instruments such as taxes and charges or tradeable permits. However, these presuppose that the likelihood of damage is known. There is otherwise a danger that taxes and charges or tradeable permits are used to pursue pure minimization strategies. These instruments thus cannot substitute the efficacy of individual liability and of funds in generating new knowledge. They can only control known, expected damage, in which case ex ante risk reduction may indeed be more cost-effective than funds. As an alternative to payments from funds, compensation can also be provided by health insurance systems (Karl, 1994). Here the link between polluter and compensation is severed completely. Nonetheless, in cases where the compensation function of the fund dominates because the link between fund contributors and damage covered by the fund is highly indeterminate, providing such compensation through general social security systems can be advantageous.

Preventive function

One circumstance weakening the preventive function of funds is that assessing contributions that are proportionate to the risks emanating from contributors would cause high costs. The more comprehensive the compensation provided by a fund, the weaker the preventive function becomes. The more diverse the types of damage that are to be compensated, the more undifferentiated the contributions will be, and the more undifferentiated the precautionary incentives. Nor does the collectivization of liability promote learning in a society (Ladeur, 1993). Individualized liability gives the individual potential polluter incentives to activate and expand his knowledge of possible damaging effects and precautionary measures. Insurers collect knowledge about causes of damage and precautionary options from a variety of sources of experience, and can pass on this knowledge to potential polluters through requirements tied to premium cuts. Knowledge is thus produced individually, collected centrally and disseminated. Dedicated funds (e.g. for certain air pollutants) may also produce learning effects. If individual fund members can bring about reduced contributions by developing new organizational forms and technologies that lead to reduced risks, all other potential polluters will profit from this in the course of time. Moreover, dedicated funds provide a forum in which experience on possible damaging effects of substances and on causes of damage can be collected and disseminated to fund members. From this, too, societies profit in the course of time. Generic funds, in contrast, to which many potential polluters contribute and from which many different types of damage are compensated without detailed knowledge of cause-effect relationships, do not promote learning. Rather, they promote free-rider behavior. The same applies if dedicated funds lack incentives to reward risk-reducing behavior. Funds are thus no substitute for individualized liability (Rehbinder, 1992b). They can only have a supplementary function in areas where individualized liability fails.

Even in such areas, specific cases must be examined to see whether the fund still generates an efficiency-enhancing effect. If the fund is only to have a compensation function, it needs to be considered which efficiency-reducing effects may result. If contributions to the fund are linked positively to the level of premiums for individual insurance – because it is assumed that a high premium indicates a high risk – considerable incentive distortions can result. This is because a high risk in areas amenable to insurance need by no means imply that the risk is high in an area not amenable to liability law (Ladeur, 1993). The commencement of insurable activities then becomes dependent upon mandatory contributions to a fund.

Statutory environmental insurance agencies

'Statutory environmental insurance agencies' (German: 'Umweltgenossenschaften') offer an alternative to liability funds (Kloepfer, 1988; Rehbinder 1992b, c; Wagner and Janzen, 1994). They transfer to the environmental protection sphere the model of the Occupational Health and Safety Agencies ('Berufsgenossenschaften', social accident insurance institutions) established under the German social security system. The great advantage compared with funds is that such agencies are in a position to carry out monitoring and to mandate technical standards, while funds must rely upon monetary incentives, risk assessments and the provision of advice. However, it is dubious whether the successful track record of health and safety agencies in industry can be replicated in the environmental sphere outside of firms. In contrast to workplace exposures, environmental impairments are externalized costs that in many cases cannot be attributed to any specific firm. In workplace health and safety, there are preventive incentives, as preserving the work capacity of employees is in the interest of the company, and it is often relatively simple to identify connections between damage and the workplace. In cases of substance-related damage, however, the situation already becomes problematic if exposure is long-term and it thus becomes difficult to furnish proof of causation (Rehbinder, 1992c). Moreover, with a statutory environmental insurance agency the circle of claimants is much larger than with a health and safety agency; it potentially encompasses the entire population. This gives rise to considerable organizational problems. A further aspect is that conflicts of interest are not, as in the health and safety field, among actors linked organizationally within one unit, where unresolved conflicts are to the detriment of both sides, but are between external injured parties on the one side and company management and employees on the other. This hampers cooperation. In the workplace health and safety sphere, the advantages of statutory insurance agencies include close ties to those organizational structures, production processes and substances in which the risk resides, and associated advantages for injured parties in terms of access to information. These advantages do not arise in environmental protection external to the firm.

F 4 Permitting procedures

Permits are a traditional tool of preventive state control. Depending upon the branch of law and function, they are also termed approval, authorization, consent or license. Permitting procedures are an integral part of German environmental law. Permits granted in other branches of law, such as building permits, are also of relevance here, as environmentally relevant aspects must be considered when they are issued (Wahl, 1994). Furthermore, one and the same case may require several different permits.

A permit is a form of general control of commencement – without the permit, certain actions are prohibited. This does not mean that these actions are therefore automatically considered as undesirable under the law. It merely serves to give the authorities scope for carrying out a control procedure (permitting procedure) in which they can check compliance of actions with the applicable legal provisions. Permits may be required for e.g. the installation and/or operation of a facility, or for the marketing of a product (Wahl, 1994). A generic term is 'project' (German: 'Vorhaben'). The permit has a direct controlling effect upon the individual, and thus serves the project- or case-related realization of the principles of environmental law (Erbguth, 1988). Planning instruments, in contrast, do not serve case-by-case risk control, but rather strategic risk management. They have an important function in support of permits, not least because planning requirements must be taken into consideration in permitting procedures. From the perspective of the applicant, the need to obtain a permit is not just a burden – as long as a permit remains valid, i.e. has not been revoked or withdrawn, it gives the project an independent constitutive basis. To a certain degree, it provides a legal safeguard for the project (Wahl, 1994).

Three basic types of permits can be distinguished according to the constitutive elements of the decision-making process (BMU, 1998):

- The 'bound permit' ('gebundene Genehmigung'), where the applicant has an entitlement to obtain the permit if all permit requirements are met (this type applies particularly to the permitting of industrial facilities under emission control law).
- Permits upon which the authority can decide freely after a due assessment of the circumstances, even if all permitting requirements are met (e.g. consent under water resources law, and permits for nuclear facilities).
- The 'plan approval' ('Planfeststellung'), which is used above all when approving space-appropriating public infrastructure projects, and forms the legal basis for any necessary expropriation; this requires an equitable balancing of public and private concerns affected by the project.

Due to the planning discretion available to the authority, plan approval procedures are partly counted as belonging to the planning instruments. However, the difference to pure planning is that the formal public planning decision ('Planfeststellungsbeschluß') that concludes the plan approval procedure decides whether the project in question will be carried out or not (Erbguth, 1988). This discrete decision taken at the end of the plan approval procedure suggests its inclusion in the category of permitting procedures. In any case, permitting procedures and plan approval procedures have moved very close to each other under the applicable law in Germany (BMU, 1998).

Prime elements of a permitting procedure include: typically, comprehensive requirements upon the applicant to submit forms and documents, scoping of the expected framework (regulated e.g. under Art. 5 of the German Environmental Impact Assessment Act), public notice of the application, laying out of documentation for public inspection, consultation with other authorities with a concern in the project in question and, finally, a formal hearing providing a forum for third parties to voice objections (Wahl, 1994).

While permitting procedures under environmental law can be classified in the above manner, there are such great differences in the concrete structure of various procedures that it is justified to speak of a fragmentation of procedural law (BMU, 1998). This is all the more so as larger projects require an array of permits that can be subject to disparate procedural rules, the resulting fragmentation leading to frictional losses in enforcement and to coordination problems in parallel permitting procedures. Amendments to the various statutes involved further contribute to legal uncertainty among enforcement authorities and among the private parties to whom these norms are addressed. The fragmentation of permitting rules is not specific to Germany. It is an issue of concern in many other countries, too. In California, for instance, permits for industrial and commercial facilities that represent a source of air pollution are not granted for the facility as a whole, but for each individual machine or unit. It is not uncommon for one facility to require 100 and more air pollution permits (Jarass, 1993).

Proposals for reform

In Germany, two points are currently viewed as being in particular need of reform: the duration of procedures and the sectoral focus of permits. Of the numerous proposals aimed at expediting permitting procedures, many have already been implemented by the legislative body. The adoption of the relevant expedition acts has attracted considerable criticism (BMU, 1998). However, from the perspective of the risk-controlling effect of permits, the more important aspect is that of overcoming the sectoral focus of permitting rules and the associated diversity of permits required. A transmedia approach to environmental concerns has already been established in German permitting law through the German Environmental Impact Assessment Act (UVP-Gesetz). This step, which was required to implement European Community (EC) law, has thus already contributed to consolidating certain parts of the procedure. The obligation to transpose into national law the IPPC Directive of the EC now exerts a further incentive to integrate existing permitting procedures.

It is against this background that the independent commission of experts on a German Environmental Code (Umweltgesetzbuch, UGB-KomE) submitted its draft. This is based on an integrated project permit as the basic model (Arts. 82ff UGB-KomE). According to this draft, the review of environmentally related issues and the decision on these are to be integrated in a unified procedure. This shall thus integrate both the procedures and the environmental media. It is then possible to consider in the decision on a project permit the full results of an environmental impact assessment (EIA) which requires a comprehensive and transmedia assessment of the environmental impacts of a project and the participation of the public in this process (BMU, 1998).

The lack of uniformity exhibited by the various permitting procedures is only partially attributable to substantive reasons. It is mainly a result of historical circumstances, as risk-prone projects were regulated successively whenever the need arose. It was inescapable that this focus on the needs of the day was to be to the detriment of a broad consideration of the overall effect of the various permitting procedures.

In the opinion of the above commission, the various permitting procedures under environmental law can be organized around one basic type – the (integrated) project permit. Depending upon the specific characteristics of the project in question, the project permit can be organized as a bound (Arts. 83ff UGB-KomE), planning (Arts. 101f UGB-KomE) or simple project permit (Arts. 109f UGB-KomE). Where necessary, further differentiations can be made within these three variants. This then introduces a certain diversity again, but the existing plethora is stripped of its historically determined peculiarities. The advantage and aim as compared to the existing situation is not to merely systematize as an end in itself, but to integrate and approximate the applicable procedures. This has the benefit of enhancing transparency for the applicant (and also for the administration). It becomes easier for all sides to recognize whether differentiations are made for substantive reasons or not. In short, it is a matter of streamlining permitting law by means of systematization, harmonization and standardization (Koch, 1996).

- In the standard case of the 'bound' project permit, the authority is obliged to approve the project if the requirements are met by the applicant.
- The 'planning' project permit is required for particularly important projects such as final repositories for radioactive wastes, landfills, or the regulation of water courses. Under Art. 102 of the draft German Environmental Code, the authority must undertake a weighing exercise. The interests affected by the project, including environmental impacts, must be ascertained and weighed, the project must be in the public interest and the authority must come to the conclusion that the interests speaking in favor of the project predominate (Kloepfer and Durner, 1997).
- The 'simple' project permit is intended for those projects that are compatible with the protection of human health and the environment in terms of their type, extent and duration of deleterious impacts, and thus allow a permit under simplified requirements (Art. 109 para 1 UGB-KomE). The permit can only be granted if this has been determined by a statutory ordinance, and can only be provided for a certain group of projects, e.g. facilities that require permits under emission control law, genetic engineering facilities of the risk classes two to four under German law and the release of genetically modified organisms.

The choice and design of state controls are sovereign decisions of each individual state. With the exception of the special case of the European Union, an international harmonization of permitting procedures is not (yet) in sight. All the more importance attaches to the possible model role that might be played by a unified project permitting system in one nation such as Germany. The commitment to instrumentalize environmental impact assessment and the necessity to transpose into national law the IPPC Directive are tasks that exert pressure for reform in the other member states of the EU, too. The question also arises in other countries as to whether the diverse array of permitting procedures that has emerged from historical processes should not be replaced by a uniform concept in order to safeguard transparency and legal certainty and thus ultimately to enhance the efficiency of the tool. The project permit procedure, as proposed for the draft German Environmental Code and with due regard to German specificities, may provide an impulse for other countries to harmonize their permitting procedures, too. Substantive requirements (including international standards) are largely realized via permitting procedures. A unification of these procedures thus also has international relevance. It would then be easier to compare internationally the implementation of substantive standards – after all, this is the end that formal rules serve.

Environmental levies and tradeable permits F 5

F 5.1
Risk premiums and environmentally relevant innovations

Most of the tools discussed in Part F of this report can evidently make a contribution to risk policy. In additio the extent to which conventional instruments of environmental policy – such as regulatory controls, environmental levies and tradeable permits – are also of relevance to risk policy objectives needs to be examined. This is done for regulatory controls, which are the dominant tool worldwide, in Section F 4. In the following we briefly discuss to what extent economic incentive instruments (environmental levies and tradeable permits) have risk policy relevance. Regulatory controls are only touched upon here to the extent that they serve as a reference framework for presenting the advantages of economic environmental policy tools.

The purpose of environmental levies and tradeable permits is to reduce emissions. They thus do not target risks directly in the way that liability law does. Nonetheless, they do impact upon risks related to emissions, be it that the dose-response relationship associated with an individual emission causes previously unknown effects, or that cumulative and synergistic risks must be feared. It is therefore the risks that reside in emissions which typically form the connection between risk policy and environmental levies or tradeable permits. The following discussion consequently refers primarily to the Pandora, Pythia and Cassandra classes of risk.

F 5.1.1
Characteristics of economic incentive instruments

While regulatory controls generally specify a certain action, economic incentive instruments operate by modifying cost-benefit parameters of alternatives for action. The decision to pursue a certain option remains with the individual and is made on the basis of modified cost-benefit relations (Michaelis, 1996). Economic incentive instruments thus leave greater leeway for the individual in the choice of ways to implement measures that have a bearing upon environmental protection.

Economic incentive instruments target the price that is to be paid for using the environment. Through such 'pricing' of the environment, the behavior of individuals is directed towards more environmental protection. This is why economic incentive instruments are also termed pretiale control instruments.

Three classes of economic incentive instruments are generally distinguished:

1. Environmental levies increase the price of environmentally relevant economic activities, such as pollutant emissions, and thus target the price directly.
2. Tradeable permits limit the quantity of pollutants that can be released to the environment, and thus modify the price for using the environment through the scarcity imposed on the permissible total pollutant quantity.
3. Liability law can also be counted among these instruments, viewed in juxtaposition to regulatory law (Zimmermann, 1984); liability law is discussed elsewhere in this report (Sections F 2 and G).

For the sake of completeness, we might also mention subsidies here as an environmental policy instrument that, in a purely theoretical analysis, might appear to develop the same incentive effects as environmental levies. In environmental policy practice, however, there are considerable differences, as over the longer term market signals are perverted by subsidies because the relative prices are modified in favor of polluting branches of industry (Cansier, 1996). There may be further linkages between subsidy policies and rational risk policy with respect to the removal of environmentally damaging subsidies or the application of subsidies in research policy. However, a discussion of these would go beyond the scope of the present section on economic incentive instruments.

Environmentally damaging regulations that should be removed are exemplified by the case of the Indonesian 2,300% export duty on rattan, which has had a devastating impact upon the sustainable use of

Box F 5.1-1

Risks posed to the sustainable use of resources through inappropriate institutional regulations: Rattan production in east Kalimantan

Background

'Rattan' is a term referring to various palms of the genus *Calamus* or related species. The term also refers to the hard parts of the stems of such palms and to the furniture, wicker work, walking sticks etc. that are made out of it. The various species and their uses are classified in two groups having a stem diameter above or below 18 mm. The larger diameters are used mainly for furniture (frames) and artisanal crafts, while the smaller diameters are used for mats (e.g. Japanese Tatami) and wicker work, e.g. for chairs or walls.

In east Kalimantan, one of the four Indonesian provinces on Borneo, the Sega variety (*Calamus caesius*) is dominant. This has a diameter of 7–12 mm. East Kalimantan accounts for 10–15% (20,000–30,000 t $year^{-1}$) of the total Indonesian production of raw rattan (estimated in 1996 at just under 200,000 t). Eighty percent of the harvest there comes from cultivated 'rattan gardens', while 20% is collected in the forest. The same applies to most species with larger diameters, which come mainly from Sumatra and Sulawesi.

Rattan production in east Kalimantan is largely positive in all three dimensions of sustainability. In the ecological dimension, rattan extraction, including that from rattan gardens, has very low impacts compared with other forms of commercial utilization of forest space (fire cultivation, plantations etc.). Overexploitation has occurred occasionally of the collected species in natural forests – notably the larger diameters on Sulawesi. In the economic dimension, rattan production has good prospects because it goes to applications that have sales markets both in the developing countries and in industrialized countries. In the social dimension, rattan use is positive insofar as it is conducted almost exclusively by a large number of small farmers, in this region notably by families which otherwise have almost no alternative source of income.

Until the policy changes introduced in 1986/1988, the production and sale of rattan had developed very positively. Prices for raw rattan material after the first processing stage (washed, dried and largely also sulfurated) had grown eightfold between 1976 and 1986. This growth had already taken place by 1981, so that an extended period marked by high export prices had stimulated production and income generation. For good quality Sega, an equivalent of US-$ 0.45 was paid in 1987–1988. Most of the raw material was exported directly from the port of Samarinda, where in 1986 13 export-oriented rattan companies operated. The larger part of production went to the manufacturing of mats by companies in south Kalimantan, where 20,000 people were employed by this industry at that time.

New institutional regulations

In October 1986, a ban was imposed on the export of all kinds of raw rattan. As a consequence, the export of semi-finished products rose from 20,000 t in 1985 to more than 130,000 t in 1987 (ASMINO statistics). It was reported that strangely rough, huge rattan baskets were exported as finished products, then to be dismantled at the place of destination (e.g. China) in order to use the material for other finished products (Haury, personal communication).

The export ban was then extended in June 1988 to semi-finished products. In 1992, the export ban was converted into export taxes ranging from 10 to 15 US-$ kg^{-1}. This was up to 2,300% of the export price, which effectively amounted to a continued ban.

The purpose of all these measures was to channel rattan, in which Indonesia had a very strong position on the world market, to uses with higher levels of domestic value added. In these years 250 additional production units were indeed established on Java, providing total employment for approximately 70,000 people in Cirebon, Surabaya and Jakarta. However, these new domestic industries were by no means able to absorb the large quantities of raw and semi-finished rattan that had been exported until 1986 or 1987. While the planned shift from the previous export market for raw and semi-finished products to an export-oriented domestic rattan furniture industry did succeed to a certain degree, the total quantity of raw rattan sold in the country crashed. This was mainly caused by the extreme export duty.

Consequences

The outcome of these developments was that prices for most types of rattan, particularly those with small diameters such as Sega, began to fall. By 1997, producer prices for Sega had fallen to a level that was only 31% of the prices of 1989. If we further consider the devaluation of the rupee, then prices in June 1997 were only 21% of those in 1989, and by 1998 the level must be assumed to have dropped even further. The price collapse cannot be attributed solely to the export duty, as in the meantime export licenses (a quota system), i.e. quantitative restrictions, have been introduced for the rattan mat industry in south Kalimantan. At the same time demand from Japan, the main purchasing country for these products, has dropped distinctly. Nonetheless, the rapidly rising volume of illicit exports shows that this drop in demand only explains a (probably small) part of the drop in prices. By 1997, smuggling in raw rattan had peaked, with an estimated share of 30% of total Indonesian raw material production. Smuggling is largely via the Malaysian part of Borneo, above all through Tawan/Sabah, which is located opposite to the Indonesian Numukan. Here the shippers sell the rattan that they have bought up on the Indonesian coast of Kalimantan. Malaysia even maintains statistics on the totality of these imports (MIDA, no year). No import duty is levied in Malaysia (Druba, personal communication), but rattan can only be exported again if it has undergone some further processing – larger diameters are polished and smaller ones are split.

Thus, although the export of raw or semi-finished rattan from Indonesia was effectively banned by the prohibitive export duty, an international value-added chain could still be traced in 1997 (Haury, personal communication). The semi-finished material (polished, split and woven) offered at trade fairs (such as INTERZUM) in Germany by European traders evidently originates from Indonesian harvests. This semi-finished material is processed in China or – if quality requirements are particularly high – in Singapore. It generally gets there from Taiwan, Malaysia, where processing steps are carried out due to the above-mentioned Malaysian regulations. Indonesia is the country of origin of the rattan. There the freshly harvested, very moist rattan only has to be subjected to a few initial processing steps in order to prevent fungal or insect infestation.

The enormous volume of smuggling evident here is clearly a consequence of the changes in institutional regulations implemented from 1986 to 1992. Raw rattan exports thus continued, but no longer through the official channels. In some areas, smuggling has contributed to a certain stabilization of the very low producer prices. Nonetheless, illegal exports no doubt had their price, inter alia in the shape of protection money and bribe money, as compared with the or-

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derly export trading carried out by the previously numerous, competing export firms.

The effect of smuggling (instead of legal export) is only one element in the cause-effect chain that has led to negative impacts upon rattan producers. The main effect is the collapse of export options for raw material and semi-finished goods, caused by the measures adopted in 1986–1992 and further exacerbated by the declining demand from Japan since the introduction of the export license (1988–1989), and for other finished products from the Asian countries since 1996–1997.

For the rattan producers, i.e. the multitude of small farmers, the consequences have been devastating. Producer prices have become so low that farmers view their rattan stands rather as a reserve (in the hope that the quality of the rattan will not deteriorate over time). Where good offers have been made for the land, rattan gardens have also been sold, and cases are known in which farmers have been more or less forced to convert their gardens to plantations for oil palm or industrial timber. An important effect is that the impoverished farmers are increasingly engaging in illegal logging and in poaching rare bird species, in order to at least maintain their already low level of income.

The major risks to the economic position of the underprivileged rural population in terms of sustainable production (of rattan) and of course the risks resulting for biodiversity illustrate how a single inappropriate regulation can jeopardize sustainability in all dimensions at once – ecological, economic and social.

Outlook

The International Monetary Fund (IMF) has intervened with the result that the export tax is to be cut to 10% from March 1, 1998 onwards (Jakarta Post, 1998). Once the planned export tax cut has come into effect (export regulations still had not been adopted by the end of March 1998) it will emerge how long it takes to recover the lost export markets – not least in times of a very difficult economic situation in east Asia. In any event, smuggling will presumably no longer be worthwhile, so that the price pressure caused by the no doubt exceedingly high dealer's margin due to illegality can be expected to relax. It will further become clear how many of the rattan gardens still exist and in what state they are, as little is yet known about the durability of rattan that has not been harvested over extended periods.

this natural product (Box F 5.1-1). While this is not a subsidy, the example illustrates that it is often particularly expedient in terms of environmental policy to remove existing incentives that have negative effects – as is the case for many subsidies or customs duties.

F 5.1.2
Applying economic incentive instruments

The particular risk policy relevance of economic incentive instruments stems from their (potential) contribution to the two following approaches that can be pursued by environmental policy under uncertainty (Wätzold, 1997; Wätzold and Simonis, 1997):

1. *The general risk premium approach*. Under this approach, the uncertainty aspect is taken into consideration by integrating in the evaluation of environmental quality a 'risk premium' ('Risikoprämie') in the sense that a higher environmental quality is aimed at than if certain information on the consequences of human interventions in nature were available. The central proposition is that "if there is risk aversion in conjunction with ecological uncertainty, a lower level of intervention in nature is recommended than if there is ecological certainty" (Wätzold, 1997). As environmental risks will make environmental resources scarcer in the future, a higher environmental quality can be understood as a form of insurance against environmental risks (Siebert, 1987a). Following this approach, the issue is whether the application of economic incentive instruments can attain a risk premium for society as a whole.
2. *The innovation-oriented environmental policy approach*. The goal of innovation-oriented environmental policy approaches is to reduce emissions through stimulating progress in environmental engineering. Following this approach, the issue then is: what effects do economic incentive instruments exert upon the innovation behavior of economic agents?

F 5.2
Risk premiums and environmental engineering progress

F 5.2.1
Regulatory controls

The advantages of economic incentive instruments are normally debated in the context of the regulatory, or 'command and control' (CAC), approach (Endres, 1997). The CAC approach, when promulgating certain emission standards, does not differentiate according to the costs incurred by companies to achieve a unit of emissions reduction, the environmental policy goal aimed at by this approach is not achieved at the lowest macroeconomic cost. In addition to this static inefficiency, the CAC approach is not dynamically efficient, either, as it does not give any incentives to reduce emissions further below the permitted residual level and to further develop the prescribed state of the art – i.e. to be innovative. Indeed, the CAC approach is often even criticized for causing the engineering fraternity to hold back on the technically feasible opportunities for emission control.

This theoretical discussion of the shortcomings of the CAC approach does not apply without qualification in practice, as in many cases regulatory controls have some degree of differentiation or permit some degree of flexibility. They thus need not impede environmental engineering progress, and may even stimulate it under the proper circumstances. Indeed, in Germany the laws and regulations have stimulated environmental engineering progress to some extent in the spheres of air pollution control, waste prevention and wastewater treatment. Positive effects can also be noted in the area of environmentally sound product development. Nonetheless, as we shall show below, it can be assumed that economic incentive instruments are fundamentally superior in terms of their capacity to stimulate environmental engineering progress. A further point is that at the global level we may assume the applicability of regulatory controls to be subject to considerable restrictions.

However, the CAC approach is indeed suited to attain the general risk premium explained in the previous section. CAC measures can – at least theoretically – attain almost any desired environmental quality standard, although the macroeconomic costs required for this will generally be higher than if economic incentive instruments were used.

F 5.2.2
Environmental levies

Environmental charges or taxes – for which we use here the generic term 'environmental levies' – meet not only the goal of static efficiency in the sense of minimizing macroeconomic costs incurred to attain a certain environmental quality, but also meet the goal of dynamic efficiency. Each emission unit prevented means for the company a financial gain in the form of the avoided payment. In contrast to regulatory controls, environmental engineering progress is rewarded financially. The environmental engineers in the companies are then no longer viewed as mere 'cost causers', but as members of the corporate organization that can provide financial benefits to the company. Their position in the company is thus upgraded considerably, as is that of the entire environmental branch. It needs to be examined in each specific case which innovation stimuli proceed from a particular type of environmental levy (Zimmermann et al., 1996).

Environmental engineering innovations will at least tend to be stimulated by environmental levies. As concerns the attainment of a risk premium, however, we must argue more differentiatedly. The ecological effectiveness of charges and taxes depends upon the effects that the direct price increase of use of the environment has upon the behavior of economic agents. If the economic framework conditions permit, companies can pass through to the final consumers the extra costs represented by environmental levy payments. This tax shifting need not impair the incentive to seek measures for emissions reductions (Zimmermann and Henke, 1994). But such a constellation does not guarantee the effective pursuit of the given ecological goal. The innovation effects of environmental levies thus can always only be examined for the concrete case. Relevant aspects here include the level of the levy and the point at which it is raised (on the input or the emission side).

A further important restriction is that this instrument will only have a risk-reducing effect for those environmental risks whose risk potential is known. Where there is a complete lack of knowledge of the risks (Section G), the concept of the risk premium does not apply (Wätzold, 1997). As opposed to opinions frequently voiced in the literature, environmental engineering innovations cannot be assumed to always have a risk-reducing effect. Integrated pollution control does have the advantage in contrast to end-of-pipe technologies that the modification of the production process caused by improved integrated process technology not only reduces the target pollutant but possibly also a broad range of pollutants. However, the possibility cannot be dismissed that the restructuring of the production process leads to the emergence of new pollutants whose risk potentials are unknown. It thus cannot be claimed with certainty ex ante that environmentally relevant innovations automatically have a risk-reducing effect, although they are of course in principle requisite and desirable in many areas.

F 5.2.3
Tradeable permits

The basic theoretical principles for controlling environmental quality by means of tradeable permits can be outlined as follows. In a first step, an emission ceiling for a pollutant is established through the political process. Subsequently, this quantity of pollution is shared out among a limited number of freely tradeable emission permits or certificates. These certificates are distributed among the emitters and entitle the holder to emit a certain quantity of the pollutant. Emitters will compare their marginal abatement costs with the market price to be paid for an emission certificate, and will opt either for abatement or for purchasing certificates. Regardless of how certificates are distributed to the emitters, the ensuing trade in emission entitlements will ensure that individual marginal abatement costs are leveled out, thus satisfying the criterion of (static) economic efficiency. As, in contrast to levies, a tradeable permit system is not based on the price of a unit emission but upon the total quantity of permitted emissions, the environmental quality target will always be achieved.

Moreover, tradeable permit systems have the advantage, as do environmental levies, that they are both statically and dynamically efficient. Thus, and this is a prime aspect, further abatement is rewarded financially through the possibility that it offers to sell otherwise required certificates. A continuous incentive to seek cost-effective abatement measures is thus created (dynamic efficiency).

In contrast to environmental levies, tradeable permits have the further advantage that they are ecologically effective. As they are based on pollution levels, certificates can be used – measurement and monitoring problems set aside – to achieve an intended emission target and thus the desired environmental quality. Tradeable permits thus make it possible to target a general risk premium more accurately than environmental levies do.

How strong the innovative incentives proceeding from certificate schemes actually are depends upon the evolution of certificate prices on the markets. This is in turn determined by numerous intervening factors (number of market participants, competitive situation on the sales markets, general state of the economy etc.), so that the innovation incentive can vary greatly. Consequently, an accurate assessment of a tradeable permit scheme also always requires an analysis of the specific case. However, it can certainly be said generally that potentially positive effects upon innovation behavior are to be expected. Naturally the same restrictions concerning the risk-reducing effect of environmentally relevant innovations can be stated for tradeable permit schemes as for environmental levies, as discussed above.

F 5.3
Overall comparison

Economic incentive instruments serve to attain a general risk premium and to promote environmental engineering progress. While environmental levies cannot achieve ecological targets with absolute accuracy, tradeable permit schemes do indeed realize the intended emission target. In terms of attaining a general risk premium, tradeable permits are thus superior to environmental levies. Both instruments will tend to have a positive stimulating effect upon environmentally relevant innovations. However, it needs to be noted that environmental engineering progress cannot generally exclude the emergence of new, unknown risks associated with the application of the innovative environmental technology. Thus both instruments, even where they have a prospect of global relevance (as may be the case for tradeable permits), can only make a limited contribution to dealing with completely unknown risks. This primarily requires other tools (Section G).

F 6 Political strategies

F 6.1
Introduction

In the previous sections, the Council has shown that there can be no such thing as *one* risk strategy. Each type of risk must be countered by specific political measures. In many cases, decentralized instruments such as liability law or funds are suited to creating incentives to produce risk knowledge and to prevent risks (Sections F 2, 3 and 5). However, such market-based instruments cannot yield the desired outcomes in all constellations.

The effectiveness of liability, particularly its compensation function, is restricted where the state has set liability ceilings. This should not be understood as a fundamental objection to the principle of liability, but rather concerns the problem of state restrictions upon the liability principle that do not always appear to make economic sense. Another way in which liability may be restricted is through its inadequate enforceability, e.g. due to deficiencies in the rule of law. Liability can only exert its preventive effect if actors must really expect to be held accountable for any damage that their actions may cause. Typical factors that restrict the effectiveness of liability law include inadequate judicial enforcement, insufficient executive competencies and also corruption. In states where such factors prevail, it must be assumed that actors need not expect to be held liable later for their actions. They thus do not have sufficient incentives to produce risk knowledge and to prevent risks.

Liability is, as such, a tool that is in accordance with market principles and expedient, but due to the above restrictions it needs to be complemented by state initiatives, particularly

- In cases where risks belong to risk-classes in which it is not possible to assign liability to generators, as is at least the case for long-distance, gradual and cumulative damage (e.g. Pandora- and Cassandra-type risks);
- In the case of global change risks whose extent of potential damage approaches infinity and for which liability ceilings have been set that constrain the efficacy of the liability principle;
- In societies and regions where the institutional preconditions for implementing the tool of liability are not (yet) given.

F 6.2
The risks of global change and development cooperation

Development cooperation as risk prevention policy

Risk prevention also means keeping the total sum of the costs of risk reduction policies plus the costs incurred by not adopting risk reduction policies as low as possible. This applies particularly to cumulative risks (such as impending climate change) and the risks associated with food crises. Strengthening people's resilience and capacity for adaptation to the risks of global change is a prime task of Germany's development cooperation with the states of Africa, Asia and Latin America. German development cooperation efforts currently have three focuses: poverty alleviation; environmental protection and the conservation of natural resources; and education and training.

In the following, the Council evaluates these focal areas from the perspective of risk prevention and management, and highlights the importance attaching to development cooperation in dealing with the risks of global change. The Council further submits proposals for enhancing the capability of developing countries to deal with their risks.

However, it needs to be noted that development cooperation *alone* cannot be expected to remove or attenuate the prime risk amplifiers. Development processes in the poor countries in particular – and thus the enhancement of their respective risk management capacities – also depends upon improving the structural economic and societal framework conditions in whose evolution the industrialized countries also play a part. Purposeful measures to improve such framework conditions include, for instance, removing protectionism and thus creating fair conditions of trade, or resolving the debt crisis. The Council takes the view that this is a long-term and overarching task of German policy in efforts to promote global sustainable development.

As development cooperation is a crucial element of global precautionary risk management policies and risk potentials are growing worldwide, its strategic relevance will continue to grow in the future. The Council has thus repeatedly recommended that official funding for financial development cooperation be increased (WBGU, 1996, 1997a, 1998a).

Poverty alleviation: Building individual capacity to deal with risks

In Section E 2, the Council has shown that strengthening the capacities of vulnerable groups to deal with risks must be an important part of precautionary policies. Such a risk prevention policy is suited particularly to reduce the extent of damage associated with the Damocles, Cyclops and Pythia classes of risk.

In the opinion of the Council, poverty alleviation oriented to self-help principles is an important component of global risk prevention policy, because this aims at broad impacts and stimulates structural reforms in state and society. The potential extent of damage can thus be reduced significantly (Section E 2). The goal of such measures must be to expand the leeway for action by social groups in their attempts to deal with risks. This can be done by means of strengthening a series of 'assets' (Section E 2). These include economic assets (above all property rights), social and political assets (social networks and political participation), ecological assets (clean environment), infrastructural assets (access rights e.g. to drinking water) and personal assets (notably health and education). In the opinion of the Council, these assets are the essential spheres of action for a global risk prevention policy that targets its actions to the level of social groups. Increasing these types of assets reduce in most cases susceptibility to the risks of global change. Experience has shown that, particularly in ecologically vulnerable regions, combining different sources of income is an essential precondition to securing the livelihoods of the poor. Too little consideration has been given to this in the past.

An important aspect here is that new social security systems need to be established that safeguard the basic needs of the most endangered groups against the risks of global change. Such systems can be established by promoting private security funds. They can just as well consist in strengthening culturally specific and traditional forms of social security. A third option is to establish modern, target-group oriented social security systems that can adapt dynamically to the needs of 'the vulnerable'.

Environmental protection and resource conservation: Reducing environmental criticality

The analysis of the risks of global change has shown that the ecological susceptibility of regions, i.e. their specific environmental criticality, is a prime risk amplifier (Section E 2). Development cooperation thus already makes an important contribution to managing the risks of global change by promoting efforts to preserve the natural bases of human existence and assisting partner countries in their efforts to participate in global environmental protection and to structure their development processes in an environmentally sound manner. Moreover, it is often the case that global environmental protection measures can be implemented more cost-effectively in developing countries than in industrialized countries. A further important aspect is that compliance with ecological standards can be promoted early on in the development process, so that environmental degradation can be prevented from the outset. However, the German Ministry for Economic Cooperation and Development (BMZ, 1997) has stressed that the goal of globally sustainable development is only achievable if the necessary reforms and structural adjustments also take place and above all in the industrialized countries. Against this background, environment and development policy has a completely new role – safeguarding a sustainable global future and contributing to crisis prevention. This needs to be reflected more strongly in the political process.

Education and training: Integrating risk knowledge

Education and training are key areas for promoting sustainable development. The capacity of societies to deal with the risks of global change, their knowledge of causal structures and cause-effect relationships and their ability to communicate risks all depend directly upon the level of education and scientific competence. With respect to the risks of global change, education and scientific competence are essential preconditions to building own risk management capacities (Section F 7). This is particularly so in the developing countries.

However, it is precisely in the education sector that the North-South gradient has become ever steeper in recent years (Section E 2). Producing risk knowledge in the innovation process is particularly important for those countries which are embarking upon industrialization and where pivotal decisions in key sectors of all branches of the economy are due to be taken in the future. Greater attention needs to be given to this aspect in the education and training sector.

As discussed in more detail in Section E 2, there is a considerable need for action in this respect, but also considerable options for action. Not least, the role of non-state environment and development associations should be strengthened within the education and training focus, because these associations are important catalysts in the development processes of these countries and assume functions precisely in those areas where the state fails. This is exemplified by the role of the environment and development associations in implementing the Desertification Convention. This has once again highlighted the crucial contribution of development cooperation to globally sustainable development.

Improving the national risk management capacities of developing countries and transition countries

To manage the risks of global change, it is essential to have functioning societal institutions. These are in urgent need of improvement – particularly in developing countries, but also in some transition countries. In the context of a global risk management strategy, states should be offered assistance in strengthening their judicial and administrative systems. In developing countries, this might specifically mean educating and above all training judicial and administrative staff. Such efforts could be modeled on the training of customs officials in handling CFC trade that has been carried out in many developing countries. This was financed by the industrialized countries through the Multilateral Fund for the Implementation of the Montreal Protocol.

For all global change risks, particularly potential climate change, it is essential to keep the potential extent of damage as small as possible. In this endeavor it is crucial to strengthen particularly vulnerable states, and the particularly vulnerable segments of the population. This can include mitigation measures to prevent consequential climate impacts such as drought, floods or harvest losses and famine. With respect to the activities of the German government, the Council recommends maintaining and, where possible, expanding these forms of development cooperation as part of a global risk management strategy.

A particular problem is that it is precisely the developing countries that have inadequate capacities to assess new risks. In many instances (such as the protection of the ozone layer), the fact that they have to rely on the research findings of the industrialized countries has led to distrust and delay in negotiations. All modern environmental agreements do contain provisions under which the corresponding capacities are to be promoted in the developing countries – but these provisions always only apply to the issue regulated by the agreement after that issue has been recognized (such as building climate research capacities in developing countries under the Climate Convention).

The cooperation of the developing countries in dealing with *future* environmental problems (the 'new ozone holes') could be improved considerably if developing countries could participate in addressing these problems with their own expertise from the outset. The ozone issue is precisely the sort of case in which, due to their specific constellation of interests (scarcely polluter interests but strong interests as affected parties), one might have expected the developing countries to be among the driving forces of the ozone regime.

Therefore, in order to enhance the risk management capacities of developing countries while at the same time promoting and accelerating universal agreement on new environmental policy enterprises, the Council recommends for German development cooperation, but also for foreign policy, that the establishment of Risk Assessment Panels or similar structures be promoted in developing countries.

F 6.3 Building international risk management capacity

(UN) Risk Assessment Panel

As at the national level, international politics is also inadequately equipped to manage the risks of global change. There is, however, an array of international organizations and institutions that specifically address the core risks identified by the Council, such as WHO (infectious diseases), FAO (food risks) or the Conference of the Parties to the UN Climate Convention (climate risks), to the Biodiversity Convention (risks associated with biodiversity loss) or to the Desertification Convention (drought risks). As these organizations already work on specific aspects of global risk evaluation, they are particularly relevant to global risk management strategies. It follows that all risk-relevant activities of these organizations need to be enhanced appropriately and networked among each other. This is all the more urgent in view of the continuing criticism of the activities of e.g. the WHO (Section D 3). Nonetheless, the activities of these sectoral organizations do not substitute the functions of a reasonably integrated and interdisciplinary overall evaluation of the existing and future risks associated with global change. One argument for this is that risks of global change can have only small relevance in one sector or one region, but can present a considerable risk in their overall connections and cumulative effect. This suggests the need for an institution capable of carrying out an integrated, trans-sectoral evaluation of the risks of global change.

A second argument is that existing international institutions generally have a response focus, i.e. they react to known risks. Often, however, a long period elapses between the discovery of a risk and the formation of an international regime; just under 15 years for CFCs and – if we go back to Arrhenius (1896) – 100 years for the climate risk. This period could be shortened if risks were researched and evaluated early on and systematically and if – this is the central argument – this evaluation could lead to timely negotiations being initiated at the intergovernmental level.

The Council therefore recommends that the German government launches the project of a (UN) Risk Assessment Panel, which should be attached to an existing international organization, such as the UN Secretariat or the UN Environment Programme (UNEP). The work of the Panel should concentrate upon the core policy spheres (perhaps four–five fields) and should identify for these the 'safety margins'. The main task of this Panel would accordingly be, firstly, to evaluate in an interdisciplinary, risk-oriented and systematic manner the existing research findings, e.g. in the form of a Global Risk Report. The second task should be to establish an international 'diagnosis system' for the risks of global change. This process should mainly make use of the existing facilities in the individual states, which could be commissioned to address specific issues. In parts, this is already happening, as exemplified by the internationally valuable role played by US institutes in researching the El-Niño phenomenon. Where suitable institutes do not yet exist for individual issues, their establishment should be promoted accordingly.

The function, if not necessarily the structure, of the (UN) Risk Assessment Panel should be oriented to that of the Intergovernmental Panel on Climate Change (IPCC).

As a whole, the (UN) Risk Assessment Panel should above all assume a coordinating and collating function. Its political function should be the interdisciplinary concentration of the scientific research findings (policy-oriented weighing of all individual findings). This process should be, as far as possible,

- Free of the direct interests of individual states,
- Free of special interests of industry, and
- Free of the direct influence of non-state political associations.

Civil society actors should also be among those heard when global change risks are identified and evaluated. This is an avenue by which new risks could be placed on the agenda of the (UN) Risk Assessment Panel. This influence – institutionally filtered and scientifically substantiated – could be incorporated in the recommendations of the Panel, such as in a Global Risk Report. The civil society actors that should be heard by the Panel include, for instance, environment and development associations, insurance companies (with their special knowledge of liability risks) and other industrial branches affected by the risks of global change.

The IPCC process has illustrated how, in the international system, such an institution can support the political process through providing information and expert knowledge. Through preparing a regular UN Global Risk Report, representing, as in the IPCC, the outcome of an independent assessment process, the following could be achieved:

- Existing risks could be dealt with more efficiently, insofar as their global distribution and relevance has been assessed with sufficient accuracy; early detection can thus save the costs of post-event response.
- Existing risks could receive a higher priority on the international political agenda (accelerating the political process through reducing uncertainty).
- Future risks, which will tend to increase due to ever shorter innovation cycles, could be detected more rapidly and 'objectively'.
- Through timely intervention, the prospects for effective risk management could be improved, for early detection saves substantial post-event costs.

An effective and efficient networking with the sectoral and regional divisions of the UN system is essential to the success of a (UN) Risk Assessment Panel. One way of doing this would be to establish specialized Risk Assessment Units or Risk Assessment Focal Points in many UN specialized agencies. The Council has already pointed to the necessity of a new UN Organization for Sustainable Development (WBGU, 1998a). This was also proposed in 1997 by the then German Chancellor Helmut Kohl.

Compared to the UN, it is in fact the World Bank and the International Monetary Fund that have the greater influence upon environment and development policy, as became apparent anew in 1997/1998 during the Indonesian crisis. These institutions therefore need to be integrated in the (UN) Risk Assessment Panel. One effect of this would be that their policies could be evaluated as to risk amplifying and attenuating elements and modified accordingly, and the debate on social and ecological standards could be enriched by the risk aspect. A further effect would be that findings of the Panel could be integrated directly in the policies of both institutions. In particular, it would be purposeful to establish a link by setting up within the World Bank an independent Glo-

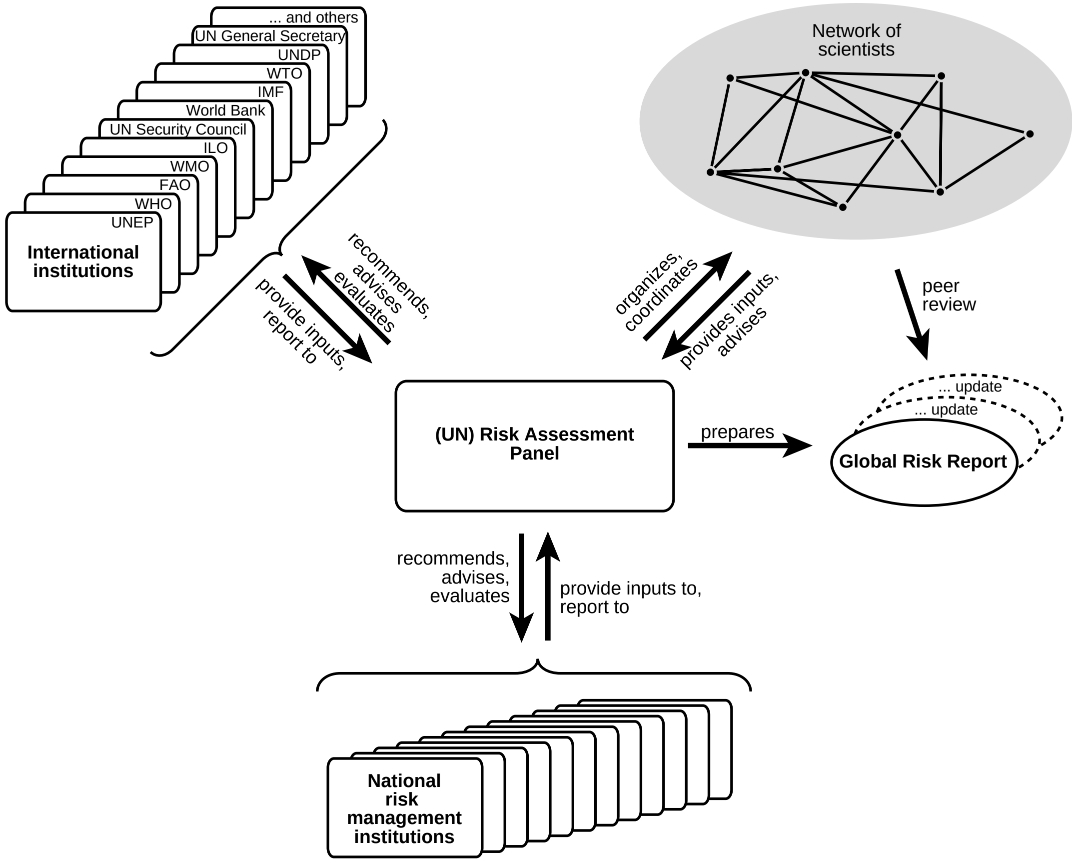

Figure F 6.3-1
Institutional integration of a (UN) Risk Assessment Panel.
Source: WBGU

bal Risk Assessment Unit connected to the Panel (Fig. F 6.3-1).

There is also a debate in the scientific literature on the extent to which the Security Council could – in extreme cases – assume new tasks. The Security Council is already now *de facto* a risk assessment body, as it is called upon by the UN Charter to identify threats to world peace and to take action where necessary pursuant to chapter VII of the Charter (Box F 6.3-1). In 1992 – at a 'historic' Council meeting at the level of heads of state and government – the president of the Security Council declared on behalf of the members that ecological problems can also represent a 'threat to world peace'. The UN Secretariat has the right to bring such threats to the attention of the Security Council.

This would need to be a part of an international strategy to manage the risks of global change, as several of the core risks treated by the Council are typical candidates for an ecological security threat.

Building on the Prior Informed Consent procedure

In order to reduce asymmetries among individual states in their knowledge of risks, a series of recent legal and political documents have taken up the principle of Prior Informed Consent (by a recipient country; PIC). The principle of PIC links two elements, the one building upon the other. In the first step, exporting countries communicate information on the risks of specific goods to the countries importing these goods. In a second step, the importing countries are able to decide whether to approve or disapprove the import of such risky goods on the basis of this information.

The core of the PIC procedure is thus to support the sovereign decision-making process of those recipient countries which do not themselves have sufficient knowledge to evaluate a risk (Rublack, 1993). Above all, the removal of information deficits serves to counter the undesired shift of risks from industrialized to developing countries.

Box F 6.3-1

Managing ecological crises: Also a task of the UN Security Council?

The primary purpose of the United Nations (UN) is to maintain international peace and security (preamble and Article 1, para 1 of the UN Charter). Under the system of collective security established under Chapter VII of the Charter, the UN is also empowered to maintain and restore peace by means of a variety of collective measures that can extend to the use of military force. To do so, the Security Council must first determine pursuant to Article 39 of the Charter whether a 'threat to the peace', a 'breach of the peace' or an 'act of aggression' is given. Only if this is the case may the Security Council make use of its special powers under Chapter VII of the Charter.

In contrast to a breach of the peace or an act of aggression, the concept of 'threat to the peace' contains a preventive component; Article 39 of the Charter can thus become effective before a breach of the peace has actually occurred (Frowein, 1991). Moreover, the concept of threat to the peace extends the substantive competencies of the Security Council because a precise definition of a 'threat to the peace' is difficult.

Ecological problems, as severe as they may be, do not fall under the concepts of breach of the peace or act of aggression, because peace is construed narrowly in Chapter VII of the Charter to mean the absence of organized violence among states. The concept of act of aggression presupposes the use of armed force; this follows from the definition provided by the UN General Assembly (Article 1 of UN Resolution 3314 XXIX). In contrast, the concept of threat to the peace can be given an exceedingly broad interpretation, if the Security Council is in agreement on this (Fro-wein, 1991). It follows that ecological problems could in principle be viewed as a threat to the peace (but for a contrary view see Winkler, 1995). The statement given by the President of the Security Council in 1992 could be construed in this sense, according to whom the non-military sources of instability in the economic, social, humanitarian and ecological realms have become threats to peace and security (UN, 1992). However, it is only admissible to classify the severest and most immediate ecological threats as threats to the peace, and only then and insofar as they pave the way for armed conflict. As long as the UN Charter is not amended, the UN thus has environmental competence only in very rare cases whose debate has only just commenced, such as the event that the World Bank forecast should prove true that the wars of the 21st century will be fought over access to water (Nettesheim, 1996). On the other hand, the Council can factually determine itself under which conditions it may take action. Voices have been raised that warn against a 'universal competency' of the Security Council, but the final conclusion is that collective ecological intervention is indeed legally feasible on the basis of Article 39 of the UN Charter (Reimann, 1997). Article 39 of the UN Charter should not be construed too loosely – for environmental reasons, too. For it is the principle of cooperation – not of conflict and not of intervention – that is rightly viewed as the foundation of modern international law. The progress made in international environmental protection, in particular since the 1992 Rio Earth Summit, would otherwise not have been possible.

If collective coercive measures were made possible in the form of a blanket entitlement, it must be feared that this would at present do more harm than good to the overall process. On the other hand, the Council wishes to reassert its recommendation made in its previous annual report that the sustainable conservation of the natural bases of human existence be enshrined in the UN Charter, possibly in Article 1. This would legally bolster the common international endeavor of environmental protection, giving it the formal priority that, to judge by the activities of the UN in this sector, it factually already enjoys.

The principle of PIC was introduced as an instrument of environmental law for the first time in 1989 through the extension of the information exchange procedure on certain chemicals (Decision 15/30, UNEP Governing Council) for which provision is made in the UNEP London Guidelines. In the same year, a similar, also voluntary procedure for international trade in pesticides was established through an amendment to the FAO International Code of Conduct on the Distribution and Use of Pesticides. UNEP and FAO have established a joint program on PIC for the implementation of the two voluntary procedures. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal also establishes the principle of PIC; here, it is even legally binding for the parties to the Convention.

Article 15 para 5 of the Convention on Biological Diversity (CBD) also provides for a PIC procedure. Here, however, the concrete design of the procedure is left to the countries in question and is not regulated by the Convention itself. Furthermore, under the CBD the PIC procedure has the opposite protection purpose (Box F 6.3-2). Here developing countries that export genetic resources are to be protected against the exploitation of these resources in other countries because, due to knowledge deficits, they could not be used industrially in the country of origin. In return for the exporting country permitting the extraction of genetic resources, it shall share in the research and, in a fair and equitable way, in the results of research and the benefits arising from the utilization of genetic resources (Art. 15 para.s 6 and 7; Hendrickx et al., 1993).

Beyond these procedures, a further legally binding instrument has been negotiated under the auspices of the United Nations. All of the chemicals-related procedures – those of FAO and UNEP, the new instrument on the application of the principle of PIC to certain hazardous chemicals and pesticides in international trade and the Basel Convention – provide for an iterative application of the principle.

A common feature of these procedures is that they provide for a systematic comparison of laws and regulations on certain hazardous goods. Exporting countries inform importing countries about the law

Box F 6.3-2

The Biosafety Protocol

Within the CBD (Convention on Biological Diversity) process, a protocol on biological safety (Biosafety Protocol) has been in preparation since July 1996. The Protocol aims to regulate the safe handling and transfer of genetically modified organisms and would be the first agreement in this sphere that is binding under international law. The objectives of the Convention on Biological Diversity, which forms the framework under which the Protocol would operate, are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" ('benefit-sharing'; WBGU, 1995b). Article 19 para 3 of the Convention commits the Parties to consider "the need for (...) a protocol setting out appropriate procedures, including, in particular, advance informed agreement, in the field of the safe transfer, handling and use of any living modified organism resulting from biotechnology that may have adverse effect on the conservation and sustainable use of biological diversity". In accordance with decisions taken at the first and second meetings of the Conference of the Parties (1994 and 1995), the Open-ended Ad hoc Working Group on Biosafety (BSWG) was established and has prepared a draft protocol after five rounds of negotiations. Nonetheless, controversy remains over important issues. The decision was taken at the fourth meeting of the Conference of the Parties in May 1998 to complete by February 1999 a draft protocol capable of gaining consensus. but no agreement was found. No new developments can be expected until the 5th meeting of the Conference of the Parties to the Convention (May 15–26, 2000; Gupta, 1999).

Substantive provisions

One point of controversy is the substantive scope of the Protocol. Of its 42 articles, those provisions that are substantively important or politically volatile are contested either in their entirety or in large part. As expected, the interests of the industrialized countries diverge from those of the developing countries (G77 and China). A remarkable aspect of these negotiations is that for the first time since UNCED (United Nations Conference on Environment and Development, Rio de Janeiro 1992) the developing countries are actively advocating strong environmental and health protection.

The Council will deliver a detailed opinion on the Biosafety Protocol in the context of its next annual report. Nonetheless, some particularly volatile points of the Protocol, which are partially directly linked to the present report, shall be touched upon briefly here.

A basic point of contention is the area of application of the Protocol. One line of argument, following a narrow reading of Article 19 para 3 of the Convention, is that the Protocol should serve to prevent only adverse effects of genetically modified organisms (termed in the draft protocol 'living modified organisms', LMOs) upon biological diversity, but not upon human health. While the mandate for preparing the Protocol also only refers to biological diversity, the relevant decisions adopted at the first and second meetings of the Conference of the Parties show that for the majority of the parties human health was also one of the motivations for preparing a protocol. Moreover, Article 19 para 3 should be read in conjunction with Article 8(g) of the Convention, which demands control of risks associated with the use or release of LMOs, "taking also into account the risks to human health".

A further point of contention is whether the protective provisions of the Protocol should apply exclusively to 'living' modified organisms or also to final products (in particular foodstuffs) in which LMOs were processed. Nor has any agreement been reached on the issue of whether the Protocol should serve to secure the safety of transboundary movements of LMOs (i.e. when they cross national boundaries) or rather to protect against the risks of biotechnology in general. States that wish the Protocol to only have a narrow scope base their argumentation inter alia on the wording of Articles 8(g) and 19 para 3 of the Convention.

Several sections of the Protocol treat the issue of risk assessment. Here there is dispute over whether assessment of the safety of the use or release of LMOs should take the precautionary principle as an evaluation basis. This has been negated primarily by some industrialized countries, which have proceeded in the negotiations on the Biosafety Protocol from the assumption that genetically manipulated organisms pose no hazard. The outcome of this dispute decides the question of whether the country of import or the country of export of the LMO bears the burden of proving its risks (and thus the associated research costs). If the precautionary principle were taken as the basis, then this burden would rest with the exporting states. If, however, the Protocol assumes that LMOs generally pose no hazard, then the states of import would have to prove the presence of a hazard in the concrete case; otherwise their refusal could represent an unjustified barrier to trade. The preamble of the Convention notes that "lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat" (to biological diversity). Furthermore, the framework within which the Biosafety Protocol is embedded urgently points towards a consideration of the precautionary principle. This is expressly noted in Article 15 of the 1992 Rio Declaration. The stance taken by a number of EU member states concerning marketing approval of genetically manipulated maize shows that there certainly are reservations as to its lack of hazard – reservations that shall be transported into the negotiations on the Protocol.

Further points addressed by the draft protocol include liability risk and prior informed consent (PIC; termed in the draft protocol 'advance informed agreement', AIA) – both of these being tools of risk prevention discussed by the Council in the present report. As yet, no consensus is in sight concerning the application of these tools, either.

applicable in the former, and communicate information on handling, properties and risks of the good. On the basis of this information, importing countries can also take measures and communicate these to the exporting countries. Exporting countries then in turn inform the relevant industries and distributors. This systematic comparison of national regulations is coordinated by a central body. Under the Basel Convention, this is its Secretariat. Under UNEP's London Guidelines and FAO's International Code of Conduct on the Distribution and Use of Pesticides, these are specialized departments at UNEP (IRPTC) and FAO (Plant Production and Protection Division).

Box F 6.3-3

International standard setting and monitoring mechanisms

At the national level, permitting law has overarching importance in risk management. Here there are, on the one hand, permitting procedures with the purpose of ensuring compliance with substantive rules, for instance concerning operational safety or concerning the protection of human health and the environment when establishing or operating a facility. On the other hand, there is also permitting law in the broader sense, being rules by which the permissibility of an activity is reviewed. Both are subject as a matter of principle to the regulatory competence of nation states. However, international organizations also operate in this sphere, and are entrusted with elaborating international standards and performing international monitoring duties.

Such international standard setting can also be carried out by non-state actors. However, where sovereign interests are affected, standards are either set by intergovernmental organizations or are negotiated among nations through treaties under international law on an ad-hoc basis. International standards can be integrated into international law and are then enforced by national authorities. Where provision has been made for international monitoring of standards, this is usually restricted to mere observation of the behavior of states or individuals. Only in exceptional cases have international organizations been entitled to carry out targeted on-site reviews or inspections (Hahn, 1995).

The International Organization for Standardization (ISO), founded in 1946, is important in this sphere. As ISO is an association of non-state organizations, it is itself a non-state organization. Standard-setting by ISO is based on voluntary consensus and does not develop legally binding effect. Nonetheless, ISO standards can become effective through adoption by national standards institutes. ISO itself has no enforcement powers. As a rule, compliance with its standards is based on the power of conviction that flows from the market benefits that can be achieved thereby. International standardization can also serve to reduce technological risks, such as standardizing components for industrial facilities or bridges. ISO has recently also begun to draft standards for environmental management. The first such standards were adopted in October 1996 (ISO 14004 and 14001). These are concerned with guidelines for elements of an environmental management system (EMS) and its implementation, and the requirements placed by ISO upon such a system through EMS specifications.

The International Atomic Energy Agency (IAEA), the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) are prominent examples of intergovernmental organizations that work towards improving safety and environmental protection through international standard setting. Membership of these technical organizations is confined to nations.

ICAO was founded in 1947. Its standards concern technical issues of rather apolitical nature (Buergenthal, 1969), such as the flightworthiness of aircraft, communication systems, navigation aids, the characteristics of airports and landing strips, log books and suchlike (Hailbronner, 1995). All member states are free to participate in the drafting of standards, which are then adopted by the ICAO Council with a two-thirds majority (Buergenthal, 1969). However, with the exception of flight and maneuvering rules, national standards are permitted to differ at any time. Different national standards must merely be notified to the Council. It may thus appear surprising that the operations of ICAO are considered by experts to be an extremely successful example of international standard setting. Legally binding force evidently is not a necessary criterion for the success of standards. The success of ICAO is not least due to the circumstance that it lies in the very nature of the matter that standardization in international civil aviation is advantageous for all participants. An important determinant of ICAO's success can be assumed to be that the issues handled, which tend to be of technical and apolitical nature, are addressed by a technical organization, so that its work is not impeded by extraneous political motives.

The IAEA was founded in 1957, with the objectives of promoting worldwide the peaceful use of nuclear energy and ensuring at the same time, within the bounds of its possibilities, that the materials subject to its controls are not used for military purposes (‘safeguards’). Initially, the direct promotion of nuclear energy by the IAEA played a certain role, but increasingly lost relevance in contrast to its safeguarding functions (Lohman, 1993). International safety and health standards were initially rather a marginal issue (Ipsen, 1989). Nor are there any procedures in place by which to monitor compliance with safety and health protection standards that might correspond to those in place for preventing a military use of materials in violation of agreements. IAEA experts only monitor safety standards in nuclear facilities upon the request of the country concerned. In this sphere, the services of IAEA thus lie mainly in initiating international agreements aimed at promoting the safety of the peaceful use of nuclear energy. These have included the 1963 Vienna Convention on Civil Liability for Nuclear Damage, the 1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy and the 1986 Vienna Conventions on Early Notification of a Nuclear Accident (Notification Convention) and on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Assistance Convention), which were adopted in the wake of the Chernobyl disaster. In 1994, a further Convention on Nuclear Safety was adopted, which has been signed by 65 states and has already been ratified by 40 states. This Convention essentially commits states to comply with certain safety standards developed by the IAEA, in particular with regard to the choice of site, design, the operation of facilities and sufficient funding and personnel. However, it does not provide for monitoring and enforcement mechanisms for safety and health standards. The Convention relies rather upon the 'group pressure' of the conferences of the parties (‘review meetings’), where the reports submitted by the parties are subjected to a peer review. A further incentive is provided by the publication of a final document.

Originally, one of the principal tasks of the IAEA was to receive, store and distribute nuclear material supplied by member states. For this, agreements were concluded with the three states that operated the largest nuclear programs, but these were neither applied nor substituted by other agreements. It was only through the transfer of the nuclear material of Iraq to the IAEA that the organization again became active in this field, whereby the inspections in Iraq were not based on the IAEA Statute, but upon authorization by the UN Security Council (Resolution 687 of 3 April 1991).

Concerning the monitoring of agreements on the peaceful use of nuclear energy, its Statute did not give the IAEA any immediate monitoring rights. The Statute merely contains requirements concerning the content of the safeguards agreements that the IAEA concludes with states. The IAEA has repeatedly codified the conditions under which it is prepared to conclude such safeguards agreements with states. Particular importance attaches here to the standard agree-

►

ment that was developed for the conclusion of safeguards agreements with signatories to the Non-Proliferation Treaty (IAEA Doc. INF-CIRC/153).

The Non-Proliferation Treaty entrusted the IAEA with implementing safeguards in all non-nuclear-weapon states. The most effective monitoring instrument is inspection, whereby inspectors can only be appointed in agreement with the state concerned. However, IAEA chooses the point in time of inspections – sometimes without prior announcement or even on a permanent basis if the nature of the facility requires this. Further, there is an obligation for monitored and third states to provide information. This initially concerns the own national data, but also includes an obligation to complement the information provided by other states where this appears necessary. Safeguard agreements can establish obligations to notify the export of nuclear materials, equipment and facilities and the making available of technological information. If inspections are refused or losses of nuclear materials and other discrepancies are found, the IAEA Board of Governors can impose sanctions itself, such as an embargo upon further nuclear support or demanding the return of material that was supplied internationally to the state. In special cases, the IAEA can also inform the UN Security Council about the situation, which can then in turn impose sanctions.

This shows that the otherwise very sovereignty-conscious community of states has been willing to devolve far-reaching monitoring powers to an international body in order to prevent the diversion of nuclear material from peaceful to military uses. Here the IAEA assumes both international standard-setting responsibilities and, in defined areas, international monitoring and inspection duties.

Closing information gaps is an essential precondition to enabling states to take sovereign decisions on the import of hazardous goods. Compared to international bans, the principle of PIC has the advantage that countries are placed in a position to evaluate risks themselves. It is left to their discretion whether they wish to accept the risks associated with goods or not.

Implementation of the principle of PIC may also be useful in other sectors where individual countries, particularly developing countries, have information deficits, e.g. international trade in pharmaceuticals or high-risk technologies. The formalized commitment to communicate national information in the form of national profiles indicating the status of laws and regulations, as required under the PIC procedure, is a fitting approach to such information deficits. It should therefore be examined whether PIC procedures might not be expedient in other fields, too. In many areas, promoting the decentralized harmonization of environmental, health and safety regulations through a formalized commitment to communicate information is easier to achieve than international consensus on the matter as such.

Global codes of conduct for companies

Liability is no exception to other risk policy tools in that it requires improved international cooperation for effective enforcement. In a globalized economy, it is essential to significantly strengthen international cooperation in order to be capable of setting the framework conditions required for efficient markets (Box F 6.3-3).

Concerning liability, in the opinion of the Council three different forms of improved international cooperation are conceivable:

1. Greater international harmonization of national liability laws is a possible avenue, which can be used by means of international agreements if the circumstances allow. This is exemplified by the Paris Convention on Third Party Liability in the Field of Nuclear Energy, for instance.
2. Secondly, agreements within the private sector of the economy are a promising avenue, such as the private liability agreements covering marine pollution exemplified by the Tanker Owners Voluntary Agreement concerning Liability for Oil Pollution (TOVALOP).
3. A third approach could be to pursue a legally non-binding voluntary commitment of (transnationally operating) companies such that these companies subject themselves worldwide to a certain (private-law) liability regime. The addressees of such a solution would be in particular the (large) transnational corporations who could subscribe to a Global Code of Responsibility with the intent of improving their public image.

Risk communication F 7

The concept of risk implies an effort to assess and render calculable, in a process of societal debate, the costs and benefits of constellations associated with potential damage (Sections B and C; Evers, 1993). Another important characteristic of risks is that they are generated by human actions and decisions (Luhmann, 1991). It is this societal debate that we term 'risk communication'. It is a process of exchange (communication and comprehension) of information among actors concerning risk analysis (perception), definition, evaluation and management (Wiedemann et al., 1991). Understood in a broader sense, risk communication is not a specific technique or strategy that might be applied anywhere particular. The term initially merely refers to the analysis of the entire spoken, written or pictorial exchange of information on a certain issue.

As in any analysis of communication, we need to distinguish in risk communication who communicates how with whom about what and with which goal. It makes a great difference whether the purpose of communication is to educate about risks through expanding and supplementing knowledge, or whether it is to whip up controversies over the evaluation and proper handling of risks. Communication on the possible consequences of a chemical accident must differ from communication on long-term, possibly risk-generating changes caused by global warming. Municipal decision-makers, journalists, environmental associations or those immediately affected by an environmental disaster will all need to be addressed differently. Here it is of course quite decisive who is communicating with these various target persons or groups – a scientific expert, a representative of the authorities or the manager of a chemical company that has caused an accident. Finally, the dramaturgy of communication is also important, i.e. whether level-headed information is given on causes, whether emotions are stirred up, whether images evoking pity or fear are introduced or whether risks are played down by comparing them to others. A steadily growing body of analysis and empirical study is now available on the various aspects of risk communication (Jungermann et al., 1991; Peters, 1995). In the following, we highlight some representative facets of communication – a tool of importance to both national and global risk policy.

F 7.1
Values and norms in communication

In the course of risk communication, it is often impossible to find consensus. This is due to personal, cognitive and social factors (Section E 1.2). As has been discussed elsewhere in this report (Sections C and E), it is not possible to evaluate risks solely on the basis of 'objective and scientific' data. Above all (different) values and norms influence the perception, evaluation and handling of risks. They need to be integrated explicitly in the communicative debate on risks (Jungermann et al., 1991; Turner and Wynne, 1992; Becker, 1993).

Neglecting these dimensions regularly leads to the confusion of comprehension and acceptance. This becomes apparent when experts or decision-makers refuse to take seriously the concerns of potentially affected persons, claiming that the latter are irrational. The accusation of irrationality is frequently made when people react with greater aversion to a risk that has a low probability of occurrence but high magnitude of damage (e.g. nuclear technologies) than to a risk that, statistically, has already claimed many more victims (e.g. road traffic). When concerns are brushed aside by labeling them irrational, technical risk assessment (extent of damage x probability) is frequently declared the sole valid perspective. This signals to those affected that all other dimensions – such as voluntariness, reversibility of damage or fair balancing of benefits and costs – will play no role and will not be taken seriously. Loss of trust and hardening fronts in the communication process are then preprogrammed. Affected people are often accused of craving – naively – absolute safety in their lives. However, this is regularly not the central problem in risk communication. Often the issue is rather one of the lack of trust in 'risk emitters' that they will handle risks competently, responsibly and with due regard to the interests of the potentially affected people (Wynne, 1991).

It is essential to a viable negotiation of risk management options that the interests and values of all concerned (including the powerless and the poor) are taken into consideration. The Council expressly rejects risk management strategies that have the goal of enforcing the perspective of one party and 'communicating away' the concerns of potentially affected parties. The explicit consideration of values and norms in the communication process does justice to the experience that risks cannot be viewed in isolation from the specific social context within which they are negotiated. The importance of the asset at risk (e.g. drinking water in water-poor or water-rich areas; a healthy environment or profitable technologies), religious belief systems and further aspects of the situation in life (e.g. fear of losing employment) play a role for the risk context. These value differences must be given appropriate consideration in the communication process.

Successful management of uncertainties requires collective and individual learning processes which lead, in the best case, to a solution acceptable to all. To come as close as possible to this best case, cooperative measures should ensure that the interests and values of all concerned can be negotiated with equal standing. This presupposes certain communicative competencies on the part of the actors (Section F 7.3). Similarly, care needs to be taken that resources such as knowledge, access to knowledge, management competencies in stressful situations, reproduction of options for action etc. are available to all parties. This often means that active steps need to be taken to ensure that groups which are weaker and particularly vulnerable due to poverty, lack of education or socio-political status (Section E 2) can acquire the necessary resources for risk management (Section F 6).

F 7.2
Communicative competencies

Risk communication is characterized by a great diversity of possible conflicts that have situative sources (e.g. conflicts over substantive issues or over goal dimensions; von Winterfeld and Edwards, 1984). These have been discussed in more detail in the previous annual report of the Council (WBGU, 1998a). In all these conflicts and in the aspects set out above (credibility or norms and values), fundamental problems of communication play a recurring role. The cause of communication problems is often that the fundamental divide between the source and the audience of a message is overlooked. In interpersonal communication, a message rarely arrives at the receiver in the same way as it was sent or intended by the sender (Luhmann, 1988; Watzlawick et al., 1993). This need not mean that understanding is fundamentally impossible. That would run counter to everyday experience. Rather, successful communication must be measured by its functionality, i.e. how well the individual actors find their interests satisfied. Many mechanisms can come into play that stand in the way of this functionality.

Based upon classic communication models the 'message square' (Schulz von Thun, 1993) gives a representation of sender-receiver problems. As communication problems can only be solved if their potential causes are known, we shall briefly present this concept in the following. Communication – sending and receiving messages – can take place at four levels or with respect to four goal functions: the substance level, the relationship level, the self-presentation level and the appeal level (Fig. F 7.3-1). These levels and functions cannot be separated strictly; as a rule, a message has elements of all levels – both in the way it is sent and received.

At the *substance level*, information is presented (Section F 7.4). In many cases, the various actors can agree upon a statement of fact ('the traffic light is green'). When debating risks that involve highly complex issues, different actors will identify and evaluate risks differently. Thus at this level disputes will already arise over the substance of the matter, the proper method by which to approach it and the interpretation of the findings of that method.

The *relationship level* is a matter of the relations among the actors – these are generally not addressed

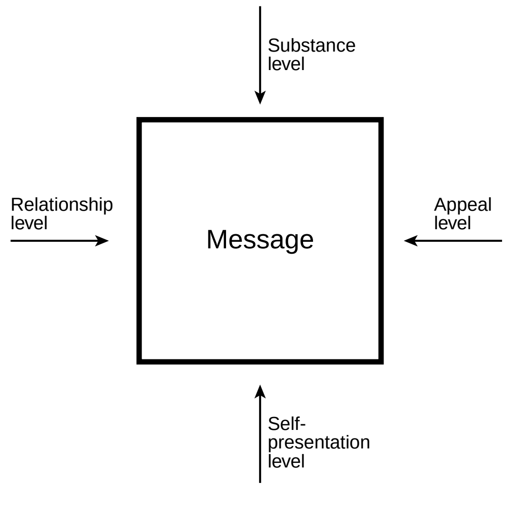

Figure F 7.3-1
The message square.
Source: Schulz von Thun, 1993

directly. Thus, for instance, the rhetorical question 'Do I rightly understand that...' can mean and can be heard as 'I think you are naive or clever!' Particularly such exchanges in which the participants, often using the lexicon of the substance level, express their mutual disrespect are counterproductive. This is especially so where the goal is to agree on a certain issue. It is generally helpful to openly state the type of relationship and the mutual hypotheses concerning that relationship, thus making it manageable.

At the *self-presentation level* actors attempt to present their person in a certain manner, e.g. as competent, as trustworthy or as sympathetic. Non-verbal means (facial expression, posture, tone of voice, clothing) are often used. Here, too, what is sent is not necessarily received in the same way. For instance, persons of whom we believe that they wish to appear particularly credible will often be perceived as the opposite. Moreover, quite regardless of how a sender may wish to present him- or herself, negative and positive stereotypes may determine the perception of that person ('complicated way of expression and elegant clothing = arrogant'). In every message, the 'substantive information' is always associated with the sending and receiving of self-presentation. It is even possible that some receivers have no ear for the substantive information, but perceive exclusively the self-presentation and in the most unfavorable case evaluate the entire message negatively.

At the *appeal level*, attempts are made to modify emotional and cognitive behavior. Thus the presentation of how small the hazards of a technology are can also be understood as an appeal: 'give up your protest'.

Educational campaigns frequently use the appeal 'Protect yourself against this hazard'. In risk communication, in particular, messages are often understood at the appeal level. If the appeal is rejected, this can lead to strong reactions that are incomprehensible to the sender at the substance level. A particular role is played here by fear appeals, where worrying dramatizations of an issue presented as a risk lead the addressees to affective reactions. Severe disturbances arise if the sender communicates at quite a different level than the receiver and vice versa.

Risk communication largely takes place in public. Here experienced moderators or mediators can partly attenuate communication difficulties. The conviction that someone meant something exactly as it was said often leads to deep divides of misunderstanding and hardening fronts. People involved in risk communication (public relations officers, members of NGOs etc.) should therefore have training to sensitize them to the fundamentals of communication.

F 7.3
Presenting risks

Credibility strategies

Communicators generally go to some efforts to make and maintain an impression of credibility. This impression, however, is undermined if disparate and contradictory information is released on risks. Thus expert appraisals of secondary damage will differ particularly in cases where the magnitude of consequences might approach infinity and the certainty of assessment is very low. Often attempts are made to prevent the associated loss of credibility of the sources of information (companies, scientists, associations, institutes etc.) by forcefully stressing the competencies and capabilities to manage the existing risks (such as in the advertising campaigns of the chemical and genetic engineering industries; Becker, 1993). However, credibility is not based solely on competency. It also depends upon openness of information, fairness in dealing with divergent opinions, the consideration of relevant social values and the consistency between words and actions (Wiedemann et al., 1991). The willingness of risk generators and decision-makers to enter into an open dialog on the risks and opportunities presented by e.g. a new technology contributes to a germane dispute.

Information strategies

Information strategies aim towards an appropriate presentation of the risk. For this, concrete proposals have been made that should be observed by all actors who wish to give information about risks (Ruff, 1993). How must information on risks be structured in order that the audience understands it properly? Box F 7.4-1 assembles guidelines for the presentation of risks and damage. Observing these guidelines improves the acceptance of information.

In order to make risks more readily understandable, comparisons are often made with situations that are easier to grasp or better known to the audience. Here care needs to be taken that the comparisons chosen are appropriate and thus acceptable. Through the choice of different references, risk presentations can be magnified or diminished (e.g. expected fatalities within 1 or within 30 years, disaggregation according to certain groups of victims (children, elderly) or presentation of data across the whole population). The reference chosen must correspond to the everyday context of the target group if the risk is to be presented and understood appropriately. Comparisons should not be used that attempt to produce acceptance through reference to an already accepted risk. The following example illustrates such a cross-risk comparison: "the lung cancer risk posed by as-

Box F 7.4-1

Guidelines for risk and damage presentations

Correctness. Use valid and reliable data.
Fairness. Select references that fit the risk of the affected public. For instance, reference to the general risk in everyday life is misleading when debating the risks in the neighborhood of a waste incineration plant or a power plant.
Completeness. When in technology decisions long-term risks and environmental risks are also of relevance in addition to immediate risks of fatalities, then the former must also be stated.
Comprehensibility. Risk statements need to be formulated in a comprehensible manner. The information that there is a risk of 0.0018 is less comprehensible than the information that there is a risk for only two out of 1,000 people.
Relevant comparisons. When choosing risk comparisons, care needs to be taken that these make sense from the perspective of laypeople and are not in conflict with their perceptual habits. For instance, it is not correct to compare involuntary risks with voluntary ones.
Source: Ruff, 1993

bestos is, for a life-long exposure in ambient air with 1,000 fibers m^{-3}, the same as the cancer risk of a smoker who consumes three cigarettes annually" (Ruff, 1993). Table F 7.4-1 classifies risk comparisons according to their anticipated acceptability. Wherever possible, first choice comparisons should be used, and where necessary second or third choice comparisons too; it must be kept in mind, however, that these may well not be accepted.

F 7.4 Actors in risk communication

The field of risk communication in which the aspects discussed above exert their influence is defined by a variety of actors (scientific community, authorities etc.; Rohrmann, 1991). The goals and interests of these actors vary depending upon the issues at stake (chemical risks, technological risks, biological and medical risks etc.), so that we can only discuss representative examples here. Similarly, possible interactions among the various actors can only be touched upon briefly, as this only makes sense in connection with specific issues. Each group participating in risk communication offers access points from which to structure the communication process more successfully. The communication process is considered to be successful if all groups interested in the process can participate effectively and with equal standing. Measures are proposed for each actor with due regard to the aspects set out in Section F 7.2.

The generators

Organizations or people generate risks through their actions. These can be companies that use or produce hazardous technologies (e.g. nuclear power plant operators), emit or (improperly) use substances (CFC-containing substances, pesticides, hazardous material transports). Research institutions (experimental reactors, genetic engineering laboratories) are also noteworthy here. Generators can make their contribution to an open and fair risk debate by embarking on a dialog with the affected and by abstaining from uni-directional acceptance strategies. In addition to the local activities that companies can organize themselves, such as establishing discussion groups or question-and-answer forums with local residents, more formalized procedures can also be expedient. Risk assessment procedures analogous to Environmental Impact Assessment (EIA) could be considered. Similar assessments are already carried out by the German safety standards authorities (TÜV), but in most countries there are no comparable institutions. Such institutions would thus need to be established with the purpose of performing an EIA-type risk assessment. The results could be taken up in a national risk report or could be collated by a national Risk Assessment Panel (Section F 6) and disseminated to the public.

A further question is to what extent generators could be obliged (or are willing to commit themselves voluntarily) to actively ensure that resource imbalances on the part of potentially affected parties or the interested public are compensated for. It would be conceivable, for instance, to require that funds are set aside during the development of a new technology which can later be used for the comprehensive information and organization of the interested public. A precondition to this would be that these funds are administered by an independent institution. Affected parties or NGOs should then be involved in the decision-making process on the implementation of the technology. A contribution could thus be made to more equitable distribution of the costs and benefits of high-risk technologies. Liability law offers a further tool by which to hold the generators of risks responsible for their actions (Section F 2).

The affected

The affected are the people who are (potentially) exposed to the risks. These include, for instance, the neighbors of industrial plants, the users of products (medicines, genetically modified food), or the inhabitants of arid, coastal or riverine regions. Commu-

Table F 7.4-1
Guidelines for risk comparisons.
Source: Ruff, 1993

Types of risk comparison	Examples
FIRST CHOICE RISK COMPARISONS (MOST ACCEPTABLE)	
• Comparisons of the same risk at two different times	The health risk posed by air pollutant X is 40% lower than before installation of the flue gas purification plant
• Comparisons with a standard	The exposure of plant workers is substantially below the statutory industrial threshold limit value (TLV)
• Comparisons with different estimates of the same risk	Our best estimate of the risk is x, the estimate of the national study commission is y, that of the research institute is z
SECOND CHOICE RISK COMPARISONS	
• Comparisons of the risk of doing and not doing something	If we deploy the newest and most advanced pollution control technology, the risk is x; if we do not deploy it and remain at the present standard, the risk is y
• Comparisons of alternative solutions to the same problem	The risk associated with a waste incineration plant is x. The risk of landfilling the waste is y
• Comparisons with the same risk as experienced in other places	Berlin has the largest air pollution problem; our air pollution problem is only half as large as that of Berlin
THIRD CHOICE RISK COMPARISONS	
• Comparisons of average risk with peak risk at a particular time or location	The health risk caused by air pollutant y for the average community resident is 90% lower than the risk for the plant worker
• Comparisons of the risk from one source of a particular adverse effect with the risk from all sources of that same adverse effect	The lung cancer risk posed by air pollutant X is about $^{3}/_{100}$ of our total lung cancer risk
FOURTH CHOICE RISK COMPARISONS (ONLY RARELY ACCEPTABLE)	
• Comparisons of risk with cost or of cost/risk ratio with cost/risk ratio	Through eliminating asbestos in school buildings, saving one human life would cost US-$ y, while saving one human life through providing mobile coronary treatment units would only cost US-$ z
• Comparisons of risk with benefit	Chemical x, whose disposal releases air pollutant y, is used in hospitals to sterilize surgical instruments and thus contributes to saving many human lives
• Comparisons of occupational with environmental risks	Neighbors are exposed to lower concentrations of air pollutant x than our plant workers, and medical tests in the plant have revealed no health impairments
• Comparisons with other risks from the same source, such as the same facility or the same risk agent	Our problem with air pollutant x is not more serious than our problem with air pollutant y, which is also released from this plant and which the neighbors have accepted for some time
• Comparisons with other specific causes of the same disease, illness, or injury	Air pollutant x causes much less cancers than the natural background radiation of geological radon
FIFTH CHOICE RISK COMPARISONS (ONLY VERY RARELY ACCEPTABLE)	
• All comparisons that are extraneous to the matter at hand or that violate the legitimacy principles of laypeople	The health risk posed by air pollutant x is lower than the risk of driving or smoking
• In particular, comparisons of two or several unrelated risks	It therefore follows that (a) the risk associated with air pollutant x logically must be more acceptable, and (b) people who drive or smoke have forfeited their right to oppose the release of air pollutant x from the plant

nicative disputes are of particular relevance to the affected if there are generators on the 'other side' to whom the production of the risk can be attributed. This is generally not the case for 'natural' risks, nor for risks for which no clear generator can be identified (climate change, infectious diseases etc.). The focus of the following discussion thus lies on technological risks (Damocles type). Those potentially affected by a high-risk technology must generally tackle the subject in their 'spare' time while the potential risk emitters can devote their full time to advancing their plans. The latter are generally well equipped with the requisite resources.

Discursive procedures (mediation, round tables, discussion groups) offer an avenue by which to create a large degree of equal opportunity in risk negotiation processes (Section F 8). These procedures do not determine the outcome, but merely determine the manner in which the people and groups involved make their decisions. Mediation procedures are often able to cushion existing resource imbalances. Through the formalization and guidance of the process by a mediator, it is ensured that a knowledge head start of one side does not immediately determine the decision, as this knowledge must first be recapitulated by the other participants and its validity checked. Such procedures also ensure that different interpretation patterns and value systems receive equal standing, instead of the one value system that is presented the most professionally becoming dominant.

The question of compensating for resource imbalances gains particular relevance when we consider the situation in developing countries. In countries where no liability law or comparable arrangements are in place, or no constitutional instruments are effective (state and policy failure), the affected have no options for action. Under these conditions, they have no chance to defend themselves against the destruction of their bases of existence by the superior strength of financially powerful corporations. The example of Shell in Nigeria bears dismal testimony to this. Here there is a need to create international standards that are binding upon globally operating corporations (Section F 6).

Non-governmental organizations (NGOs)

In a narrower sense, NGOs are special interest groups which, while not feeling directly threatened, do either view themselves as being threatened over the long term (e.g. by global climate change) or view themselves as the advocates of nature at risk. There is a fluid transition from these organizations to the 'interested public' which, while not organized in any formal way, also has a mobilization potential (Rohrmann, 1991). The possibilities of NGOs intervening should also be strengthened in the international negotiating arenas. Joining forces to form a network that properly represents the relatively heterogeneous groups would appear to be an efficient way to do this.

A good example of such networking is the establishment of the German NGO Forum on Environment & Development in Bonn, which, with its working groups on the individual focal themes of global change (e.g. climate, social development, biodiversity, desertification, oceans, trade), is integrated in the international negotiation processes in many ways. While in terms of negotiating power NGOs do not have equal standing with government representatives, they have acquired more weight over recent years. These participation rights are not given as an end in themselves, but are due to NGOs playing an increasingly important role in the implementation of international agreements. This is exemplified by the Desertification Convention. At the first Conference of the Parties in 1997, a joint session of NGOs and official government representatives was held in connection with an official plenary session, and it was agreed to repeat this novum in the history of convention negotiations in the following years. Communication training measures should be established to support NGOs. Here particular attention needs to be given to the psychological aspects of risk perception (Section E 1.2).

Regulatory bodies

Regulatory bodies are governmental or intergovernmental institutions that create the framework conditions for risk management or are responsible for these framework conditions (e.g. parliaments, regulators, agencies, commissions). The introduction of referendums in certain municipal decisions is an example of the creation of such framework conditions. An example of an intergovernmental arrangement that could, inter alia, set standards for the disclosure of information by companies, is the Risk Assessment Panel proposed in the present report (Section F 6). This should assess, on the basis of independent scientific expertise, the risk potential of large-scale industrial facilities, genetic engineering experiments, the hazards posed to coastal zones by climate change or the risk of food crises posed by drought and soil degradation. The outcomes of this assessment process should be communicated externally, perhaps in the form of risk reports.

The scientific community

This refers to those working at universities or research institutes who have expert knowledge relevant to the analysis or effects of risks. It includes both independent scientists and formal scientific-technical bodies (study commissions, advisory councils etc.). The guidelines for the presentation of risks and choice of risk comparisons (Section F 7.3) intended for public education apply particularly to experts. Who the public (target group) in question is needs to be taken into consideration and perceived in a differentiated manner. Different topics and language will be appropriate for different subgroups. An important goal of the transfer of knowledge to the public must be to create transparency about impending developments, opportunities and risks. The existing scientific bodies (advisory councils, technology assessment, study commissions etc.) could be provided with larger resources by which to efficiently undertake such communication efforts.

The internal flow of information within the scientific community also offers scope for improvement (WBGU, 1997a). Improving internal communication is not essential to successful external communication (and is difficult to achieve due to the multi-layered nature of the scientific community), but successful networking could certainly make external communication more effective. The continuous presentation of the latest state of climate research by the Intergovernmental Panel on Climate Change (IPCC) offers a good example of transparent knowledge production in the scientific treatment of global change problems. Several thousand scientists are involved in each of the IPCC reports, which integrate the latest climate research and represent the best available knowledge at that time. The preparation of the reports passes through a review procedure, which makes it possible for all participating scientists to integrate their knowledge. Such a formalized body of scientists without affiliations to any specific government could also be established for other risk domains (e.g. for the Biodiversity Convention and Desertification Convention), whereby care would need to be taken that the findings are made readily accessible to the public.

The media

Radio, TV and print media serve as transmitters of information on risks and opportunities to the public. The media assume a particularly important role in risk communication when presenting risks that were previously unknown or that escape the human faculties. This aspect is discussed in detail in Section E 1.2. In the interests of germane risk communication, it is essential that the diversity of opinions on any issue can also be reflected in the media. This means that any media censorship or instrumentalization by an opinion monopoly which is effectively censorship must be prevented. However, what is important above all is that the media assume this role in an appropriate manner through accurate and germane presentation of the issue at hand. Risk communication is a field in which there is particular scope for greater collaboration between the media and the scientific community.

F 8 Discursive approaches

F 8.1
Potentials of discursive approaches

A lot of talk about an issue does not necessarily make a discourse. A discourse is a form of communication aiming to reach understanding, in which argumentative statements are examined as to their validity according to fixed rules and without regard to the status of the person presenting a given statement (Habermas, 1971, 1992).

Discourses are no panacea for all the problems of our times, nor can they get rid of problems of ambiguity and uncertainty that are inherent in risk assessment and evaluation (Giegel, 1992). The mere fact that parties to a conflict have met around a table and have talked to each other has rarely contributed to clarifying an issue, arriving at new understandings or resolving a conflict. What is essential is that, in a discursive process, the substantive issues are clarified on the basis of a stipulated methodology, evaluative questions are debated and consequences for action are derived in a consistent manner (Burns and Überhorst, 1988; Renn and Webler, 1998).

Discourse and consensus orientation are often misunderstood by the public. 'Another talking shop' say some, 'further proof of the lack of political leadership' say others (Weinrich, 1972). Both accusations may be justified by the measure of many discourses that have taken place, but are irrelevant to the internal logic and immanent capacity of discursive conflict resolution. Discourse does not mean agreement upon the smallest, usually trivial denominator. It is rather a matter of resolving conflicts in a manner in which arguments are exchanged in all clarity and, if necessary, in all sharpness, and divergent values and interests are presented. A discourse will often not end in consensus, but in an agreement to disagree. In this event, all participants know why the one side is in favor of a measure and another is opposed. The various arguments have been examined in debate and their strengths and weaknesses sounded. Remaining differences are no longer based on illusory conflicts or misjudgments, but upon clearly definable differences in the evaluation of the consequences of specific decisions (Schimank, 1992). All parties know what consequences their preferences for the one or other solution may be expected to entail, with all associated uncertainties. The outcome of a discourse is more clarity, but not necessarily unity.

Even if disagreement is the outcome of discourse, this outcome is just as important to decision-making processes in industry and politics as consensus would be. In both cases, the legitimate decision-makers can take balanced and, in the classic sense, rational decisions. For consensual proposals this is less painful, but in the event of dissent, decision-makers must give precedence to one or the other solution, reverting to superordinate values or to their own programmatic agenda. In a democracy, just as under all other forms of government, it is not possible for all to always win. If the dissent is clear and argumentatively founded, then the political leadership for which so many clamor is indeed called for. A decision must be taken either way. If the decision is taken on the basis of a discursive debate, this not only improves the outcomes of the decision, but also its prospects for acceptance, even among those who have not been able to enforce their preferences.

The ideal of discourse is based on the premise that agreement (including why disagreement prevails) can be established among conflicting interests and values of various parties without one party being excluded or its interests or values remaining unconsidered. The purpose of such a discourse is to evaluate options for collective decisions according to their degree of desirability. There will be conflicts among the participants in a discourse. Nonetheless, understanding is possible if the following conditions are met (Bacow and Wheeler; 1984; Renn and Webler; 1998):

1. All parties within the discourse have equal rights and obligations.
2. All parties unanimously decide the procedure by which agreement on collectively binding decisions is to be established.
3. All factual claims made during the debate must be proven or confirmed by appropriate experts (although, depending upon the type of knowledge,

these need not necessarily be scientists); however, ambiguous, not definitely verifiable or refutable statements can also be included in the discourse.
4. Disparate interpretative templates and value systems have equal standing, as long as they do not contradict the rules of logic or other formal rules of argumentation.
5. All participants are willing in principle to disclose their own interests and values.
6. All participants are willing to work towards a fair resolution of the conflict, in which all interests and values are recognized in principle as legitimate and worthy of negotiation, but without this calling into question the necessity to substantiate interests or values.

Today, discursive procedures are employed at the local, regional, national and international level. An essential precondition is that a manageable number of actors can negotiate with each other as delegates of interest groups or as representatives of the general public. Discourses are generally informal, i.e. they should take place in the run-up to political decision-making. Particularly in the international arena, such informal negotiations with affected groups or parties can pave the way for subsequent political agreement.

F 8.2 Classes of discourse

The literature contains many different classification systems for discourses (Bacow and Wheeler, 1984; Burns and Überhorst, 1988; Zilleßen, 1993). One may argue about issues, about evaluations, about requirements for action or about esthetic judgments. A classification according to four categories of discourse appears useful for dealing with risks:

- In a *cognitive discourse*, knowledgeable experts (not necessarily scientists) strive to clarify an issue. The objective of such a discourse is to represent and explain a phenomenon in a manner as close to reality as possible (such as the question of which health effects are to be expected if a certain substance is emitted). The more multi-layered, transdisciplinary and uncertain the phenomenon is, the more necessary is a communicative exchange among the experts in order to arrive at a homogeneous description and explanation of the phenomenon.
- The *reflection discourse* is concerned with interpreting issues, clarifying the available knowledge, preferences and values and arriving at a normative evaluation of the present situation and proposals for improvement. Reflection discourses are suited particularly as tools for preparing decisions and for anticipating potential conflicts. They yield an impression of moods, preferences and discomforts, without aiming to evaluate concrete decision options.
- The *formative discourse* aims to evaluate options for action and/or solve concrete problems. Mediation procedures and direct citizen participation belong in this category, as do conciliation procedures bringing together the operator, regulator and neighbors of a planned risky facility. Political and industrial advisory bodies that propose or evaluate concrete policy options also belong in this category.
- Strictly speaking, the *educational discourse* is not really a discourse, as it deviates from the ideal type of a discourse through its clearly hierarchical structure – from source to audience. However, as mutual learning can have distinct discursive features, it appears justified to include this as a category of discourse. In the discourse, the outcomes of the other three types of discourse (or outcomes, evaluations and proposals for action brought about through other processes) are disseminated to external parties.

F 8.3 An overview of discursive approaches

In mediation, a nonpartisan mediator takes part in the round table in addition to the representatives of the groups affected by a decision (Breidenbach, 1995). The role of the mediator is to advance the process of finding agreement, so to speak as a catalyst. Mediation is useful where conflicts already arise in advance of certain projects, which can be the case in siting issues or when the construction of large-scale technological facilities or controversial research institutions such as genetic engineering laboratories is planned. With the help of the neutral mediator, an attempt can be made to find a solution acceptable to all parties. In discussion panels, as in round table procedures, the perspectives of the affected parties are disclosed and different solution options are developed. The mediator ensures that conflicts do not escalate and that certain rules of fairness are observed. Successful mediation yields recommendations on how to proceed in the concrete case. In the USA, this approach to conflict mediation and resolution is in widespread use. In Germany, too, such procedures are employed, mainly in the environmental policy sphere (Renn and Oppermann, 1995).

The 'cooperative discourse' procedure is a refinement of the round table procedure. This combines a variety of distinct discursive approaches. Like all mediation techniques, the cooperative discourse technique revolves around a dialog among the individuals and groups with a stake in the planned measure, and a balancing of interests, values and world views. The model of cooperative discourse follows a three-phase sequential procedure (Renn and Webler, 1998). The phases are distinguished according to value survey, factual survey and balancing. These three tasks are preferably carried out by those actors of whom one can assume that they are particularly suited to the specific type of work. The three levels are linked in the following steps:

- In a first step, all groups affected by a risk are asked to disclose their values and criteria for evaluating different options with potentially risky outcomes (such as technology deployment, an environmental policy measure, or a novel breeding proposal). This takes place in interviews between the discourse organizers and the representatives of each group. The methodological tool used here is value tree analysis, an interactive approach to making conscious evaluations and structuring values and attributes that has been developed in the USA (Keeney et al., 1984).
- In a second step, the value dimensions are converted into indicators by a research team that, as far as possible, is considered to be neutral by all participants. These indicators represent measurement instructions by which to ascertain the anticipated effects of the measures in question. Since many effects are not physically measurable and some may also be subject to scientific controversy, it is not possible to state a single value for each indicator. This applies particularly to uncertain consequences. At the same time, the consequences are by no means arbitrary, but are a logical outcome of the available knowledge and of the application of methodological rules within various scientific camps. Crucially, the discourse must ascertain as accurately as possible the range of scientifically legitimate assessments. To this end, the cooperative discourse method has developed a special form of expert workshop, the so-called 'Group Delphi Procedure', in which groups of experts formulate appraisals jointly and resolve discrepancies in direct confrontation within the expert groups (Webler et al., 1991).
- Once the value dimensions have been ascertained and the consequences of the various options for action have been assessed, the difficult process of balancing follows. In the cooperative discourse method, it is left to a group of citizens selected at random to carry out this balancing on behalf of all (Dienel, 1978; Dienel and Renn, 1995). The selected citizens have several days in which to study the profiles of the different options for action, to query experts, to hear evidence, to carry out on-site inspections and to consult with each other at length. The process ends with their recommendation for action, which they must substantiate in depth in a citizen report. They are remunerated for this. Such citizen panels have already proven their usefulness at the municipal and regional levels, and were used for the first time to resolve a national conflict in the early 1980s (Renn et al., 1985).

In addition to the participation in decision-making procedures of directly affected parties, there are further forms of agreements between state and societal actors. For instance, companies can work on a voluntary basis to solve certain risk problems, entering into cooperative arrangements or voluntary commitments to achieve specified environmental and safety goals. Cooperation, industry covenants and voluntary commitments are generally reactions of potentially affected parties to state moves towards regulating certain environmental concerns. Corporate self-regulation can preempt the adoption of new laws and regulations that often permit less implementational flexibility. Hence, companies or company groupings often enter into voluntary agreements in order to counter impending statutory impositions. However, as such agreements cannot integrate each and every company in an industry, free-rider problems can easily arise. The more members of an industry participating voluntarily in an agreement, the greater its prospects of success.

Agreement of companies to cooperate voluntarily to solve a certain problem is also known in Germany from the climate debate and the discussion on ways to reduce CO_2 emissions. The spring 1996 voluntary commitment of German industry to reduce specific CO_2 emissions (CO_2 per unit production) by 20% by the year 2005 (1990 baseline) was instrumental in the postponement by the German government of its plans to introduce an energy or CO_2 tax. Voluntary commitments can be based on formal contracts or informal promises. They are generally monitored by independent third parties and the public (the press).

Industry will enter into voluntary agreements above all when it can assume that the effects will be less negative for it than those of a regulatory measure. This tool therefore harbors the danger that its use may in fact constrain and delay the attainment of the necessary risk reduction targets (Kurz and Volkert, 1995). Deep-seated reforms and changes that go beyond developments anticipated in any case will most probably not be achieved by means of voluntary commitments and cooperation. A further problematic aspect is that such negotiated solutions exclude third parties who are equally affected. This is a danger inherent in every kind of round table (Hoffmann-Riem and Eifert, 1995; Bergmann et al., 1996).

Nonetheless, discursive tools have the great strength that with their help the balancing process required for risk evaluation can be performed according to rationally and politically legitimatable criteria. The question of which risks are reasonable and how ambiguity and uncertainty should be dealt with goes far beyond political administrative action. The question of the reasonable degree of risk instead necessitates broad public consensus. Responsible behavior can only arise in awareness of one's limits, impending dangers and possible opportunities. Such a level of responsibility can be best achieved in discursive procedures involving collective decision-making and own, voluntary commitment. A structured negotiating process that integrates the necessary technical expertise, observes norms and laws, incorporates social interests and values in a fair and representative manner and enables the integration of substantive, emotional and normative statements offers new perspectives for resolving the conflicts of interest that emerge in the context of risk policy decisions.

Discursive tools have their limits. Their effectiveness and efficiency cannot be assessed in advance. Discursive approaches are applicable wherever direct damage or a direct hazard to health and the environment is not to be feared and there is no urgency, but where interventions are associated with partially controversial value judgments. Even if the parties participating in the discourse find solutions that can be supported in a binding fashion by all participants, politicians are not bound to the recommendations elaborated. They should, however, integrate these recommendations in their own decision formulae.

F 8.4
A procedural proposal for the discursive management of risks

How should we structure risk evaluation discourses? Table F 8.4-1 shows an ideal-type course of a risk regulation decision process with discursive elements.

The following tasks need to be performed in connection with this decision process:

- A normative debate must be led over evaluation criteria by which to judge the acceptability of risks. This debate should involve not only experts but also representatives of special interest groups and interested citizens. This debate should take place in the extra-statutory space, i.e. presuppose the validity of the law but supplement this with risk-specific norms. Codified law can be construed in varying ways, but the leeway for action is not arbitrary. It is therefore necessary to use such 'objective standards', if simply for the reason that a society cannot renegotiate every aspect again.
- The current diversity of opinions prevailing in the population and in selected groups needs to be surveyed, in order to ascertain the specific degrees of subjective value attainment and value infringement, and to gain an improved understanding of public preferences. This information is also important simply to be able to assess whether the controversy is real or whether it is an extrinsic problem. At the same time, perception studies can reveal to what extent opinions are polarized and whether there are avenues for consensus.
- The expected social outcomes associated with the spread or utilization of certain risky options must be assessed. Here particular care must be taken to characterize the remaining uncertainties. It is in this phase that the risk would be assigned to the classes of risk identified by the Council in the present report.
- The outcomes must be evaluated using normative criteria and involving interest groups, citizens and experts. This evaluation process must be carried out in close collaboration with the legitimated decision-makers. Whether a balancing of interests and values succeeds is of course questionable.

Formal evaluation procedures have the potential to offer a starting point for comparative evaluation when judging options. They do not, however, have automatic validity. In each case it is necessary to balance values and goals. This is why it is essential that a dialog comes about in which all sides can exchange information and also learn from each other. The goal of precautionary risk policy is to deliver guiding support to decision-makers in the political realm, in industry and in societal groups – support that is based

Table F 8.4-1
Course of a risk regulation decision process that integrates discursive elements.
Source: WBGU

Decision-making steps	Principal actors
Problem perception	Politicians, stakeholder groups, experts
Goals, values	Politicians, interest groups
Criteria	Politicians, experts, focus groups, representatives of the broader public
Options	Experts, groups, public
Impacts of options	Experts
Weighting of criteria	Politicians, public
Decision	Politicians (participation)

upon up-to-date expert knowledge and at the same time makes the values and preferences of the people affected by the outcomes its standard of desirability. Discursive approaches to reaching understanding are a suitable tool by which to intermesh these two elements systematically and validly.

Strategies for dealing with unknown risks G

The importance of unknown risks: Preventing 'future ozone holes' G 1

The overall heading of this annual report, as of all previous ones, is 'World in Transition'. This expresses the need to give particular attention to future developments and their associated risks. Moreover, the Council has always stressed the plurality of dimensions that make up the concept of sustainability. In addition to ecological sustainability, equal consideration must always be given to economic and social sustainability. This is all the more important as an advisory council on 'global' environmental change must always maintain an awareness of the interests of the – by far the largest – part of humanity whose material wealth is far below that of the OECD countries. The risks of a 'World in Transition' thus always need to be contrasted with the opportunities of change.

From this overall complex of known and unknown risks and associated opportunities, the present report has until now largely treated the known risks. Information was therefore available about damage potentials, on the basis of which risks could be assigned to specific classes. Part G of this report is concerned with unknown risks, i.e. risks for which no information is available – not even about the concrete source. The transition between unknown and known risks is fluid in places. For the Pythia and Pandora types, in particular, no further concretization of the probability or extent of damage is possible. In many cases, however, assumptions of damage can at least be made. It is further conceivable that entirely unknown risks exist in addition to these assumed risks. The following discussion thus provides guideposts for strategies to tackle Pythia- and Pandora-type risks.

It may at first appear unnecessary to deal with this topic at all. Why should we ponder risks that perhaps do not exist at all or about which no knowledge is available? No doubt unknown risks, precisely because of their unknown properties, cannot be treated as well as known ones – this will become apparent in the further course of the discussion. They nonetheless have major importance because they are usually linked to innovations. Innovations, in turn, are the prime driving force of economic growth and globalization and are set to gain rather than lose importance in the future. Innovations are tied to people and to the institutions that influence them. The aim must thus be to create predispositions in this complex of innovatively focused people and institutions in order that when previously unknown risks begin to emerge, mechanisms are in place that almost automatically enable their recognition and evaluation. Innovations can generally follow a variety of trajectories and can then be directed in the least risky direction.

To take an example pertinent to global environmental change: if the development of a new chemical presents the threat of a new risk, in the way that the ozone hole could perhaps have been anticipated at the time when CFCs were developed, the innovator should take such effects into consideration at an early stage. This basic tenet is well illustrated by the varying definitions of the hazard potential of chemical substances. The German Act on Protection Against Hazardous Substances (Chemikaliengesetz, ChemG) is mainly based on the harmful properties of a substance, i.e. the determination of their 'immanent hazard potential'. For risk policy, however, it is decisive how these inherent properties may actually impact upon human health and the environment through dispersal or mobility and exposure. Ideally, research chemists should integrate this 'endpoint hazard potential' in their research decisions (Breuer, 1986; Rehbinder, 1997).

In a similar manner, innovative technologies such as genetic engineering and animal cloning can constitute risks whose type and extent are still entirely unknown. In order to reduce these still unknown risks, it is essential to develop tools that sharpen the awareness and attentiveness of researchers and innovators to such risks, without destroying from the outset through harsh interventions the opportunities offered by the innovation. In the case of genetic engineering, in particular, it would appear possible to seek out risks in a decentralized manner, as here a 'conceivable risk trajectory' is clear and there are concretizable notions of the extent of damage. The risk assumption thus has a minimum degree of directedness, which in many cases is the precondition to the decentralized discovery of risks. Risk knowledge can also emerge as a co-product of genetically modified product development (Gawel, 1997).

At the Council's constitutive session in 1992, the then German Minister for Research and Technology, Dr. Heinz Riesenhuber, noted that the Council's task was to 'discover the new ozone holes'. This task necessarily only refers to already existing risks, which then only need to be 'discovered'. In contrast, the risk of a new ozone hole being caused by a chemical that has yet to be developed can, to remain within our example, probably be surmised best by chemical researchers themselves or their colleagues. For example, in the broad field of chemical substances, zones of higher or lower risk are clearly known and can elicit enhanced attention. The same applies to the decision as to which technological paths will be followed or left alone.In any event, it is in the immediate environment of the innovative individual that we may find the information which offers a prospect for seeking out previously unknown risks.

While this part of the report centers on unknown risks, it must always be borne in mind that these risk-generating activities and decisions are driven by the quest for opportunities. This applies particularly to new technologies or new chemical substances whose contribution to development cannot yet be assessed and that necessarily harbor the possibility of still unknown risks. If we look back at history, we find that many technological innovations such as railways, cars or steam boilers were initially classified as highly risky technologies. In the course of time, however, it became apparent that the risks were smaller than had previously been assumed or that it was beneficial to tolerate them in view of the welfare gains offered by further technological development.

As the focus of this part of the report – 'dealing with unknown risks' – logically excludes concrete risks, the following discussion is at times somewhat abstract. Nonetheless concrete recommendations can be delivered at many points on how a society should handle unknown risks or the phenomenon of uncertainty in general. A more passive strategy would be to enhance response capacities and to reduce vulnerability to the occurrence of risks (Section E 2). In view of the general character of the matter, the discussion would then differ only marginally from that of a similarly passive strategy by which to address known risks. The argument therefore concentrates mainly upon what we may term an 'active' strategy, asking which options for action are available to a society and – in the case of global environmental risks – to the global community to discover unknown risks as early on as possible and thus to be in a position to institute risk reduction measures in time.

With this in mind, we argue as follows:

1. At first, the entirety of unknown risks is subdivided according to unknown environmental risks resulting from routine operations, which are not treated any further in the following, and those that stem from innovation processes, on which we shall concentrate (Section G 1.2).
2. A brief general discussion of the emergence of risks leads to a perspective in which we view unknown risks as knowledge deficits, and identify the locations in society where this knowledge can be sought out or generated.
3. The lengthy second section of this part of the report is then devoted to options for compensating for such knowledge deficits (Section G 2).
4. The requisite production of knowledge about unknown risks is often constrained by cognitive, motivational and social factors, which are discussed separately due to their considerable importance (Section G 3).
5. Up to here the discussion is concerned with knowledge that, while not yet available, can be created. There is also knowledge that is fundamentally impossible to create, for instance where there are genuine stochastic processes. Moreover, the production of new knowledge is not a linear, positively growing function of resource inputs. Intensified research efforts are not a sufficient condition for discovering unknown risks (Tietzel, 1985). Where gaps in knowledge are thus unavoidable, but also where knowledge has not yet been created or has not yet been implemented, precautions need to be taken to ensure that these unknown risks are reduced as far as possible (Section G 4).
6. Part G is concluded by a brief synthesis of these novel issues (Section G 5).

G 1.1
Unknown environmental risks from routine activities and from innovation processes

One possible source of unknown environmental risks is the continuous emission of long-known substances. Neither now nor in the foreseeable future can it be expected that knowledge about the complex systemic processes in nature and the effects of anthropogenic interventions in these ecosystemic complexes will be at all complete. It follows that numerous unknown risks can result from *routine activities* that have been under way for a long time. In particular, this leads to the following types of risk (Siebert, 1987b):

1. *Cumulative risks.* If there is only patchy knowledge about the threshold value above which ecosystems will collapse due to anthropogenic chemical inputs, there is a risk that these unknown

threshold values are transgressed.

2. *Synergistic risks*. This refers to the risk that a substance which is not hazardous in itself may react in an unforeseen manner with other substances already present in the environmental media, thus causing damage.

It is very hard for research activities to discover these types of unknown risks. As the number of toxic substances impacting upon humans and the environment is enormous, it is practically impossible to analyze the damage potential of all conceivable interactions among the substances. In theory and practice, this problem is tackled by seeking mechanisms that make control of the risk probable. From such approaches, we may derive general principles which can be applied by analogy to risk constellations that have not yet been studied (Projektgruppe 'Umweltstandards', 1998).

Despite such approaches to tackle combined exposures, the field of combinatory effects is largely considered by toxicologists to be poorly researched. This is presumably mainly due to the complexity of the issue (Projektgruppe 'Umweltstandards', 1998). As cumulative and synergistic risks generally offer no personal point of departure from which to achieve knowledge-producing effects, it is most difficult to generate knowledge of such combinatory effects in a decentralized fashion. The assignment of risk responsibility is almost impossible here. Such knowledge should therefore perhaps be created predominantly by state-funded research institutions (Section G 2.3).

This section accordingly concentrates upon unknown risks caused by *innovations*. In such cases, no experiential knowledge of potential side-effects is available from the past (Zylicz, 1987). Unknown risks stemming from innovation processes also deserve particular attention because, firstly, innovations play a key role in the sustainability debate and, secondly, innovations are inseparably linked with risks.

Innovation processes are associated with risks by definition, as it is impossible to assemble all necessary information on the consequences of innovative actions such that risks are avoided completely. In return, innovations harbor an enormous development potential. They can thus contribute to the goals of all three dimensions of sustainability (economic, ecological, social). Moreover, they may even be able to join all three dimensions, and thus to resolve the partially prevailing goal conflicts among these dimensions. The debate on suitable approaches to unknown risks thus embraces the entire spectrum pertinent to the evaluation of the opportunities and risks of technological development.

Here we are interested particularly in the globally relevant innovation risks (Box G 1.2-1). For these, the criteria of the global filter developed in Section C can be applied. It is of course not possible to make any statements about the global character of unknown risks *ex ante*. Such statements can only be made *ex post* after discovery of the risk. Most of the recommendations derived from the following analysis thus apply equally to national risks. A rigorous distinction between national and global unknown risks is not possible, nor is it essential to the basic message of this part of the report.

The effects of CFCs upon the Earth's ozone shield and those of CO_2 upon global climate are well-known examples of global risks that remained unknown for long periods. Quite different types of global unknown risks can stem from the circumstance that technologies that have long been known (or are innovative) are implemented in countries that are less able to manage the associated risks than the regions of origin (e.g. nuclear power plants in developing countries).

The aspect of asymmetries in the distribution of information, which we shall treat in more detail below (Section G 2.3), presents a further globally relevant problem. The exchange of technologies, products, chemical substances etc. around the world is increasing. This is accelerated by the growing interpenetration of the global economy. Companies are thus able to transfer risks from region to region, for instance by shifting high-risk production technologies to countries with weaker liability regimes, or by withholding knowledge about the risk potential of certain chemicals from their users. Options for tackling such problems related to the asymmetrical distribution of information at the international level through the principle of prior informed consent (PIC) are discussed elsewhere in this report (Section F 6.3) and are therefore not treated further here.

G 1.2
On the generation of risks

Determinants of risk-relevant decisions

For the purposes of the present section of this report, risks are understood to mean the circumstance that events evaluated negatively can occur as a consequence of human decisions to take certain actions (Section C); natural disaster risks such as earthquakes are thus excluded here. This definition underscores the importance of the central decision-making entity – 'people'. Risk-relevant decisions directly attributable to people are, for example, economic decisions on the utilization of natural resources or individual consumption decisions by which demanders express their preferences for certain products on the market.

Box G 1.2-1

Do innovations amplify or reduce risks?

As innovations represent new combinations of factors of production, they will by definition be associated with unknown risks, as no experiential knowledge gained in the past is available on the environmental impacts of innovation processes. However, from the perspectives of economics and systems theory, there are arguments which suggest that innovations can also exert a risk-reducing effect.

The systems theory of evolution is concerned with the self-organization and structural characteristics of systems (Baumann, 1993). From this perspective, environmental problems and environmental risks result from the complex interactions among the various societal subsystems. At a low level of differentiation, we may distinguish between the economic, political, cultural and ecological subsystems. Environmental problems ultimately result from the adaptive capacity of the ecological system being increasingly overstrained, which jeopardizes the coevolution connection between the ecological system and the societal subsystems (Pasche, 1994).

The capacity of a system to adapt to changing system environments is crucial to its viability. A system can adapt passively or reactively to changing processes in its environment, or it can have an active capacity to create and structure its environment itself through expanding its range of capabilities. In order to be able to react actively to environmental changes, a system must be capable of producing novel, innovative forms of behavior (Röpke, 1977). This underscores the importance of innovations, for these represent a creative response of the system to increased external complexity. Ashby's law of requisite variety thus states that increased complexity of the system environment can only be mastered by increased behavioral flexibility, i.e. through increasing the number of different states that a system can assume (Ashby, 1974). A loss of flexibility thus implies an increase in vulnerability to environmental changes (Holzheu, 1987). Innovations therefore have a risk-reducing effect from this perspective. This applies all the more to currently unknown risks, because innovations increase the future action space of a society. This can be illustrated for the example of genetic engineering. Completely blocking this highly innovative branch of development would avoid the (until now mostly only assumed) risks associated with this technology. Such an approach would, however, forego the problem-solving potential of this technology for future environmental problems and risks.

There is of course no final answer to the question of the risk-reducing or risk-amplifying effect of innovations. What is certain is that there is a trade-off relationship between avoiding risks from innovation processes in the status quo and retaining future options for action. Identifying these trade-offs in the specific case and communicating them to the public can help to enhance the acceptance of novel solutions and may prevent the emergence of diffuse anti-technology attitudes which constrain desirable innovations.

Companies, in particular, take such risk-relevant decisions. Accordingly, entrepreneurial decisions on the development, production and distribution of products are frequently at the center of risk debates. In this case, the subject of risk analysis is the decision-making entity 'the person', integrated in a corporate organization. With this focus upon risks as dependent upon human action, we must now ask which framework-setting institutions determine these risks.

1. The *state* is the fundamental entity that determines the institutional framework conditions of human action decisions. The legislative branch creates the superordinate legal framework, while many details are determined by secondary law established by the executive branch (bureaucracy). These state activities have a decisive influence upon the costs and benefits – or, in other words, the risks and opportunities – of action alternatives. The state can be viewed as a super-entity, as its framework-setting competency also decisively influences the way in which the three following institutional factors come into play.
2. In addition to statutory framework conditions, the internal rules of *corporate organizations* influence the people who are integrated in a corporate organization and take risk-relevant decisions in that setting. The many different forms of management and organizational concepts can exert varying incentives upon staff to discover ecological risks and to take these into consideration in corporate decisions after balancing them against the expenditure incurred by taking precautionary action (Sections G 2.2 and G 4).
3. In economics, the *market* is viewed as the most efficient allocation mechanism, as it is capable of transforming important information into price signals, thus directing factors of production to uses in which goods are produced cost-efficiently and in accordance with preferences. The preferences evidenced on the markets are a central determinant of the corporate decision-making system. The institution of the market further underscores the important role of the state as a rule-making entity; for the extent to which the market can perform its allocation function depends greatly upon whether the state creates appropriate framework conditions. From a risk policy perspective, restrictions of the market allocation function can be justified in order to contain certain risks. With regard to global risks, the world trade order is of particular interest as an institutional determinant, as it is a crucial element for all companies oriented to foreign trade and operating internationally in their decisions on the production, distribution and sale of goods. Insurance markets are also of relevance to the risk policy debate, because in developed industrialized nations these represent an institution by which to manage risks through market mecha-

nisms.

4. *Culture* and *social norms* greatly influence human action decisions. In many peoples, cultural norms determine the way in which natural resources are handled. This suggests a need to analyze the relevance of environmental awareness and the environmental preferences prevailing in a society for risk-relevant decisions.

Strategies aimed at early recognition of risks need to take into consideration the entirety of these determinants, for it is from the combination of these various influences upon human decisions that risks ultimately result. These factors offer a point of departure from which to develop early recognition strategies.

A need for state action can be diagnosed in such cases where the risk has, at least partially, the characteristics of a public good. We may speak of public or collective risks if individuals are permitted to appropriate for themselves possible benefits exclusively and to distribute possible disadvantages completely or partially to others. The problem of public risk is therefore that risk generators do not take into consideration adequately the potential costs of their decisions (Karl, 1987).

In order that each economic agent balances individual benefits against private costs and, in the case of environmental changes, macroeconomic costs, too, liability for decisions taken in economic life is a basic principle of regulatory policy (Eucken, 1952). If a full enforcement of the liability principle were feasible, there would be no risk problem, as a risk level corresponding to preferences would emerge. The discussion of liability law from the juridical perspective (Section F 2) reveals, however, that this is a fiction. Due to gaps in the liability system, there will always be risks that exceed the societally desirable level.

Where liability law fails, measures can be taken to reduce undesirably high levels of risk if knowledge is available on potential environmental damage caused by human action (Section F). The present discussion assumes, however, that specific risk knowledge is not (yet) available; there are only very vague assumptions about potential damage, or none at all.

The problem: Unknown risks as a knowledge deficit

Against the backdrop of this discussion of the determinants of risk-relevant decisions, we must now return to the question of the special characteristics of unknown risks. From the knowledge deficit perspective, these can be grouped into two categories (-Hecht, 1998; Gawel, 1997).

1. Knowledge about a damage potential is available nowhere in a society and therefore needs to first be produced.
2. The relevant knowledge is available at a decentralized level. However, because of, for instance, gaps in the liability system, it is not utilized in decisions. In this case there is an asymmetrical distribution of information. This prevents societal discourse on the risks and opportunities for alternatives, and also stops measures from being taken to reach the desirable level of risk.

From the macroeconomic perspective, risk knowledge is a productive good, as it forms the basis for rational risk management. At the microeconomic level, in contrast, risk knowledge is initially a value-reducing good, because, due to the knowledge generated, state regulatory measures may be taken that can be disadvantageous to the company. Consequently, the task of state control could be circumscribed as follows: the goal of state risk management must be to resolve the contradiction between the private disadvantage and public advantage of risk information (Gawel, 1997).

We will return to this exposition of the problem when examining the relevance of specific environmental policy tools to unknown risks. The above argumentation now yields three elementary tasks that must be performed by a risk management effort that wishes to seek out unknown risks:

1. *Generating risk knowledge.* This is the most urgent task for the first type of unknown risks. Sections G 2 and G 3 are thus largely devoted to this task.
2. *Disseminating risk knowledge.* This concerns the second case in which knowledge is distributed asymmetrically. Here the dissemination of knowledge should be stimulated.
3. *Utilizing risk knowledge.* Once risk knowledge has been produced, appropriate incentives need to be in place for this knowledge to be taken up in action decisions.

G 2 Discovering unknown risks as an environmental policy task

An active strategy for dealing with unknown risks aims to close gaps in ecological knowledge, i.e. to generate risk knowledge. Knowledge must be produced about ecological systems and about the consequences of anthropogenic interventions in these systemic processes. If this knowledge is already available anywhere in society, institutional arrangements need to be in place in order to ensure that it is disseminated to the affected parties and to political decision-makers.

This production or dissemination of risk knowledge is a necessary precondition to instituting the societal process in which the risks and opportunities of action alternatives are balanced. While unknown risks cannot be addressed in a concrete manner, it is nonetheless fundamentally necessary to consider which institutional arrangements are available to fulfill the tasks of generating, disseminating and utilizing risk knowledge set out in the previous section.
Social institutions thus have a key function, for their existence and structure decides how societal uncertainties are handled and, ultimately, how opportunities and risks are distributed in a society. Building upon the above exposition of the problem – namely to characterize environmental risks as knowledge gaps – we use the term 'institutions' here to mean the manner in which a society deals with incomplete and imperfect information (Bayerische Rückversicherung, 1987).

Ecological knowledge is predominantly a public good that will not be produced at a decentralized level if there are no institutional incentives. Consequently it must either (1) be created by government-funded research institutions (Section G 2.3); however, in many cases this is inefficient and necessarily fails to capture unknown risks resulting from innovations under way in the private sphere. Or (2) incentives must be provided to generate this knowledge in the private sphere and to utilize it in decisions. The production of ecological knowledge at the private or state levels need not imply two separate processes. In fact, private actors require publicly produced knowledge as the basis for their own knowledge production. Similarly, the basic knowledge produced in government-funded research institutions often only then gains practical and political relevance if it is introduced to risk analysis and policy in conjunction with privately generated knowledge.

Two noteworthy possible barriers may arise on the path from the unknown risk to its prevention. For one thing, it is possible that risk knowledge is not sought intensively enough or even not at all. Reasons for this can include a lack of or improper motivation, as exemplified by various 'risk traps' (Section G 3). The other possible barrier is that knowledge about unknown risks is generated but not implemented. This can be due to strategic reasons, and may then lead to the problem of asymmetric information distribution (Section G 2.3). It may also be due to a lack of motivation to implement the knowledge, which points to a need for improved risk communication. Strong liability laws support implementation.

In the following, we first examine the available spectrum of environmental policy tools according to the extent to which they promote or constrain the generation of risk knowledge (Section G 2.1). We subsequently address the question of how early recognition of global environmental risks can be improved through public research (Section G 2.2). We finally discuss the phenomenon of the asymmetrical distribution of risk knowledge (Section G 2.3).

G 2.1 Stimulating the decentralized production of ecological knowledge

G 2.1.1 Environmental policy tools and their knowledge-producing effect

The literature on environmental economics usually evaluates environmental policy tools according to the criteria of economic efficiency and ecological effectiveness. These criteria cannot be applied to unknown risks, for the reason alone that the information necessary for their application is absent. Viewed thus, the environmental policy tools preferred by economists, such as taxes and tradeable permits, are not entirely convincing. They ultimately aim at a defined and thus definite emissions level. The state then assumes the risk of targets being set wrongly and remains the sole party responsible for a risk having been taken (Siebert, 1988; Pahl, 1998).

It might be argued that these tools do stimulate environmental engineering progress (Zimmermann et al., 1996; Hemmelskamp, 1997). The environmentally relevant innovations thus generated would then need to be examined in each case as to whether they do at the same time have a risk-reducing effect. For instance, it is possible that they merely shift the pollution pathway (Wegner, 1994).

The drawback of these tools with regard to unknown risks is that they scarcely generate incentives to produce ecological knowledge, as they cannot be brought to bear directly upon unknown risks. If we consider regulatory controls from this perspective, we arrive at a similar assessment. Here, too, risk responsibility remains solely with the state, as regulatory impositions generate no decentralized knowledge-producing effects.

Liability law, in contrast, particularly in the form of strict liability, can be assessed very positively in terms of the production of ecological knowledge. A company subject to a liability regime must balance the expenditure for risk prevention measures and the level of compensation payments that it must make if environmental damage occurs. The benefit of liability law is not to be seen primarily in the circumstance that the risk generator can be forced to compensate for damage that has occurred. The particular advantage of this tool is rather that it arouses the own interest of a company to engage in risk-reducing activities. The company has a financial incentive to acquire information on the consequences of its environmental interventions and thus to generate ecological knowledge. As opposed to other tools, these mechanisms of liability law, particularly when instituted in the form of strict liability, are effective even if risks are unknown (Findenegg and Karl, 1998; Pahl, 1998). It has further been shown that strict liability can influence development risks and can bring about a macro-economically efficient scale of research activities (Shavell, 1987; Panther, 1992).

This positive assessment of liability law does however need to be qualified on some points. One is that all too severe liability rules can greatly reduce innovation incentives, because the previous public risk is then converted completely into an individual risk channeled to the individual company. Liability assignment in the form of strict liability thus reduces the gains to be derived from the monopoly situation that can emerge from a successful innovation. However, the willingness to take development risks depends upon various factors, for instance upon the level and duration of temporary monopoly profits and the prospects for reducing development risks through research activities. We thus cannot speak in a generic way of innovation incentives. When analyzing the effects of liability law upon innovation incentives, we must rather take into consideration both the competitive environment and the options for dealing with such risks that may arise (Findenegg and Karl, 1998).

A further point that needs to be considered with respect to possible innovation-constraining effects of liability approaches in risk policy is that the introduction or tightening of an existing liability system represents a redistribution of property rights by means of political decision. The state then assumes responsibility for any impairment of innovative activities in a country – activities that it must watch over in general and with regard to increasing international competition in particular, and all the more so with respect to employment concerns. It is thus essential when designing tools for unknown environmental risks that the risk-reducing incentives of liability law are enabled to develop their strongest effect while at the same time avoiding any innovation constraints.

One proposal aimed at mitigating the potential jeopardy of industrial innovative capacity presented by liability law is the introduction of a form of collective strict liability (Ladeur, 1995). This would make other companies in the branch to which the innovative company belongs participate in the innovation risks. This might be justified by arguing that in the event of damage occurring, experiential knowledge is generated that can be utilized by all other companies to further develop the technology in question. Here it needs to be examined carefully which incentives might proceed from such a regulation for companies to take excessive risks since they would then no longer be held solely responsible for the damage.

Despite the last objection, such an approach does point in the right direction. Unrestricted strict liability does indeed constrain innovation too much. Nonetheless, strict liability should be the reference framework for dealing with unknown risks. Such a liability regime should then include mechanisms that permit a relaxation of liability requirements for companies that can furnish proof that their activities do not pose any threat to human life and health (Box G 2.1-1). This would give a financial incentive to produce ecological knowledge. If, in contrast, the high premium payments that insurance companies would have to demand for such risks (insofar as they are insurable at all, which presents new questions if answered in the negative) were to be publicly subsi-

Box G 2.1-1

The idea of environmental bonds

A particular problem of innovative activities is that they cannot take recourse to empirical knowledge of risks and opportunities gained in the past. Information can only be generated through intensive research efforts. Therefore, a balance needs to be sought between innovative activities and research on the associated risks, i.e. the time resources and intensity devoted to these activities should be appropriate to each other (Zylicz, 1987). Environmental bonds can help to achieve this.

The concept of environmental bonds was originally developed for chemical and waste policy (Mill, 1972, Solow, 1971). The payment of a fee was to cover the social costs that would be incurred in the worst case, i.e. if wastes were disposed of in the most environmentally harmful manner. If a company disposes of the substances in an environmentally sound way, a part of the fee is reimbursed. If the substances can even be completely recycled, then the entire fee is repaid. This provides an incentive to recycle wastes wherever possible. It also creates financial resources by which to compensate for potential environmental damage through funding appropriate measures.

This basic idea can also be transferred to the management of unknown risks. The proposal has been made that every person whose activities involve interventions in nature should deposit an environmental bond sufficient to compensate for the maximum credible environmental damage (Perrings, 1987, 1989). If this damage does not occur, the deposit is reimbursed. The environmental bond system can thus be viewed as a form of social insurance against environmental risks. The system could further include incentives to produce knowledge. If a company produces, through intensified research efforts, the knowledge that the maximum credible environmental damage cannot occur or not with the originally assumed magnitude, it receives a part of or possibly the entire deposit back. This creates financial incentives to produce risk knowledge. This knowledge must moreover be submitted to an authority for review. The process of knowledge dissemination is thus also accelerated (Pahl, 1998).

Numerous points of criticism have been leveled against this conception in the literature. An initial problem is that of how to fix the deposit sum. In addition to the normal problems encountered when monetarizing environmental damage, unknown environmental risks present the further problem of finding any kind of criterion for monetarization, as there is no information on the potential extent of damage. Assessments can thus only be based on assumptions. Furthermore, companies would have to be subject to strict liability as a further security, in order to cover the event that damage exceeds the originally assessed deposit sum. This implies the loss of the insurance effect that the environmental bond initially had for an innovative company (Torsello and Vercelli, 1994). A further problem put forward in the literature is that of the financing difficulties which a company can experience if it is forced to deposit a very high sum before commencing innovative activities. For potentially globally relevant environmental damage, it is immediately clear that this damage can easily exceed the entire company assets. Innovations can thus be impeded that would have been most beneficial ex post from a macroeconomic perspective (Shogren et al., 1993). Particularly when considering global environmental problems, we cannot fully share the optimistic appraisal that insurance and bank markets will emerge in response to such problems (Costanza and Perrings, 1990) that will help companies to finance the bonds.

The criticism notwithstanding, the idea of environmental bonds is indeed an interesting tool and appears particularly suited to dealing with unknown risks. It is used very little in practice. One such example is provided by the 'surface mining bonds' in Pennsylvania and West Virginia. These must be paid by mining companies to cover the recultivation cost of compensating for environmental damage resulting from the surface mining of natural resources (Shogren et al., 1993). To study the suitability of this risk policy tool in more depth, further pilot projects should be initiated in order to evaluate and possibly solve the relevant problems in practice (Torsello and Vercelli, 1994).

dized, then this would reduce the incentive to prevent these risks. This could be avoided by using the subsidy, not to reduce the premium, but, for instance, to enhance the market returns realized through a successful innovation. In both cases the income effect for the innovator would be attenuated, but at the same time a new form of subsidy would be created, giving rise to new claims upon state support and serving as a foothold for further state intervention.

In all, too little attention has been devoted to such institutional arrangements, so that we can state a considerable need for research here. This is all the more so if we consider that, as already indicated above, liability law generates further effects upon markets in addition to the effect upon the innovator that we have described. Liability law increases the financial risk associated with entrepreneurial decisions. In this connection, insurance policies are an institutional solution that has evolved with the aim of converting this individual uncertainty into security in return for paying an insurance premium. Insurance markets are thus viewed as the most important risk balancing mechanisms besides stock markets (Sinn, 1986).

The prime point of interest here is not that insurance arrangements permit the compensation of damage caused by unknown risks. Indeed, on the contrary, gaps in knowledge concerning the level of damage or the cause-effect relationships can in many cases preclude insurance cover (Endres and Schwarze, 1992). The important aspect is that, on the basis of a strict liability regime that also applies to damage caused by presently unknown risks, it can be argued that insurance companies are actors on the market who have a professional interest in discovering unknown risks and in disseminating this knowledge to the generating companies in order to be able to enter into possibly lucrative insurance contracts. We might even conclude from the existence of numerous insurance companies that strict liability stimulates a decentralized, competitive searching process for unknown risks – a process whose efficiency is generally superior to that of governmental attempts to discover risks (Freemann and Kunreuther, 1997; Pahl, 1998). It is of interest in this connection that recent studies have shown the German Environmental Liability Act to have generated a considerable preventive effect through the necessity of taking out insurance cover and thus initiating interaction between the insured and their insurers (Schwarze, 1998).

The argumentative chain set out above is of course in need of some qualification. If, for instance, a risk is discovered which, due to the level of damage, is assessed as uninsurable, the argument of the decentralized competitive searching process among insurance companies no longer applies. The option to deploy liability law as a risk policy tool nonetheless remains if risks are uninsurable. In such cases, liability ceilings can be introduced, and the residual risk must then be either accepted or covered by the state. The preventive effect of liability law is not entirely removed thereby, although it may not be as strong as if there were no liability ceilings.

We may state in conclusion that, compared with the other environmental policy tools (regulatory controls, taxes and charges, tradeable permits) liability law is most likely to target knowledge gaps, the characteristic attribute of unknown risks. This is the only tool, particularly when applied in the form of strict liability, that creates incentives to produce ecological knowledge at a decentralized level. This positive assessment does however need to be qualified by stating that excessive regulation imposed not only on perceptible but also on unknown hazards is in danger of subjecting all societal leeway for innovation to state restrictions (van den Daele, 1993).

Mechanisms therefore need to be introduced in the body of statutory law which ensure that strict regulations can be relaxed if proof can be furnished that an entrepreneurial activity is largely free of hazard. This is also the line taken by the German Technology Council (Rat für Forschung, Technologie und Innovation) with regard to legislative approaches to genetic engineering. In view of the indubitable uncertainty of environmental risks that potentially result from the application of genetic engineering, strict regulations are initially requisite in order to do justice to the precautionary principle. However, in order to avoid innovation barriers being placed upon this opportunity-rich technology of the future, the Technology Council recommends adapting regulations to the advancement of knowledge, i.e. either relaxing or, if necessary, tightening standards (Der Rat für Forschung, Technologie und Innovation, 1997). The German Council of Environmental Advisors (SRU) similarly considers that in many cases it is possible to deregulate the provisions governing the release and marketing of genetically modified plants if back-up research and long-term environmental monitoring succeed in generating appropriate risk knowledge. Here it needs to be examined carefully whether this process of knowledge generation should be carried out – as suggested in the present section – at a decentralized level or rather by public research and monitoring institutions (Section G 2.3). In any event, stimulating the production of knowledge is a necessary condition for creating a regulatory system that does justice to the state of available knowledge. The statutory bases that this requires largely remain to be established (SRU, 1998).

G 2.1.2
The need for corporate environmental policy tools to deal with unknown risks

It has been noted in Section G 1.1 that individuals work within organizations and take risk-relevant decisions there within the setting created by internal organizational rules. In this context, we must criticize the environmental policy tools that dominate in practice, for both regulatory controls and economic incentive instruments (taxes and charges, tradeable permits) give inadequate consideration to the company as an independent decision-making system. A risk strategy oriented to the timely recognition of still unknown risks therefore requires rules and tools "that remain aware of decision-making processes in companies, rather than viewing them simply as a black box that produces emissions" (Führ, 1994).

Such approaches also do justice to the realization that the advancing knowledge avalanche can scarcely itself be controlled or influenced in a targeted manner. It therefore becomes necessary to introduce mechanisms to this process which ensure that high-risk development trajectories are discontinued in time. For this, it is indispensable to consider the internal decision-making structures of the risk generators – both in the analysis and then in the corresponding risk policy measures.

This may be concretized here for the example of an 'Energy Tower' (Zaslavsky, 1997). This proposal suggests that towers of up to 1,200 m height and 40 m diameter be built in coastal desert zones, in which the hot ambient air is greatly cooled by the evaporation of sea water. The resulting downdraft air would drive turbines and generators for electricity production. If such a tower could really yield some 4 billion kilowatt-hours per year at a price of approximately 3 cents/kilowatt-hour at a 5% discount rate (or approximately 5 cents at an 8% discount), then an energy source would have been found that is both economical and sustainable in terms of its inputs (air and sea water). But are the risks manageable? These include the technological risks of such a gigantic structure, but also possible effects upon regional climate or the risk of bacterial infections resulting from the circulating and cooling water vapor. Once publicly promoted research has made its contribution, the liability of the company that constructs or operates the tower must serve to research these risks in more depth.

The economic system functions on the basis of scarcity, cost-benefit analyses and monetary logic. Risks or environmental problems in general must first be translated into the language of the system for them to be integrated by the system and thus also by companies as elements of this system, and implemented adequately in decisions (Schneider, 1996). This 'translation effort' has been performed in many countries in the shape of environmental legislation – at least in certain subsectors. In addition to these direct state activities, environmental problems and risks can also be made a part of corporate experience through the channels of environmental awareness and the environmental preferences in society. A publicly accepted environmental pollution standard can thus serve as a guidepost and point of departure for corporate risk management (Wagner and Janzen, 1994; Wagner, 1991). Similarly, corporate environmental management systems normally embrace the notion of pollution prevention. Accordingly, corporate environmental management systems are focused not only on managing present and thus known risks, but also upon identifying unknown critical points and risks (Wagner and Janzen, 1994).

It was in this context that the idea of using eco-audits as an environmental policy tool emerged. Here the basic idea is to assess and certify the environmental and risk management performance of companies, in order that society at large is informed about the priority given to environmental protection by the company in question. On this basis, the environmental behavior of companies can be sanctioned, both positively and negatively, by consumption decisions or through business relationships.

The eco-audit was introduced as a formal tool at the EU level in 1993. Numerous points of criticism have been raised from the economic perspective against the EU Eco-Audit and Management Scheme (EMAS), so that EMAS has not developed great relevance as an environmental policy tool. However, the criticism is not leveled against the type of tool as such, but against its concrete design (Box G 2.1-2).

Despite the criticism that EMAS has experienced, the basic concept of this tool does at least show the direction that needs to be taken to manage unknown risks – namely to arouse the own interest of companies to engage in environmental protection efforts and thus the creation of incentives for companies to seek out and avoid these risks of their own accord. The interesting proposal has even been made to make the severity of impositions under environmental law, for instance liability law, dependent upon the internal procedural environmental management standard observed by a company, arguing that if standards are high it is justified for society to have a certain degree of confidence in that company's innovative activities (Ladeur, 1995).

Codes of behavior for occupational or professional groups are a further strategy by which to create favorable framework conditions in industry for generating knowledge of unknown risks. These can heighten the attention given by the individual 'innovator' in a company to unknown environmental risks. Such risk awareness could further be promoted by applying internal 'rewards' and 'sanctions'. For instance, the German association of chemical engineers has developed a code of behavior especially for environmental aspects, whose non-compliance can even lead to expulsion from the association (GDCh, no year).

Information systems that organize known risks into risk classes can offer guideposts or tools for selecting low-risk strategies. As already indicated above (Section G 1.1), a precondition to this is that the still unknown risks can be assumed to be related to classes of known risks. For toxic substances, for instance, various classifications have been designed under which substances can be rated according to their hazard potential (e.g. Swiss toxics classes, water hazard classes or various approaches to classifying carcinogenic substances; Kaiser et al., 1998). If newly developed substances are found to have a close relation to known substances on the basis of their formation and discovery history, a researcher receives a first indication of the hazard potential of the new substance currently being discovered. 'New' means here that the substance has not yet been subjected to the formal approval procedure (as opposed to the German Act on Protection Against Hazardous Substances – Chemikaliengesetz, ChemG). When searching for new substances, particularly risk-prone classes of substances can then either be left out of consideration from the outset, or subjected to intensified risk testing if they hold out particular opportunities.

It needs to be kept in mind when discussing approaches for generating knowledge on unknown risks at decentralized levels that such strategies will not suffice by themselves. They must be supplemented by research carried out or funded by the public sector where the anticipated results will largely have the character of a public good (Section G 1). A second point is that public sector intervention may be necessary for risks that prove to be uninsurable (or

Box G 2.1-2

Presentation and critique of the EU Eco-Management and Audit Scheme (EMAS)

Environmental audits involve a systematic evaluation of corporate environmental performance, generally concluded with an external audit and the award of a certificate confirming compliance to a certain corporate environmental management standard. Such audits can focus on compliance with the provisions of environmental law, fulfillment of corporate policy targets or the functioning of the corporate environmental management system itself (Sieler and Sekul, 1995; Wagner and Janzen, 1994).

Building upon initial experience from the USA and among a number of European companies which had introduced environmental audits on a voluntary basis, in 1993 the European Union (EU) adopted its Regulation No. 1836/93 allowing voluntary participation by companies in the industrial sector in a Community eco-management and audit scheme (referred to in the following as EMAS, being short for Eco-Management and Audit Scheme). The objective of the scheme is to promote continuous improvements in the environmental performance of industrial activities by (Art. 1 para 2):

- The establishment and implementation of environmental policies, programs and management systems by companies, in relation to their sites;
- The systematic, objective and periodic evaluation of the performance of such elements;
- The provision of information on environmental performance to the public.

The procedural steps required for participation in EMAS can be distinguished according to four phases (Hemmelskamp and Neuser, 1994):

- *Phase 1.* At first, the company's environmental policy must be determined. This comprises the environmentally related overall goals and principles of action of a company, established in accordance with the objectives of the EMAS Regulation.
- *Phase 2.* Using a comprehensive catalog of criteria, the environmental impacts of the site are ascertained. On the basis of this internal environmental review, an environmental program is subsequently elaborated, containing a catalog of environmental protection measures and possibly also a schedule. Moreover, an effective environmental management system needs to be introduced in this phase.
- *Phase 3.* After concluding the planning period, an internal environmental audit is carried out. This environmental audit forms the basis for the preparation of an environmental statement setting out the activities of the company and the environmental management at the specific site. Data on pollutant emissions and resource consumption must also be documented.
- *Phase 4.* Finally, the environmental statement is verified by an accredited and independent external verifier with respect to compliance with the requirements of the EMAS Regulation. Upon positive validation of the environmental statement, this can be submitted to the com petent authority, which enters the site in the national list of sites. This listing entitles the company to exhibit an EU eco-audit logo which can be used for advertising purposes, but not for product advertising.

The approach of the eco-audit scheme is to promote environmentally sound economic development and to improve the availability to the public of information on environmentally relevant corporate activities. Through the incentive of the image gains offered by the environmental logo, it is hoped to mobilize the voluntary commitment of companies to corporate environmental protection and to providing information (Karl, 1992). In terms of dealing with unknown risks, the eco-audit can be viewed as an environmental policy tool that has the capacity to generate knowledge on environmentally related risks and opportunities in a timely manner (Steger, 1995).

From an economic perspective, the standardization aspect of the eco-audit scheme is considered to be negative, as it stresses the static character of the procedure (Maier-Rigaud, 1993). The annex to the EMAS Regulation does contain a number of lists of keywords intended to outline good management practices. However, the vague character of these organizational and institutional requirements illustrates clearly that efficient corporate environmental management systems cannot be prescribed by the state; rather, they should be discovered by companies in the course of a competitive searching process (Klemmer, 1990). The efficiency-enhancing effect of such decentralized searching processes is restricted by voluntary standardization, and all the more so by state standards. Ultimately, there is a danger that such centralist approaches stifle advances in environmental performance (Karl, 1993). A further point of criticism is that the auditing of complex issues such as those relating to the environmentally sound operations of companies relies under EMAS primarily upon formal criteria (such as compliance with statutory requirements) and thus by no means provides a basis on which to evaluate the environmental conformity of corporate activities (Klemmer and Meuser, 1995).

These largely negative assessments of the EMAS Regulation that are to be found in the economic literature need to be set against experience to date with the implementation of the Regulation through the German Eco-Audit Act (Umwelt-Audit-Gesetz) of 1996. Here it has been found that corporate environmental performance has indeed improved in many cases (Hermanns, 1998). Nonetheless, many issues remain unresolved. The pending amendment to the Regulation shall offer an opportunity to address these. They concern, for instance, whether to opt for auditing the overall corporate organization or individual sites, whether to award one or several environmental logos differentiated according to service-sector and manufacturing companies, and moves towards reducing the bureaucratic effort that is currently necessary to participate in the audit system (SRU, 1998). Therefore before carrying out any thoroughgoing evaluation of the eco-audit scheme as an environmental policy tool it must first be seen how the statutory framework develops and what practical experience is gained in the future.

insufficiently insurable), for instance due to their long-term character (i.e. for classes of risk characterized by high persistency, such as Cyclops or Pythia). Where this is the case, fund arrangements can be used to cover potential damage (Section F 3), and there must be open debate on the extent to which residual risks are to be borne by individuals or by the state as the price for innovation.

G 2.2
Producing ecological knowledge through research: Using syndrome analysis for the early recognition of risks

In contrast to technological knowledge, ecological knowledge generally has the special characteristic that it refers to a public good – the environment. This knowledge cannot be exploited on the market in the way that the development of a new manufacturing technology can. The production of such basic knowledge remote from application interests, while primarily driven by scientific interest, is gaining importance in the environmental policy realm, since it serves as the scientific basis for such policies. As ecological knowledge has the character of a public good, the production of such knowledge is generally viewed as a task of the state.

We have explained above that environmentally relevant knowledge is often produced more efficiently at a decentralized level than at the centralized level – and that this applies particularly to unknown risks (Section G 2.1). Nonetheless, in addition to the resultant recommendation to integrate the decentralized level more closely in risk policy, it remains an indispensable task of the state to create an appropriate research landscape. The knowledge created in environmental research institutions operated or financed by the public sector generally forms the basis for decentralized research activities.

Public-sector production of risk knowledge is made all the more important by the circumstance that new risks often have the character of 'experiential risks', meaning that the risk potential only becomes apparent in the course of time. Here the main problem is to collect and channel dispersed risk knowledge (Gawel, 1997). This task of bringing together dispersed risk knowledge will most probably not be possible by means of market mechanisms and is therefore presumably best transferred to state institutions.

The Council has already examined German research on global change in a previous report (WBGU, 1997a) and found that the prevailing breakdown of research structures along the lines of sectors and disciplines is inappropriate to the issue, or in need of supplement. As the phenomenon of global change and the global environmental risks on which interest consequently focuses are the outcome of multilayered interactions between the ecosphere and the anthroposphere, these cannot be analyzed within the confines of individual sectors or from the perspective of only one discipline. Rather, it is essential to consider complex interactions between processes in the ecosphere and in the anthroposphere. To achieve this objective, the Council has set new guideposts for global change research in the shape of its syndrome approach.

Section E 4.2 has already discussed the fundamental importance and the positive contribution to the analysis of global environmental risks that is offered by syndrome analysis. The Council is confident that implementing the syndrome approach in global change research can furthermore make an important contribution to an improved early recognition of risks that are currently still unknown. Of course this approach cannot guarantee that all unknown risks are discovered. Due to the ubiquitous phenomenon of uncertainty, this is impossible. Nonetheless, applying the syndrome approach can improve the probability of early recognition of risks, since for this task a systemic approach is indispensable. To underscore the benefits offered by the syndrome approach for the early recognition of risks through research activities, we may put forward the following arguments:

Interdisciplinarity and transdisciplinarity in research

Specialization is a necessary but certainly not sufficient condition for successful early recognition of risks. Due to the complex cause-effect relationships that ultimately determine a global risk, efforts must center not on isolating phenomena but on constructing these relationships (Weber, 1988). Analysis from one single scientific perspective alone does not suffice.

This is exemplified by the debate on the proper way to deal with genetic engineering. Biologists can research the risks of deliberate release experiments and can provide the information basis on which to take political decisions concerning ways to deal with this technology. Ultimately, however, recommendations for managing genetic engineering can only be formulated if the risks associated with genetic engineering applications are not treated purely as technological risks but are also understood as risks of society. An improved understanding will not be yielded by the isolated study of this technology, but only through an analysis of the societal setting and trends within which the development and application of genetic engineering are embedded. This requires specialized knowledge in both the natural and social sciences. Syndrome analysis is an approach that applies these two realms of knowledge in combination. Such a combination of natural and social science knowledge gains particular relevance if we accept that knowledge on environmental risks cannot be neutral and objective knowledge, but is always determined by the cultures and norms of a society (Irwin, 1997).

Syndrome analysis, with its interdisciplinary and transdisciplinary approach, creates the preconditions for recognizing the complexity of cause-effect relationships and thus ascertaining which trends may generate risk potentials.

Modeling syndromes
The presentation of syndromes in the global network of interrelations provides an illustration of the complex cause-effect relationships that characterize global environmental problems and risks. Beyond this, such a presentation further provides the basis from which to model syndrome developments. Such qualitative modeling has the potential to capture future developments and thus to enhance the ability to diagnose and forecast potential environmental risks. However, the present state of research in this field does not yet suffice to utilize this early recognition potential of the syndrome approach comprehensively in practice. In the interests of discovering unknown risks, the Council recommends that this research deficit be removed as soon as possible.

G 2.3
Asymmetrically distributed risk knowledge as a problem of rational risk policy

The above discussion has concentrated on the generation of knowledge about unknown risks. However, we have argued previously (Section G 1) that, while such knowledge is often present and risks are not entirely unknown, this knowledge is not made available regularly to the affected parties and to the state that represents them. We are thus dealing with asymmetrically distributed risk knowledge – by no means a rare or unusual problem. Such a distribution of knowledge seems to be a ubiquitous phenomenon that needs to be kept in mind in numerous areas of risk policy. It is therefore of fundamental importance to both regulatory and risk policy to create institutions for disseminating risk knowledge. This phenomenon is particularly important to risks in innovative areas where many risks are still really unknown and knowledge elements already available are all the more important. If these elements were generally known, they could be used elsewhere to discover still unknown risks because there are often substantive connections between different risk phenomena, as illustrated by hazard classes for chemicals.

Regardless of whether we are dealing with global or national risks, we can basically distinguish two decentralized loci where risk knowledge can reside:
1. Scientific research institutions, and
2. Decentralized decision-makers, particularly companies.

The first case should not be too problematic, for research institutions are generally funded publicly in order to provide, among other things, risk knowledge for political decisions. Improved knowledge dissemination is possible in public research, too. However, the following discussion concentrates particularly upon the second case. This is a significant problem because in most cases companies have no incentive to disclose risk knowledge. If decentralized knowledge is available, then it will reside with companies which carry out environmental interventions and have identified the risk relevance of their activities through internal tests and audits. If they behave rationally, such companies will withhold this information, for if they disclose it they must fear that political decision-makers will react to the new knowledge and possibly impose stricter regulatory controls upon the company. Additional regulatory controls generally mean financial losses for the company. In sum, there is thus a strong incentive to withhold risk information.

Under a strong liability law regime, the company will utilize its knowledge to take corresponding precautions out of its own interest. However, as already noted repeatedly in this report, important preconditions for the applicability of liability law are often absent. If risk policy has set itself the goal of making greater use of decentralized knowledge, it is necessary to give financial incentives to pass on this knowledge. One conceivable strategy would be to give companies which disseminate risk knowledge a form of risk discovery premium in the shape of a subsidy, which would also serve to compensate them for the losses incurred through subsequent regulation. Buying the information rent from companies in this manner would only be expedient for risk-relevant activities that are carried out by a large number of companies. If a company is the sole producer of a specific risk, the absurd incentive would result in e.g. chemicals policy to find new, hazardous substances and to receive a premium for passing on knowledge about the toxicity of this substance. Given the nascent research and the lack of experience in practice, the prospects for finding an arrangement that differentiates between these two cases of company- and branch-specific activity are not good at present.

Improved risk communication (e.g. social discourse, mediation) involving all segments of society in the risk debate is a further strategy (Section F 8). From the perspective of companies disclosing risks, it is decisive that they receive an opportunity in such a communication strategy to point out opportunities at the same time. For the capacity for entrepreneurial innovation, and thus also the entire societal potential for sustainable development, it is crucial that despite limited risk knowledge companies retain sufficient scope for action to undertake innovative activities and to furnish step-by-step proof of the harmlessness or manageability of risks associated with innovation activities. Such a climate is most likely to produce incentives to disseminate risk information. Moreover, recent studies have shown that a constructive dialog among affected parties can make use of considerable leeway for innovation within the existing statutory framework without jeopardizing human health or the environment (Staudt et al., 1997). Such an approach would do justice to the proposition that where knowledge is incomplete risk management can only proceed through an experimental, cooperative and interactive approach that relies on self-auditing (de Geus, 1992; Ladeur, 1995).

It would need to be examined to what extent environmental impact assessment (EIA) can contribute to this. The German EIA Act, for instance, explicitly provides for public involvement. Furthermore, scoping is limited under the Act to those environmental effects that are rated as being most relevant. The Act thus recognizes that not all risk factors can be scrutinized, for such scrutiny would create a considerable negative incentive for innovative activities (Eberhardt, 1992; Ladeur, 1994).

The above discussion has been concerned with ways to stimulate knowledge dissemination at the national level. Completely new problems emerge when we extend the analysis to the global level. Here national governments operate as actors in global environmental policy, and it would need to be examined in each individual case how interests are structured. Such politico-economic considerations play a role in all global environmental problems. As they are not immediately relevant to the core problem here, namely how to deal with unknown risks, they shall not be examined further. Rather, it is assumed that governments will place risks on the political agenda at the global level, too, if they have gained the corresponding knowledge.

Knowledge dissemination at the global level can be promoted by interdisciplinary networks of scientists. It became clear when the ozone hole was discovered how important such a worldwide research network can be. The existence of a monitoring program was an important precondition to this discovery. The rapid interpretation of the cause-effect relationships succeeded because of the worldwide availability of a stock of knowledge about processes in atmospheric chemistry and meteorology. This confluence of knowledge also facilitated the explanation of the rising incidence of malignant forms of skin cancer and the elaboration of protective measures (ProClim, 1997).

The importance of cognitive, motivational and social factors for dealing with unknown risks G 3

The development and deployment of technologies and substances (nuclear power, chemical products, genetic engineering) or the introduction of new patterns of behavior (global mobility and networking, novel dietary habits, risky sports such as bungee jumping) represent a quest for new technological options or new ways of life that hold out the promise of economic gain or escape from scarcity, or also novel experiences, enjoyment and forms of structuring or handling one's life. New opportunities are sought and utilities expected. In this quest, risks are taken. These risks can be known, but can also be quite new, for which no knowledge whatsoever is available; the latter must then be counted as belonging to the Pythia class of risk. For such constellations, it is essential to promote the production of knowledge, but also to promote further forms of risk awareness, such as attitudes, communication structures and processes. In addition to necessary incentives to produce and disseminate relevant knowledge by which to prevent or handle risks generated by the state, the market, corporate organizations or a variety of societal conditions (Section G 2), further processes also need to be taken into consideration. Precisely these, however, may impede knowledge production and utilization. 'Risk traps' may emerge, ensnaring individuals and societies and often generating unintended high-risk situations. These forms of risk are termed traps in the social sciences because they have something of the main characteristics of all traps: firstly, they generally contain an enticement (bait), i.e. an assumed advantage of entering the trap; secondly, a small touch may make them snap and become an inescapable situation. To avoid them, it is essential to know them and to handle them extremely carefully. Such traps are generated by our thinking habits (cognitive risk traps), motivational constellations (motivational risk traps) and social constellations (social risk traps).

G 3.1
Cognitive risk traps

The development or deployment of technologies is often analyzed in terms of action in complex, networked, dynamic and occasionally obscure situations. Errors can lead to catastrophic effects, as exemplified eloquently by Bophal, Exxon Valdez or Chernobyl. Many of these and other technological disasters were considered to be almost impossible before they happened. Even afterwards, it continues to be maintained that such misfortune does not really happen and can be explained by the inadequate safety systems and operator errors in a special situation, but is, the argument goes, by no means a general characteristic of complex situations. There are however various indications that these errors are fundamental in nature and cannot be compensated for solely by generating more knowledge and operating safety.

Beyond specific risk research, valuable contributions can be provided by the study of complex system control (Dörner, 1989), the conditions of human failure (Reason, 1994) and workplace safety and health protection (Wenninger and Hoyos, 1996). These need to be applied to global environmental problems, in particular to still 'unknown ozone holes'.

G 3.1.1
Blunders and lapses

If we view errors as the outcome of cognitive activity, it is purposeful to distinguish between unintended blunders and lapses as the consequences of certain cognitive strategies and forms of behavior (Reason, 1994). For 'blunders and lapses', it is comparatively simple to develop precautionary measures.

'Blunders and lapses' are errors that are relatively superficial and often easy to notice. They take place while carrying out a usually routine sequence of actions. Blunders include slips of tongue, slips of pen, slip-ups in general. Lapses are usually slips of memory, not necessarily apparent and often only noticed by the person who commits them (e.g. when a person forgets something). These types of error can quite well be relevant to catastrophes when something is forgotten – to activate a safety system when dealing with highly toxic substances (in genetic engineering laboratories) or to close certain valves (in nuclear power plants). This is generically termed human failure. Such errors are most frequently caused by disturbances in attention due to interruptions of an activity, distraction or stress (Reason, 1994).

The development of new technologies or substances partially takes recourse to known processes for which empirical data are already available for the most frequent or most severe implementational errors. These errors can be avoided by means of standardized checks, e.g. checklists enabling efficient self-monitoring or regular external safety checks. Care needs to be taken that the creation of the necessary framework conditions is not neglected in favor of other priorities.

G 3.1.2 Errors

In contrast to routine operations, the management of complex systems is characterized by planned and deliberate action. Here, as opposed to blunders and lapses that take place 'unintentionally', errors are the outcome of conscious, active thought processes that have been based upon false assumptions, false conclusions, false linkages etc. Errors caused by a false plan or inadequate deliberation are far harder to discover and prevent than blunders or lapses. Complex and dynamic systems show a particular tendency to deliver no direct feedback for errors. Latent errors can thus remain completely unnoticed over long periods, only becoming apparent through dramatic developments that then may no longer be stoppable. Through the interdependence of the various components, completely unexpected side-effects and consequences can occur. It is often not known which components change according to which rules. It is generally impossible to have complete knowledge of the functioning of the system. A series of cognitive factors make it particularly hard for humans to deal with complex systems (Dörner, 1993).

Monocausal linear thinking

As we are used to thinking monocausally, not least due to schooling that is one-sided in this respect, i.e. assuming one cause for one effect, we easily fall into a cognitive trap. The quest for the one cause obscures the possibility of several other causes for an event, and the one that we seek, if it exists at all, need not be the decisive one. Moreover, the often frustrating search for a certain cause stands in the way of an understanding of the complex of potential side-effects and consequences.

Reduction of hypotheses

In the quest for certainty, people are often unwilling to discard a hypothesis once it has been set up. This often has 'economic' reasons, as effort and energy have been invested and people are averse to seeing this going to waste. In order to support a preferred hypothesis, one will tend to select such information that confirms the hypothesis, while contradictory information will tend to be overlooked or undervalued. Particularly in situations where problems need to be solved under time pressure, too little of the flexibility required for creative solutions may remain.

Isolation of issues

A danger closely related to the tendency to concentrate upon a single hypothesis is that of isolating the issue. This is all the greater the more sub-issues emerge in a novel and complex system – which is what, in principle, a still unknown, potentially global environmental problem represents. In order to reduce the associated uncertainty, attention concentrates upon a preferred problem that continues to be demanding enough but permits the experience of success. 'Side issues' that may quite well emerge later as 'prime issues' are overlooked.

Overgeneralization of rules

A further cognitive trap emerges when, given suspicion or clear indications of an error, an attempt is initially made to find analogies to problems that have occurred in the past. Already known problem-solving strategies are preferred and applied where at all possible. Setting up these analogies can be erroneous *per se*, as this greatly constrains the search for and also the perception of indications of error that would require other rules. Once identified, rules are generalized, but may not be appropriate to new constellations.

Invulnerability fallacy

The development and deployment of potentially risk-prone technologies and modes of behavior is associated generally, although not always contemporaneously ('first an accident must happen'), with the development of safety precautions. Such safety measures are often viewed as being absolutely reliable and sufficient to meet all contingencies. This view overlooks the circumstance that complex safety systems are frequently prone to error, or are fundamentally incapable of achieving their objective when unexpected events occur (such as the most sophisticated protective mechanisms in laboratories that can be rendered useless by 'a small accident').

In addition to the cognitive traps, the list of which is not exhaustive, that have crystallized in studies of complex problem-solving situations, there are further strategies already described above in Section E 1.2. These include cognitive heuristics which operate as a bias in the perception and evaluation of problems. In view of the difficulties that emerge when dealing with complex systems, it cannot be expected that errors or unforeseen events can be prevented entirely, even through the best possible accumulation of knowledge (Reason, 1994). Nonetheless, information on the existence and modes of effect of such 'cognitive economies' and on the existence of enticing but precarious traps often helps to promote deliberate preventive measures. Beyond raising the awareness of individuals, communication among the various parties involved must be made mandatory. In addition, inspection and test operations involving various internal and external actors (e.g. in-house monitoring, external auditing by technical standards authorities) should be made transparent in order that deviations from defined safety plans can be recognized rapidly.

The goal must be to keep the consequences that can result from errors as small as possible. Where this appears impossible, the option of discontinuing a research project or technology must also be considered.

G 3.2
Motivational risk traps

The production or utilization of knowledge is not always an entirely rational process. In addition to achieving a concrete target, goals of a more individual nature, such as getting 'finished' soon, being successful or becoming famous also play a role. Such action goals can be dangerous if they are so emotionally charged that it is scarcely possible to pause for thought.

Social dilemmas

Individuals and groups are often in situations in which a choice must be made between an immediately tangible gain, utility or success and a less certain but all the greater later utility. Often the decision is taken in favor of the former; for immediate satisfaction of needs is more attractive than the mere prospect of later, if albeit greater utility. Present gain or pleasure is even preferred if later costs must be expected ('enjoy now, pay later').

This individual dilemma becomes a social one if the orientation to the (short-term) gain of the individual or group means neglecting or tolerating (long-term) costs for the social community or the environment. This is the central characteristic of commons dilemma problems, which can be understood as socio-ecological dilemmas or 'social traps' (Platt, 1973). Here priority is given to pursuing egoistic interests and short-term gains (e.g. through exploitation of a resource) for an individual, group or nation, realized at the cost of the long-term, justified interests of the social community. The spatial, temporal and social proximity between those who profit and the victims can vary; for instance, it is above all following generations that will have to suffer under the damage caused by polluting soil, water and air.

One form of individual profit maximization is the empirically confirmed tendency for success to be individualized, i.e. attributed to one's own capabilities and efforts, but to socialize failure or damage and the associated costs, i.e. to impose them upon society. There is a tendency for success to be attributed internally, but costs to be externalized. One wishes to win fame for oneself, but to make others responsible and liable for any failures.

The illusion of invulnerability already described above as a cognitive trap can also be characterized as a motivational problem. As health research findings demonstrate, people who expose themselves to risky situations or lifestyles (motorcycling, smoking) or expect a certain disease will lean towards unrealistic optimism in their expectation of damage ('I'll be all right, but others may well suffer harm'). For the individual, this egocentric view has the function of maintaining his or her self-esteem and protecting it against injury, and thus preserving that individual's belief in his or her own competence and capacity to act in difficult situations. This often leads to an overestimation of that individual's own capabilities and capacity to control those situations (self-serving bias). This can become a trap, particularly when dealing with Pythia-type situations that are still unclear.

When dealing with still unknown risks, conflicts between disparate values are always preprogrammed. These are quite likely to have emotional expressions, too. The recent referendum in Switzerland on whether to pursue genetic engineering or not was clouded by two emotions, namely fear of the future on the one side and naive faith in progress on the other; one component of the latter is the fear of losing the scientific and technological race of the nations.

Thrills and challenges

Difficult situations are by no means always experienced as stress that one wishes to bring to an end. The tendency to avoid such situations competes with the thrill of the new, exciting, uncertain. This has been confirmed repeatedly by studies on the conflict between approach and avoidance tendencies and research on the desire for sensation (Zuckerman, 1979; Schneider and Rheinberg, 1996). Tasks that are highly challenging but nonetheless hold out a prospect of repeated emotional experience of success exert a particular attraction and are experienced as a positive challenge (the 'explorer thrill'). Pursuing a research idea at all costs with its alternation between the production and release of tension, the fear of failure and the triumph in success can be associated, in much the same way as, for instance, the thrill of speeding and risky driving can be, with a flow of experiences during which thoughts of dangers, accidents and damage are suppressed far into the background.

G 3.3 Social risk traps

Research and development efforts that harbor new potential hazards normally do not take place in the ivory tower of a sole scientist, but in a research team or company, i.e. in a social context. Thus recognizing and evaluating possible hazards, willingness to accept and pass on risk knowledge and also behavior in risky situations is not only a question of individual competencies and motivational tendencies. It is also subject to the influence of group processes. These need not, but can become social traps, as they are associated with a rising incidence of risky decisions that can have catastrophic consequences.

The phenomena of 'groupthink' and 'risky shift' are well established in the literature. These result from processes of social comparison and influence in groups and ultimately lead to less good – or more risky – decisions that are more detrimental to safety than an individual person would have taken. Such phenomena have been described repeatedly (e.g. 1961 Bay of Pigs invasion, 1962 Cuba crisis, 1985 Challenger accident). Analyses of the Chernobyl disaster (Dörner, 1989; Reason, 1994) have shown that the staff involved were willing to take a continuously growing risk in the way they operated the system, which finally had catastrophic effects.

Such developments can be explained as a consequence of 'groupthink' (Janis, 1972), which results when discussions in cohesive groups (i.e. with group members who are well known to each other) strives for consensus or unanimity. It then occurs that

- Objectives are no longer debated in sufficient depth,
- Concerns of individual members are ignored or rationalized away, or are adapted to the majority opinion through pressure to conform,
- Only few alternative options for action are considered,
- Earlier (accepted or rejected) proposals are not taken up again,
- External advice is either not sought or is only processed selectively, and
- An illusion of invulnerability ('we are strong') arises.

In such situations, which are further exacerbated by time pressure or other stress factors, 'risky shift' regularly occurs. However, 'cautious risks' have also been observed. Both types of shift can be explained as group polarization processes in which the initially prevailing tendency (towards risk or towards caution) is amplified. Techniques have been developed to counter the effects of groupthink and risky shift. These aim to identify problems and objectives precisely, to record the proposals of individual members in written form and to permit individual deviating evaluations.

G 3.4 Conclusions

- Already available standard inspection and testing procedures to avoid erroneous behavior in routine tasks must be given necessary priority, and their use monitored.
- People working in risk-prone environments should be trained in handling complex systems. Although this will not necessarily prevent the traps described above, staff will be sensitized as to the effects of these traps.
- In order to improve awareness of possible side-effects or consequences, the supervision of trained teams should become the rule. In 'reflecting sessions', error hypotheses are established and tested. An error-tolerant climate in the organization is a precondition to debating possible errors. Those who point out deviations, admit their own errors or focus on safety problems must not be branded as inadequate personalities or even punished. Blunders and errors must be understood as a normal part of activities, to which great attention needs to be given. Errors can then be exploited as an important learning basis for the further development of approaches and monitoring procedures.
- 'Safety circles' should involve all staff, in order to make use of risk- or safety-specific experience and knowledge, to mutually stimulate the search for problems and their solutions and, finally, to ensure improved acceptance of proposed solutions.
- Training should be carried out to create an awareness of all three types of risk trap – cognitive, motivational and social.

- Computer-based simulations of complex situations make it possible to train people in ways to handle these. Simulations must be designed specifically for the target group, so that they reflect the real operational field as closely as possible. However, it lies in the nature of unforeseen events that each is different and is unique in its combination of responsible causes. The requirement thus remains to react to contingencies flexibly and differently than previously trained in simulated situations.

G 4 Preventive risk management under uncertainty

By definition, risks are associated with some degree of uncertainty. This can range from slight inaccuracies in predictions through to fundamental indeterminacy of prime processes (Section C 1.2). When new products, technologies or structures are introduced rapidly, this creates particular difficulties, as it can engender scarcely manageable hazards in a yet hazy future. The problem is further exacerbated where complex cause-effect relationships prevail, as is generally the case in environmental systems. The pivotal question for preventive risk management is thus: are there principles for designing the societal innovation processes that assist in preventing the very emergence of unpredictable ecological risks, thus removing the need for reactive management?

A trivial response to this question would be to cease all human interventions in nature. This is neither desirable nor feasible. We must therefore find intelligent strategies that help to prevent anthropogenic environmental risks without profoundly impeding socio-economic development opportunities.

G 4.1
Unavoidable knowledge gaps

There are a variety of reasons for gaps in knowledge of the risks possibly associated with new or existing technologies and systems. Ignorance can be immanent, i.e. determined by the character of the system under consideration. Complex, nonlinear systems thus have fundamental limits of predictability (Section E 4.1). Environmental systems always count among these, particularly with regard to their human-environment interactions. A further reason why societies must always live with knowledge gaps is that their members and their science have only limited capabilities to predict or forecast possible hazards. This is a matter both of the limits of science itself – such as limited computational capacity for climate modeling – and of the psychological 'traps' that can prevent people from perceiving risks (Section G 3).

The present discussion is concerned with the strategies that can be taken to preclude undesirable risks as far as possible, despite these knowledge gaps. We might say that the issue here is one of preventing new ozone holes without discovering them (Section G 1).

The case of the ozone hole can provide valuable indications here. The substances responsible for the depletion of the ozone layer (CFCs, H-CFCs and halons) were used on such a large scale because they are non-flammable and non-toxic. It was not before 1975 that first warnings of an ozone-depleting effect were sounded and substantiated by preliminary analyses (Rowland and Molina, 1975). During that phase, the risks of ozone depletion caused by CFCs and other substances could have been assigned to the Pythia class of risk. Coming from a state of ignorance about a possible problem (impacts of CFCs upon stratospheric ozone), improvements in knowledge revealed the outlines of a risk, whose probability and extent of damage were not yet quantitatively estimable. The ozone hole observed yearly during the Antarctic spring and the improved scientific understanding of its formation finally led to growing certainty, so that the risk is now also quantitatively estimable.

From the prevention perspective, the decisive question is whether it might not have been possible to already warn of the ozone hole when CFCs were being developed. Of course we cannot expect that science would have developed the explanatory models that have led to the present understanding of stratospheric processes without the incentive delivered by the observations. Nonetheless, the high levels of ubiquity and persistency attaching to this technology should indeed have raised the question of whether the broad use of this class of substances was justified without more intensive prospective technology appraisal and assessment. Such preventive technology assessment on the basis of general criteria is thus distinct from the commonly applied problem-induced technology assessment procedures (Ewen et al., 1998).

The case of the ozone hole further illustrates that it is crucial in 'prospective technology assessment' to keep in mind all relevant system levels – from toxic effects upon cells through to effects upon the global environmental system – of both the natural system and the intervening system (i.e. the technology and its framework conditions). Indeed, the immediate impacts of CFCs upon the biosphere pose no hazard. It is when we look at the entire Earth System, including the atmosphere, that considerable damage potentials become apparent.

G 4.2
Structure of the environmental effects of anthropogenic systems

In the following, we shall first briefly outline the structure of the issue at hand (Fig. G 4.2-1).

Risks can result in two ways from the intervention of an anthropogenic system (agent) in an ecological system (reagent) and incomplete knowledge of the cause-effect pathways of both systems and their interactions – first as a direct consequence of this intervention, and second as an outcome of interactions between the two systems or within the systems. Affected systems can be individual organisms or entire ecosystems, but also human societies or a national economy. Intervening systems can be individual people, human societies or technologies. Many systems can contain both intervening and affected elements. Nonetheless, the distinction between intervening and affected systems is important from the perspective of risk management, as risk prevention or reduction strategies can differ accordingly.

There is a 'cognitive barrier' between intervening and affected systems that generally cannot be avoided entirely. This barrier symbolizes knowledge gaps or even ignorance of the precise cause-effect mechanisms and thus of the possible consequence of an intervention.

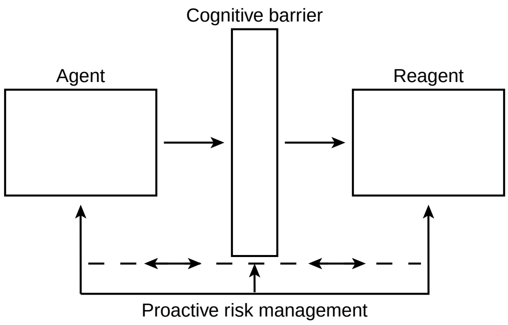

Figure G 4.2-1
Structure of the state of 'causal ignorance', which calls for preventive strategies. Here an anthropogenic agent operates which, via environmental processes, has the potential to damage a reagent of civilizational importance. The cause and effect, however, are separated by a cognitive barrier that is generally not statistical, but fundamental in nature. Proactive risk management can impact upon all three structural elements.
Source: WBGU

Knowledge gaps can emerge because either the affected or the intervening system is not sufficiently known or calculable. They may also emerge because the effects of the intervening system upon the affected system are known or calculable to only a limited extent or not at all. This type of knowledge gap may also concern possible feedback between the systems. A further source of knowledge gaps can be found in psychological, motivational or social 'risk traps' that prevent people from gaining knowledge that would in principle be accessible (Section G 3).

For both the individual systems and for the interactions between intervening and affected systems, a hierarchy of system levels needs to be taken into consideration (Ewen et al., 1998):

1. *The level of the individual substance, facility or organism*. It is to this level of affected and intervening systems that the traditional instruments of technology assessment and of (technological) risk management often refer.
2. *The level of the technological or natural system*. As an example of an *affected* system, we shall discuss here the global climate system, upon which the energy industry impacts as an *intervening* system. The energy industry comprises both the technologies selected and the associated infrastructure, and also the political and economic framework conditions. It can indirectly become an affected system itself, for instance through feedback from climatic change, or through the interventions of other systems that may impact upon the political or economic framework conditions.
3. *The level of society or of nature as a whole.* Here it is a matter of analyzing the interactions between various pairs of intervening and affected systems in order to appraise possible outcomes with due regard to these interactions; to what extent are control equilibria or energy and materials cycles affected? This is exemplified by the interactions between the climate system and the biosphere.

For a prospective assessment of the undesirable consequences of a technology, it does not suffice to examine system elements in isolation from each other. For instance, to assess the consequences of energy technologies upon the climate system, it will not suffice to assess the emissions or possible accidents of individual power plants. Nor will it be enough to merely compare individual plants (such as a coal-fired with a nuclear plant; first level). To understand and anticipate possible negative impacts upon the climate system, it is essential to analyze and evaluate both the global climate system and the entire energy system, including its organizational, economic and legal framework conditions (second level). Finally, the assessment of an energy system requires study of the interactions between the climate system and the biosphere, or between energy supply and other interests worthy of protection, such as 'democracy' or 'food security' (third level: interactions between totalities).

In view of this complexity, it is clear that even when routinely implementing a technology (which emerged at a certain point in time through an innovative process) knowledge gaps must be expected regarding the complex interactions within and among system levels. This is once again exemplified by ozone-depleting substances, whose hazards only became apparent when their interactions with the Earth's atmosphere were considered. A further example is given by the utilization of fossil fuels, whose impacts upon the climate system need to be assessed quite differently from their local effects.

The risks associated with individual facilities are often the result of undesired side effects that can be prevented or reduced without dispensing with the desired main effect. For instance, pollutant emissions or the accident frequency of a facility for manufacturing chlorine products can be reduced considerably by means of technological risk management without dispensing with their production entirely (Hartwig, 1998; Box G 4.2-1). However, this only addresses the first level risks of the individual facility and its immediate environment.

It is however characteristic of global environmental problems that the problematic interactions at higher system levels (such as between energy supply and the climate system) result precisely from the *desired* effects of the intervening system. In our example of the energy industry, this is the supply of energy through the combustion of fossil fuels, with the unavoidable release of carbon dioxide. The carbon dioxide intervenes in the climate system as a radiatively active gas, leading to global warming and to spatial and temporal shifts in climate patterns (Section D 6). It is precisely the intentional, 'normal' utilization of intervening systems that can have undesirable consequences at a different system level (Hartwig, 1998). This frequently results from accumulation effects or synergisms emanating from known technologies, whose extent was not or could not be predicted (Section G 1).

If we now apply the typology of risk developed in the present report (Section C), then we find that the above cases generally involve risks of the Pandora or Pythia classes. Timely recognition of the underlying class of risk can provide indications for possible strategies by which to deal with unknown risks (Section H 2.1).

Accumulation risks often pose no hazard to individual organisms and are therefore initially overlooked or underestimated because higher system levels were not taken into consideration in the assessment process. Moreover, such risks typically escape the imposition of complete liability regimes. It is therefore essential here to develop preventive risk reduction strategies.

The risk R can be expressed in a generalized manner as

$$R = P \cdot E \quad ,$$

where $P \in \{0.1\}$ is the probability of occurrence of the event causing damage and $E > 0$ is the extent of damage (Section C). Preventive risk management must either aim to reduce *ex ante* P and E without actual knowledge (agent-reagent management) or to define these factors more precisely by means of overcoming the cognitive barrier (knowledge production) with due regard to the unavoidable 'risk traps' (Section G 3). Furthermore, compound strategies are possible that combine all of these elements. The available options are discussed in the following. Here the intention of the Council is to outline as many qualitatively distinct options as possible, but not to give any political evaluation of these.

4.3 Knowledge management

Fig. G 4.3-1 shows the 'normal' case, in which a risk is perceived and recognized as such.

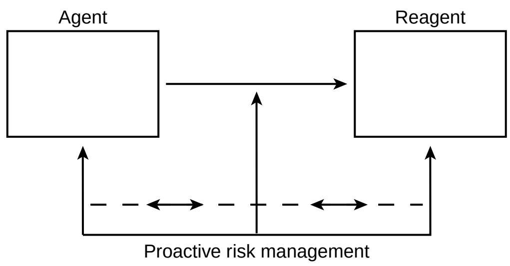

Figure G 4.3-1
Management options in the state of 'causal perception' (the normal case), where there is no fundamental cognitive barrier. The risk can be reduced e.g. by means of removing the agent, interrupting the pathway or protecting the reagent.
Source: WBGU

In the case of ignorance, the most obvious (but not necessarily simplest) strategy is to bring the problem back to the normal case by means of precautionary knowledge production without specific goal orientation. It is precisely because the risks under discussion here cannot be researched systematically that the op-

Box G 4.2-1

Risk management in engineering

Safety engineering and risk management have developed an array of methods by which the risks of engineering systems can be prevented or minimized. However, these are usually only applied to individual facilities (Hartwig, 1998). By means of designing systems appropriately, the consequences of system failure can be preempted and mitigated, for instance by making provision for retention systems. Beyond this, the design of a system can also be made more fundamentally error-tolerant by applying a series of principles that minimize risks through improved reliability of technical systems. The most important design principles here are (Hartwig, 1998):

- *Functional diversity and redundancy*. For one function, several different options are provided. If one fails, orderly operations can still be maintained with another.
- *Independence (decoupling)* and *separation of sub-units*. Systems that work in unison are designed such that they have as little joint coupling as possible. It can thus enhance the reliability of a system comprising several electric units if each electric unit has a separate power supply.
- *Modularity*. Sub-units are designed to have as much autarky as possible. Coupling between sub-units is as linear as possible. If the system fails, errors can then be analyzed and identified more readily. Moreover, if one subunit fails, its function can be substituted by a new subunit without needing to consider unexpected interactions.
- *Elasticity and resilience*. Elastic systems (also termed robust or resistant systems) return after an external disturbance to their initial or equilibrium state. They are thus, within certain limits, insensitive to disturbances. In engineering terms, this property is often achieved through connections in series with strong negative feedback.

These design principles improve the error-tolerance of the system, thus endowing it with a passive safety. System reliability can in principle also be improved by means of automation, as technology failure is calculable and generally less probable than human failure (Hartwig, 1998). In addition, indicators can be introduced at critical points of a system that provide information on the state of the system. Repeated testing of systems can also prevent risks. The task of risk management is then, using an array of controlled variables and control loops, to maintain the desired normal state or, in the event of a deviation (disturbance), to return the system to this state. Risk management is thus linked to a series of well-defined preconditions (Hartwig, 1998):

- It must be clear which *damage categories* are targeted or which types of damage are feared. In closed technological systems, such as industrial manufacturing plants, the damage categories are clear. Damage in a manufacturing plant can imply excessive production costs, faulty products, health hazards or accidents, but also damage in product use, environmental pollution (from accidental or continuous emissions) and accidents.
- A limit value must be stipulated for the *extent of damage*, in order that when this limit is crossed a controlled parameter triggers measures to mitigate or prevent damage. Statutory industrial threshold limit values (TLV) are an example of this. Limit values triggering control mechanisms are determined not only for damage categories, but also for their probability of occurrence. If the *probability of occurrence* is too low, no control mechanism is triggered.

For a technology functioning according to the above principles, risk management can be described as a control loop. The controlled variables are the technical design of the system, the production process, the products and the embedding in the organizational, political and technological setting. For risk management, control and limit values must be defined for these variables. However, this does not cover the risks of normal product use.

Inherent security is a further concept that addresses the level of the individual industrial plant. We speak of inherent safety if a technical plant remains without damage, even if essential parts fail (Ewen et al., 1998). The concept was originally developed for nuclear reactors. It suggests that it is possible by means of technological design to make the system completely safe, even if the system handles potentially hazardous substances. Experience has shown, however, that there is no such thing as inherent safety, but at most reduced susceptibility (Ewen et al., 1998). In any event, the concept concerns individual plants or the handling of hazardous substances. The concept does not aim to avoid these but rather to prevent the manifestation of hazard. This approach to risk management thus does not apply to global environmental problems, for these are not generated at the level of individual plants or substances, but reside in the interplay between natural and human systems (Hartwig, 1998).

Thus CFCs, for instance, do not present themselves as a problem to the control loop, for there is no controlled parameter that signals the necessity to activate risk management at all. The problem here is not the individual technological system, but the fact that this system already causes changes in the environment under normal operations (which is typical for global environmental risks of the Pandora, Pythia and Cyclops class). The risks are thus inherent to technology and cannot be modified by means of improving technology. They can often only be attenuated through the reduced use of a technology – such as through substitution.

portunity must be retained to discover them 'by chance' in the context of basic research that is designed as broadly as possible. For this, it is necessary that the more general growth in knowledge is several times larger than the risk knowledge gaps generated anew by innovations. In other words, the rates at which system competence and complexity are produced must be in an appropriate relationship to each other. Here we must also take into consideration the psychological and social factors that frequently lead to knowledge being overlooked which is essentially extant or available (Section G 3). Broad participation of all affected segments of society in the process of generating system competence can contribute to overcoming or at least containing social dilemmas (such as the tolerance of risks for short-term gain).

In modern physics, random searching techniques, termed Monte Carlo methods, play an important role in resolving highly complex problems that are not amenable to targeted strategies. One frequently applied technique is to undertake computer-based 'random-walks' in the potential solution space. However, such an approach is only promising if these possible solutions can be scanned with a sufficiently high resolution and rapidity. In mathematically well-defined cases, the success rates can even be stated precisely, depending upon the solution and scanning function.

The chance discovery of global environmental risks is a far more difficult enterprise, and would have been viewed as completely hopeless only a few decades ago. In the meantime, however, the great advances that have been made in process analysis, data collection and information technology cast a more favorable light upon this problem. Generating and researching virtual realities by means of massively parallel computation procedures is set to play an increasingly important role in this context (Schellnhuber and Kropp, 1998a). These techniques make it possible to simulate the real-world global environmental system by means of random processes of an ensemble of artificial 'computer worlds', thus revealing even analytically inaccessible risk constellations.

In the case of the knowledge gaps described above, where normal operation of the 'intervening system' already affects higher system levels, government-assisted and internationally coordinated knowledge production may be necessary, as private, decentralized knowledge production can scarcely take the level of the overall system into consideration adequately. Moreover, due to the scales of the problems concerned, research structures and tools are necessary that can only be organized and operated effectively at a central level (e.g. climate computation center for global climate simulations; Section G 1). Here centralized and decentralized knowledge production are complementary.

Knowledge production can also be promoted by ensuring that as many segments of society as possible are involved in decisions on the introduction of innovations and in their assessment. Decisive aspects here are the transparency of procedures and decision-making processes on the one hand, and public access to information on the other. This can enhance the probability of discovering possible negative consequences. It is also more likely to do justice to the cognitive, motivational and social 'risk traps' – which usually cannot be avoided entirely – than if knowledge production and evaluation is restricted to a small group of specialists. Such a process can also be associated with step-wise introduction of innovations and accompanying monitoring.

G 4.4
Agent management

For individual facilities, risks can be prevented by giving consideration to certain *design principles* (fault tolerance through modular design, redundancy etc.; Box G 4.2-1). This strategy is only applicable where a desired principal effect can be distinguished from undesired side effects (caused e.g. by internal or external disturbances). One such strategy is *technological risk management*, which monitors controlled system variables and relates these to limit values (Hartwig, 1998). Furthermore, there are various *organizational management principles* (high reliability, reflection systems, redundancy etc.) which can reduce the frequency of errors in systems. We may also count among these strategies those that aim at timely detection of undesirable developments by means of appropriate organizational principles (early warning systems, monitoring).

As already noted, these techniques of technological and organizational risk management are restricted to the level of individual facilities or systems. Technological risk management cannot be brought to bear if the desired principal effects (such as energy generation under normal operations) are inseparably linked with hazardous effects at a higher system level (for instance effects upon the climate system). In such cases it is necessary to compare and evaluate the known and unknown risks associated with alternative technology pathways (including the political and economic framework conditions that these require).

In the following, we present a number of distinct, basic strategies that can be applied for preventive risk management.

Exclusion

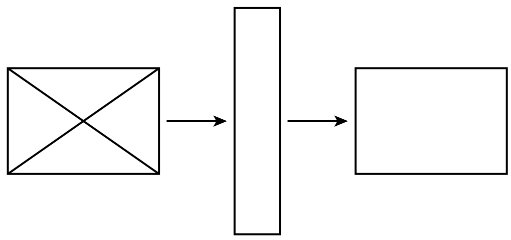

Figure G 4.4-1
Exclusion.
Source: WBGU

By exclusion (Fig. G 4.4-1), the Council means far-reaching abstention from the implementation of substances, processes and structures, without any empirical 'trial'. This strategy must accordingly aim to maximize societal value-added by 'natural' means and with minimum resource inputs and minimum dynamic-structural interventions (Bleischwitz, 1998). This includes material flows minimization strategies.

Deflection

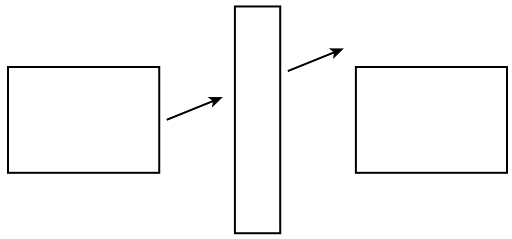

Figure G 4.4-2
Deflection.
Source: WBGU

Despite the absence of any concrete concern, the deflection strategy (Fig. G 4.4-2) aims at the precautionary prevention of impacts of innovative agents upon certain environmental components. This is exemplified by efforts to avoid the introduction of alien species (Section D 4) or to reduce the reactivity of substances in trophic processes or in atmospheric chemistry.

Containment

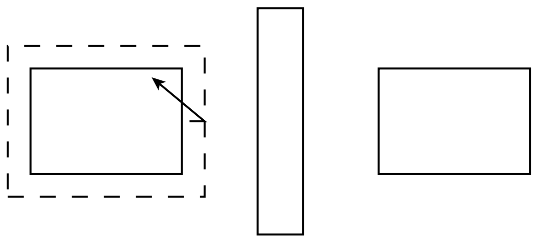

Figure G 4.4-3
Containment.
Source: WBGU

Risks can also be prevented by containing to the greatest extent possible the spread of potentially environmentally effective substances or processes (Fig. G 4.4-3). This is exemplified by the use of working media, catalysts etc. in closed cycles in industrial production. In contrast, the use of substances with a very large aftercare horizon (e.g. plutonium) is particularly problematic.

G 4.5 Reagent management

Complementary strategies 'beyond the cognitive barrier' aim at safeguarding natural and civilizational assets against an as broad as possible spectrum of damaging impacts. Here particular attention needs to be devoted to strengthening systemic properties of these assets, such as learning and development capabilities. An improved understanding of the evolution of biological systems will be of great use. For social and economic systems, indeterminate risks can also be prevented or reduced by means of reducing *vulnerability* (Section E 2).

The strategies described here are based on systemic properties that are often aimed at in technological risk management in order to enhance the passive safety of technological systems (Hartwig, 1998; Box G 4.2-1). In this, they are similar to the agent management strategies.

Exposure reduction

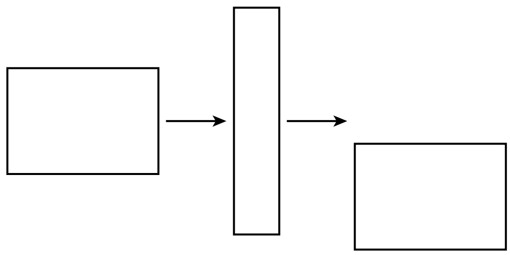

Figure G 4.5-1
Avoidance.
Source: WBGU

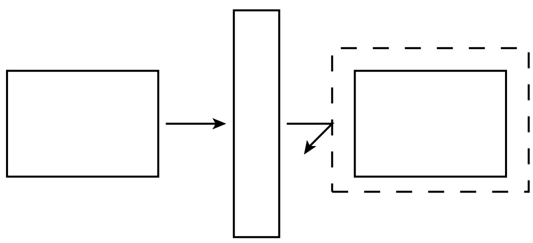

Figure G 4.5-2
Protection.
Source: WBGU

On the side of the reagent, one can either attempt to keep the endangered system out of the range of high exposure (avoidance strategy, Fig. G 4.5-1) or to protect it against interventions (protection strategy, Fig. G 4.5-2). Examples of the avoidance strategy range from purity standards for certain foodstuffs through to preventing settlement expansion into areas with certain morphologies (with excessive or inadequate morphological diversity). Measures that pursue a protection strategy range from small-scale nature conservation areas through to the continental Antarctic Treaty.

Desensitization

Desensitization strategies aim at making environmental systems or social or technological systems more robust against disturbances of all kinds. Here two particularly important systemic properties need to be strengthened: modularity and elasticity.

Modularity

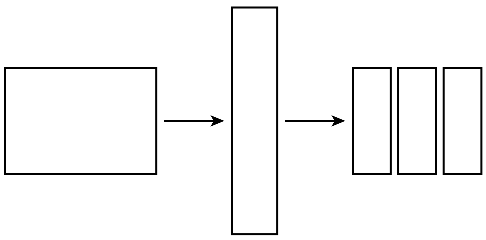

Figure G 4.5-3
Modularity.
Source: WBGU

A modular structure with loosely coupled compartments (Fig. G 4.5-3) should be aimed at particularly in such environmental systems that are linked intimately to human systems, such as freshwater supply. This can prevent 'domino effects'. The propagation of disturbances in complex systems can be prevented by various means, such as the introduction of rupture joints, strong restoring forces, retardation and dispersion of reaction speeds by means of nonlinear composition or, finally, the distribution of elements over large areas.

Elasticity

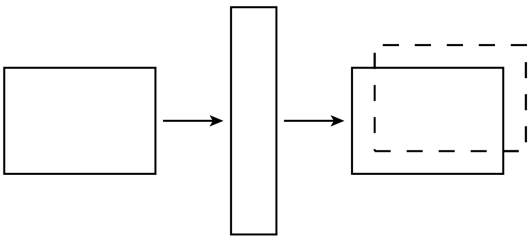

Figure G 4.5-4
Elasticity.
Source: WBGU

This is a matter of strengthening the properties of the protected asset that permit autonomous 'avoidance' of disturbances of all kinds or 'self-healing' or even positive evolution of the environmental system after damaging impacts. Elastic systems (Fig. G 4.5-4) can be contrasted to 'brittle' systems, which show scarcely any reaction up to a certain critical stress, but then collapse ('fracture') completely. Systems that return to their original state after severe disturbances are termed resilient in ecological theory. The resilience of ecosystems, e.g. to climatic changes, depends, among other factors, upon the availability of migration corridors and geographic refuges. However, it needs to be noted that modularity and diversity can compromise elasticity. For social and economic systems, strategies aimed at reducing vulnerability count among the desensitization strategies (Section E 4).

Substitution

Substitution strategies comprise a set of strategies that take into consideration the possibility of the failure of the system or of one of its subsystems. The following strategies can be pursued in order to maintain the functionality of the overall system despite failure of a subsystem.

Redundancy

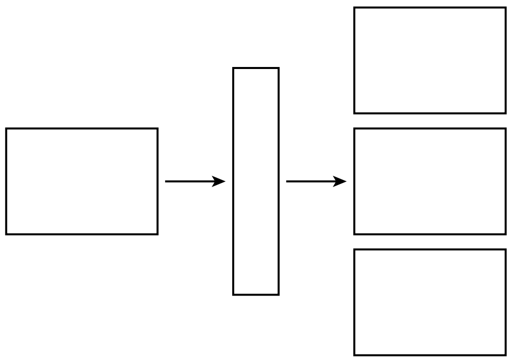

Figure G 4.5-5
Redundancy.
Source: WBGU

Redundancy means the multiple availability of relevant system components so that if one component fails the backup can come on line and system collapse is prevented (Fig. G 4.5-5). This strategy is generally only viable under favorable economic conditions (e.g. in a sparsely populated industrialized country such as Sweden) or if efficiency drawbacks are accepted in favor of safety aspects.

Diversity

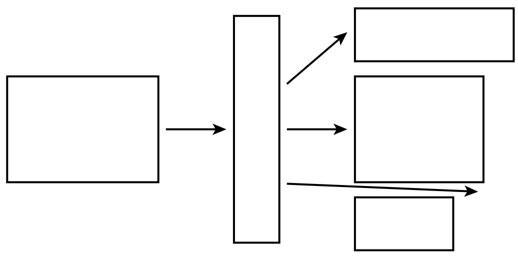

Figure G 4.5-6
Diversity.
Source: WBGU

Diversity strategies (Fig. G 4.5-6) aim at increasing the heterogeneity of the protected asset or retaining a collection of non-identical specimens of a type of protected asset. For instance, these strategies can be applied in agriculture and forestry, where biogenic disturbances have their own development dynamics.

Compensation

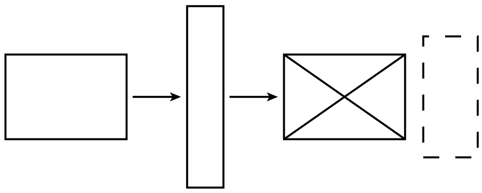

Figure G 4.5-7
Compensation.
Source: WBGU

The risk of damage to protected assets is of course of only slight importance if there are simple options by which to adequately replace the endangered natural or civilizational services (Fig. G 4.5-7). In the utopian case, an 'omnipotent' public sector could assume blanket liability for all compensation measures that may need to be provided.

G 4.6
Combined management

Dynamic, adaptive compound strategies are also suited in practice to manage the risks of complex dynamic systems. Here the first step is to clarify the interplay between the agent and the reagent by means of indirect knowledge production techniques, in order to then keep the system outside of hazardous regions by means of appropriate management.

Adaptation

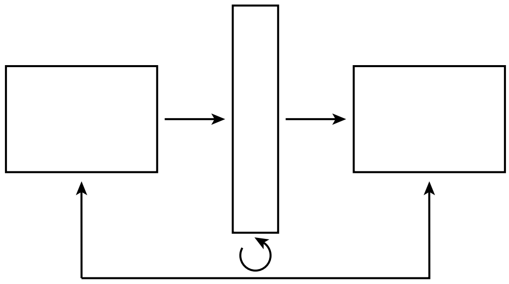

Figure G 4.6-1
Adaptation.
Source: WBGU

The strategy of mutual adaptation (Fig. G 4.6-1) of the development processes of the agent and the reagent is based on introducing agents in a step-wise process, while continuously further developing the reagents. Here the temporal dimension of adaptation is particularly important. With careful implementation, adaptation effects can even be realized without explicit risk knowledge. The practical implementation of such an adaptation strategy with the aim of avoiding unknown risks of global change requires a long-term evaluation process integrating all relevant groups.

Iteration

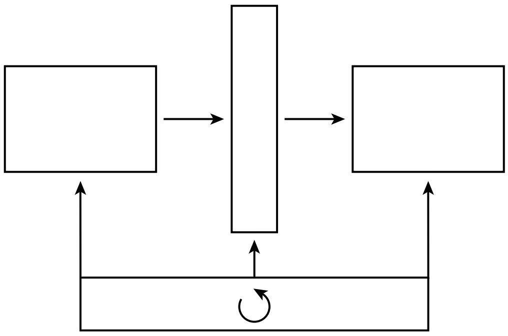

Figure G 4.6-2
Iteration.
Source: WBGU

This strategy (Fig. G 4.6-2) aims at making use, in an iterative process, of the various options for action available on both sides of the cognitive barrier. In each step, small learning effects are achieved that permit gradual, mutual adaptation (coevolution). This progress can be supported by means of suitable discursive fora (e.g. expert teams, round tables, auditoria etc., cf. Section F 8).

For both strategies, the spatial and temporal dimensions of adaptation are crucial. The speed at which new technologies are developed and introduced must be adapted to the time scales of the reacting systems, and also needs to be related suitably to the psychological factors. The appropriateness of the agents themselves (appropriate technology) and of the speed of their introduction to the basic psychological and social structures also needs to be taken into consideration.

Fuzzy control

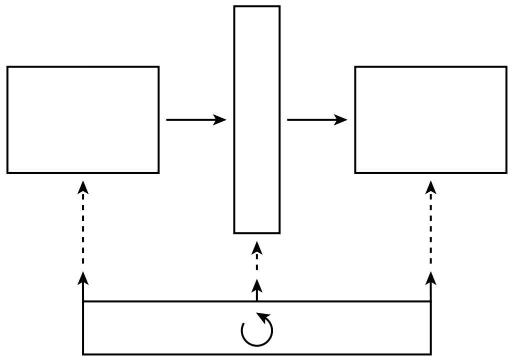

Figure G 4.6-3
Fuzzy control.
Source: WBGU

Where uncertainty is very large, this strategy for managing the risks of complex systems is the most effective approach (Schellnhuber and Wenzel, 1998b). While this is an iterative strategy (Fig. G 4.6-3), it is distinguished from the standard approach by two crucial elements. Firstly, all management measures are realized in a *fuzzy* manner, which can be compensated for by means of a higher re-adjustment frequency. Secondly, the management instruments themselves are kept so *flexible* (e.g. a Climate Protection Protocol) that even a complete change of course is possible at short notice.

G 4.7 Recommendations for research and action

In order to discover still unknown risks, it is indispensable to promote basic research that is as broad as possible. This research must address the entire Earth System, but also the fundamentals crucial to understanding and controlling complex nonlinear systems. One task of the (UN) Risk Assessment Panel proposed by the Council (Section H) would be to evaluate the rapidly developing body of Earth System research and to draw conclusions for risk avoidance. Government-assisted and internationally coordinated centers of competency are essential to global change research.

A broad-based involvement of civil society actors, both in the knowledge production process and in the introduction of novel technologies or substances, can exert a risk-reducing effect. Free access to all relevant information and participation in the evaluation of research results are prerequisites to this involvement. One way of implementing this at the international level would be to ensure that civil society actors can put forward their views in the Risk Assessment Panel process.

The available tools of technology assessment should be further developed to provide a basis for institutionalizing prospective technology and risk evaluation (early warning systems) at the national and international levels. The aim should be to formulate appraisals very early on – such as when defining research priorities – that can be integrated in the political decision-making process. The general strategies developed here (agent management, reagent management, combined management) have an important role to play in this endeavor.

Knowledge generation on the one side and the introduction of new technologies and substances on the other need to proceed iteratively and need to be adapted to each other. Approvals for the deployment or expanded application of technologies or substances should be granted step by step. Here care needs to be taken that the speed of innovation is appropriate to the speed of knowledge generation (while making efforts to avoid the often inescapable cognitive, motivational or social risk traps; cf. Section G 3). These processes must be accompanied by monitoring schemes that cover all system levels. The need for this is illustrated by the fact that, until now, ecological parameters have only been studied for less than 1% of all deliberate release trials worldwide (Ewen et al., 1998).

It further needs to be examined and reviewed to what extent the tools described in Section F, notably strict liability, can be deployed to avoid unknown risks. For instance, it is conceivable to introduce strict liability for the dispersal of persistent and ubiquitous substances even if no indications are yet available that these substances may be hazardous. Under regulatory law, too, the criteria of persistency and ubiquity could be made relevant, e.g. in permitting procedures. Discursive risk communication approaches for evaluating technologies or substances (Section F 8) are particularly relevant to prevent unknown risks. Where regulatory and economic instruments are deployed to prevent risks that are already known, the precautionary principle requires that a risk premium is included in the assessment in order to reflect possible, still undiscovered risks.

Synthesis G 5

Unknown risks – the subject of Section G of this report – are gaining importance. This is due first to the pace of technological development and second to the continuing avalanche of knowledge production. As innovation gains impetus, the number of associated risks grows – but without concrete cases of damage yielding empirical knowledge about these new risks. In view of the importance of innovation to the vision of sustainability, the solution surely cannot be to stop innovation. It must rather be to build into it mechanisms which induce innovators to inform themselves about the potential consequences of their actions, i.e. to generate risk knowledge.

The difficulties of dealing with these phenomena are illustrated by the circumstance that, precisely because of ignorance as to their existence, unknown risks cannot be positioned within the typology of risk developed by the Council. In some fields the treatment of unknown risks requires a different theoretical and political approach than that of known risks. The aspect of knowledge dominates the debate on how to deal properly with unknown risks. Risk knowledge that has not yet been generated or is not available in the 'right' places in society must be viewed as the crucial controlled variable for strategic considerations in relation to unknown risks.

Despite the differences in approaches to known and unknown risks, we may note that between known risks and unknown risks, for which no risk knowledge is yet available, the boundary is to some extent fluid. This applies particularly to the Pythia and Pandora classes of risk, where damage can be assumed but the possibility cannot be dismissed that the risk-generating constellation harbors numerous other unknown risk potentials in addition to those anticipated. The strategies discussed here are also suitable to deal with known risks: for instance, by stimulating the production of knowledge about the probability and extent of damage. This can alter the classification of a risk within our typology, thus calling for a different package of risk policy tools.

Section G 2 centers on this aspect of the production of decentralized risk knowledge. The starting point is the realization that environmental policy tools, notably liability law, particularly when applied in the form of strict liability, have on the one hand knowledge-producing but on the other hand also innovation-constraining effects. There is thus a need to analyze and test in practice institutional arrangements which permit companies to relax liability regimes if they can furnish evidence that their activities are associated with lower risks to human health and ecosystems, or that the risks produced by their activities can be controlled readily. It is essential to attenuate in this manner the innovation constraints of liability law while nonetheless doing justice to the precautionary principle by stimulating companies to generate appropriate risk knowledge or prevention knowledge.

Decentralized production of risk knowledge alone will not suffice as the sole tool for dealing with unknown risks. In many cases the necessary knowledge cannot be generated at the decentralized level. Government-assisted research is therefore indispensable. Furthermore, research exclusively within individual disciplines will not do justice to the complexity associated with discovering, researching and evaluating globally relevant, unknown risks. The Council therefore recommends a more interdisciplinary design of the global change research landscape, as already proposed in the shape of the syndrome approach in its previous reports (WBGU, 1997a). Research will only be able to discover unknown risks if it takes a systemic and networked view.

Beyond actively stimulating knowledge production, risk policy strategies tailored to dealing with the complex problems of the environmental risks arising from innovation processes must also take heed of the factors – notably the psychological ones – which can impede knowledge production or which, despite knowledge being generated, prevent this knowledge from being integrated into decisions (Section G 3). Here we note in particular the cognitive, motivational and social factors that can form 'risk traps'. These risk traps can impede knowledge production and promote the emergence of new risks. There is a need for in-depth study to avoid such traps.

In addition to these psychological factors, further circumstances need to be kept in mind that cannot be addressed by knowledge production alone. One is that a certain degree of ignorance is inescapable because knowledge gaps can be intrasystemic. It is not possible to model all processes in complex, nonlinear systems to the point at which completely reliable information is available on the responses of all system processes to external interventions.

The discussion in Section G 4 is to be understood in this setting. This is concerned with strategies for dealing with unavoidable knowledge gaps, and outlines a systemic risk management approach that aims to avoid undesirable risks as far as possible despite such gaps. The axiom of this approach is that for early warning of risks it is essential to consider all relevant system levels. Only then can the complexity of the issue be understood and possible risk potentials perceived. On the basis of such systemic early detection, resilience strategies need to be developed. These can be passive (fault tolerance in industrial systems) or active (risk management). They ensure that systems do not enter states incompatible with societal risk preferences.

Our overall conclusion is that unknown risks stemming from innovation processes will become more and more relevant in the future. To produce risk knowledge and tackle the problems and solutions set out in Sections G 3 and G 4, the body of both theoretical understanding and empirical experience is meager. The Council therefore strongly recommends eliminating these deficiencies and improving the basic structures for dealing with unknown risks.

Recommendations H

Recommendations for research H 1

H 1.1
Concepts of risk research

For the interdisciplinary analysis and evaluation of risks, it is essential that we continue to refine theoretical concepts, models and typologies of risk in order to identify opportunities and risks in ever more complex social systems. This can yield a basis on which to derive rational risk management strategies. Such strategies are of particular importance to development and technology policy, and to emergency prevention, preparedness and response. In addition to the natural and technological sciences, social science risk research is, by virtue of its interdisciplinary approach, increasingly gaining relevance. The Council therefore recommends further intensifying and expanding risk research capacities in the natural and technological sciences and particularly in the social sciences.

H 1.2
Technological risks

It is a prime principle of research on reducing and controlling technological risks that its subject matter must extend beyond the purely technical optimization of safety. Integrative research on technological risks should:

- Give due regard to the institutional, political and social context in which the technology in question is embedded,
- Extend its scope to include the structures and safety cultures of organizations that develop, operate and monitor high-risk technologies, and
- Explore and integrate in risk analysis the ways in which individuals and groups react within the boundaries and scope of their psychological, social, institutional and cultural action space.

This calls for an interdisciplinary or even transdisciplinary research enterprise that integrates knowledge of technological risk factors with knowledge derived from research on the human-machine interface, organizational culture and institutional, social and cultural contextual conditions. The goal of this research enterprise should be to advance technological development in a direction that minimizes risk potentials while at the same time being appropriate to the contextual conditions of the development, application and control of a specific technology. In this endeavor, the criteria described in Section G for precautionary risk reduction can serve as elements of a guiding vision for technological and organizational development. Giving greater consideration to criteria such as diversity, resilience and robustness in technology development requires on the one hand basic research at the interface between technological and social systems, and on the other hand cross-cutting, applied research that extends to the concrete, parallel development of technological and organizational systems.

In the global change context, we may distinguish two types of technology. For the first type (which we may equate with the Damocles class of risk), the components of risk are largely known. These technologies are a cause for concern because of their large catastrophic potential. For such technologies, which are exemplified by nuclear installations, research efforts need to concentrate on two fields. The first is to research alternative technology trajectories or modifications of the original technology so that the catastrophic potential can be appreciably reduced. The second is to research interactions among technologies, their control and their social setting, with the goal of improving the resilience of technological systems.

The second type of technology that can be associated with global risks is characterized by uncertainty as to the extent and/or probability of damage. Technologies of this type belong to the Cyclops, Pythia or Pandora classes of risk. For these, the primary aim must be to engage in research in order to reduce uncertainties. The first step is to move from incertitude to statistically quantifiable uncertainties. The range of uncertainties can then be further reduced in a targeted manner. This requires basic research on the mathematical and statistical identification of uncertainties, but also research on methods by which to collect and evaluate more targeted empirical experience in certain areas of risk and to utilize these for risk quantification. Finally, much as for the technologies with a high catastrophic potential, research is necessary that enables resilient risk management under the uncertainty that remains.

Researching technological risks requires close collaboration among engineers, natural scientists and social scientists. Postulating this is easier than implementing it in practice. In its 1996 annual report, the Council discussed in detail the possibilities, problems and solutions relating to cooperation among the sciences (WBGU, 1997a). The proposals developed there should above all be implemented in research on technological risks.

H 1.3 Health risks through infectious diseases and anthropogenic emissions

Some of the risks associated with health-impairing pathogens and anthropogenically released substances that have endocrinological or genotoxic effects present largely or entirely unknown damage potentials. One task of broad and independent basic research is to generate and provide the knowledge by which to swiftly construct, when the need arises, new analysis tools and, building upon these, new management tools for emerging problems. Furthermore, targeted applied research must provide an understanding of the interactions among pathogens, the environment and infected organisms, and of the effects of chemical substances such as endocrine disruptors in the various biological systems. These are clearly highly complex issues. The risk evaluation of substances newly released to the environment underscores the necessity to promote greater networking in basic research, because such substances can have impacts at all system levels (e.g. soil, water, climate, biosphere).

- Prevention of damage caused by infectious diseases and endocrine disruptors requires *highly qualified toxicology and epidemiology*, making use of state-of-the-art techniques of biology, chemistry and molecular biology.
- In *infection biology*, there is a need to clarify the processes of exchange of genetic material among organisms, including the formation of resistance in pathogens. Particular research efforts need to be devoted to infection mechanisms, pathogen spread and immune response types, as an understanding of these is essential for the development of new vaccines.
- Because *endocrine disruptors* impact upon several system levels, with potentially significant combination effects and conclusively significant differentiation-related effects, classic laboratory methods sometimes fail. The enzyme action of hormone disruptors, their pharmacokinetics and pharmacodynamics, their bioavailability and their accumulation potential therefore need to be studied individually, as complex molecular effects and control mechanisms render simplifications and analogies largely impossible. Adequate measurement parameters for the effects of substances during the various human development stages are either absent or in need of improvement. Studies of known cases of exposure (e.g. Seveso) should concentrate above all upon the identifiable hormonal and carcinogenic effects, and upon effects damaging the nervous system.

H 1.4 Biological risks

The discussion of biological risks has shown that, due to the prevailing gaps in knowledge, risk assessment embodies major uncertainties. Only long-term and ecosystem-oriented basic research, which is frequently not possible in the usual time schedules for project funding, can bridge the gaps and do justice to risk assessment requirements. The following research focuses should be pursued:

- *Intensified basic research* in soil biology, in ecosystem theory (stability criteria), on the quantification of ecosystem processes as a function of biodiversity, and in population biology.
- Intensification of applied research on *plant production* in marginal locations, in phytopathology and on the evaluation of high-yielding varieties and transgenic crop species with particular regard to securing food production under changing climatic conditions (increasing climate variability and weather extremes).
- Quantifying the *functions of biodiversity* and the ecological and economic damage caused by the loss of these functions due to climate change, land-use changes or land management.
- Studies on the increase of the *fitness of alien species* through spread across isolated populations.
- Improving and expanding ecologically oriented and long-term *back-up and safety research on the release of transgenic organisms*. This includes inter alia the further clarification and quantification of the exchange of genetic information among organisms, and intensified research in the field of phytopathology. When transgenic plants are marketed, research should further be complemented by long-term and ecosystem-oriented *post-ap-*

proval monitoring.

- Refining methods for a complete *valuation of types of ecological damage* that escape market valuation, particularly regarding the loss of biodiversity.

H 1.5
Chemical risks

The available knowledge about the potential risks associated with multiple chemical loading of ecosystems is still very limited. In particular, the ability to adequately quantify the effects of human disturbances is lacking. Risk assessment is further hampered by inputs of new substances whose impacts upon the individual compartments of ecosystems are still entirely unknown. To improve the evaluation of chemical risks, further research efforts are necessary:

- Improved quantification of the ecosystemic consequences of multiple chemical loading, including dry nitrogen deposition and gaseous nitrogen uptake by vegetation, and determination of critical loads ('guard rails').
- Further research on the dynamics and predictability of nitrate release to groundwater.
- Elaboration of complete carbon input-output inventories for all ecosystems and countries and for different forms of management. In particular, greater consideration needs to be given to soil carbon and to the long-term effects of soil management.
- Quantifying the interactions of the carbon and nitrogen balances of various types of vegetation, including impacts upon biodiversity. Models offer valuable support here, but need to be further supplemented by experimental data.
- Improving the predictability and quantifying the interactions of climate protection measures with the objective of biodiversity conservation. In particular, further research needs to address the role of natural or near-natural vegetation in climate protection, with due regard to soils.
- Increased attention to imports of elemental chemicals through international trade and to associated secondary effects. Here there is a considerable research backlog, particularly concerning carbon and nitrogen cycles.

H 1.6
Climate risks

High priority must continue to be given to research on the effects of elevated greenhouse gas and aerosol concentrations upon the global climate, bearing in mind that in the past, more detailed analysis has revealed a series of novel risks to be larger than initially assumed (instabilities in the coupled ocean-atmosphere-vegetation system, synergisms between natural and anthropogenic climate variability, nonlinear responses to perturbations of the hydrological cycle etc.). Specifically, the following research focuses should be pursued in this context:

- Further research on natural climate variability, based on improved regional climate predictions.
- Improving the understanding of the climate system through analysis of interactions among the subsystems (Earth System Analysis).
- Exploring geophysical events of the 'low probability – high consequence' Damocles type, such as destabilization of the West Antarctic ice sheet.
- Study of social vulnerability, firstly to climatic changes and, secondly, to their consequences (food, health etc.).

H 1.7
Natural disasters

Natural disaster risks can be reduced most effectively if forecasts are available that extend as far as possible into the future, on the basis of which strategies can be developed for reducing the exposure or vulnerability of regions at risk. Specifically, the Council recommends:

- *Extreme weather events*. Intensified research should be carried out on whether the incidence of extreme weather events (excessive rainfall, storms, floods and drought) has already risen due to global climate change. This could proceed from an evaluation of long-term weather statistics.
- *Earthquakes*. Earthquake-prone areas should be monitored continuously, using both terrestrial and satellite-based techniques (e.g. deformation measurements, geological-tectonic structure investigations). Using these findings, more reliable earthquake early warning systems based on seismic measurement stations should be developed.
- *Volcanic eruptions*. Volcanological studies should be intensified with the aim of developing deterministic forecasts of volcanic eruptions. Automatic measurement stations should be installed on volcanoes that present a particularly high hazard potential.
- *Meteorite impacts*. The Council recommends the development of an internationally coordinated asteroid early warning system, utilizing already existing monitoring programs. This should be based on methods of classic optical astronomy and on radar measurements. In addition, an asteroid database needs to be established, and automated mon-

itoring techniques developed.

H 1.8 Risk amplifiers and attenuators

The present report has made it amply clear that risk sources – be they natural factors, technologies, cultural habits or people-environment interactions – only partly determine the actual magnitude of risk. Whether a damage potential is manifested and what extent this has depend largely upon the social, institutional and cultural factors within which the specific risk is embedded. Many risks that have only a small potential for destruction in industrialized countries can cause major damage in highly vulnerable regions.

Since, for identical risks, the magnitude of damage varies greatly as a function of geographical location and social situation, particular importance attaches to research on the contextual conditions of risk modulation. In addition to the organizational and institutional framework conditions already noted above in the research recommendations for technological risks, this includes the material, social and cultural resources that are available in a society for dealing with risks. In poor societies, risks have quite different impacts than in a society whose members have a broad resource basis and actively deploy these resources in the event of damage. Only scant knowledge is available as yet on the factors that amplify and attenuate vulnerability to risks. Intensified research efforts should be undertaken here, as in many cases (e.g. natural risks) it is easier to influence the contextual conditions than the risk itself.

Research on risk modulators is largely the province of the social sciences and humanities. Historical traditions are just as important elements of the risk-moderating context as are social commitments, institutional arrangements, world views and religiously determined patterns of behavior. Further issues that need to be analyzed in the context of studies on vulnerability and risk modulation include the allocation of economic resources and the distribution of income and opportunities in life. Specifically, the Council recommends the following:

- Elaborating a system of indicators measuring regional and social group specific risk vulnerability that differentiates according to individuals, households and social groups is fundamental to an improved understanding of risk-amplifying factors.
- The systematic mapping of risks at different scales, thus visualizing the vulnerability of different social groups to the risks of global change, is an important supporting tool for development cooperation and emergency relief.
- In order to improve analytical capabilities, the available approaches and theories for explaining risk vulnerability are in need of refinement. This requires establishing a more consistent linkage between the external and internal risk factors of livelihood security.
- While valuable work has already been carried out in Earth System research, such as the development of a freshwater criticality index by the Council (WBGU, 1998a), a global overview of environmental criticality remains to be provided.

H 1.9 Risks to food security

The risks posed to global food security count among those that require continuous political re-evaluation informed by step-wise scientific analysis, for in this domain the imponderabilities and magnitudes of damage can be particularly large. The discussion of risks to the global food supply has shown that the uncertainties associated with assessing food security have gained a new quality stemming, in particular, from the interplay of numerous core problems of global change.

- Due to the systemic interconnections among various core problems, there is a major and presumably long-term need for further research in order to gain an improved understanding of the dynamics of food security and global change.
- Particular attention needs to be given to the possibility of widespread crop failures. Considering the danger of persistent damage to natural resources, e.g. through climate change or soil degradation, options for early warning, prevention or substitution need to be examined.

H 1.10 Risk potentials of complex environmental systems

The methodological fundamentals for analyzing complex environmental systems urgently need to be expanded. There is a particular need to press ahead with research on the decision and control theory of complex nonlinear systems under incomplete information. This is a challenging and modern branch of science that could not have been established without recent advances in mathematics, physics and computer science. For the context of global environmental risks, the Council recommends:

- Further developing computer simulations of environmental systems with the aim of exploring virtual catastrophes.
- Refining Bayes analysis in order to utilize expert knowledge for the appraisal of environmental

risks, e.g. in the climate sector.
- Improving the methods of fuzzy systems analysis and fuzzy control in order to overcome cognitive deficits in environmental assessment and policy.
- Studying, on a systems analysis basis, the resilience of social systems to environmental shocks.
- Refining the syndrome approach from the aspect of the production of environmental risks in prototypical contexts.

H 1.11
Risk policy

The Council takes the view that among the available environmental policy tools private-law liability gives particular incentives to produce knowledge and should therefore be used primarily, although not exclusively, to manage unknown and insufficiently researched risks (Section H 1.12). Intensified interdisciplinary research efforts need to be devoted to designing and implementing national and international liability rules in a manner that is both appropriate to the matter at hand and viable in legal practice. This is necessary to create unison between liability and the – justifiably – disparate requirements of the various disciplines. The Council sees a need for further research in the following fields, in particular:
- Initial work on categorizing 'ecological damage' as a form of injury of legal interests and class of damage has already been carried out. This work needs to be set on a firmer interdisciplinary footing.
- Detailed study needs to be devoted to the role of the specific elements of liability law, such as liability ceilings as an adequate means by which to prevent the threat of liability creating barriers to innovation.
- With the exception of a few specialized areas (e.g. oil tanker accidents), global liability regimes are generally not yet realizable, even over the medium term. This makes it all the more necessary to apply research efforts to the vigorous support of the moves of the Hague Conference towards developing an internationally acceptable *convention on conflict of laws* pertaining to environmental liability.
- In addition to elaborating general conflict of laws provisions, there is a need for international research on the question of how internationally negotiated liability regulations can be implemented uniformly despite disparities among national institutions (inter alia national procedural law, court organization, assessment of non-material damage, lawyer's fees).

H 1.12
Strategies for dealing with unknown risks

At the present rapid pace of technological development, unknown risks are gaining importance. As innovation gains impetus, the number of associated risks is growing – but without concrete cases of damage yet yielding empirical knowledge about these new risks. In many instances, high damage potentials make it necessary to prevent errors from which society cannot learn. The central recommendation for research on unknown risks is to study the impacts of institutional arrangements upon the three pivotal tasks of risk management that is focused on foresight and prevention: the production, dissemination and application of risk knowledge. In this endeavor, consideration needs to be given to 'cognitive risk traps'. Furthermore, preventive risk management approaches need to be developed for complex environmental systems.
- Of all environmental policy tools, liability law has the strongest knowledge-producing effect. It thus provides a comprehensive institutional framework within which to deal with unknown risks. The importance of liability law suggests two main fields of research:
  1. Study of the connection between innovation incentives and liability regulations.
  2. Analysis of options for relaxing strict liability regimes if proof can be furnished by the innovator that innovation risks pose no hazard or are manageable, i.e. if risk knowledge is produced and disclosed.
- Syndrome analysis has proven its usefulness in many spheres of global change research. In the interests of discovering unknown risks, too, further development of the syndrome approach is most desirable. There is a particular need for further research on syndrome modeling, firstly in order to comprehend the complexity of global environmental risks over time, and secondly in order to gain indications of the emergence of new risks.
- To discover unknown risks, it is desirable to promote basic research on the understanding and control of complex nonlinear systems.
- There is presently a lack of systematic analyses of local or regional decision-making processes with a potential to have globally risky (side) effects for ecosystems and human society.
- The potentially global character of unknown risks calls for the national and international institutionalization of 'prospective technology and risk evaluation' ('early warning systems'; cf. Section H 2.2.3). There is a need for intensified research in order to determine the extent to which the gener-

ic strategies developed in this report (agent management, reagent management, combined management) could contribute to this endeavor.

Recommendations for political action H 2

H 2.1
Class-specific recommendations for risk reduction action

The six classes of risk proposed by the Council in the present report call for specific strategies. The associated tools are presented here in summary and illustrated in a decision tree (Fig. H 2.1-1). The Council further makes important recommendations for the classic risk management policies (Section H 2.2). The goal of the specific strategies based on the six risk classes is to shift these from the prohibited or transitional area into the normal area (Section A 4). The aim is thus not to reduce risks down to zero, but to a level that permits routine management. Both the strategies and the tools or measures are listed in receding order of priority. Naturally, more than one strategy and more than one tool will be necessary in most cases. If, however, a limited selection must be made, the items at the top of the list should be considered first.

Strategies for the Damocles risk class

For Damocles-type risks, the Council recommends three prime strategies: firstly, reducing disaster potential through research and technological measures, secondly, strengthening resilience, i.e. the robustness of a system against surprise, and finally, ensuring effective disaster management (Table H 2.1-1).

The first strategy – reducing damage potential and preventing the occurrence of damage – is concerned with improving technological measures to reduce the disaster potential and with researching and implementing measures to contain the spread of damage. In nuclear energy, for instance, the main strategy implemented in the past has been to further minimize the probability of occurrence of core meltdown by means of technological barriers. This has not been adequate to move this risk from the transitional area into the normal area. Design changes aimed at reducing the disaster potential would have been more expedient (and this is indeed the avenue now pursued). The Council further recommends introducing or strengthening liability rules, which can provide an incentive to improve knowledge and to reduce residual risks. It is further necessary to research and develop alternatives to technologies with unavoidably high disaster potential, and to substitute them with others whose disaster potential is significantly lower. Under certain conditions, this can require subsidization in the introductory and trial phase.

The second strategy is aimed at enhancing resilience to risk potentials. This necessitates strengthening the overarching institutional and organizational structures that impact upon licensing procedures, monitoring, training etc. At the same time, liability law can promote a careful approach to these risks. In addition, technological methods for enhancing resilience need to be introduced or improved. This can be done through, for instance, redundant design measures for technologies and safety-relevant organizational units, through introducing leeway, buffers and elasticity (error-friendly systems) and through diversification, i.e. thinly spreading risk potentials or sources. Organizational forms and proven licensing procedures that are viewed as resilient should be made available to other states, as a template or model, through the transfer of technology and knowledge. Furthermore, international control and monitoring needs to be strengthened, and an international safety standards authority established.

Disaster management is the third and last priority among the strategies for action in this risk class. While not unimportant, this should nonetheless be subordinated to risk-reducing strategies as a backend strategy aimed at limiting damage. Here, as before, human resources and institutional capacities need to be further strengthened by developing and promoting national emergency planning, preparedness and response programs. Through technology and knowledge transfer, the emergency planning measures and techniques that have proven themselves in many industrialized countries can be passed on to local risk managers in the form of education, training and empowerment. Finally, international, precautionary disaster relief, such as is aimed at under the aegis of the International Decade for Natur-

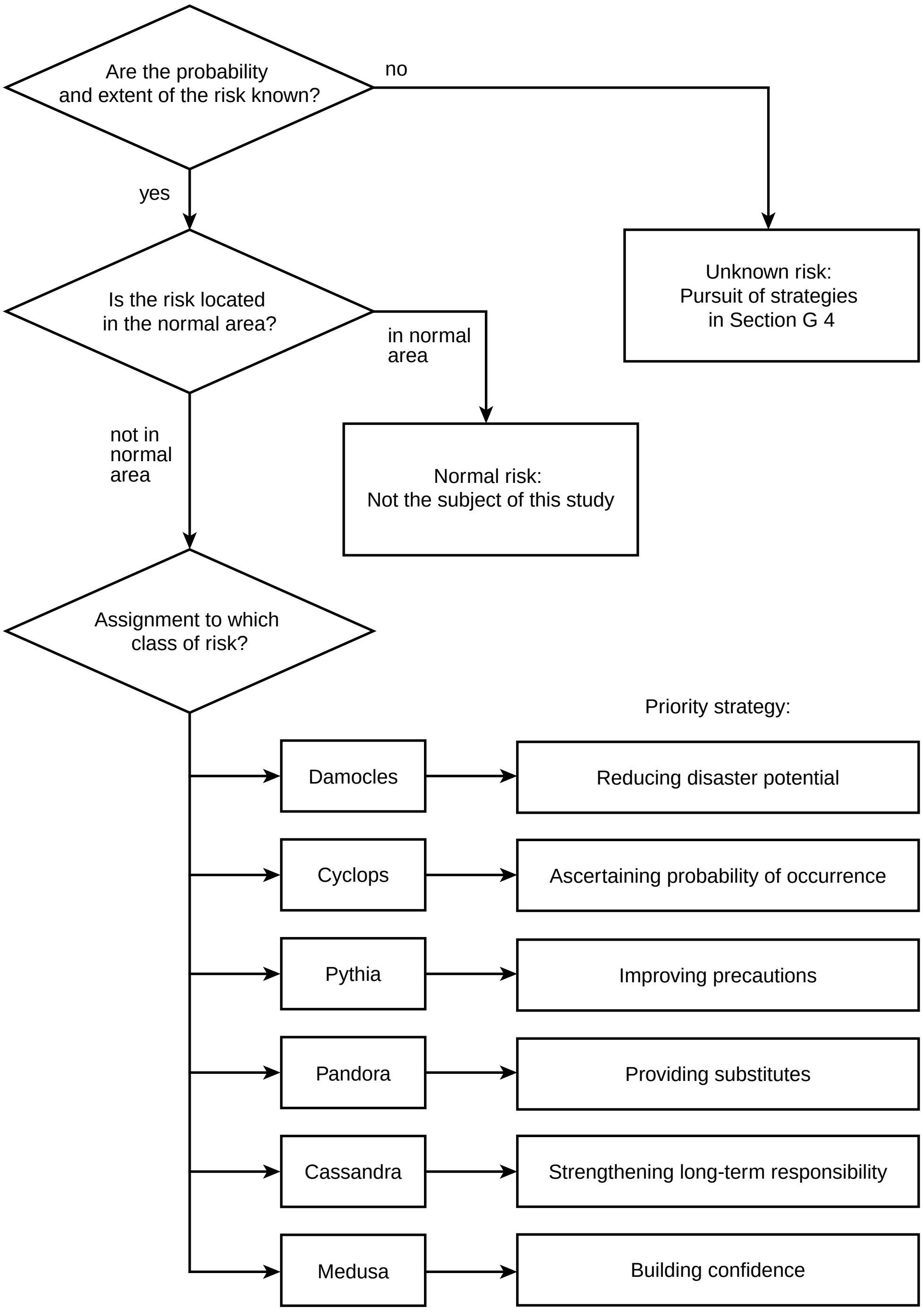

Figure H 2.1-1
Decision tree for classifying the risks of global change.
Source: WBGU

al Disaster Reduction (IDNDR) initiated by the UN, is also requisite to counter human-induced disasters.

Strategies for the Cyclops risk class

Among the measures and tools for the Cyclops class, determining the probability of occurrence has supreme priority. This calls for promotion of the necessary research (Table H 2.1-2). Furthermore, international monitoring needs to be ensured through national and international risk centers. Here, the Council relies above all upon the establishment of a UN Risk Assessment Panel, whose task would be to net-

Table H 2.1-1
Strategies and tools for the Damocles risk class. The main problem in this class is the high disaster potential.
Source: WBGU

Strategies	Tools
1. Reducing disaster potentials	• Research aimed at developing substitutes and reducing the disaster potential • Technological measures for reducing the disaster potential • Stringent liability regimes • International safety standards authority • Subsidization of alternatives that have equal utility • Containment (minimizing the spread of damage) • International coordination (e.g. to mitigate meteorite hazards)
2. Strengthening resilience	• Human-resource and institutional capacity building (licensing procedures, monitoring, training etc.) • International liability commitments • Expansion of technological procedures by which to improve resilience (redundancy, diversity etc.) • Blueprint for resilient organizations • Model role: licensing procedures • International controls (IAEA)
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Education, training, empowerment • Technological protective measures, including containment strategies • International emergency groups (e.g. fire services, radiation protection etc.)

work the national risk centers and to collate and evaluate the knowledge gained about global risks. The tasks, structure and functions of this Panel are explained in detail in Sections F 6.3.1 and H 2.2.

The second strategy for action is aimed at preventing undesirable surprises and safeguarding society against these. One option for doing this is to introduce a strict liability regime. Under certain preconditions, mandatory insurance (or possibly a fund model) should be considered. The tools for strengthening human-resource and institutional capacities and the technological measures correspond largely to those set out for the Damocles class above.

The third strategy, disaster management, applies the same tools as in the Damocles class.

Table H 2.1-2
Strategies and tools for the Cyclops risk class. The main problem in this class is the uncertainty of occurrence.
Source: WBGU

Strategies	Tools
1. Ascertaining the probability of occurrence *P*	• Research to ascertain numerical probability *P* • International monitoring through – National risk centers – Institutional networking – International Risk Assessment Panel • Technological measures aimed at estimating probabilities
2. Preventing surprises	• Strict liability • Compulsory insurance for risk generators (e.g. floods, settlements) • Capacity building (licensing procedures, monitoring, training etc.) • Technological measures • International monitoring
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Education, training, empowerment • Technological protective measures, including containment strategies • International emergency groups (e.g. fire services, radiation protection etc.)

Table H 2.1-3
Strategies and tools for the Pythia risk class. The main problem in this class is the low certainty of assessment, in conjunction with plausible scenarios suggesting high damage potentials. *P* signifies the probability of occurrence and *E* the extent of damage.
Source: WBGU

Strategies	Tools
1. Improving precautions and mitigating effects	• Institutionalized, precautionary technical standards such as ALARA, BACT, state-of-the-art etc. • Fund solutions • Mitigation (minimizing the spread of damage) • International agreements on control, monitoring and safety measures • Human-resource and institutional capacity building (licensing procedures, monitoring, training etc.) • Technological measures aimed at enhancing resilience (redundancy, diversity etc.)
2. Improving knowledge	• Research to ascertain *P* and *E* • International early warning structure through: – National risk centers – Institutional networking – International Risk Assessment Panel • State-sponsored (basic) research
3. Emergency management	• Containment strategies • Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Education, training, empowerment • Technological protective measures • International, rapidly deployable task forces (e.g. for decontamination)

Strategies for the Pythia risk class

In the Pythia class, which is characterized by particularly high uncertainties concerning both components of risk – probability and severity – it is similarly necessary to improve knowledge, particularly in basic research (Table H 2.1-3). However, compared with the Cyclops class, an even stronger focus needs to be placed on precautionary strategies, as the liability principle can possibly only be enforced to a limited extent and the severity of effects can assume global proportions. Regulatory impositions and containment measures are generally indispensable in this area.

Concerning precautions, the Council recommends pursuing a strategy that employs tools such as the ALARA (As Low As Reasonably Achievable) principle or the 'best available scientific knowledge and technology' test, under which the sum of the costs of not implementing risk reduction policies plus the costs of risk reduction policies implemented is to be kept as low as possible. Limiting the sphere of action and impacts in which the risk is permitted is also an important precautionary tool. The severity of an unpredictable disaster can thus be contained expediently. Instruments of liability law are, in principle, recommended here, too, but are possibly not always enforceable. This is why the use of fund models should also be considered. Global Pythia-type risks call for international institutions in order to carry out controls and monitoring and to put in place safety precautions. Tools aimed at containing the spread of damage, strengthening human resources and institutional capacities and improving resilience have already been discussed for the previous two classes of risk.

The second strategy is to improve knowledge in order that future risk analyses can deliver more reliable appraisals. This necessitates research to identify probabilities and possible severities. An international early warning system is further necessary here, as in the Cyclops class.

The specific tools of damage management are very similar to those of the previous risk classes. The distinguishing feature here is the limitation of damage severity through local restrictions upon risk-generating activities.

Strategies for the Pandora risk class

The Pandora class of risks is characterized by uncertainty as to both probability and severity (only assumptions) and by high degrees of persistency and ubiquity (Table H 2.1-4). As the negative effects of these risk sources are still unknown, but can, in the worst case, assume global proportions with irreversible consequences, there is an urgent need for research efforts to develop substitute substances, and for regulatory measures aimed at containing or reducing these sources of risk. Implementation needs to cover the international context, too.

In the Pandora class, the provision of substitute substances or processes has priority over all other strategies. As concerns researching and developing substitutes, the same applies in principle as in the Damocles class. Beyond this, the Pandora class re-

Table H 2.1-4
Strategies and tools for the Pandora risk class. The main problem in this class is the uncertainty of both the probability and extent of damage, in conjunction with high degrees of persistency and ubiquity.
Source: WBGU

Strategies	Tools
1. Developing substitutes	• Research aimed at developing substitutes • Technological measures aimed at disseminating and enforcing substitutes • Promotion of basic research • Subsidization of alternatives that have equal utility
2. Enforcing restrictions upon substance quantities and dispersal, through to outright bans	• Regulatory limitation of quantities, through – environmental standards or – incentive schemes (certificates) • Strict liability, where appropriate • Improving and extending retention/containment technologies • Command-and-control limit values and bans • Capacity building (technological know-how, technology transfer, training) • Joint Implementation
3. Emergency management	• Human-resource and institutional capacity building (emergency prevention, preparedness and response) • Technological protective measures, including containment strategies • Education, training, empowerment

quires wide-ranging basic research that needs to be promoted accordingly.

In a second step, the risk potentials should be reduced by minimizing, locally containing or even completely prohibiting certain sources of risk. Here, a command and control approach is suitable, for instance through quantitative restrictions by means of environmental standards, and economic incentive systems using certificates. In some cases, the implementation of a strict liability regime is also appropriate. Technological approaches to risk reduction and strengthening human resources and institutional capacities apply as in the previous classes of risk.

Strategies for the Cassandra risk class

With Cassandra-type risks, there is scarcely any uncertainty, but people dismiss these risks in view of their gradual form or the time lag between triggering event and occurrence of damage (Table H 2.1-5). Frequently, the short-term legitimization of politicians brought about by short periods of office leads to a lack of motivation to tackle such long-term threats. Here, the Council takes the view that long-term responsibility needs to be strengthened worldwide, by means of collective self-commitments (such as codes of behavior of multinational corporations), by means of global institutions with a long-term perspective (UN Risk Assessment Panel) and by means of international conventions. To minimize the risks themselves, restricting the emissions of substances is a suitable tool.

Where there is a substantial time lag between triggering event and damaging effect, appropriate instruments need to be used to strengthen long-term responsibility to future generations. Here, the Council relies primarily upon voluntary commitments of states and important actors (such as multinational corporations or reinsurers). Fund models may also be useful here. At the more individual level, those potentially affected can gain more capacity for action through a combination of participation and empowerment, thus receiving impulses for long-term responsibility vis-à-vis their own life world.

The second priority is to continuously reduce risk potentials by developing alternatives in the form of substitute substances and processes, and containing unsubstitutable risk potentials through quantitative limits or at least limits upon the scope of application. The requisite tools have already been discussed for the other risk classes.

Strategies for the Medusa risk class

The Medusa class of risks requires measures aimed at building confidence and improving knowledge in order to reduce the remaining uncertainties (Table H 2.1-6). Public education alone does not suffice here. Those affected must also be involved in the structuring of their own life worlds, and must constructively integrate in their own decisions the uncertainties and contradictions that remain intrinsic to these risks.

In this class of risk, the severity of effects and the probability of their occurrence are low, but the potential for mobilization is particularly high. In order to be able to make the public aware of the actual severities and probabilities, confidence needs to be built first of all. Independent institutions providing open information about the findings of scientific research but also about the purely hypothetical character of many fears can play a role here. Furthermore,

Strategies	Tools
1. Strengthening long-term responsibility	• Voluntary commitments, codes of conduct of global actors • Coupling participation, empowerment and the institutional bolstering of long-term strategies • Remedying state failure • Fund models • International coordination
2. Steady reduction through substitutes and quantitative restrictions, through to outright bans	• Incentive schemes (certificates and levies) • Strict liability, where appropriate • Quantitative restrictions through environmental standards (also international) • Improving and extending retention/containment technologies • Human-resource and institutional capacity building (technological know-how, technology transfer, training) • Joint Implementation
3. Contingency management	• Human-resource and institutional capacity building (ecosystem restoration, emergency prevention, preparedness and response) • Technological protective measures, including containment strategies • Education, training, empowerment

Table H 2.1-5
Strategies and tools for the Cassandra risk class. The main problem in this class is the delay between triggering event and damage (high latency, insidious risks).
Source: WBGU

those affected should have an opportunity to participate actively in structuring their life world. This confronts them with decisions that frequently involve making a choice between options that constitute different levels of risk. When weighing these risks, they must then decide themselves to what extent they accord more weight to the often poorly founded fears in the public than to the proven damage potentials of alternative options. Affected parties should also be able to participate in licensing procedures in order to weigh for themselves the value conflicts and to select the most acceptable from the ran-ge of options. To deal with the problem of Medusa-type risks in society, social science research that studies mobilization potentials and the social handling of risk conflicts needs to be promoted.

For this class, too, the knowledge of presumed risk potentials should be improved. There is a need for research to improve the certainty of assessments and for basic research. In addition, effective and credible risk communication measures need to be instituted.

Strategies	Tools
1. Building confidence	• Establishing independent institutions for information and public education • Improving opportunities for individuals to participate in decisions affecting their own life worlds, with an obligation to choose among conflicting options • Promotion of social science research on mobilization potentials • Model function: licensing procedures with participation rights of affected parties • International controls (IAEA) • International liability commitments
2. Improving knowledge	• Research aimed at improving the certainty of risk assessments • State-sponsored (basic) research
3. Communicating risks	• Clear presentation of the cause-effect relationships between triggers and consequences • Intensified environmental education in schools and in adult education • Direct feedback of measured data to the public

Table H 2.1-6
Strategies and tools for the Medusa risk class. The main problem in this class is the high mobilization potential, while the probability and extent of damage tend to be low.
Source: WBGU

H 2.2
Key recommendations for transnational and global policies

H 2.2.1
Extending strict liability

We find that there is an array of global trends which may compromise the sustainability of society (for instance, growing world population, economic development, socio-economic interpenetration of nations and economies). Reactions to this can take two forms. One approach is to attempt to use expert stipulations, technology assessment and consensual debate in society to define a development path that proves to be sustainable. At the global level, limits are imposed upon such an approach by the diversity of preferences and interests, disparities in the risk acceptance of individual societies and gaps in available knowledge. There are, however, global environmental risks for which a global consensus is emerging concerning the developments that are viewed as undesirable and unsustainable. Thus for climatic risks, for instance, (variable) 'guard rails' or 'development corridors' can be stated which should not be overstepped or left (WBGU, 1995b, 1997b; Klemmer et al., 1998b).

This approach has its limits. Limited knowledge of the consequences of today's actions for the future and the associated assessment problems, in conjunction with limited capacity to control complex economic and social systems, hamper a stringent formulation of 'guard rails' and targeted direction of systems. Sustainability is thus not so much a definable target than rather a charge upon the people living today to develop rules and regulations that point the production of knowledge in a direction guided by long-term perspectives. Furthermore, through timely revelation of the negative implications of today's activities, these rules and regulations should make it possible to trigger rapid societal adaptation reactions in terms of risk reduction (Klemmer et al., 1998a). Sustainable societies must thus be continuously innovating and learning systems equipped with incentive arrangements for risk reduction.

The Council therefore accords great importance not only to creating new knowledge, but also to mobilizing the potentials of problem-solving competence which are available decentrally within society but unknown to any central agency. This is above all a matter of revealing previously unidentified risks and promoting the innovation of new, less risky lines of technological development. Because an assessment of risk consequences is not possible, or only to a limited extent, appropriate incentives should be provided for the production and mobilization of knowledge. In addition to promoting basic research, this further entails guaranteeing room for maneuver, and thus also assigning clearly defined property and utilization rights (Kerber, 1998). The door can thus be opened to diverse searching processes, taking place in the market under competitive conditions, which are able to reveal errors and avoid mistakes in time. An important element in such processes is the enforcement of the liability principle, which, due to its preventive effect, can contribute to precluding damage. As the Council has repeatedly stressed, the preventive side of liability is the main aspect. This preventive effect is enhanced if the risks in question are insurable. The insurance companies will then set up expert groups to assess these risks and will arrive at premiums reflecting their assessments. This will in turn lead to the acceleration of risk-reducing knowledge production – for insurer and insured alike will conduct risk research in their own best interests in order to avoid faulty assessments and in order to limit losses and reduce the probability of these losses occurring.

Where risks are found to be uninsurable, this might well have the effect that the risk-generating activity is discontinued. If that is not in the interest of the state, liability must be limited.

H 2.2.2
Precautionary knowledge production

Knowledge of the causes, mechanisms and adverse effects of possible, undesired events forms the basis for managing global environmental risks. The production of new knowledge, however, which is generally by processes of technological innovation, can itself generate new risks with previously unknown characteristics. In a highly dynamic society, policymakers are under a particular obligation to ensure that the 'ignorance coefficient' – the ratio between the totality of risks and the relevant prevention and management knowledge – at least does not deteriorate.

The ignorance coefficient can be positively influenced by issue-focused risk research tackling such hazards that are known or that can at least be surmised. It follows that it is essential to maintain or indeed even raise the high standards that research has reached in this field (from technology assessment to global systems research). This cannot be delivered for free, but the requisite expenditure is politically reasonable.

Managing still unknown or not systematically identifiable risks that may perhaps be far in the future is a much more problematic situation. Here, clearly defined, objectives-oriented knowledge production with short-term safety yields is impossible. The Council has discussed this situation repeatedly and in detail elsewhere.

Proactive risk management does not turn on ad-hoc knowledge production, but on a store of knowledge produced in advance. This can only be delivered by broad, 'value- and purpose-free' basic research. Only a continuously replenished and extended stock of knowledge not subject to direct exploitation requirements will make it possible to discover complex risk constellations coincidentally, in passing or playfully, and to find management strategies in a similar manner. This is why the Council advocates an undiminished *basic funding for the environmental sciences* in the broadest sense, whereby the long-term objective must be to significantly improve our understanding of the interconnections in the Earth System. Such research will uncover real risks which are presently not visible in the slightest, but will presumably be amenable to management by appropriate measures.

The Council notes in this connection that research thrives on diversity and competition: it would be a dangerous fallacy to assume that basic research can be made 'leaner' through rigidly avoiding duplication and parallel efforts – such as by commissioning *one* institute worldwide with researching *one* specific compartment of the ecosphere. Quite the contrary – a spectrum of opinions, approaches and methods is necessary in order to subject the space of possible risk constellations to a sufficiently tightly meshed scan. This applies particularly to simulation models for the climate, ocean circulation, vegetation dynamics and so forth, where it is precisely a broad spread of different research designs and realization that will permit the coincidental identification of critical – i.e. *not* evident – hazard aspects. Knowledge is venture capital, and this capital needs diversification!

H 2.2.3
International mechanism for risk detection and assessment

Knowledge thus holds the key to risk management – but the key must also be used. Worldwide, this use has in the past been completely inadequate. Various factors have been responsible for this inadequacy: insufficient integration of specialist knowledge, asymmetrical access to knowledge, ineffective structures of knowledge transfer and so forth. We do not mean here the implementation of insights in concrete actions for dealing with risk, but a preliminary stage where knowledge provides an indication of the need to act. Particularly in terms of global environmental threats, there can as yet be no talk of any such processing of the already available insights. Here action-relevant risk knowledge would need to make global hazard potentials visible in a geographically explicit manner. Concerning, for instance, the perspectives of global food security, we presently have nothing more than an array of speculations, built on shaky ground, that do not even begin to make use of the knowledge already available today (e.g. on the impacts of expected climate change or continuing soil degradation processes).

The Council therefore recommends that a (UN) Risk Assessment Panel be established. The essential functions of this Panel should be similar to those of the Intergovernmental Panel on Climate Change (IPCC), but the task of the (UN) Risk Assessment Panel would be less to analyze already detected risks, and more the timely and integrated detection of novel risks of global import that are only just beginning to become visible.

The (UN) Risk Assessment Panel should not conduct research of its own, but should underpin and stimulate existing relevant research structures, condense their findings and – after a comprehensive international scientific assessment process – present these to policy-makers in a purposeful form. The main aim would be to establish a network node in which various national risk identification and assessment processes come together, are collated and coordinated. Thus, under the aegis of this Panel, certain tasks or functions set out in Section F 6 could partially be delegated to already existing international organizations or institutions. Such a Panel would not involve founding a new international organization, but would make use of the capacities and competencies of existing bodies.

In particular, the Panel should assume five focal tasks:

- *Early warning system*. For an international networking of early detection and early warning, as much scientific data and findings of early detection research as possible should be collected, systematized and synthesized worldwide. This can ensure reliable forecasting of impending threats. A precondition would presumably be to support certain countries in the creation of national early detection systems or risk centers, particularly in vulnerable areas.
- *Evaluation of monitoring*. The Panel should evaluate the findings of monitoring systems in a timely and action-focused manner. The task would be to monitor, control and regulate risk potentials. In order to ensure effective monitoring, states would

need to commit themselves to certain technical and organizational standards. The review of and compliance with these standards could be the remit of an international safety standards authority (Section H 2.2.4), which could be modeled on institutions such as the International Atomic Energy Agency (IAEA). International monitoring can only be effective if national monitoring structures are effectively coordinated through institutional linkages.
- *Knowledge production and dissemination.* A (UN) Risk Assessment Panel can function as a multiplier of 'risk knowledge' by making available to all interested actors the scientifically substantiated findings of risk analysis and risk assessment (Section C). In addition, the Panel should stimulate, support and coordinate basic risk research in order to close the gaps in knowledge relating to the analysis and assessment of certain risk potentials (in the transitional area, see Section C).
- *International risk evaluation methodology.* The proposed (UN) Risk Assessment Panel could also contribute to ensuring that a uniform method of risk analysis and assessment attains collective validity. Risk assessments would then become easier to compare and to operationalize. The Council proposes basing such a methodology on the differentiation according to normal, transitional and prohibited areas set out in Section C. Global risk potentials would need to be treated in accordance with this risk classification. This means that a collectively recognized risk assessment procedure would evaluate those risk potentials that are located in the prohibited area as being unacceptable, and would ban them. Risk potentials located in the transitional area would need to be handled by regulatory policies, whereby considerable importance would attach to continuous knowledge production.
- *Focusing on essential issues and determining the 'safety margin'.* The (UN) Risk Assessment Panel should identify the essential policy domains (perhaps four or five), concentrate its work on these and determine for these the respective 'safety margins', i.e. the just acceptable boundary zones to intolerable conditions.

The function of the Panel would thus be to condense, in an interdisciplinary fashion, the scientific research on the risks of global change (policy-oriented weighing of all individual findings). In this, it should make all efforts to be:
- Independent of the direct interests of individual states,
- Independent of the direct exploitation interests of private industry,
- Independent of the direct influence of non-state political associations and lobby groups.

The (UN) Risk Assessment Panel should moreover serve as a – scientifically substantiated – interface between non-state actors (environmental and development organizations, industry federations) and the body politics, by permitting submissions of non-governmental organizations and scientifically examining and assessing these. A further important task of the Panel would be to inform both state and non-state actors (at all levels) about the state of knowledge of all environmental risks of international relevance.

H 2.2.4
Building effective capacities for dealing with risk

The above recommendations are geared to ensuring that environmental risks cannot arise in the first place, or are detected early on and assessed properly. However, these political measures will not lead by themselves to a complete prevention of global hazard potentials, nor to a total suppression of regionally damaging events. It remains essential to transpose knowledge into action and contingency measures. There is a lack of the necessary institutional and technical capacities. This already applies to many industrialized countries, and all the more to most developing countries. At the international level, we can only find the first rudiments. The Council makes the following recommendations in this area:
- *Enhancing national and international civil protection.* Almost all of the risks of global change call for investment in emergency prevention, preparedness and response capacities. Where existing mechanisms are not fully operative, the establishment of new structures should be considered in order to resolve acute problems. At the national level, each government will have to make its own provisions, whereby the financially constrained developing countries should be offered financial and technical assistance by the international community. At the international level, the establishment of supra-state 'stand-by' emergency response units should be considered. The emergency relief units of the Red Cross or the international task force for decontamination at the IAEA are examples of such units. These could be expanded to form 'rapid deployment forces' and, with due regard to considerations of national sovereignty, could be specially trained to deal with environmental disasters. The control center for these units should be integrated in an international organization in the United Nations system, and closely linked to the (UN) Risk Assessment Panel proposed above. It also needs to be examined in this context whether the implementation of a voluntary international

environmental inspection system could enhance risk regulation and remediation.

- *Strengthening non-state actors, in particular NGOs.* Strengthening non-state environmental associations could form a crucial element in the long-term management of global environmental risks. In intrastate politics, it needs to be considered to what extent environmental associations might be allowed to use collective litigation (or individuals might be allowed to bring environmental citizen suits) to champion the interests of the environment and of future generations more effectively than has been the case in the past. However, there are concerns that an unconsidered widening of avenues of litigation, or indeed the introduction of public-interest popular action in environmental law, may create opportunities for abuse, and may further lead to international competitive distortions. Nonetheless, a careful broadening of access to justice would correspond to the general tendency of European Community law. A precondition to this would be to promote a culture of open communication, in firms, in municipalities and within states – a culture open to different value judgments and different notions of what constitutes environmental quality and the quality of life. In international politics, environment and development groups have attained ever growing importance. In some arenas, non-governmental organizations (NGOs) are already granted the right to be heard at diplomatic conferences and within the United Nations system, and have access to many documents. It should be examined to what extent NGOs could be integrated even more effectively in the international negotiation and implementation processes. With a view to a global strategy for dealing with risk, the Council recommends an extensive right of NGOs (including industry federations) to initiate proceedings in the proposed (UN) Risk Assessment Panel. Here, the problem of a possible lack of legitimization of non-state actors needs to be taken into consideration.
- *Promoting self-help potentials in developing countries.* In its previous reports, the Council has repeatedly noted that the risks of global change are distributed very unevenly among the countries and populations of the world. People in developing countries are particularly at risk. Strengthening capacities to cope with these risks in the developing countries, particularly among the poor, who are those most at risk, is therefore an important element of effective global risk policy. A further reason why combating poverty through self-help is such an important part of global risk prevention and attenuation policy is that it not only aims at a broad impact, but at the same time stimulates structural reform in state and society. In some cases, the basic essentials for an effective handling of the risks of global change first need to be created, namely the basic structures of an issue-focused state administration. Here, too, the international community is called upon to exercise solidarity. In sum, further technical and financial development cooperation can be brought to bear in such a way that the potential extent of damage of risks is significantly reduced. Through its three focuses – 'poverty alleviation', 'environmental protection and the conservation of natural resources' and 'education and training' – German development cooperation already makes an important contribution to hand-ling the risks of global change. Nonetheless, the available funding does not suffice. The Council has therefore repeatedly called for a significant boost in government funding for development cooperation (WBGU, 1996–1998a).
  The capacity of a society to deal with the risks of global change, its knowledge of causation and cause-effect linkages and its ability to communicate about risks depend directly upon the level of education and the available scientific competence. But the education sector is an area where the North-South gradient has become particularly steep in recent years. The production of risk knowledge in the innovation process is gaining particular importance for those countries whose industrialization is only just beginning, and where crucial decisions are due to be taken in the future in key sectors of the economy. Knowledge transfer in all purposeful forms between industrialized and developing countries is thus an indispensable instrument of global risk management. Here, the (UN) Risk Assessment Panel proposed above could play a pivotal role.

H 2.2.5
Ecological criteria in development cooperation

Even best-intentioned solidarity with the countries and groups that are particularly vulnerable to global change is doomed to fail if the recipients of solidarity inputs do not themselves observe a number of basic rules concerning the protection of our common environment. The Council therefore recommends giving greater consideration to ecological criteria in development cooperation.

Environmental protection was included by the German government in 1975 in its catalog of development policy objectives, and was declared in 1986 to be one of the five thematic foci of development cooperation. Since the Rio Earth Summit, this trend has gathered momentum. More than a quarter of all bilateral development cooperation commitments now relate to the field of environmental protection. In recent years this has amounted to more than DM 1 billion.

The Council views these activities as a very important contribution to reducing global environmental risks. It welcomes the fact that environmental acceptability has now been integrated as an element in the project promotion procedures of the German Federal Ministry for Economic Cooperation and Development (BMZ). Environmental standards should gain a higher priority in the future as a basis of development cooperation. In this connection, the ongoing efforts of the OECD Development Assistance Committee to harmonize the protection and monitoring measures of the various donor countries deserve support. Not least, it should be examined at the European Community level whether the protection of the global environment should be enshrined as a Community-wide objective of development cooperation through insertion in Article 130u para 2 of the EC Treaty (or, after entry into force of the Amsterdam Treaty, Article 177 para 2).

H 2.2.6
Promoting risk awareness

If indispensable socio-economic opportunities are to be seized, then there is no risk-free path for a dynamically developing global community. In fact, a policy of risk aversion can be all the more hazardous over the long term, as avoiding known hazards can mean foregoing opportunities for later handling currently unknown risks. However, global change harbors risks with novel characteristics (e.g. the danger that ocean circulation patterns are changed) which concern practically everyone on the planet, albeit in most cases with a highly asymmetrical distribution of consequences, and whose potential effects can extend far into the future of humankind. This special quality of risk demands a new quality of risk responsibility such as can only be assumed by the *'risk-aware citizen'*.

The risk-aware citizen

- Should be adequately informed about the current state of knowledge of global environmental risks,
- Should be involved to the greatest possible extent in really critical decisions on the acceptability of certain environmental risks, and
- Should continue to monitor and observe the consequences of previous risk decisions and demand changes in policies if previous assumptions have been proven wrong.

The Council recommends that the German Federal Government examines whether the existing tools for promoting these three principal elements of risk-awareness have in the past really been exploited, and whether these tools should be further developed. The not exactly confidence-inspiring events surrounding BSE and shipments of radioactive material give ample reason to presume that distinct improvements are indeed possible here.

This endeavor needs to address two fundamental challenges: firstly, when dealing with global hazards – i.e. in particular hazards that transcend national boundaries and human generations – competent, fair and efficient forms of political representation and participation need to be developed. It is around this challenge that the debate on the perspectives of 'global governance' currently revolves. The process of forging and implementing the UN Framework Convention on Climate Change (FCCC) may offer a paradigm for what could correspond in the global context to local consensus-building processes (including 'round tables').

Secondly, risk-awareness is not an objective whose realization devolves entirely to politicians or public authorities. Opportunities for information, discourse, co-determination and joint responsibility must be made use of by the 'global citizen'. This summary ends with a call to all those who feel themselves or their descendants put at risk by global environmental changes to engage in a risk partnership. Even relative safety is not an asset that can be made freely fungible – not by any collectivity, no matter what kind.

References

I

Ahl Goy, P. and Duesing, J. H. (1996): Assessing the environmental impact of gene transfer to wild relatives. BioTechnology 14, 39–40.

Ahrens, T. J. and Harris, A. W. (1994): Deflection and fragmentation of near-earth asteroids. In: Gehrels, T. (ed.): Hazards due to comets and asteroids. Tuscon: University of Arizona Press, 897–928.

Ainsworth, M. (1998): Die Festlegung staatlicher Prioritäten zur Vermeidung von HIV/AIDS. Finanzierung & Entwicklung (3), 18–21.

Akademie der Wissenschaften zu Berlin (ed.) (1992): Umweltstandards. Berlin: de Gruyter.

Alcamo, J., Shaw, R. and Hordijk, H. (1990): The RAINS model of acidification. Science and Strategies in Europe. Dordrecht: Kluwer.

Alcamo, J., Krol, M. and Posch, M. (1995): An integrated analysis of sulfur emissions, acid deposition and climate change. Water, Air and Soil Pollution 85 (3), 1539–1550.

Alewell, C., Bredemeier, M., Matzner, E. and Blanck, K. (1997): Soil solution response to experimentally reduced acid deposition in a forest ecosystem. Journal of Environmental Quality 26, 658–665.

Ammann, K., Jacot, Y. and Rufener Al Mazyad, P. (1996): Field release of transgenic crop in Switzerland, an ecological risk assessment. In: Schulte, E. and Käppeli, O. (eds.): Gentechnisch veränderte krankheits- und schädlingsresistente Nutzpflanzen – Eine Option für die Landwirtschaft? BATS (Biosafety Research and Assessment of Technology Impacts of the Swiss Priority Programm Biotechnology) – TA Hefte. Bern: Schweizerischer Nationalfonds, 101–158.

Amthor, J. S. (1995): Terrestrial higher-plant response to increasing atmospheric CO_2 in relation to the global carbon cycle. Global Change Biology 1, 243–274.

Anderson, D. M. (1995): Toxic red tides and harmful algal blooms. Reviews of Geophysics 33, 1189–1200.

Anderson, R. M., Donnelly, C. A., Ferguson, N. M., Woolhouse, M. E., Watt, C. J., Udy, H. J., MaWhinney, S., Dunstan, S. P., Southwood, T. R., Wilesmith, J. W., Ryan, J. B., Hoinville, L. J., Hillerton, J. E., Austin, A. R. and Wells, G. A. (1996): Transmission dynamics and epidemiology of BSE in British cattle. Nature 382 (6594), 779–788.

Arnold, S. F., Klotz, D. M., Collins, B. M., Vonier, P. M., Guillette, L. J. and McLachlan, J. A. (1996): Synergistic activation of estrogen receptor with combinations of environmental chemicals. Science 272, 1489–1492.

Arnold, V. I (1992): Catastrophe theory. Berlin, Heidelberg, New York: Springer.

Arnone III, J. A. and Hirschel, G. (1997): Does fertilizer application alter the effect of elevated CO_2 on *Carex* leaf litter quality and in situ decomposition in an alpine grassland? Acta Oecologica 18, 201–206.

Arrhenius, S. (1896): On the influence of carbonic acid in the air upon the temperature on the ground. Philosophical Magazine and Journal of Science 41 (251), 237–269.

Arrow, K. and Hurwicz, L. (1971): An optimality criterion for decision making under uncertainty. In: Carter, C. F. and Ford, J. L. (eds.): Uncertainty and expectations in economics. Clifton: Kelley, 1–11.

Arthur, W. B. (1989): Competing technologies, increasing returns, and lock-in by historical events. The Economic Journal 99, 116–131.

Ashby, W. R. (1974): Einführung in die Kybernetik. Frankfurt/M.: Suhrkamp.

Assmann, H.-D. (1988): Rechtsfragen des Kausalitätsnachweises bei Umweltschäden. In: Nicklisch, F. and Assmann, H.-D. (eds.): Prävention im Umweltrecht. Heidelberger Kolloquium Technologie und Recht. Heidelberg: Müller, 155–178.

Atwater, T., Salwen, M. and Anderson, R. (1985): Media agenda-setting with environmental issues. Journalism Quarterly 62, 393–397.

Augstein, E. (1991): Die Bedeutung des Ozeans für das irdische Klima. In: Hutter, K. (ed.): Dynamik umweltrelevanter Systeme. Berlin, Heidelberg, New York: Springer, 141–169.

Aurand, K. and Hazard, B. P. (1992): Die Rolle und Bedeutung von Information für die Umweltmedizin. In: Aurand, K., Hazard, B. P. and Tretter, F. (eds.): Umweltbelastungen und Ängste. Opladen: Westdeutscher Verlag, 15–27.

Auswärtiges Amt (1997): Bericht zur Rüstungskontrolle, Abrüstung und Nichtverbreitung 1997. Unterrichtung durch die Bundesregierung. Bericht der Bundesregierung zum Stand der Bemühungen um Rüstungskontrolle, Abrüstung und Nichtverbreitung sowie über die Entwicklung der Streitkräftepotentiale (Jahresabrüstungsbericht 1997). Bonn: Auswärtiges Amt.

Bächler, G., Böge, V., Klötzli, S., Libiszewski, S. and Spillmann, K. R. (eds.) (1996): Kriegsursache Umweltzerstörung. Ökologische Konflikte in der Dritten Welt und Wege ihrer friedlichen Bearbeitung. Chur: Rüegger.

Bacow, L. S. and Wheeler, M. (1984): Environmental dispute resolution. New York, London: Plenum Press.

Bak, P., Tang, C. and Wiesenfeld, K. (1987): Self-organized criticality – an explanation of 1/f noise. Physical Review Letters 59, 381.

Banse, G. (1996): Herkunft und Anspruch der Risikoforschung. In: Banse, G. (ed.): Risikoforschung zwischen Disziplinarität und Interdisziplinarität. Berlin: Edition Sigma, 15–72.

Baram, M. (1980): Cost-benefit analysis: an inadequate basis for health, safety, and environmental regulatory decision making. Ecology Law Quarterly 8, 473–531.

Bartsch, D. (1997): Ecological impact of transgenic virus-resistance in crop, weed, and wild plant populations (due to potential alterations of plant invasiveness). In: Tepfer, M. and Balázs, E. (eds.): Virus-resistant transgenic plants: Potential ecological impact. Berlin, Heidelberg, New York: Springer, 107–113.

Bartsch, D. and Schuphan, I. (1998): Gentechnische Eingriffe an Kulturpflanzen. Bewertung und Einschätzung möglicher Probleme für Mensch und Umwelt aus ökologischer und pflanzenphysiologischer Sicht (Gutachten im Auftrag des Rats von Sachverständigen für Umweltfragen, Wiesbaden). In: SRU – Rat von Sachverständigen für Umweltfragen (ed.): Zu Umweltproblemen der Freisetzung und des Inverkehrbringens gentechnisch veränderter Pflanzen. Stuttgart: Metzler-Poeschel, 51–122.

Baumann, B. (1993): Offene Gesellschaft, Marktprozeß und Staatsaufgaben – Möglichkeiten und Grenzen ökonomischer Theorien zur Erklärung der Funktionsweise offener Sozialsysteme und zur Legitimation staatlichen Handelns in offenen Gesellschaften. Baden-Baden: Nomos.

Bayerische Rückversicherung (ed.) (1987): Gesellschaft und Unsicherheit. Karlsruhe: Versicherungswirtschaft e.V.

Bazzaz, F. A. (1986): Life history of colonizing plants: Some demographic, genetic and physiological features. In: Mooney, H. A. and Drake, J. A. (eds.): Ecology of biological invasions of North America and Hawaii. Berlin, Heidelberg, New York: Springer, 96–110.

Bechmann, G. (1990): Großtechnische Systeme, Risiko und gesellschaftliche Unsicherheit. In: Halfmann, J. and Japp, K. P. (eds.): Riskante Entscheidungen und Katastrophenpotentiale. Elemente einer soziologischen Risikoforschung. Opladen: Westdeutscher Verlag, 129–149.

Bechmann, G. (1994): Risiko und gesellschaftlicher Umgang mit Unsicherheit. Probleme und Perspektiven. Österreichische Zeitschrift für Soziologie 4, 8–33.

Beck, T. (1995): How the poor fight for respect and resources in village India. Human Organization 54 (2), 169–191.

Beck, U. (1986): Risikogesellschaft. Auf dem Weg in eine andere Moderne. Frankfurt/M.: Suhrkamp.

Becker, U. (1993): Risikowahrnehmung der Öffentlichkeit und neue Konzepte unternehmerischer Risikokommunikation. In: Rück, B. (ed.): Risiko ist ein Konstrukt. Munich: Knesebeck, 343–363.

Bederman, D. J. (1990): International control of marine pollution by exotic species. Ecology Law Quarterly 18 (4), 677–717.

Begon, M., Harper, J. L. and Townsend, C. R. (1996): Ecology. Individuals, populations and communities. Boston: Blackwell.

Bell, P. A., Fisher, J. D., Baum, A. and Greene, T. C. (1996): Environmental psychology. Fort Worth: Harcourt Brace.

Belshe, R. B. (1998): Influenza as a zoonosis: How likely is a pandemic? Lancet 351, 460–461.

Berg, B. and Matzner, E. (1997): Effect of N deposition on decomposition of plant litter and soil organic matter in forest systems. Environmental Review 5, 1–25.

Berg, M., Erdmann, G., Hartmann, M., Jaggy, M., Scheringer, M. and Seiler, H. J. (eds.) (1994): Was ist ein Schaden? Zur normativen Dimension des Schadensbegriffs in der Risikowissenschaft. Dokumente Nr. 2. Zürich: Vdf Hochschulverlag.

Berg, M., Erdmann, G., Leist, A., Renn, O., Schaber, P., Scheringer, M., Seiler, H. J. and Wiedemann, R. (eds.) (1995): Risikobewertung im Energiebereich. Zürich: Vdf Hochschulverlag.

Bergmann, H., Brockmann, K. L. and Rennings, K. (1996): Möglichkeiten und Grenzen von freiwilligen Umweltschutzmaßnahmen der Wirtschaft unter ordnungspolitischen Aspekten. Kurzfassung des Endberichtes. Mannheim: Institut für Europäische Wirtschaftsforschung.

Berner, E. K. and Berner, R. A. (1996): Global environment: Water, air and geochemical cycles. New Jersey: Prentice Hall.

Beroggi, G. E. G. and Kröger, W. (1993): Risikoanalyse technischer Systeme. Methoden und Modelle, Verfahren und Hilfsmittel. Schweizer Ingenieur und Architekt 47, 877–883.

Beroggi, G. E. G., Abbas, T. C., Stoop, J. A. and Aebi, M. (1997): Risk assessment in the Netherlands. Arbeitsbericht Nr. 91 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.

Berz, G. (1997a): Changing weather extremes: the viewpoint of the international reinsurer. Munich: Münchner Rückversicherung.

Berz, G. (1997b): Naturkatastrophen – Auffangnetz Rückversicherung. Spektrum der Wissenschaften 2, 101–104.

BfN – Bundesamt für Naturschutz (1997): Erhaltung der biologischen Vielfalt. Bonn: BfN.

Biermann, F., Petschel-Held, G. and Rohloff, C. (1998a): Integrated assessment of environmental security. The syndrome-based approach to conflict research. Paper prepared for the Pilot Study 'Environment and Security in an International Context' of the Committee on the Challenges of Modern Society (CCMS) of the NATO. Bremerhaven, Potsdam, Heidelberg: Mimeo.

Biermann, F., Petschel-Held, G. und Rohloff, C. (1998b): Umweltdegradation als Konfliktursache? Theoretische Konzeptualisierung und empirische Untersuchung des Zusammenhangs von 'Umwelt' und 'Sicherheit'. Zeitschrift für Internationale Beziehungen 5 (2), 273-308.

Birnbacher, D. (1994): Das Risiko in einer prozeduralen Risikoethik. Ethik und Sozialwissenschaften. Zeitschrift für Erwägungskultur 5 (1), 137–139.

Blaschczok, A. (1993): Gefährdungshaftung und Risikozuweisung. Köln: Heymann.

Blatter, R. and Wolfe, M. S. (1996): Die Verwendung molekularbiologischer Technologien zur Erzeugung von Wirtsresistenz gegen Schaderreger. Mögliche Folgen einer Anpassung der Krankheiten und Schädlinge. In: Schulte, E. and Käppeli, O. (eds.): Gentechnisch veränderte krankheits- und schädlingsresistente Nutzpflanzen – Eine Option für die Landwirtschaft? BATS (Biosafety Research and Assessment of Technology Impacts of the Swiss Priority Programm Biotechnology) – TA Hefte. Bern: Schweizerischer Nationalfonds, 253–295.

Bleischwitz, R. (1998): Ressourcenproduktivität. Berlin, Heidelberg, New York: Springer.

Bloom, B. R. and Small, P. M. (1998): The evolving relation between humans and *Mycobacterium tuberculosis*. The New England Journal of Medicine 338, 677–678.

BMBF – Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (1997): Bekanntmachung der Förderrichtlinien 'BioMonitor' im Programm der Bundesregierung 'Biotechnologie 2000'. Internet location http://www.bmbf.de/foerderprog/biomon.htm. Bonn: BMBF.

BMFT – Bundesministerium für Forschung und Technologie (1987): Klimaprobleme und ihre Erforschung. Bonn: BMFT.

BML – Bundesministerium für Ernährung, Landwirtschaft und Forsten, ZADI – Zentralstelle für Agrardokumentation und -information and IGR – Informationszentrum für Genetische Ressourcen (1997): Special Volume 4. Internationale Technische Konferenz der FAO über Pflanzengenetische Ressourcen. Konferenzbericht, Leipziger Deklaration, Globaler Aktionsplan und Weltzustandsbericht. Bonn: ZADI.

BMU – Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (ed.) (1996): Umweltbewußtsein in Deutschland. Ergebnisse einer repräsentativen Bevölkerungsumfrage 1996. Bonn: BMU.

BMU – Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (ed.) (1998): Umweltgesetzbuch (UGB-KomE)-Entwurf der unabhängigen Sachverständigenkommission zum Umweltgesetzbuch beim Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. Berlin: Dunkker & Humblot.

BMZ – Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (ed.) (1997): Grundlagen der deutschen Entwicklungszusammenarbeit. Bonn: BMZ.

BMZ – Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (ed.) (1998): Deutsche Entwicklungspolitik. Ausgewählte Reden (1995–1998) von Carl-Dieter Spranger. Bonn: BMZ.

Bobbink, R., Boxman, D., Fremstad, E., Heil, E., Houdijk, A. and Roeloefs, J. (1992): Critical loads for nitrogen eutrophication of terrestrial and wetland ecosystems based upon changes in vegetation and fauna. In: Grennfelt, P. and Thörnelof, E. (eds.): Critical loads for nitrogen. Copenhagen: Nordic Council of Ministers, 111–159.

Bodewig, T. (1985): Probleme alternativer Kausalität bei Massenschäden. Archiv für die civilistische Praxis 185, 505–558.

Bohle, H.-G. (1994): Dürrekatastrophen und Hungerkrisen. Sozialwissenschaftliche Perspektiven geographischer Risikoforschung. Geographische Rundschau 46 (7–8), 400–407.

Bohle, H.-G., Downing, T. E. and Watts, M. J. (1994): Climate change and social vulnerability: Toward a sociology and geography of food insecurity. Global Environmental Change 4 (1), 37–49.

Bohle, H.-G., Mayer, M. and Weber, E. (1998): Livelihood security and vulnerability in Nepal, India and Sri Lanka. Bulletin of the International Geographical Union (IGU) 48 (1), 5–19.

Böhler, D. (1995): Ethik für die Zukunft erfordert Institutionalisierung von Diskurs und Verantwortung. In: Jänicke, M., Bolle, H.-J. and Carius, A. (eds.): Umwelt Global. Veränderungen, Probleme, Lösungsansätze. Berlin, Heidelberg, New York: Springer, 239–248.

Böhme, G. (1993): Fuzzy-Logik – Einführung in die algebraischen und logischen Grundlagen. Berlin, Heidelberg, New York: Springer.

Bolin, B. (1997): Scientific assessment of climate change. In: Fermann, G. (ed.): International politics of climate change: key issues and critical actors. Oslo: Scandinavian University Press, 83–109.

Bonß, W. (1991): Unsicherheit durch Gesellschaft – Argumente für eine soziologische Risikoforschung. Soziale Welt 2, 258–277.

Bonß, W. (1996): Die Rückkehr der Unsicherheit. Zur gesellschaftstheoretischen Bedeutung des Risikobegriffes. In: Banse, G. (ed.): Risikoforschung zwischen Disziplinarität und Interdisziplinarität. Berlin: Edition Sigma, 166–185.

Borsch, P. and Münch, E. (1983): Die Sicherheit von Kernkraftwerken. In: Münch, E. (ed.): Tatsachen über Kernenergie. Essen, Munich: Girardet, ETV, 37–52.

Bradbury, J. A. (1989): The policy implications of differing concepts of risk. Science, Technology, and Human Values 14 (4), 380–399.

Brandt, P. (1995): Transgene Pflanzen. Basel: Birkhäuser.

Brauch, H. G. (1997): Weltweite Abschaffung der Chemiewaffen in Sicht. Von der Unterzeichnung zum Inkrafttreten des Übereinkommens. Vereinte Nationen 45 (3), 94–101.

Braun, R. and Feudel, F. (1996): Supertransient chaos in the two-dimensional complex Ginzburg-Landau equation. Physical Review E 53(6), 6562–6565.

Brehmer, B. (1987): The psychology of risk. In: Singleton, W. T. and Howden, J. (eds.): Risk and decisions. Chichester, New York: Wiley, 25–39.

Breidenbach, S. (1995): Mediation. Struktur, Chancen und Risiken von Vermittlung im Konflikt. Köln: Schmidt.

Breuer, R. (1986): Eingriffsmöglichkeiten nach dem Chemikaliengesetz. In: Gesellschaft für Rechtspolitik (ed.): Chemikaliengesetz. Volume 3. Munich: Beck, 155–305.

Broecker, W. S. (1997): Thermohaline circulation, the Achilles heel of our climate system: Will man-made CO_2 upset the current balance? Science 278, 1582–1588.

Brösse, U. (1995): Planungsorientierte Umweltpolitik. In: Junkernheinrich, M., Klemmer, P. and Wagner, G. R. (eds.): Handbuch zur Umweltökonomie. Berlin: Analytica, 204–210.

Brown, D. (1993): Breaking the cycle: environmental control of *Borrelia*. Annuals of the Rheumatic Diseases 52, 407.

Brown, H. and Goble, R. (1990): The role of scientists in risk assessment. Risk: Issues in Health and Safety VI, 283–311.

Brüggemeier, G. (1989): Umwelthaftungsrecht – Ein Beitrag zum Recht der 'Risikogesellschaft'. Kritische Justiz 22 (1), 209–230.

Brun-Vezinet, F., Rouziouc, C., Barre-Sinousi, F., Klatzmann, D., Saimot, A. G., Rotenbaum, W., Christol, D., Gluckman, J. C., Montagnier, L. and Chermann, J. C. (1984): Detection of IgG antibodies to lymphadenopathy-associated virus in patients with AIDS or Lymphadenopathy Syndrome. Lancet 1, 8389, 1253–1256.

Bryceson, D. F. (1990): Food insecurity and the social division of labour in Tanzania, 1919–85. New York: St. Martin's Press.

BUA – Beratergremium für umweltrelevante Altstoffe der Gesellschaft Deutscher Chemiker (ed.) (1976): Auswahlkriterien und Stoffliste. Weinheim: VCH.

Budyko, M. I. (1969): The effect of solar radiation variations on the climate of the Earth. Tellus 21, 611–619.

Buergenthal, T. (1969): Law-making in the international civil aviation organization. New York: Syracuse University Press.

Burkholder, J. M. and Glasgow jr., H. B. (1997): *Pfiesteria piscicida* and other *Pfiesteria*-like dinoflagellates: behavior, impacts, and environmental controls. Limnology and Oceanography 42 (5 Part 2), 1052–1075.

Burns, T. R. and Überhorst, R. (1988): Creative democracy: systematic conflict resolution and policymaking in a world of high science and technology. Westport, CT., London: Praeger.

Burton, I., Kates, R. and White, G. (1978): The environment as hazard. Oxford, N.Y.: Oxford University Press.

California Environmental Protection Agency (1994): Toward the 21st century. Planning for protection of California's environment. Final Report. Sacramento, Ca.: EPA.

Callahan, M. A., Slimak, M. W. and Gabel, N. W. (1979): Water-related environmental fate of 129 priority pollutants. Volume 1 und 2. Washington, DC: U.S. Environmental Protection Agency.

Calließ, J. (ed.) (1995): Treiben Umweltkonflikte in Gewaltkonflikte? Ökologische Konflikte im internationalen System und Möglichkeiten ihrer friedlichen Bearbeitung. Rehburg-Loccum: Loccumer Protokolle.

Cansier, D. (1996): Umweltökonomie. Stuttgart: Lucius & Lucius.

Carius, A. and Lietzmann, M. K. in collaboration with Imbusch, K. (eds.) (1998): Umwelt und Sicherheit. Herausforderungen für die internationale Politik. Berlin, Heidelberg, New York: Springer.

Carusi, A., Gehrels, T., Hlin, E. F., Marsden, B. G., Russel, K. S., Shomaker, C. S., Shoemaker, E. M. and Steel, D. I. (1994): Near-earth objects: present search programs. In: Gehrels, T. (ed.): Hazards due to comets and asteroids. Tuscon: University of Arizona Press, 127–147.

Cassel-Gintz, M. A., Lüdeke, M. K. B., Petschel-Held, G., Reusswig, F., Plöchl, M., Lammel, G. and Schellnhuber, H.-J. (1997): Fuzzy logic based global assessment of the marginality of agricultural land use. Climate Research 8, 135–150.

CDC – Centers for Disease Control and Prevention (1996): L 285 Slide Series. Atlanta, GA : CDC.

CDC – Centers for Disease Control and Prevention (1997): L 178 Slide Series. Atlanta, GA: CDC.

Chambers, R. (1989): Vulnerability, coping and policy. IDS Bulletin 20, 1–7.

Chambers, R. (1997): Whose reality counts: putting the first last. London: Intermediate Technology Publications.

Chapin III, F. S., Sala, O. E., Burke, I. C., Grime, J. P., Hooper, D. U., Lauenroth, W. K., Amanda, L., Mooney, H. A., Mosier, A. R., Naeem, S., Pacala, S. W., Roy, J., Steffen, W. L. and Tilman, D. (1998): Ecosystem consequences of changing biodiversity. Bioscience 48, 45–52.

Chapin, F. S., Schulze, E. D. and Mooney, H. A. (1990): The ecology and economics of storage in plants. Annual Review of Ecology and Systematics 21, 423–447.

Chen, M. A. (1991): Coping with seasonality and drought. New Delhi, Newbury Park, London: Sage Publications.

Claas, E. C. J., Osterhaus, A. D. M. E., van Beek, R., De Jong, J. C., Rimmelzwaan, G. F., Senne, D. A., Krauss, S., Shortridge, K. F. and Webster, R. G. (1998): Human Influenza A H5N1 Virus related to a highly pathogenic avian influenza virus. Lancet 351, 472–477.

Clarke, L. (1989): Acceptable risk? Making choices in a toxic environment. Berkeley: University of California Press.

Clausen, L. (ed.) (1993): Sozialwissenschaften. In: Plate, E. and Plate, A. (eds.): Naturkatastrophen und Katastrophenvorbeugung. Bericht des wissenschaftlichen Beirats für das Deutsche IDNDR Komitee. Weinheim: VCH, 73–147.

Coenen, R. (1997): Die internationale Klimapolitik und die Klimarahmenkonvention. In: Kopfmüller, J. and Coenen, R. (eds.): Risiko Klima. Frankfurt/M.: Campus, 159–200.

Collingridge, D. (1996): Resilience, flexibility, and diversity in managing the risks of technologies. In: Hood, C. and Jones, D. K. C. (eds.): Accident and design. Contemporary debates in risk management. London: UCL-Press, 40–45.

Connell, J. H. (1978): Diversity in tropical rain forests and coral reefs. Science 199, 1302–1310.

Costanza, R. and Perrings, C. (1990): A flexible assurance bonding system for improved environmental management. Ecological Economics 2, 57–75.

Costanza, R., Darge, R., de Groot, R., Farber, S. Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van den Beld, M. (1997): The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Council on Environmental Quality (1980): The Global 2000 Report to the President. Washington, DC: United States Government Printing Office.

Covello V. T., Menkes, J. and Mumpower, J. (eds.) (1984): Risk evaluation and management. New York, London: Plenum Press, 275–296.

Covello, V. T. (1983): The perception of technological risks: A literature review. Technological Forecasting and Social Change 23, 285–297.

Covello, V. T. (1991): Risk comparisons and risk communication: issues and problems in comparing health and environmental risks. In: Kasperson, R. E. and Stallen, P. M. (eds.): Communicating risk to the public. Dordrecht: Kluwer, 79–124.

Covello, V. T. (1998): Risk perception, risk communication, and EMF exposure: tools and techniques for communicating risk information. In: Matthes, R., Bernhardt, J. H. and Repacholi, M. H. (eds.): Risk perception, risk communication and its application to EMF exposure. Proceedings of the International Seminar on Risk Perception, Risk Communication and its Application to EMF Exposure. Vienna, Austria, October 22 and 23, 1997. Vienna: International Commission on Non-Ionizing Radiation Protection and World Health Organization, 179–213.

Covello, V. T. and Mumpower, J. (1985): Risk analysis and risk management: a historical perspective. Risk Analysis 5 (2), 103–120.

Crooks, J. and Soulé, M. E. (1996): Lag times in population explosions of invasive species: causes and implications. In: Sandlund, O. T., Schei, P. J. and Viken, Å. (eds.): Proceedings of the Norway/UN Conference on Alien Species, Trondheim, 1–5 July 1996. Trondheim: Directorate for Nature Management (DN). Norwegian Institute for Nature Research (NINA), 39–46.

Crouch, E. A. C. and Wilson, R. (1982): Risk benefit analysis. Cambridge: Ballinger.

Crutzen, P. (1987): Acid rain at the K/T boundary. Nature 330, 108–109.

D'Antonio, C. M. and Vitousek, P. M. (1992): Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Revue of Ecology and Systematics 23, 63–87.

Dake, K. (1991): Orienting dispositions in the perceptions of risk: an analysis of contemporary worldviews and cultural biases. Journal of Cross-cultural Psychology 22, 61–82.

Daviaud, F., Bergé, P., Dubois, M., Lega, J. and Coullet, P. (1992): Spatial-temporal intermittency in a 1{D}convective pattern: theoretical model and experiments. Physica D 55 (3–4), 287–308.

David, P. A. (1985): Clio and the economics of QWERTY. The American Economic Review 75, 332–337.

de Garine, I. and Harrison, G. A. (eds.) (1988): Coping with uncertainty in food supply. Oxford: Oxford University Press.

de Geus, A. P. (1992): Modelling to predict or to learn. European Journal of Operational Research 59, 1–5.

de Kathen, A. (1996): Gentechnik in Entwicklungsländern. Ein Überblick: Landwirtschaft. Berlin: Umweltbundesamt (UBA).

deMenocal, P. B. and Bond, G. (1997): Holocene climate less stable than previously thought. Eos 78, 447–454.

Deml, R. (1998): Risiken der Freisetzung transgener Pflanzen mit verbesserter Insektenresistenz (B.t.-Endotoxine). Expertise for WBGU. Mimeo.

Derby, S. L. and Keeney, R. L. (1981): Risk analysis: understanding 'how safe is safe enough'. Risk Analysis 1 (3), 217–224.

Deutsche Stiftung Weltbevölkerung (1998): Bevölkerung und nachhaltige Entwicklung. Hannover: Deutsche Stiftung Weltbevölkerung.

DFG – Deutsche Forschungsgemeinschaft. Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe (1997): MAK- und BAT-Werte-Liste. Maximale Arbeitsplatzkonzentrationen und biologische Arbeitsstofftoleranzwerte. Weinheim: VCH.

DFG – Deutsche Forschungsgemeinschaft. Senatskommission zur Beurteilung der gesundheitlichen Unbedenklichkeit von Lebensmitteln (1998): Lebensmittel und Gesundheit. Weinheim: Wiley-VCH.

Dienel, P. C. (1978): Die Planungszelle. Opladen: Westdeutscher Verlag.

Dienel, P. C. and Renn, O. (1995): Planning cells: a gate to 'fractal' mediation. In: Renn, O., Webler, T. and Wiedemann, P. (eds.): Fairness and competence in citizen participation. Evaluating new models for environmental discourse. Dordrecht: Kluwer, 117–140.

Diesfeld, H. J. (1997): Malaria auf dem Vormarsch? Geographische Rundschau 49, 232–239.

Diffey, B. (1998): Sun-light, skin cancer and ozone depletion. The Globe 42, 10–11.

Dixon, R. K. and Wisniewski, J. (1995): Global forest systems: An uncertain response to atmospheric pollutants and global climate change? Water, Air and Soil Pollution 85, 101–110.

Dörner, D. (1989): Die Logik des Mißlingens. Strategisches Denken in komplexen Situationen. Reinbek: Rowohlt.

Dörner, D. (1993): Denken und Handeln in Unbestimmtheit und Komplexität. Gaia 2 (3), 128–138.

Douglas, M. (1966): Purity and danger: concepts of Pollution of Taboo. London: Routledge and Kegan Paul.

Douglas, M. and Wildavsky, A. (1982): Risk and culture. An essay on the selection of technological and environmental dangers. Berkeley: University of California Press.

Downing, T. E. (1991): Assessing socio-economic vulnerability to famine. Research Report, Alan Shawn Feinstein Hunger Program. Providence, RI: Brown University.

Downing, T. E. (1992): Climate change and vulnerable places: global food security and country studies in Zimbabwe, Kenya, Senegal and Chile. Oxford: Oxford University Press.

Downing, T. E. (1993): Concepts of vulnerability to hunger and applications for monitoring famine in Africa. In: Bohle, H.-G. (ed.): Coping with vulnerability and criticality. Saarbrücken, Fort Lauderdale: Breitenbach, 205–259.

Drake, B. G., Gonzàles–Meler, M. and Long, S. P. (1997): More efficient plants: a consequence of rising atmosphere CO_2? Annual Reviews of Plant Physiology and Plant Molekular Biology 48, 609–639.

Drake, J. A., Mooney, H. A., di Castri, F., Groves, R. H., Kruger, F. J., Rejmánek, M. and Williamson, M. (eds.) (1989): Biological invasions. Chichester, New York: Wiley.

Driesel, A. J. and Danneberg, G. (1996): Stand der Sicherheitsforschung zur Freisetzung transgener Organismen. Berlin: Umweltbundesamt (UBA).

DRK – Deutsches Rotes Kreuz (1997): Weltkatastrophenbericht des Deutschen Roten Kreuzes. Bonn: DRK.

Drottz-Sjöberg, B.-M. (1991): Perception of risk. Studies of risk attitudes, perceptions, and definitions. Stockholm: Center for Risk Research.

Duffing, G. (1918): Erzwungene Schwingungen bei veränderlicher Eigenfrequenz und ihre technische Bedeutung. Braunschweig: Vieweg.

Dyck, S. and Peschke, G. (1997): Grundlagen der Hydrologie. Berlin: Verlag für Bauwesen.

Eberhardt, A. (1992): Verfahrensgestaltung der Umweltverträglichkeitsprüfung. Zeitschrift für angewandte Umweltforschung 5 (2), 166–183.

EC – European Commission (1993): Guidelines for risk analysis of technological systems. Report IEC-CD (Sec) 381 issues by the Technical Committee QMS/23. Brussels: EC.

EC – European Commission (1997): Study of nutritional factors in food allergies and food intolerances. Brussels: EC.

ECRHS – European Community Respiratory Health Survey (1996): Variations in the prevalence of respiratory symptoms, self-reported asthma attacks and use of asthma medication in the European Community Respiratory Health Survey (ECRHS). European Respiration Journal 9, 687–695.

Edelstein, M. R. and Wandersman, A. (1987): Community dynamics in coping with toxic contaminants. In: Altman, I. and Wandersman, A. (eds.): Neighborhood and community environments. Volume 9. Human Behavior and Environment – Advances in Theory and Research. New York, London: Plenum Press, 69–112.

Edwards, W. (1954): The theory of decision making. Psychological Bulletin (51), 380–417.

Edwards, W. (1968): Probabilistic information processing systems: design and evaluation. IEEE Transactions on Systems, Science and Cybernetics. SSC-4, 248–265.

Edwards, W. (1977): How to use multiattribute utility measurement for social decision making. IEEE Transactions on Systems, Science and Cybernetics 1 (2), 326–340.

Eikenberg, C. (1997): Journalistenhandbuch zum Katastrophenmanagement. Bonn: Deutsches IDNDR Komitee.

Elliott, E. (1988): Torts with multiple causes under U.S. law. In: Fenvyes, A. and Weyers, H.-L. (eds.): Multikausale Schäden in modernen Haftungsrechten. Frankfurt/M.: Metzner, 9–32.

Endres, A. (1992): Haftpflichtrecht und Verhütung von Umweltschäden. In: Endres, A., Rehbinder, E. and Schwarze, R. (eds.): Haftung und Versicherung für Umweltschäden aus ökonomischer und juristischer Sicht. Berlin, Heidelberg, New York: Springer, 1–33.

Endres, A. (1997): Incentive-based instruments in environmental policy: conceptual aspects and recent developments. Konjunkturpolitik – Zeitschrift für angewandte Wirtschaftsforschung 43 (4), 299–343.

Endres, A. and Schwarze, R. (1992): Gibt es Grenzen der Versicherbarkeit von Umweltrisiken? Eine ökonomisch-technische Analyse der Besonderheiten einer Umwelthaftpflicht-Versicherung. In: Endres, A., Rehbinder, E. and Schwarze, R. (eds.): Haftung und Versicherung für Umweltschäden aus ökonomischer und juristischer Sicht. Berlin, Heidelberg, New York: Springer, 83–117.

Erbguth, W. (1988): Rechtsdogmatische Grundfragen des Umweltrechts. Berlin: Duncker und Humblot.

Erdmann, G. and Wiedemann, R. (1995): Risikobewertung in der Ökonomik. In: Berg, M., Erdmann, G., Leist, A., Renn, O., Schaber, P., Scheringer, M., Seiler, H. and Wiedemann, R. (eds.): Risikobewertung im Energiebereich. Zürich: Vdf Hochschulverlag, 135–190.

Eucken, W. (1952): Grundsätze der Wirtschaftspolitik. Tübingen: Mohr.

Evans, G. and Cohen, S. (1987): Environmental stress. In: Stokols, F. and Altmann, I. (eds.): Handbook of environmental psychology. Chichester, New York: Wiley.

Evers, A. (1993): Umgang mit Unsicherheit. Zur sozialwissenschaftlichen Problematisierung einer sozialen Herausforderung. In: Bechmann, G. (ed.): Risiko und Gesellschaft. Grundlagen und Ergebnisse interdisziplinärer Risikoforschung. Opladen: Westdeutscher Verlag, 339–374.

Evers, A. and Nowotny, H. (1987): Über den Umgang mit Unsicherheit. Die Entdeckung der Gestaltbarkeit von Gesellschaft. Frankfurt/M.: Suhrkamp.

Ewald, F. (1993): Der Vorsorgestaat. Frankfurt/M.: Suhrkamp.

Ewen, C., Hahn, L. and Weber, B. (1998): Resilienzstrategien. Expertise for WBGU. Mimeo.

Fangmeier, A., Hadwiger–Fangmeier, A., van der Eerden, L. and Jäger, H.–J. (1994): Effects of atmospheric ammonia on vegetation – a review. Environmental Pollution 86, 43–82.

FAO – Food and Agricultural Organisation (1995): The digital soil map of the world. Rome: FAO.

FAO – Food and Agricultural Organisation (1996): Code of conduct for the import and release of exotic biological control agents. International Standards for Phytosanitary Measures. Part 1 – Import Regulations. Rome: FAO. Secretariat of the International Plant Protection Convention.

FAO – Food and Agricultural Organisation (1998): FAOSTAT nutrition data. Internet location http://apps.fao.org/cgi-bin/nph-db.pl?subset=nutrition. Rome: FAO.

Farinelli, L. and Malnoë, P. (1996): Heterologous encapsidation and recombination in transgenic plants containing viral sequences. In: Schulte, E. and Käppeli, O. (eds.): Gentechnisch veränderte krankheits- und schädlingsresistente Nutzpflanzen – Eine Option für die Landwirtschaft? BATS (Biosafety Research and Assessment of Technology Impacts of the Swiss Priority Programm Biotechnology) – TA Hefte. Bern: Schweizerischer Nationalfonds, 193–252.

Feinberg, M. (1980): Chemical oscillations, multiple equilibria and reaction network structure. In: Warren, E., Stewart, W., Ray, W.-H. and Conley, C.-C. (eds.): Dynamics and modelling of reactive systems. New York: Academic Press, 59ff.

Femers, S. and Jungermann, H. (1991): Risikoindikatoren. Eine Systematisierung und Diskussion von Risikomaßen und Risikovergleichen. Arbeiten zur Risiko-Kommunikation. Jülich: Forschungszentrum Jülich.

Findenegg, K. and Karl, H. (1998): Gefährdungshaftung und Innovation: Probleme der Haftung für Entwicklungsrisiken. Jena: University of Jena. Mimeo.

Fiorino, D. J. (1989): Technical and democratic values in risk analysis. Risk Analysis 9 (3), 293–299.

Fischer, D. (1973): Kosten-Nutzen-Analyse – Hilfe für rationale Entscheidungen. Zeitschrift für die gesamte Staatswissenschaft 129, 230–245.

Fischhoff, B. (1996): Public values in risk research. In: Kunreuther, H. and Slovic, P. (eds.): Challenges in risk assessment and risk management. Annals of the American Academy of Political and Social Science. Special Issue. Thousand Oaks: Sage, 75–84.

Fischhoff, B., Slovic, P. and Lichtenstein, S. (1985): Weighing the risks. In: Kates, R. W., Hohenemser, C. and Kasperson, J. X. (eds.): Perilous progress: Managing the hazards of technology. Boulder: Westview, 265–283.

Fischhoff, B., Slovic, P., Lichtenstein, S., Derby, S. L. and Keeney, R. L. (1981): Acceptable risk. Cambridge, New York: Cambridge University Press.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S. and Combs, B. (1978): How safe is safe enough? A psychometric study of attitudes toward technological risks and benefits. Policy Sciences 9, 127–152.

Fischhoff, B., Watson, S. R. and Hope, C. (1984): Defining risk. Policy Sciences 17, 123–129.

Fitchen, J. M., Heath, J. S. and Fessenden-Raden, J. (1987): Risk perception in community context: a case study. In: Johnson, B. B. and Covello, V. T. (eds.): The social and cultural construction of risk. Essays on Risk Selection and Perception. Dordrecht: Reidel, 31–49.

Flaig, H. and Mohr, H. (1996): Der überlastete Stickstoffkreislauf: Strategien einer Korrektur. Leipzig, Heidelberg: Barth.

Foster, D. R., Aber, J. D., Melillo, J. M., Bowden, R. D. and Bazzaz, F. A. (1997): Forest response to disturbance and anthropogenic stress. Bioscience 47, 437–445.

Fowlkes, M. and Miller, P. (1987): Chemicals and community at Love Canal. In: Johnson, B. B. and Covello, V. T. (eds.): The social and cultural construction of risk. Essays on risk selection and perception. Dordrecht: Reidel, 55–80.

Fox, G., Gilman, A., Peakall, D. and Anderka, F. (1978): Behavioral abnormalities of nestling Lake Ontario gulls. Journal of Wildlife Management 42 (3), 477–483.

Franck-Oberaspach, S. and Keller, B. (1996): Produktesicherheit von krankheitsresistenten Nutzpflanzen: Toxikologie, allergenes Potential, Sekundäreffekte und Markergene. In: Schulte, E. and Käppeli, O. (eds.): Gentechnisch veränderte krankheits- und schädlingsresistente Nutzpflanzen – Eine Option für die Landwirtschaft? BATS (Biosafety Research and Assessment of Technology Impacts of the Swiss Priority Programm Biotechnology) – TA Hefte. Bern: Schweizerischer Nationalfonds, 17–100.

Freemann, P. K. and Kunreuther, H. (1997): Managing environmental risk through insurance. Dordrecht: Kluwer.

Friehe, H.-J. (1992): Der Ersatz ökologischer Schäden nach dem Konventionsentwurf des Europarates zur Umwelthaftung. Natur und Recht 14 (10), 453–459.

Friehe, H.-J. (1995): Die Europarats-Konvention zur Umwelthaftung. Natur und Recht 14 (10), 512–515.

Fritzsche, A. F. (1986): Wie sicher leben wir? Risikobeurteilung und -bewältigung in unserer Gesellschaft. Cologne: TÜV Rheinland.

Frowein, J. A. (1991): Kapitel VII. Maßnahmen bei Bedrohung oder Bruch des Friedens. In: Simma, B. (ed.): Charta der Vereinten Nationen. Munich: Beck, 559–595.

Führ, M. (1994): Proaktives unternehmerisches Handeln – Unverzichtbarer Beitrag zum präventiven Stoffstrommanagement. Zeitschrift für Umweltpolitik und Umweltrecht 17 (4), 445–472.

Gäfgen G. (1963): Theorie der wirtschaftlichen Entscheidung. Tübingen: Mohr.

Gallo, R. C. and Reitz jr., M. S. (1985): The first human retroviruses: are there others? Microbiological Science 2, 101–104.

Ganten, R. (1997): Internationale Gefahrguthaftung beim Seetransport. Transportrecht 1997, 397–403.

Gawel, E. (1997): Reguliertes Wissen um Unwissen. Zur Generierung und Distribution von Risikoinformationen aus ökonomischer Sicht. In: Hart, D. (ed.): Privatrecht im 'Risikostaat'. Baden-Baden: Nomos, 265–323.

GDCh – Gesellschaft deutscher Chemiker (no year): Informationsbroschüre der Gesellschaft deutscher Chemiker. Frankfurt: GDCh.

Gebhard, F. and Smalla, K. (1998): Transformation of *Acinetobacter* sp. Strain BD413 by transgenic sugar beet DNA. Applied and Environmental Microbiology 64 (4), 1550–1554.

Gersonde, R., Kyte, F. T., Bleil, U., Diekmann, B., Flores, J. A., Gohl, K., Grahl, G., Hagen, R., Kuhn, G., Sierro, F. J., Völker, D., Abelmann, A. and Bostwick, J. A. (1997): Geological record and reconstruction of the late Pliocene impact of the Eltanin asteroid in the Southern Ocean. Nature 390, 357–363.

Gethmann, C. F. (1993): Zur Ethik des Handelns unter Risiko im Umweltstaat. In: Gethmann, C. F. and Klöpfer, M. (eds.): Handeln unter Risiko im Umweltstaat. Berlin: de Gruyter, 1–54.

Giam, C. S., Atlas, E., Powers, M. A. and Leonard, J. E. (1984): Phthalic acid esters. In: Hutzinger, O. (ed.) (1984): Handbook of environmental chemistry. Volume 3C. Berlin, Heidelberg, New York: Springer, 67–142.

Giegel, H.-J. (1992): Kommunikation und Konsens in modernen Gesellschaften. In: Giegel, H.-J. (ed.): Kommunikation und Konsens in modernen Gesellschaften. Frankfurt/M.: Suhrkamp, 7–17.

Giles, G. G., Armstrong, B. K., Burton, R. C., Staples, M. P. and Thursfield, V. J. (1996): Has mortality from melanoma stopped rising in Australia? Analysis of trends between 1931 and 1994. BMJ 312, 1121–1125.

Godt, C. (1997): Haftung für ökologische Schäden. Verantwortung für Beeinträchtigungen des Allgemeingutes Umwelt durch individualisierbare Verletzungshandlungen. Berlin: Duncker & Humblot.

Gould, L. C., Gardner, G. Y., DeLuca, D. R., Tieman, A., Doob, L. W. and Stolwijk, J. A. J. (1988): Perceptions of technological risk and benefits. New York: Russell Sage Foundation.

Graham, J. D., Green, L. C. and Roberts, M. J. (1988): In search of safety. Chemicals and cancer risk. Cambridge, Ma.: Harvard University Press.

Grebogi, C. and Kurths, J. (eds.) (1995): Structure formation in continuous dynamical systems. Special issue of chaos solutions & fractals. Amsterdam: Elsevier.

Greene, A. E. and Allison, R. F. (1994): Recombination between viral RNA and transgenic plant transcripts. Science 263, 1423–1425.

Gregory, P., Ingram, J., Campbell, B., Goudriaan, J., Hunt, T., Landsberg, J., Linder, S., Smith, M. S., Sutherst, B. and Valentin, C. (1998): Managed production systems. In: Walker, B., Steffen, W., Canadell, J. and Ingram, J. (eds.): The terrestrial biosphere and global change. Cambridge, New York: Cambridge University Press (in print).

Grime, J. P. (1977): Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. American Naturalist 11, 1169–1194.

Grünewald, U. (1998): Interdisziplinäre Studie zu Ursachen, Verlauf und Folgen des Sommer-Hochwassers 1997 an der Oder sowie Aussagen zu bestehenden Risikopotentialen. Cottbus: IDNDR.

Guckenheimer, J. and Holmes, P. (1990): Nonlinear oscillations, dynamical systems, and bifurcations of vector fields. Berlin, Heidelberg, New York: Springer.

Gülden, M., Turan, A. and Seibert, H. (1997): Substanzen mit endokriner Wirkung in Oberflächengewässern. Berlin: Umweltbundesamt (UBA).

Gundersen, P., Emmett, B. A., Kjonaas, O. J., Koopmans, C. J. and Tietema, A. (1998): Impact of nitrogen deposition on nitrogen cycling in forests – a synthesis of Nitrex data. Forest Ecology and Management 101 (1–3), 37–55.

Gupta, A. (1999): Framing 'biosafety' in an international context. The Biosafety Protocol negotiations. ENRP Discussion Paper. Cambridge, Ma.: Harvard University. John F. Kennedy School of Government.

Guski, R., Matthies, E. and Höger, R. (1991): Psychosomatische Auswirkungen von Altlasten und deren Sanierung auf die Wohnbevölkerung. Bochum: University of Bochum.

Habermas, J. (1971): Vorbereitende Bemerkungen zu einer Theorie der kommunikativen Kompetenz. In: Habermas, J. and Luhmann, N. (eds.): Theorie der Gesellschaft oder Sozialtechnologie. Was leistet die Systemforschung? Frankfurt/M.: Suhrkamp, 101–141.

Habermas, J. (1992): Faktizität und Geltung. Beiträge zur Diskurstheorie des Rechts und des modernen Rechtsstaates. Frankfurt/M: Suhrkamp.

Häfele, W., Renn, O. and Erdmann, H. (1990): Risiko, Unsicherheit und Undeutlichkeit. In: Häfele, W. (ed.): Energiesysteme im Übergang – Unter den Bedingungen der Zukunft. Landsberg/Lech: Poller, 373–423.

Hager, J. (1997): Europäisches Umwelthaftungsrecht. Zeitschrift für Europäisches Privatrecht 5 (1) 9–40.

Hahn, H. (1995): International controls. In: Bernhardt, R. (ed.): Encyclopedia of international law. Amsterdam: Elsevier, 1079–1084.

Hailbronner, K. (1995): International Civil Aviation Organization. In: Bernhardt, R. (ed.): Encyclopedia of international law. Amsterdam: Elsevier.

Haines, A. and McMichael, A. (1998): Focus on global change and human health. The Globe 42, 1–3.

Haller, M. (1990): Risiko-Management und Risiko-Dialog. In: Schüz, M. (ed.): Risiko und Wagnis: Die Herausforderung der industriellen Welt. Volume 1. Pfullingen: Neske, 229–256.

Hampel, J. (1998): Die europäische Öffentlichkeit und die Gentechnik. Arbeitsbericht Nr. 111 der Akademie für Technikfolgenabschätzung in Baden-Württemberg. Stuttgart: Akademie für Technikfolgenabschätzung.

Hampel, J., Keck, G., Peters, H .P., Pfenning, U., Renn, O., Ruhrmann, G., Schenk, M., Sonje, H. D., Stegat, B., Urban, D., Wiedemann, P. M. and Zwick, M. (1997): Einstellungen zur Gentechnik. Tabellenband zum Biotech-Survey des Forschungsverbunds 'Chancen und Risiken der Gentechnik aus der Sicht der Öffentlichkeit'. Arbeitsbericht Nr. 87 der Akademie für Technikfolgenabschätzung in Baden-Württemberg. Stuttgart: Akademie für Technikfolgenabschätzung.

Hampicke, U. (1991): Kosten und Wertschätzung des Arten- und Biotopschutzes. UBA Forschungsbericht 3/91. Berlin: Schmidt.

Hansmeyer, K.-H. and Rürup, B. (1975): Staatswirtschaftliche Planungsinstrumente. Tübingen: Mohr.

Harriss, R. C., Hohenemser, C. and Kates, R. W. (1979): The burden of technological hazads. In: Goodman, G. T. and Rowe, W. D. (eds.): Energy risk management. London: Academic Press, 103–138.

Hartkopf, G. and Boehme, E. (1983): Die Ausgangssituation unserer Umweltpolitik. Aus Politik und Zeitgeschichte 42, 3–12.

Hartwig, S. (1998): Anwendung des Risikomanagements im Bereich Technik/Technologie zur Minderung globaler Umweltrisiken. Expertise for WBGU. Mimeo.

Hartwig, S. (1998): Infrared active gases are likely to change the dynamics and the stability of the atmosphere. Atmospheric Environment (in print).

Harvey, C. M. (1985): Decision analysis models for risk in distant futures. In: Lave, L. B. (ed.): Risk assessment and management. New York, London: Plenum Press, 509–558.

Hattis, D. and Minkowitz, W. S. (1997): Risk evaluation: legal requirements, conceptual foundations, and practical experiences in the United States. Arbeitsbericht Nr. 93 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.

Hauptmanns, U. (1997): Risk assessment in the Federal Republic of Germany. Arbeitsbericht Nr. 94 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.

Hauptmanns, U., Herttrich, M. and Werner, W. (1987): Technische Risiken: Ermittlung und Beurteilung. Berlin, Heidelberg, New York: Springer.

Hazard, B. and Seidel, G. (1993): Informationsbedingte und psychosoziale Ursachen für die Angst vor Gesundheitsschäden durch Radon. In: Aurand, K., Hazard, B. and Tretter, F. (eds.): Umweltbelastungen und Ängste. Opladen: Westdeutscher Verlag, 113–132.

Hecht, D. (1998): Stoffpolitik jenseits des Dirigismus. In: Klemmer, P., Becker-Soest, D. and Wink, R. (eds.): Liberale Grundrisse einer zukunftsfähigen Gesellschaft. Baden-Baden: Nomos, 409–425.

Hegerl, G. C., Hasselmann, K., Cubasch, U., Mitchell, J. F. B., Roeckner, E., Voss, R. and Waszkewitz, J. (1997): On Multifingerprint detection and attribution of greenhouse gas and aerosol forced climate change. Climate Dynamics 13, 613–634.

Heidenreich, B. (1998): Horizontaler Gentransfer. In: UBA – Umweltbundesamt (ed.): Nutzung der Gentechnik im Agrarsektor der USA. UBA Texte 47/98. Volume 1. Berlin: UBA, 157–237.

Hemmelskamp, J. (1997): Umweltpolitik und Innovation – Grundlegende Begriffe und Zusammenhänge. Zeitschrift für Umweltpolitik & Umweltrecht 20 (4), 481–511.

Hemmelskamp, J. and Neuser, U. (1994): Die EG-Umwelt-Audit-Verordnung – Anreiz zu Innovationen oder zu potemkinschen Dialogen? Environmental Economics and Logistics Series. Mannheim: Zentrum für Europäische Wirtschaftsforschung (ZEW).

Hendrickx, F., Koester, V. and Prip, C. (1993): Convention on Biological Diversity access to genetic resources: a legal analysis. Environmental Policy and Law 23 (6), 250ff.

Herbst, C. (1996): Risikoregulierung durch Umwelthaftung und Versicherung. Berlin: Duncker & Humblot.

Herd, R. M., Tidman, M. J., Prescott, R. J. and Hunter, J. A. A. (1996): The cost of atopic eczema. British Journal of Dermatology 135, 20–23.

Hermanns, K. (1998): Das Öko-Audit – Aktuelle Trends. Zeitschrift für angewandte Umweltforschung 11 (2), 287–289.

Hester, G. L. (1998): Mental models and EMF risk perceptions of the U.S. general public. In: Matthes, R., Bernhardt, J. H. and Repacholi, M. H. (eds.): Risk perception, risk communication and its application to EMF exposure. Proceedings International Seminar on Risk Perception, Risk Communication and its Application to EMF Exposure, Vienna, Austria, October 22 and 23, 1997. Vienna: International Commission on Non-Ionizing Radiation Protection and World Health Organization (WHO), 243–251.

Heywood, V. H. and Watson, R. T. (eds.) (1995): Global Biodiversity Assessment. Cambridge, New York: Cambridge University Press.

HHS – United States Department of Health and Human Services (1993): DEHP – toxicological profile. Washington, DC: HHS.

Hilbeck, A., Baumgartner, M., Padruot, M. F. and Bilger, F. (1998): Effects of transgenic *Bacillus thuringiensis* corn-fed prey on mortality and development time of immature *Chrysoperla carnea* (Neuroptera: Chrysopidae). Environmental Entomology 27 (2), 480–487.

Hinman, G. W., Rosa, E. A., Kleinhesselink, R. R. and Lowinger, T. C. (1993): Perception of nuclear and other risks in Japan and the United States. Risk Analysis 13, 449–456.

Hoberg, G. (1994): Risk, science, and politics. Regulating toxic substances in Canada and the United States. Montreal: McGill-Queen's University Press.

Hocken, E. (1995): Reaktorsicherheit. In: Michaelis, H. and Salander, C. (eds.): Handbuch Kernenergie. Kompendium der Energiewirtschaft und Energiepolitik. Frankfurt: VWEW, 603–669.

Hoffmann-Riem, W. and Eifert, M. (1995): Umweltpolitische Kooperation. In: Junkerheinrich, M., Klemmer, P. and Wagner, G. R. (eds.): Handbuch zur Umweltökonomie. Berlin: Analytica, 318–327.

Hohenemser, C., Kasperson, R. E. and Kates, R. W. (1985): Causal structure. In: Kates, R. W., Hohenemser, C. and Kasperson, J. X. (eds.): Perilous progress. Managing the hazards of technology. Boulder, London: Westview Press, 25–43.

Hohenemser, C., Kates, R. W. and Slovic, P. (1983): The nature of technological hazard. Science 220, 378–384.

Hohloch, G. (1994): Entschädigungsfonds auf dem Gebiet des Umwelthaftungsrechts: rechtsvergleichende Untersuchung zur Frage der Einsatzfähigkeit einer 'Fondslösung'. Berlin: Schmidt.

Holling, C. S., Peterson, G., Sendzimir, J., Redford, K., Gunderson, L. and Lambert, D. (1996): Self-organization in ecosystems: Lumpy geometries, periodicities and morphologies. In: Walker, B. and Steffen, W. (eds.): Global change and terrestrial ecosystems. Cambridge, New York: Cambridge University Press, 346–384.

Holzheu, F. (1987): Gesellschaftliche Verfahren zur Bewältigung von Unsicherheit. In: Bayerische Rückversicherung (ed.): Gesellschaft und Unsicherheit. Karlsruhe: Versicherungswirtschaft e.V., 11–36.

Holzheu, T. (1994): Umweltpolitik durch Haftungsregeln: Schadensverhütung und Risikoallokation. Munich: VVF.

Hood, C. and Jones, D. K. C. (eds.) (1996): Accident and design. Contemporary debates in risk management. London: UC-Press.

Hood, C. C., Jones, D. K. C., Pidgeon, N. F., Turner, B. A. and Gibson, R. (1992): Risk management. In: Royal Society Study Group (ed.): Risk analysis, perception and management. London: The Royal Society, 135–192.

Horner, R. A., Garrison, D. L. and Plumley, F. G. (1997): Harmful algal blooms and red tide problems on the U.S. West Coast. Limnology and Oceanography 42 (5 Teil 2), 1076–1088.

Houghton, R. A., Davidson, E. A. and Woodwell, G. M. (1998): Missing sinks, feedbacks, and understanding the role of terrestrial ecosystems in the global carbon balance. Global Biogeochemical Cycles 12, 25–38.

Hoyt, E. (1992): Conserving the wild relatives of crops. Gland, Geneva: The World Conservation Union (IUCN) and World Wide Fund for Nature (WWF).

Hungate, B. A, Chapin III, F. S., Zhong, H., Holland, E. A. and Field, C. B. (1997): Stimulation of grassland nitrogen cycling under carbon dioxide enrichment. Oecologia 109, 149–153.

Hungerbühler, K., Ranke, J. and Mettier, T. (1998): Chemische Produkte und Prozesse. Grundkonzepte zum umweltorientierten Design. Heidelberg, Berlin, New York: Springer.

Huss-Ashmore, R. and Katz, S. H. (eds.) (1989): African food systems in crisis: Part One: Microperspectives. Food and nutrition in history and anthropology. Volume 7. New York, London, Paris: Gordon and Breach.

IAEA – International Atomic Energy Agency (1995): Guidelines for integrated risk assessment and management in large industrial areas. Technical Document: IAEA-TECDOC PGVI-CIJV. Vienna: IAEA.

IDNDR – Deutsches Komitee zur Katastrophenvorbeugung (1993): Naturkatastrophen und Katastrophenvorbeugung. Bericht des Wissenschaftlichen Beirats der DFG für das Deutsche Komitee für die 'International Decade for Natural Disaster Reduction'. Weinheim: VCH.

IFCS – International Forum on Chemical Safety (1997): Forum II. Second session of the Intergovernmental Forum on Chemical Safety. Final Report. Document IFCS/FORUM-II/97.25w. Geneva: World Health Organisation (WHO).

IKSR – Internationale Kommission zum Schutz des Rheins (1995): Grundlagen und Strategie zum Aktionsplan Hochwasser. Koblenz: IKSR.

IKSR – Internationale Kommission zum Schutz des Rheins (1997): Hochwasserschutz am Rhein. Bestandsaufnahme. Koblenz: IKSR.

IKSR – Internationale Kommission zum Schutz des Rheins (1998): Aktionsplan Hochwasser. Koblenz: IKSR.

IPCC – Intergovernmental Panel on Climate Change (1990): Climate change: The IPCC Scientific Assessment. Cambridge, New York: Cambridge University Press.

IPCC – Intergovernmental Panel on Climate Change (1995): Climate change 1994. Cambridge, New York: Cambridge University Press.

IPCC – International Panel on Climate Change (1996a): Climate change 1995 – the science of climate change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, New York: Cambridge University Press.

IPCC – International Panel on Climate Change (1996b): Climate change 1995 – impacts, adaptations and mitigation of climate change: scientific-technical analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, New York: Cambridge University Press.

IPCC – International Panel on Climate Change (1996c): Climate change 1995. Contribution of Working Group III to the Second Assessment Report of the IPCC. Cambridge, New York: Cambridge University Press.

IPCC – International Panel on Climate Change (1997): The regional impacts of climate change. An assessment of vulnerability. Cambridge, New York: Cambridge University Press.

IPCC – International Panel on Climate Change (1998): The regional impacts of climate change. An assessment of vulnerability. A Special Report of IPCC Working Group II. Cambridge, New York: Cambridge University Press.

Ipsen, K. (1989): Prävention oder Reaktion? Sicherheitsmaßnahmen und Sicherheitsstandards im Rahmen der Internationalen Atomenergie-Organisation und die Konvention über kerntechnische Unfälle vom 26.9.1986. Festschrift Fabricius. Stuttgart: Boorberg, 315–376.

Irwin, A. (1997): Risk, The environment and environmental knowledge. In: Redclift, M. and Woodgate, G. (eds.): The International Handbook of Environmental Sociology. Cheltenham: Edward Elgar, 218–226.

ISAAC – International Study of Asthma and Allergies in Childhood) (ed.) (1998): World-wide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis in atopic eczema. The Lancet 351, 1225–1232.

Isermann, K. (1993): Territorial, continental and global aspects of C, N, P and S emissions from agricultural ecosystems. In: Wollast, R., Mackenzie, F. T. and Chow, L. (eds.): Interactions of C, N, P and S biogeochemical cycles and global change. NATO ASI Series. Volume 1. Global Environmental Change. Berlin, Heidelberg, New York: Springer, 79–121.

IUCN – The World Conservation Union and World Bank (1997): Large dams: looking from the past, looking at the future. Gland and Washington, DC: IUCN and World Bank.

Jakarta Post (20.02.1998): Export of rattan not profitable. Jakarta: Jakarta Post.

Janis, I. L. (1972). Victims of groupthink: a psychological study of foreign policy decisions and fiascoes. Boston, MA: Houghton-Mifflin.

Jansen, W. (1995): CANDYS/QA – Algorithms, programs, and user's manual. Technical. Potsdam: University of Potsdam. Interdisziplinäres Zentrum für nichtlineare Dynamik.

Jany, K.-D. (1998): Gentechnik und Lebensmittel. In: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (ed.): Gen-Welten. Bonn: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland, 117–130.

Japp, K. P. (1992): Selbstverstärkungseffekte riskanter Entscheidungen. Zur Unterscheidung von Rationalität und Risiko. Zeitschrift für Soziologie 21, 31–48.

Jarass, H. (1993): Der Vollzug von Umweltrecht in den USA. Natur und Recht 15 (5), 197–202.

Jessen, B. (1996): Der Flutaktionsplan in Bangladesh. In: Hanisch, R. and Moßmann, P. (eds.): Katastrophen und ihre Bewältigung in den Ländern des Südens. Hamburg: Deutsches Übersee-Institut.

Johnson, B. B. and Covello, V. T. (eds.) (1987): The social and cultural construction of risk. Essays on risk selection and perception. Dordrecht: Reidel.

Jonas, H. (1979): Das Prinzip der Verantwortung. Versuch einer Ethik für die technologische Zivilisation. Frankfurt/M.: Insel.

Jonas, H. (1990): Das Prinzip Verantwortung. In: Schüz, M. (ed.): Risiko und Wagnis. Die Herausforderung der industriellen Welt. Volume 2. Pfullingen: Neske, 166–181.

Jungermann, H. (1986): Technische Systeme und menschliches Urteil. In: Held, M. and Molt, W. (eds.): Technik von gestern für die Ziele von morgen? Energiepolitische Orientierungen auf dem Weg zur postmaterialistischen Gesellschaft. Opladen: Westdeutscher Verlag, 104–112.

Jungermann, H. (1991): Inhalte und Konzepte der Risiko-Kommunikation. In: Jungermann, H., Rohrmann, B. and Wiedemann, P. M. (eds.): Risikokontroversen. Konzepte, Konflikte, Kommunikation. Berlin, Heidelberg, New York: Springer, 335–354.

Jungermann, H. and Slovic, P. (1993a): Charakteristika individueller Risikowahrnehmung. In: Bayerische Rückversicherung (ed.): Risiko ist ein Konstrukt. Wahrnehmungen zur Risikowahrnehmung. Munich: Knesebeck, 89–107.

Jungermann, H. and Slovic, P. (1993b): Die Psychologie der Kognition und Evaluation von Risiko. In: Bechmann, G. (ed.): Risiko und Gesellschaft. Grundlagen und Ergebnisse interdisziplinärer Risikoforschung. Opladen: Westdeutscher Verlag, 167–207.

Jungermann, H., Pfister, H.-R. and Fischer, K. (1998): Die Psychologie der Entscheidung. Eine Einführung. Heidelberg, Berlin: Spektrum.

Jungermann, H., Rohrmann, B. and Wiedemann, P. M. (1991): Risikokontroversen. Konzepte, Konflikte, Kommunikation. Berlin, Heidelberg, New York: Springer.

Kadner, T. (1995): Der Ersatz ökologischer Schäden – Ansprüche von Umweltverbänden. Berlin: Duncker & Humblot.

Kahn, J. and Rockel, M. (1988): Measuring the economic effects of brown tides. Journal of Shellfish Research 7, 229–239.

Kahnemann, D. and Tversky, A. (1974): Judgment under uncertainty. Heuristics and biases. Science 185, 1124–1131.

Kahnemann, D., Slovic, P. and Tversky, A. (1982): Judgment under uncertainty: heuristics and biases. Cambridge: Cambridge University Press.

Kai, S. (1992): Pattern formation in complex dissipative systems: fluid patterns, liquid crystals, chemical reactions. Kitakyushu: World Scientific Publication Company.

Kaiser, G., Wiedmann, T. and Ballschmiter, K. (1998): Organische Spurenstoffe als Emissionen aus Verbrennungsanlagen und deren humantoxikologische und ökotoxikologische Einordnung. Teil 2. Humantoxikologische und ökotoxikologische Einordnung. Arbeitsbericht der Akademie für Technikfolgenabschätzung in Baden-Württemberg (AFTA) Nr. 102. Stuttgart: AFTA.

Kaplan, S. and Garrik, J. B. (1993): Die quantitative Bestimmung von Risiko. In: Bechmann, G. (ed.): Risiko und Gesellschaft. Grundlagen und Ergebnisse interdisziplinärer Risikoforschung. Opladen: Westdeutscher Verlag: Opladen, 91–124.

Karbe, L. (1997): Auswirkungen von Umwelthormonen auf das Ökosystem. In: GSF – Gesellschaft für Umweltsystemforschung (ed.): Umweltchemikalien mit hormoneller Wirkung. Neuherberg: GSF, 2–7.

Kareiva, P. (1993): Transgenic plants on trail. Nature 363, 580–581.

Karl, H. (1987): Ökonomie öffentlicher Risiken in Marktwirtschaften. Wirtschaftswissenschaftliches Studium 16 (5), 217–223.

Karl, H. (1992): Öko-Audits – Ein sinnvolles Informationskonzept für Umweltbelastungen? Wirtschaftsdienst 72 (7), 368–373.

Karl, H. (1993): Europäische Initiative für die Einführung von Umweltschutz-Audits – Kritische Würdigung aus ökonomischer Sicht. List-Forum für Wirtschafts- und Finanzpolitik 19 (3), 207–220.

Karl, H. (1994): Marktsystem und risikoreiche Produktionstechnik. Bochum: University of Bochum. Unpublished habilitation thesis.

Kasperson, J., Kasperson, R. E. and Turner, B. L. (eds.) (1995): Regions at risk – comparisons of threatened environments. UNU Studies on Critical Environmental Regions. Tokyo, New York: United Nations University Press.

Kasperson, R., Renn, O., Slovic P., Brown, H. S., Emel, J., Goble, R., Kasperson, J. X. and Ratick, S. (1988): The social amplification of risk. A conceptual framework. Risk Analysis 8 (2), 177–187.

Kates, R. W. and Kasperson, J. X. (1983): Comparative risk analysis of technological hazards. A Review. Proceedings of the National Academy of Sciences 80, 7027.

Keeney, R. L., Renn, O., von Winterfeldt, D. and Kotte, U. (1984): Die Wertbaumanalyse. Munich, Essen: HTV.

Kelman, S. (1981): Cost-benefit analysis: an ethical critique. Regulation 5, 33–40.

Kepplinger, H. (1989): Künstliche Horizonte. Folgen, Darstellungen und Akzeptanz von Technik in der Bundesrepublik. Frankfurt/M.: Campus.

Kerber, W. (1998): Weiterentwicklung der gesellschaftlichen Wissensbasis. In: Klemmer, P., Becker-Soest, D. and Wink, R. (eds.): Liberale Grundrisse einer zukunftsfähigen Gesellschaft. Baden-Baden: Nomos, 117–134.

Kideys, A. E. (1994): Recent dramatic changes in the Black Sea ecosystem: The Reason for the sharp decline in Turkish anchovy fisheries. Journal of Marine Systems 5 (2), 171–181.

Kimmins, J. P. (1987): Forest ecology. New York: Macmillan.

Kinkel, K. (1989): Bewältigung von umwelttypischen Distanz- und Summationsschäden. Zeitschrift für die Rechtspraxis (8), 293–298.

Kinney, K. K., Lindroth, R. L., Jung, S. M. and Nordheim, E. V. (1997): Effects of CO_2 and NO_3 availability on deciduous trees: phytochemistry and insect performance. Ecology 78, 215–230.

Klages, H. (1984): Wertorientierungen im Wandel. Frankfurt/M.: Campus.

Klass, J. (1997): Zum Stand der Umwelthaftung in Deutschland. Umwelt- und Planungsrecht 17 (4), 134–144.

Kleindorfer, P. R. and Kunreuther, H. (1987): Insurance and compensation as policy instruments for hazardous waste management. In: Kleindorfer, P. R. and Kunreuther, H. (eds.): Insuring and managing hazardous risks: from Seveso to Bhopal and beyond. Berlin, Heidelberg, New York: Springer, 145–172.

Kleiner, K. (1997): Monsanto's cotton gets the Mississippi Blues. New Scientist 156 (2106), 4.

Kleinhesselink, R. R. and Rosa, E. A. (1991): Cognitive representation of risk perceptions – a comparison of Japan and the United States. Journal of Cross-cultural Psychology 22, 11–28.

Kleinwellfonder, B. (1996): Der Risikodiskurs. Zur gesellschaftlichen Inszenierung von Risiko. Opladen: Westdeutscher Verlag.

Klemmer, P. (1990): Umweltschutz und Wirtschaftlichkeit: Grenzen der Belastbarkeit der Unternehmen. Berlin: Dunkker & Humblot.

Klemmer, P. and Meuser, T. (1995): Das EG-Umweltaudit – Eine Einführung. In: Klemmer, P. and Meuser, T. (eds.): EG-Umweltaudit – Der Weg zum ökologischen Zertifikat. Wiesbaden: Gabler, 17–35.

Klemmer, P., Becker-Soest, D. and Wink, R. (1998a): Liberale Grundrisse einer zukunftsfähigen Gesellschaft – ein zusammenfassender Überblick. In: Klemmer, P., Becker-Soest, D. and Wink, R. (eds.): Liberale Grundrisse einer zukunftsfähigen Gesellschaft. Baden-Baden: Nomos, 9–23.

Klemmer, P., Becker-Soest, D. and Wink, R. (1998b): Liberalismus. Grundvoraussetzung zukunftsfähiger Entwicklungen. In: Klemmer, P., Becker-Soest, D. and Wink, R. (eds.): Liberale Grundrisse einer zukunftsfähigen Gesellschaft. Baden-Baden: Nomos, 27–43.

Kletecka, A. (1997): Der Entwurf eines Gentechnikhaftungsgesetzes. ecolex 8, 572–573.

Klodt, H. (1995): Grundlagen der Forschungs- und Technologiepolitik. Munich: Vahlen.

Kloepfer, M. and Durner, W. (1997): Der Umweltgesetzbuch-Entwurf (KomE). Deutsches Verwaltungsblatt 112 (18), 1081–1107.

Knight. F. (1921): Risk, uncertainty and profit. New York: Kelley.

Knorr, C. and von Schell, T. (eds.) (1997): Mikrobieller Schadstoffabbau – ein interdisziplinärer Ansatz. Wiesbaden: Vieweg.

Koch, G. W. and Mooney, H. A. (eds.) (1996): Carbon dioxide and terrestrial ecosystems. San Diego: Academic Press.

Koch, H.-J. (1996): Vereinfachung des materiellen Umweltrechts. Neue Zeitschrift für Verwaltungsrecht (3), 215–222.

Koch, R. (1989): Umweltchemikalien. Weinheim: VCH.

Kolluru, R. V. (1995): Risk assessment and management: A unified approach. In: Kolluru, R. V., Bartell, S., Pitblade, R. and Stricoff, S. (eds.): Risk assessment and management handbook. For environmental, health, and safety professionals. New York: McGraw Hill, 1.3–1.41.

Kolluru R. V. and Brooks, D. G. (1995): Integrated risk assessment and strategic management. In: Kolluru, R. V., Bartell, S., Pitblade, R. and Stricoff, S. (eds.): Risk assessment and management handbook. For environmental, health, and safety professionals. New York: McGraw Hill, 2.1–2.23.

Korell, M., Schittenhelm, S. and Weigel, H.-J. (1997): Aufstellen von Kriterien für die nachhaltige umweltgerechte Nutzung gentechnisch veränderter Kulturpflanzensorten. Berlin: Umweltbundesamt (UBA).

Körner, C. and Bazzaz, F. A. (eds.) (1996): Carbon dioxide, populations, and communities. San Diego: Academic Press.

Koschnick, H. (1997): Vorsorge trotz leerer Kassen. Naturkatastrophen und ihre Auswirkungen auf Menschen in Entwicklungsländern. Welternährung. Zeitung der Deutschen Welthungerhilfe 26 (4), 1.

Kröger, W. (1991): Beschreibung der nuklearen Risiken – ein Lehrstück. In: Schneider, J. (ed.): Risiko und Sicherheit technischer Systeme. Basel: Birkhäuser, 59–68.

Kröger, W. (1998): Kann Kernenergie nachhaltig sein? STZ Technik aktuell 4, 22–27.

Kowarik, I. (1995): On the role of alien species in urban flora and vegetation. In: Pysek, P., Prach, K., Rejmánek, M. and Wade, M. (eds.): Plant invasions. Amsterdam: SPB Academic Publishing, 85–103.

Kowarik, I. (1996): Auswirkungen von Neophyten auf Ökoysteme und deren Bewertung. In: UBA – Umweltbundesamt (ed.): Langzeitmonitoring von Umwelteffekten transgener Organismen – Arbeitstagung am 5./6. Oktober 1995. Berlin: UBA, 119–155.

Krewski, D. and Birkwood, P. L. (1987): Risk assessment and risk management: a survey of recent models. In: Lave, L. B. (ed.): Risk assessment and management. New York, London: Plenum Press, 339–406.

Krohn, W. and Krücken, G. (1993): Risiko als Konstruktion und Wirklichkeit. Eine Einführung in die sozialwissenschaftliche Risikoforschung. In: Krohn, W. and Krücken, G. (eds.): Riskante Technologien: Reflexion und Regulation. Einführung in die sozialwissenschaftliche Risikoforschung. Frankfurt/M.: Suhrkamp, 9–44.

Krücken, G. (1997): Risikotransformation. Die politische Regulierung technisch-ökologischer Gefahren in der Risikogesellschaft. Opladen: Westdeutscher Verlag.

Kunreuther, H. and Slovic, P. (1996): Science, values, and risk. In: Kunreuther, H. and Slovic, P. (eds.): Challenges in risk assessment and risk management. Annals of the American Academy of Political and Social Science. Special Issue. Thousand Oaks: Sage, 116–125.

Kurz, R. and Volkert, J. (1995): Ordnungspoltische Grundfragen einer Politik der Nachhaltigkeit. Tübingen: Mohr.

Ladeur, K.-H. (1993): Der 'Umwelthaftungsfonds' – ein Irrweg der Flexibilisierung des Umweltrechts? Versicherungsrecht 44 (7), 257–267.

Ladeur, K.-H. (1994): Umweltverträglichkeitsprüfung und Ermittlung von Umweltbeeinträchtigungen unter Ungewißheitsbedingungen. Zeitschrift für Umweltpolitik & Umweltrecht 17 (1), 1–24.

Ladeur, K.-H. (1995): Das Umweltrecht der Wissensgesellschaft – Von der Gefahrenabwehr zum Risikomanagement. Berlin: Duncker & Humblot.

Lafferty, K. D. and Kuris, A. (1996): Biological control of marine pests. Ecology 77 (7), 1989–2000.

Lam, C. W. Y. and Ho, K. C. (1989): Red tides in Tolo Harbor, Hong Kong. In: Okaichi, T., Anderson, D. M. and Nemoto, T. (eds.): Red tides: biology, environmental science and toxicology. New York: Elsevier, 49–52.

Lammel, G. and Graßl, H. (1995): On the greenhouse effect of NO_x. Environmental Science and Pollution Research 2, 40–45.

Lammel, G. and Flessa, H. (1998): Anthropogene Störung des Stickstoff-Kreislaufs – Ökotoxikologische Dimension. Umweltwissenschaften und Schadstoffe 10, 295–305.

Lammel, G. and Pahl, T. (1998): How to assess, prevent and manage risks from persistent chemicals in the environment. Global Environmental Change (submitted).

LaPorte, T. R. and Consolini, P. M. (1991): Working in practice but not in theory: theoretical challenges of 'high-reliability organizations'. Journal of Public Administration Research and Theory 1 (1), 19–47.

Lappe, T. (1993): Grenzüberschreitender Umweltrechtsschutz – Das Modell der Nordischen Umweltschutzkonvention im Vergleich mit dem deutschen Umweltrecht. Natur und Recht 1993, 213–217.

Lasmezas, C. I., Deslys, J. P., Demalmay, R., Adjou, K. T., Lamoury, F., Dormont, D., Robain, O., Ironside, J. and Hauw, J. J. (1996): BSE transmission to macaques. Nature 381, 743–744.

Latif, M., Kleeman, R. and Eckert, C. (1997): Greenhouse warming, decadal variability, or El Niño? An attempt to understand the anomalous 1990s. Journal of Climatology 10, 2221–2239.

Lave, L. B. (ed.) (1985): Risk assessment and management. New York, London: Plenum Press.

Lave, L. B. (1987): Health and safety risk analyses: information for better decisions. Science 236, 291–295.

Leist, A. and Schaber, P. (1995): Ethische Überlegungen zu Schaden, Risiko und Unsicherheit. In: Berg, M., Erdmann, G., Leist, A., Renn, O., Schaber, P., Scheringer, M., Seiler, H. and Wiedemann, R. (eds.): Risikobewertung im Energiebereich. Zürich: Vdf Hochschulverlag, 47–70.

Leung, R., Ho, P., Lam, C. W. and Lai, C. K. (1997): Sensitization to inhaled allergens as a risk factor for asthma and allergic diseases in the Chinese population. Journal for Allergy and Clinical Immunology 99, 594–599.

Levy, L. B. (1998): Multi-drug resistance – a sign of the times. The New England Journal of Medicine 338, 1376–1378.

Liess, M. (1998): Insektizide in Fließgewässern. UWSF-Zeitschrift für Umweltchemie und Ökotoxikologie 10, 31–36.

Lips, J. (1998): Pleiotrope Effekte und genetische Stabilität transgener Pflanzen. In: UBA – Umweltbundesamt (ed.): Nutzung der Gentechnik im Agrarsektor der USA. UBA Texte 47/98. Volume 1. Berlin: UBA, 121–156.

Löfstedt, R. E. (1997): Risk evaluation in the United Kingdom: legal requirements, conceptual foundations, and practical experiences with special emphasis on energy systems. Arbeitsbericht Nr. 92 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.

Löfstedt, R. E. and Renn, O. (1997): The Brent Spar controversy: an example of risk communication gone wrong. Risk Analysis 17 (2), 131–136.

Lohmann, T. (1993): Die rechtliche Struktur der Sicherungsmaßnahmen der Internationalen Atomenergie-Organisation. Berlin: Duncker & Humblot.

Lohmann, U. and Feichter, J. (1997): Impact of sulfate aerosols on albedo and lifetime of clouds: a sensitivity study with the ECHAM4 GCM. Journal of Geophysical Research 102, 13685–13700.

Lonergan, S. (1997): Global environmental change and human security. Changes 5 (special edition), 1–6.

Lorenz, E. N. (1964): The problem of deducing the climate from the governing equations. Tellus 16 (1), 1–11.

Lowrance, W. W. (1976): Of acceptable risk: science and the determination of safety. Los Altos: William Kaufman.

Lübbe H. (1993): Sicherheit. Risikowahrnehmung im Zivilisationsprozeß. In: Bayerische Rückversicherung (ed.): Risiko ist ein Konstrukt. Wahrnehmungen zur Risikowahrnehmung. Munich: Knesebeck, 24–41.

Luhmann, N. (1988): Soziale Systeme – Grundriß einer allgemeinen Theorie. Frankfurt/M.: Suhrkamp.

Luhmann, N. (1991): Soziologie des Risikos. Berlin, New York: de Gruyter.

Luhmann, N. (1993): Risiko und Gefahr. In: Krohn, W. and Krücken, G. (eds.): Riskante Technologien: Reflexion und Regulation. Frankfurt/M.: Suhrkamp, 138–185.

MacArthur, R. H. and Wilson, E. O. (1967): The theory of island biogeography. Princeton, NJ: Princeton University Press.

MacGregor, D. G., Slovic, P. and Granger Morgan, M. (1994): Perceptions of risks from electromagnetic fields: a Psychometric evaluation of a risk-communication approach. Risk Analysis. An International Journal, 14 (5), 815–828.

Macilwain, C. (1998): When rhetoric hits reality in debate on bioprospecting. Nature 392, 535–540.

MacLean, D. (1986): Social values and the distribution of risk. In: MacLean, D. (ed.): Values at risk. Totowa: Rowman and Allanheld, 75–93.

MacLean, D. (1987): Understanding the nuclear power controversy. In: Engelhardt jr., H. T. and Caplan, A. L. (eds.): Scientific controversies: case studies in the resolution and closure of disputes in science and technology. Cambridge, New York: Cambridge University Press, 567–582.

MAFF – Ministry of Agriculture, Fisheries and Food (ed.) (1996): Programme to eradicate BSE in the United Kingdom. London: MAFF.

MAFF – Ministry of Agriculture, Fisheries and Food (ed.) (1998): BSE Enforcement Bulletin. London: MAFF.

Maier-Reimer, E. and Mikolajewicz, U. (1989): Experiments with an OGCM on the cause of the younger Dryas. In: Ayala-Castanares, W. and Yanez-Arancibia, D. (eds.): Oceanography 1988. Mexico-Stadt: UNAM Press, 87–99.

Maier-Rigaud, G. (1993): Ordnungspolitische Aspekte der Öko-Audit-Verordnung der EG. Wirtschaftsdienst 73 (4), 193–198.

Manabe, S. and Stouffer, R. J. (1993): Century-scale efficiencies of increased atmospheric CO_2 on the ocean-atmosphere system. Nature 364, 215–218.

Manderscheid, B., Matzner, E., Meiwes, K.-J. and Xu, Y. (1995): Long-term development of element budget in a norway spruce (*Picea abies* (L.) Karst.) forest of German Solling area. Water, Air and Soil Pollution 79, 3–18.

Marburger, P. (1986): Umweltschäden. Ein Prüfstein für die Wandlungs- und Leistungsfähigkeit des Deliktsrechts. Neue Juristische Wochenschrift 39 (32), 1961–1971.

Marcus, A. D. (1988): Risk, uncertainty, and scientific judgment. Minerva 26, 138–152.

Margolis, H. (1996): Dealing with risk. Why the public and the experts disagree on environmental issues. Chicago: University of Chicago Press.

Markowitz, J. (1990): Kommunikation über Risiken – Eine Theorie-Skizze. Schweizerische Zeitschrift für Soziologie 3, 385–420.

Marschner, H. (1990): Mineral nutrition of higher plants. London: Academic Press.

Marwich, C. (1998): Investigators present latest findings on Hong Kong bird flu to the FDA. Medical News & Perspectives. Leads From the Morbidity and Mortality Weekly Report 46, 1204–1207.

Masters, C. L., Gajdusek, D. C. and Gibbs jr., C. J. (1981): The familial occurrence of Creutzfeldt-Jakob Disease and Alzheimer's disease. Brain 104, 535–558.

Matthies, E. (1995): Aspekte der Bedrohlichkeit von Umweltbelastungen. Eine explorative Untersuchung mit der Repertory-Grid-Technik. Bochum: University of Bochum. Institute for Psychology.

Matthies, E., Krömker, D. and Höger, R. (1995): Das Planspiel als Lern- und Forschungsfeld in der Risikokommunikation. Bochum: University of Bochum. Institute for Psychology.

McCully, P. (1996): Silenced rivers. London, New Jersey: Zed Books.

McGaughey, W. H. and Whalon, M. E. (1992): Managing insect resistance to *Bacillus thuringiensis* toxins. Science 258, 1451–1455.

MacGregor, D. G., Slovic, P. and Granger Morgan, M. (1994): Perceptions of risks from electromagnetic fields: a psychometric evaluation of a risk-communication approach. Risk analysis. An International Journal, 14 (5), 815–828.

Meadows, D. L. (1972): The limits of growth. New York: Universe Books.

Medvedev, G. (1991): The truth about Chernobyl. New York: Basic Books.

Mee, L. D. (1992): The Black Sea in crisis: a need for concerted international action. Ambio 21, 278–286.

Merkhofer, L. W. (1984): Comparative analysis of formal decision-making approaches. In: Covello, V. T., Menkes, J. and Mumpower, J. (eds.): Risk evaluation and management. New York, London: Plenum Press, 183–220.

Merkhofer, L. W. (1987): The use of risk comparison to aid the communication and interpretation of the risk analyses for regulatory decision making. In: Lave, L. B. (ed.): Risk assessment and management. New York, London: Plenum Press, 581–607.

Merz, E. (1983): Der Brennstoffkreislauf von Kernkraftwerken. In: Münch, E. (ed.): Tatsachen über Kernenergie. Essen, Munich: Girardet, ETV, 53–72.

Michaelis, P. (1996): Ökonomische Instrumente in der Umweltpolitik – Eine anwendungsorientierte Einführung. Heidelberg: Physica.

MIDA – Malaysian Industrial Development Authority (o. J.): Malysian import of processed raw rattan from Indonesia. Malaysia: MIDA.

Mikkelsen, T. R., Andersen, B. and Jorgensen, R. B. (1996): The risk of crop transgene spread. Nature 380, 31.

Mikolajewicz, U. and Maier-Reimer, E. (1990): Internal secular variability in an Ocean General Circulation Model. Modeling Climate Dynamics 4, 145–156.

Mill, E. S. (1972): Urban economics. Glenview: Scott Foresman.

MMWR (1996): MMWR Mortal Weekly Report 45 (5), 110–111.

Mohr, H. (1995): Qualitatives Wachstum. Lösung für die Zukunft. Stuttgart: Weitbrecht.

Mohr, H. and Müntz, K. (eds.) (1994): The terrestrial nitrogen cycle as influenced by man. Halle (Saale): Deutsche Akademie der Naturforscher Leopoldina.

Mooney, H. A. and Drake, J. A. (1986) (eds.): Ecology of biological invasions of North America and Hawaii. Berlin, Heidelberg, New York: Springer.

Mooney, H. A., Canadell, J., Chapin, F. S., Ehleringer, J., Körner, C., McMurtrie, R., Parton, W. J., Pitelka, L. and Schulze, E.–D. (1998): Ecosystem physiology responses to global change. In: Walker, B., Steffen, W., Canadell, J. and Ingram, J. (eds.): The terrestrial biosphere and global change. Cambridge, New York: Cambridge University Press (in print).

Mooney, H. A., Cushman, J. H., Medina, E., Sala, O. E. and Schulze, E.-D. (eds.) (1996): Functional roles of biodiversity – a global perspective. SCOPE 55. Chichester, New York: Wiley.

Mooney, P. R. (1985): Saat-Multis und Welthunger. Hamburg: Rowohlt.

Morgan, M. G. (1990): Choosing and managing technology-induced risks. In: Gleickman, T. S. and Gough, M. (eds.): Readings in risk. Washington, DC: Resources for the Future, 5–15.

Morrison, D., Chapman, C. R. and Slovic, P. (1994): The impact hazard. In: Gehrels, T. (ed.): Hazards due to comets and asteroids. Tuscon: University of Arizona Press, 59–91.

Mortimore, M. (1989): Adapting to drought: farmers, famines, and desertification in West Africa. Cambridge, New York: New Rochelle.

Müller, H. and Frank, K. (1997): Nukleare Abrüstung – neue Schritte sind notwendig. HSFK-Standpunkte. Friedensforschung aktuell (3). Frankfurt/M.: Hessische Stiftung für Friedens- und Konfliktforschung (HSFK).

Müller-Chen, M. (1997): Entwicklungen im europäischen Umwelthaftungsrecht. Schweizerische Zeitschrift für Internationales und Europäisches Recht 7 (2), 213–245.

Müller-Herold, U. (1998): Anpassung der Reichweiteindikatoren bei der Chemikalienbewertung an die globale Analyseebene. Expertise for WBGU. Mimeo.

Münchner Rückversicherungs-Gesellschaft (1998): Statistik aus dem Jahr 97/98. Munich: Mimeo.

Murakawa, M. (1987): Marine pollution and countermeasures in Japan. Oceanus 30, 55–60.

Murdoch, W. W. and Briggs, C. J. (1996): Theory for biological control: recent developments. Ecology 77 (7), 2001–2013.

Murdoch, W. W., Chesson, J. and Chesson P. L. (1985): Biological control in theory and practice. The American Naturalist 125 (3), 344–366.

Naylor, R. (1996): Invasions in agriculture: assessing the cost of the Golden Apple Snail in Asia. Ambio 25 (7), 443–448.

Nettesheim, M. (1996): Die ökologische Intervention. Archiv des Völkerrechts 34 (2), 168–217.

Newhall, C. G. and Self, S. (1982): The volcanic explosivity index (VEI): an estimate of explosive magnitude for historical volcanism. Journal of Geophysical Research 87, 1231–1238.

Niemelä, P. and Mattson, W. J. (1996): Invasion of North American forests by European phytophagous insects. Bioscience 46, 741–753.

Nöh, I. (1996): Risikoabschätzung bei Freisetzungen transgener Pflanzen: Erfahrungen des Umweltbundesamtes beim Vollzug des Gentechnikgesetzes (GenTG). In: UBA– Umweltbundesamt (ed.): Langzeitmonitoring von Umwelteffekten transgener Organismen. UBA Texte 58/96. Berlin: UBA, 9–26.

Nohlen, D. (1989): Grüne Revolution. In: Nohlen, D. (ed.): Lexikon Dritte Welt. Länder, Organisationen, Theorien, Begriffe, Personen. Hamburg: Rowohlt, 281–282.

Nordhaus, W. D. (1994): Managing the global commons: The economics of climate change. Hazards Research 4, 336.

Nordhaus, W. D. (1997): Discounting in economics and climate change. Climatic Change 37, 315–328.

Nordhaus, W. D. and Yang, Z. (1996): A regional dynamic general-equilibrium model of alternative climate-change strategies. The American Economic Review 86, 741–765.

Nordlee, J. A., Taylor, S. L., Townsend, J. A., Thomas, L. A. and Bush, R. K. (1996): Identification of a Brazil-Nut allergen in transgenic soybeans. The New England Journal of Medicine (3), 688–692.

North, D. C. (1992): Institutionen, institutioneller Wandel und Wirtschaftsleistung. Tübingen: Mohr.

Nothbaum, N. (1997): Die Akquisation von unsicherem Wissen bei Experten – Kognitive Didaktik und situative Rahmung bei der Erhebung von Verteilungswissen. Bielefeld: University of Bielefeld (dissertation).

NRC – National Research Council. Committee on Risk and Decision Making (1982): Risk and decision making: perspectives and research. Washington, DC: National Academy Press.

NRC – National Research Council. Committee on the Institutional Means for Assessment of Risks to Public Health (1983): Risk assessment in the Federal Government: managing the process. National Academy of Sciences. Washington, DC: National Academy Press.

NRC – National Research Council, Climate Research Committee, Board on Atmospheric Sciences and Climate and Commission on Geosciences, Environment, and Resources (eds.) (1996): Learning to predict climate variations associated with El Niño and the Southern Oscillation: accomplishments and legacies of the TOGA Program. Washington, DC: National Academy Press.

Nuscheler, F. (1997): Alter Wein in neuen Schläuchen – Kritische Anmerkungen zu den UNDP-Berichten. epd-Entwicklungspolitik (November), d1–d7.

O'Riordan, T. (1983): The cognitive and political dimension of risk analysis. Environmental Psychology 3, 345–354.

Oehlmann J., Schulte-Oehlmann, U., Stroben, E., Bauer, B., Bauer, C., Bettin, C., Fiorni, P. and Markert, B. (1995): Androgenic effects of organotin compounds in molluscs. In: UBA – Umweltbundesamt (ed.): Endocrinically active chemicals in the environment. Berlin: UBA, 111–118.

Oldeman, L. R. (1992): Global extent of soil degradation. ISRIC Bi-Annual Report 1991–1992. Wageningen: International Soil Science and Information Centre (ISRIC).

Olsen J., Watts J. A. and Allison L. J. (1985): Major world ecosystem complexes ranked by carbon in live vegetation: a database. NDP-017. Oak Ridge: Oak Ridge National Laboratory.

Opp, K.-D. (1996): Aufstieg und Niedergang der Ökologiebewegung in der Bundesrepublik. In: Diekmann, A. and Jaeger, C. C. (eds.): Umweltsoziologie. Sonderheft 36 der Kölner Zeitschrift für Soziologie und Sozialpsychologie. Opladen: Westdeutscher Verlag, 350–379.

Osebold, J. W., Gershwin, L. J. and Zee, Y. C. (1980): Studies on the enhancement of allergic lung sensitization by inhalation of ozone and sulfuric acid aerosol. Journal of Environmental Pathology and Toxicology 3, 221–234.

Ott, E., Grebogi, C. and Yorke, E. (1990): Controlling chaos. Physical Review Letters 64 (90), 1196–1199.

Paerl, H. W. (1997): Coastal eutrophication and harmful algal blooms: importance of atmospheric deposition and groundwater as 'new' nitrogen and other nutrient sources. Limnology and Oceanography 42 (5, Teil 2), 1154–1165.

Pahl, T. (1998): Umweltpolitische Instrumente und die Produktion ökologischen Wissens. Marburg: Mimeo.

Panther, S. (1992): Haftung als Instrument einer präventiven Umweltpolitik. Frankfurt/M.: Campus.

Pasche, M. (1994): Ansätze einer evolutorischen Umweltökonomik. In: Beckenbach, F. and Diefenbacher, H. (eds.): Zwischen Entropie und Selbstorganisation – Perspektiven einer ökologischen Ökonomie. Marburg: Metropolis, 75–118.

Pastor, J., Mladenoff, D. J. and Bryant, J. (1996): Biodiversity and ecosystem processes in boreal regions. In: Mooney, H. A., Cushman, J. H., Medina, E., Sala, O. E. and Schulze, E.-D. (eds.): Functional roles of biodiversity – a global perspective. SCOPE 55. Chichester, New York: Wiley, 33–69.

Pennisi, E. (1998): Versatile gene uptake system found in cholera bacterium. Science 280, 521–522.

Perrings, C. (1987): Economy and environment – a theoretical essay on the interdependence of economic and environmental systems. Cambridge, New York: Cambridge University Press.

Perrings, C. (1989): Environmental bonds and environmental research in innovative activities. Ecological Economics 1, 95–110.

Perrow, C. (1984): Normal accidents. Living with high-risk technologies. New York: Basic Books.

Perrow, C. (1992): Unfälle und Katastrophen – ihre Systembedingungen. Journal für Sozialforschung 32 (1), 61–75.

Peters, H. P. (1995): Massenmedien und Technikakzeptanz: Inhalte und Wirkungen der Medienberichterstattung über Technik, Umwelt und Risiken. Jülich: Forschungszentrum Jülich.

Petringa, N. (1997): Risk regulation: legal requirements, conceptual foundations and practical experiences in Italy. Case Study of the Italian energy sector. Arbeitsbericht Nr. 90 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.

Petschel-Held, G. and Reusswig, F. (1998): Climate change and global change: the Syndrome concept. In: Hacker, J. (ed.): Goals as instruments for the achievement of global warming mitigation in Europe. Dordrecht: Kluwer (in print).

Pfeiffer, T. (1993): Der Umweltgerichtsstand als zuständigkeitsrechtlicher Störfall. Zeitschrift für den Zivilrechtsprozeß 106 (2), 159–179.

Pfetsch, F. R. (ed.) (1991): Konflikte seit 1945. Freiburg, Würzburg: Ploetz.

Pfetsch, F. R. and Rohloff, C. (1998): Global trends of conflicts 1945–1995. Fifty years of peaceful and violent conflicts in and among states. Freiburg, Würzburg: Ploetz (in print).

Pidgeon, N. F., Hood, C. C., Jones, D. K. C., Turner, B. A. and Gibson, R. (1992): Risk perception. In: Royal Society Study Group (ed.): Risk analysis, perception and management. London: The Royal Society, 89–134.

Pilardeaux, B. (1995): Innovation und Entwicklung in Nordpakistan – Über die Rolle von exogenen Agrarinnovationen im Entwicklungsprozeß einer peripheren Hochgebirgsregion. Saarbrücken: Verlag für Entwicklungspolitik.

Pilardeaux, B. (1997): Desertifikationsbekämpfung im Aufwind? – 1. Vertragsstaatenkonferenz der UNCCD. Nord-Süd Aktuell 11 (4), 744–749.

Pilardeaux, B. and Schulz-Baldes, M. (1998): Desertifikation. In: Lozan, J. L., Graßl, H., Hupfer, P. and Sterr, H. (eds.): Warnsignale aus der Klimaentwicklung. Berlin: Parey.

Pimm, S. L. (1991): The balance of nature? – ecological issues in the conservation of species and communities. Chicago: The University of Chicago.

Pipers, F. (1995): The Lugano Convention on Civil Liability for Damages Resulting From Activities Dangerous to the Environment and the intents of the European Union with regard to reinstatement of the environment. In: von Bar, C. (ed.): Internationales Umwelthaftungsrecht – Auf dem Weg zu einer Konvention über Fragen des Internationalen Umwelthaftungsrechts. Volume 1. Cologne: Heymann, 15–29.

Plate, E. (1998): Hochwasser und Hochwasserschutz. Expertise for WBGU. Mimeo.

Platt, J. (1973): Social traps. American Psychologist 28, 641–651.

Plöchl, M. (1997): The Dust-Bowl syndrome. Abschlußbericht des Werkvertrags für das BMBF-Projekt 'Syndromdynamik'. Dezember 1997. Potsdam: PIK. Mimeo.

Posch, M., Hettelingh, F., Alcamo, J. and Krol, M. (1996): Integrated scenarios of acidification and climate change in Asia and Europe. Global Environmental Change 6 (4) 375–394.

Poumadère, M. and Mays, C. (1997): Energy risk regulation in France. Arbeitsbericht Nr. 89 der Akademie für Technikfolgenabschätzung. Stuttgart: Akademie für Technikfolgenabschätzung.

Pretty, J. N. (1995): Regenerating agriculture: policies and practice for sustainability and self-reliance. Washington, DC: Joseph Henry Press.

ProClim – Forum für Klima und Global Change der Schweizerischen Akademie der Naturwissenschaften (1997): Forschung zu Nachhaltigkeit und Globalem Wandel – Wissenschaftspolitische Visionen der Schweizer Forschenden. Bern: ProClim.

Projektgruppe 'Umweltstandards' (1998): Vorläufiges Arbeitspapier der Projektgruppe 'Umweltstandards' der Europäischen Akademie Bad Neuenahr-Ahrweiler. Bad Neuenahr-Ahrweiler: Europäische Akademie.

Protess, D. (1987): The impact of investigative reporting on public opinion and policymaking. Public Opinion Quarterly 51 (2), 166–185.

Pryer, J. (1990): Hunger and women's survival in a Bangladesh slum. In: Bernstein, H. (ed.): The food question. New York: Monthly Review Press, 125–133.

Pühler, A. (1998a): Einfluß von freigesetzten und inverkehrgebrachten gentechnisch veränderten Organismen auf Mensch und Umwelt (Gutachten im Auftrag des Rats von Sachverständigen für Umweltfragen, Wiesbaden). In: SRU – Rat von Sachverständigen für Umweltfragen (ed.): Zu Umweltproblemen der Freisetzung und des Inverkehrbringens gentechnisch veränderter Pflanzen. Stuttgart: Metzler-Poeschel, 1-50.

Pühler, A. (1998b): Horizontaler Gentransfer und seine Bedeutung für die unbeabsichtigte Verbreitung transgener Eigenschaften. Expertise for WBGU. Mimeo.

Puttfarken, H.-J. (1997): Seehandelsrecht. Heidelberg: Recht und Wirtschaft.

Pyragas, K. (1992): Continuous control of chaos by self-controlling feedback. Physics Letters A170 (6), 421–428.

Rager, G., Klaus, E. and Thyen, E. (1987): Der Reaktorunfall in Tschernobyl und seine Folgen in den Medien. Eine inhaltsanalytische Untersuchung. Abschlußbericht. Dortmund: University of Dortmund. Institute for Journalism.

Rahmstorf, S. (1995): Bifurcation of the Atlantic thermohaline circulation in response to changes in the hydrological cycle. Nature 378, 145–149.

Rahmstorf, S. (1997): Risk of sea-change in the Atlantic. Nature 388, 825–826.

Raiffa, H. (1973): Einführung in die Entscheidungstheorie. Munich: Oldenbourg.

Rat für Forschung, Technologie und Innovation (1997): Biotechnologie, Gentechnik und wirtschaftliche Innovation. Bonn: Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF).

Rau, B. (1991): From feast to famine: Official cures and grassroots remedies to Africa's food crisis. London, New Jersey: Zed Books.

Rawls, J. (1971): A theory of justice. Cambridge: Harvard University Press.

Rawls, J. (1974): Some reasons for the maximin criterion. American Economic Review 1, 141–146.

Rayner, S. (1984): Disagreeing about risk: the institutional cultures of risk management and planning for future generations. In: Hadden, S. G. (ed.): Risk analysis, institutions, and public policy. Port Washington, N.Y.: Associated Faculty Press, 150–178.

Rayner, S. (1992). Cultural theory and risk analysis. In Krimsky, S. and Golding, D. (eds.): Social theories of risk. Westport, CT., London: Praeger, 83–116.

Rayner, S. (1993): Risikowahrnehmung, Technologieakzeptanz und institutionelle Kultur: Fallstudien für einige neue Definitionen. In: Bayerische Rückversicherung (ed.): Risiko ist ein Konstrukt. Munich: Knesebeck, 213–244.

Reason, J. (1994): Menschliches Versagen: Psychologische Risikofaktoren und moderne Technologien. Heidelberg: Spektrum.

Regal, P. (1986): Models of genetically engineered organisms and their ecological impact. In: Mooney, H. A. and Drake, J. A. (eds.): Ecology of biological invasions of North America and Hawaii. Ecological Studies 58. Berlin, Heidelberg, New York: Springer, 111–129.

Regal, P. J. (1994): Scientific principles for ecologically based risk assessment of transgenic organisms. Molecular Ecology 3, 5–13.

Rehbinder, E. (1976): Umweltrecht. Rabels Zeitschrift für ausländisches und internationales Privatrecht 3, 365–372.

Rehbinder, E. (1988): Ersatz ökologischer Schäden. Begriff, Anspruchsberechtigung und Umfang des Ersatzes unter Berücksichtigung rechtsvergleichender Erfahrungen. Natur und Recht 10 (3), 105–115.

Rehbinder, E. (1989): Fortentwicklung des Umwelthaftungsrechts. Natur und Recht 11 (4), 149–163.

Rehbinder, E. (1992a): Haftpflicht und Verhütung von Umweltschäden aus juristischer Sicht. In: Endres, A., Rehbinder, E. and Schwarze, R. (eds.): Haftung und Versicherung für Umweltschäden aus ökonomischer und juristischer Sicht. Berlin, Heidelberg, New York: Springer, 34–57.

Rehbinder, E. (1992b): Der Beitrag von Versicherungs- und Fondslösungen zur Verhütung von Umweltschäden aus juristischer Sicht. In: Endres, A., Rehbinder, E. and Schwarze, R. (eds.): Haftung und Versicherung für Umweltschäden aus ökonomischer und juristischer Sicht. Berlin, Heidelberg, New York: Springer, 120–150.

Rehbinder, E. (1992c): Risikomanagement von Versicherungen, Schadensfonds und Umweltgenossenschaften zur Verhütung von Umweltschäden aus juristischer Sicht. In: Endres, A., Rehbinder, E. and Schwarze, R. (eds.): Haftung und Versicherung für Umweltschäden aus ökonomischer und juristischer Sicht. Berlin, Heidelberg, New York: Springer, 151–171.

Rehbinder, E. (1997): Stoffrecht. In: Arbeitskreis für Umweltrecht (ed.): Grundzüge des Umweltrechts. Berlin: Schmidt, 13/001–13/051.

Reimann, C. (1997): Ökologische Intervention im internationalen Recht. Natur und Recht 19 (1), 16–22.

Renn, O. (1984): Risikowahrnehmung der Kernenergie. Frankfurt/M.: Campus.

Renn, O. (1989): Risikowahrnehmung – Psychologische Determinanten bei der intuitiven Erfassung und Bewertung von technischen Risiken. In: Hosemann, G. (ed.): Risiko in der Industriegesellschaft. Nürnberg: Universitätsbibliothek, 167–192.

Renn, O. (1990): Die Psychologie des Risikos: Die intuitive Erfassung und Bewertung von technischen Risiken. Energiewirtschaftliche Tagesfragen 8, 558–567.

Renn, O. (1992): Concepts of risk: a classification. In: Krimsky, S. and Golding, D. (eds.): Social theories of risk. Westport, CT., London: Praeger, 53–79.

Renn, O. (1995): Risikobewertung aus Sicht der Soziologie. In: Berg, M., Erdmann, G., Leist, A., Renn, O., Schaber, P., Scheringer, M., Seiler, H. and Wiedemann, R. (eds.): Risikobewertung im Energiebereich. Polyprojekt Risiko und Sicherheit. Schrift Nr. 7. Zürich: Vdf Hochschulverlag, 71–134.

Renn, O. (1996): Kann man die technische Zukunft voraussagen? Zum Stellenwert der Technikfolgenabschätzung für eine verantwortbare Zukunftsvorsorge. In: Pinkau, K. and Stahlberg, C. (eds.): Technologiepolitik in demokratischen Gesellschaften. Stuttgart: Edition Universitas und Wissenschaftliche Verlagsgesellschaft, 23–51.

Renn, O. (1997a): Abschied von der Risikogesellschaft? Risikopolitik zwischen Expertise und Moral. GAIA. Ökologische Perspektiven in Natur-, Geistes- und Wirtschaftswissenschaften 4, 269–275.

Renn, O. (1997b): Three decades of risk research: accomplishments and new challenges. Journal of Risk Research 11 (1), 49–71.

Renn, O. (1998): The role of risk perception for risk management. Reliability Engineering and System Safety 59, 49–61.

Renn, O. and Oppermann, B. (1995): 'Bottom-up' statt 'Topdown' – die Forderung nach Bürgermitwirkung als (altes und neues) Mittel zur Lösung von Konflikten in der räumlichen Planung. Stadtökologie. Zeitschrift für Angewandte Umweltforschung (Sonderheft 6), 257–276.

Renn, O. and Webler, T. (1998): Der kooperative Diskurs – Theoretische Grundlagen, Anforderungen, Möglichkeiten. In: Renn, O., Kastenholz, H., Schild, P. and Wilhelm, U. (eds.): Abfallpolitik im kooperativen Diskurs. Bürgerbeteiligung bei der Standortsuche für eine Deponie im Kanton Aargau. Polyprojekt Risiko und Sicherheit der Eidgenössischen Technischen Hochschule Zürich. Dokumente Nr. 19. Zürich: Hochschulverlag AG an der ETH, 3–103.

Renn, O. and Zwick, M. M. (1997): Risiko- und Technikakzeptanz. Berlin, Heidelberg, New York: Springer.

Renn, O., Albrecht, G., Kotte, U., Peters, H. P. and Stegelmann, H. U. (1985): Sozialverträgliche Energiepolitik. Ein Gutachten für die Bundesregierung. Munich, Essen: HTV.

Renn, O., Burns, W. J., Kasperson, J. X., Kasperson, R. E. and Slovic, P. (1992): The social amplification of risk: theoretical foundations and empirical applications. Journal of Social Issues 48 (4), 137–160.

Richards, P. (1986): Coping with hunger: Hhazard and experiment in an African rice-farming system. London, Boston, Sydney: Allen & Unwin.

Riedel, F., Hasenauer, E., Barth, P. J., Koziorowski, A. and Rieger, C. H. L. (1996): Formaldehyde exposure enhances inhalative allergic sensitization in the guinea pig. Allergy 51, 94–99.

Rinio, C. (1997): Die zivilrechtliche Haftung für Ölverschmutzungsschäden nach Tankerunfällen im internationalen System. Natur und Recht 19 (1), 22–26.

Rippetoe, P. and Rogers, R. (1987): Effects of components of protection-motivation-theory on adaptive and mal-adaptive coping with a health threat. Journal of Personality and Social Psychology, 52, 596–604.

RKI – Robert-Koch-Institut (1998): Pressemitteilungen des Robert-Koch-Instituts. Internet location http://www.rki.de. Berlin: RKI.

Roberts, K. H. (1989): New challenges in organizational research: High reliability organizations. Industrial Crisis Quarterly 3 (2), 111–125.

Roberts, K. H. and Gargano, G. (1990): Managing a high-reliability organization: a case for interdependence. In: von Glinow, M. A. and Mohrmann, S. A. (eds.): Managing complexity in high technology organizations. Oxford, N.Y.: Oxford University Press, 146–159.

Rochlin, G. I. (1993): Defining 'high reliability' organizations in practice: a taxonomic prologue. In: Roberts, K. H. (ed.): New challenges to understanding organizations. New York: Macmillan, 11–32.

Roeckner, E., Arpe, K., Bengtsson, L., Christoph, M., Claussen, M., Dümenil, L., Esch, M., Giorgetta, M., Schlese, U. and Schulzweida, U. (1996): The atmospheric general circulation model ECHAM-4: model description and simulation of present-day climate. Hamburg: Max Planck Institute for Meteorology.

Rohloff, C. (1998): Konfliktforschung und Umweltkonflikte. Methodische Probleme. In: Carius, A. and Lietzmann, K. M. (eds.) (1998): Umwelt und Sicherheit. Herausforderungen an die internationale Politik. Berlin, Heidelberg, New York: Springer, 155–175.

Rohrmann, B. (1991): Akteure der Risikokommunikation. In: Jungermann, H., Rohrmann, B. and Wiedemann, P. M. (eds.): Risikokontroversen. Konzepte, Konflikte, Kommunikation. Berlin, Heidelberg, New York: Springer, 355–370.

Rohrmann, B. (1995a): Technological risks: perception, evaluation, communication. In: Mechlers, R. E. and Stewart, M. G. (eds.): Integrated risk assessment. Current practice and new directions. Rotterdam: Balkema, 7–12.

Rohrmann, B. (1995b): Risk perception research: Review and documentation. Studies in Risk Communication 48. Jülich: Forschungszentrum Jülich.

Rohrmann, B. and Renn, O. (1998): Risk perception research. An introduction. In: Renn, O. and Rohrmann, B. (eds.): Crosscultural risk perception (in preparation).

Röpke, J. (1977): Die Strategie der Innovation – Eine systemtheoretische Untersuchung der Interaktion von Individuum, Organisation und Markt im Neuerungsprozeß. Tübingen: Mohr.

Rosa, E. (1997): Metatheoretical foundations for post-normal risk. Journal of Risk Research 1 (1), 15–44.

Rosenblum, M. G, Pikovsky, A. S. and Kurths, J. (1996): Phase synchronization of chaotic oscillators. Physical Review Letters 76, 1804–1807.

Ross, L. D. (1977): The intuitive psychologist and his shortcomings: distortions in the attribution process. In: Berkowitz, L. (ed.): Advances in experimental social psychology. Volume 10. New York: Random House, 173–220.

Rowe, W. D. (1979): What is an acceptable risk and how can it be determined? In: Goodman, G. T. and Rowe, W. D. (eds.): Energy risk management. London: Academic Press, 327–344.

Rowe, W. D. (1983): Ansätze und Methoden der Risikoforschung. In: Conrad, J. (ed.): Gesellschaft, Technik und Risikopolitik. Berlin, Heidelberg, New York: Springer, 15–38.

Rowe, W. D. (1984): Risiken seltener Ereignisse. In: Lange, S. (ed.): Ermittlung und Bewertung industrieller Risiken. Berlin, Heidelberg, New York: Springer, 152–166.

Rowland, F. S. and Molina, M. J. (1975): Chlorofluoromethanes in the environment. Revue for Geophysics and Space Physics 13, 1–35.

Rublack, S. (1993): Der grenzüberschreitende Transfer von Umweltrisiken im Völkerrecht. Baden-Baden: Nomos.

Ruff, F. M. (1993): Risikokommunikation als Aufgabe für die Umweltmedizin. In: Aurand, K., Hazard, B. P. and Tretter, F. (eds.): Umweltbelastungen und Ängste. Erkennen, Bewerten, Vermeiden. Opladen: Westdeutscher Verlag, 327–364.

Sagan, S. D. (1993): The limits of safety. Organizations, accidents, and nuclear weapons. Princeton: Princeton University Press.

Salander, C. (1995): Der nukleare Brennstoffkreislauf. In: Michaelis, H. and Salander, C. (eds.): Handbuch Kernenergie. Kompendium der Energiewirtschaft und Energiepolitik. Frankfurt: VWEW, 465–558.

Salje, P. (1993): Umwelthaftungsgesetz – Kommentar. Munich: Beck.

Sandlund, O. T., Schei, P. J. and Viken, Å. (1996) (eds.): Proceedings of the Norway/UN Conference on Alien Species, Trondheim, 1–5 July 1996. Trondheim: Directorate for Nature Management (DN)/ Norwegian Institute for Nature Research (NINA).

Schack, H. (1992): Das Internationale Prozeßrecht in umweltrechtlichen Streitigkeiten. Umweltschutz im Völkerrecht und Kollisionsrecht. Berichte der Deutschen Gesellschaft für Völkerrecht. Karlsruhe: Müller, 315–357.

Schaefer, H. (1995): Gefährdet Elektrosmog die Gesundheit? Stuttgart: Akademie für Technikfolgenabschätzung.

Schäfer, T., Krämer, U., Behrendt, H., Vieluf, D. and Ring, J. (1995): Skin prick test (SPT) reactivity in areas with variing air pollution in East- and West-Germany. Journal of Allergy and Immunology 95, 210.

Schellnhuber, H.-J. and Kropp, J. (1998a): Geokybernetics: controlling a rather complex dynamical system under uncertainity. Naturwissenschaften (in print).

Schellnhuber, H.-J. and Wenzel, V. (eds.) (1998b): Earth system analysis: integrating science for sustainability. Berlin, Heidelberg, New York: Springer.

Scherer-Lorenzen, M., Elend, A., Nöllert, S. and Schulze, E.-D. (1998): Plant invasions in Germany – general aspects and impact of nitrogen deposition. In: Mooney, H. A. and Hobbs, R. (eds.): The impact of global change on invasive species. Washington DC, Covelo: Island Press (in print).

Scherzberg, A. (1993): Risiko als Rechtsproblem. Verwaltungs-Archiv 84, 484–513.

Schimank, U. (1992): Spezifische Interessenkonsense trotz generellem Orientierungsdissens. In: Giegel, H.-J. (ed.): Kommunikation und Konsens in modernen Gesellschaften. Frankfurt/M.: Suhrkamp, 236–275.

Schlehe, J. (1998): Lokale Wahrnehmung und Deutung von Naturkatastrophen in Indonesien: Die Ausbrüche des Krakatau (1883) und des Merapi (1994/1997). Antrittsvorlesung. Hagen: FernUniversität Hagen.

Schlesinger, W. H. (1997): Biogeochemistry-analysis of global change. San Diego: Academic Press.

Schlüter, K., Fütterer, J. and Potrykus, I. (1995): 'Horizontal' gene transfer from a transgenic potato line to a bacterial pathogen (*Erwinia chrysanthemi*) occurs – if at all – at an extremly low frequency. Bio/Technology 13, 1094–1098.

Schneider, U. (1996): Wirtschaftslogik. In: Königswieser, R., Haller, M., Maas, P. and Jarmai, D. (eds.): Risiko-Dialog. Zukunft ohne Harmonieformel. Cologne: Deutscher Instituts-Verlag, 61–80.

Schneider, K. and Rheinberg, F. (1996): Erlebnissuche und Risikomotivation. In: Amelang, M. (ed.): Temperaments- und Persönlichkeitsunterschiede. Göttingen: Hogrefe, 407–439.

Scholes, R. J., Schulze, E.–D., Pitelka, L. F. and Hall, D. O. (1998): Biogeochemistry of terrestrial ecosystems. In: Walker, B., Steffen, W., Canadell, J. and Ingram, J. (eds.): The terrestrial biosphere and global change. Cambridge, New York: Cambridge University Press (in print).

Scholtissek, C., Rohde, W., von Hoyningen, V. and Rott, R. (1978): On the origin of the human influenza virus subtypes H2N2 and H3N2. Virology 87, 13–20.

Schulman, P. R. (1993): The analysis of high reliability organizations: a comparative framework. In: Roberts, K. H. (ed.): New challenges to understanding organizations. New York: Macmillan, 33–54.

Schulte, E. and Käppeli, O. (eds.) (1996): Gentechnisch veränderte krankheits- und schädlingsresistente Nutzpflanzen – Eine Option für die Landwirtschaft? BATS (Biosafety Research and Assessment of Technology Impacts of the Swiss Priority Programm Biotechnology) – TA Hefte. Volume 1: Materialien. Bern: Schweizerischer Nationalfonds.

Schulte, E. and Käppeli, O. (eds.) (1997): Gentechnisch veränderte krankheits- und schädlingsresistente Nutzpflanzen. BATS (Biosafety Research and Assessment of Technology Impacts of the Swiss Priority Programm Biotechnology) – TA Hefte. Volume 2: Abschlußbericht. Bern: Schweizerischer Nationalfonds.

Schulz von Thun, F. (1993): Miteinander Reden. Störungen und Klärungen. Reinbek: Rohwohlt.

Schulze, E.-D. and Mooney, H. A. (eds.) (1994): Biodiversity and ecosystem function. Berlin, Heidelberg, New York: Springer.

Schulze, E.-D., Oren, R. and Lange, O. L. (1989): Processes leading to forest decline: A synthesis. In: Schulze, E. D., Lange, O. L. and Oren, R. (eds.): Forest decline and air pollution. Ecological Studies 77. Berlin, Heidelberg, New York: Springer, 459–468.

Schütz, H., Wiedemann, P. and Gray, P. (1997): Cognitive determinants of perceived risk (workshop report). Jülich: Forschungszentrum Jülich.

Schwartz, D. A. (1997): Emerging and reemerging infections. Progress and challenges in the subspeciality of infections disease pathology. Archives of Pathology & Laboratory Medicine 121, 776–784.

Schwartz, M. N. (1979): Another new pneumonia. Pandora's Box reopened. The New England Journal of Medicine 301, 995–996.

Schwartz, S. E. (1996): The Whitehouse effect – shortwave radiative forcing of climate by anthropogenic aerosols: an overview. Journal of Aerosol Science 27, 359–382.

Schwarze, R. (1998): Prävention von Umweltschäden durch Umwelthaftung? Eine theoretische und empirische Analyse des Umwelthaftungsrechts. Mimeo.

Seibt, C. (1994): Zivilrechtlicher Ausgleich ökologischer Schäden. Tübingen: Mohr.

Sentker, A., Tomiuk, J. and Wöhrmann, K. (1994): Manipulierte Gene – sicher unter menschlicher Kontrolle? Biologie in unserer Zeit 24 (2), 85–90.

Seralgedin, I. (1996): Sustainability and the wealth of nations. Washington, DC: World Bank.

Seydel, R. (1988): From equilibrium to chaos. Amsterdam: Elsevier.

Shafer, B. P., Garcia, M. D., Scammon, R. J., Snell, C. M., Stellingwerf, R. F., Remo, J. L., Managan, R. A. and Rosenkilde, C. E. (1994): The coupling of energy to asteroids and comets. In: Gehrels, T. (ed.): Hazards due to comets and asteroids. Tuscon: University of Arizona Press, 955–1013.

Shand, H. (1997): Human nature: agricultural biodiversity and farm-based food security. Study of the Rural Advancement Foundation International (RAFI) for the Food and Agriculture Organization of the United Nations (FAO). Rome: FAO.

Sharpe, R. M., Turner, K. J. and Sumpter, J. P. (1998): Endocrine disruptors and testis development (letter). Environmental Health Perspectives 106 85), 220–221.

Shavell, S. (1987): Economic analysis of accident law. Cambridge, Ma.: Harvard University Press.

Shinbrot, T., Ott, E., Grebogi, C. and Yorke, E. (1992): Using chaos to direct orbits to targets in systems describable by a one-dimensional map. Physical Review A45 (6), 4165–4168.

Shirakawa, T., Enomoto, T., Shimazu, S. and Hopkin, J. M. (1997): The inverse association between tuberculin responses and atopic disorder. Science 275, 77–79.

Shogren, J. F., Herriges, J. A. and Godivindasamy, R. (1993): Limits to environmental bonds. Ecological Economics 8, 109–133.

Short, J. F. (1984): The social fabric of risk: toward the social transformation of risk analysis. American Sociological Review 49, 711–725.

Shrader-Frechette, K. S. (1984): Risk-cost-benefit methodology and equal protection. In: Covello, V. T., Menkes, J. and Mumpower, J. (eds.): Risk evaluation and management. New York, London: Plenum Press, 275–296.

Shrader-Frechette, K. (1985): Risk analysis and scientific method: methodological and ethical problems with evaluating societal risks. Dordrecht: Reidel.

Shrader-Frechette, L. (1991): Risk and rationality. Philosophical foundations for populist reforms. Berkeley: University of California Press.

Shubik, M. (1991): Risk, society, politicians, scientists, and people. In: Shubik, M. (ed.): Risk, organizations, and society. Dordrecht: Kluwer, 7–30.

Siebert, H. (1987a): Umweltschäden als Problem der Unsicherheitsbewältigung: Prävention und Risikoallokation. In: Bayerische Rückversicherung (ed.) (1987): Gesellschaft und Unsicherheit. Karlsruhe: Versicherungswirtschaft, 173–185.

Siebert, H. (1987b): Risk and environmental allocation. Sonderforschungsbereich 178 'Internationalisierung der Wirtschaft'. Konstanz: University of Konstanz.

Siebert, H. (1988): Haftung ex post versus Anreize ex ante: Einige Gedanken zur Umweltpolitik bei Unsicherheit. In: Niklisch, F. (ed.): Prävention im Umweltrecht – Risikovorsorge, Grenzwerte, Haftung. Heidelberg: Müller, 111–132.

Sieler, C. and Sekul, S. (1995): Die EG-Öko-Audit-Verordnung. Wirtschaftswissenschaftliches Studium 24 (5), 253–255.

Sims, J. and Baumann, D. (1972). The tornado threat: coping styles of the North and the South. Science, 176, 1386–1392.

Singer, E. and Endreny, P. (1987): Reporting hazards: their benefits and costs. Journal of Communication 37 (3), 10–26.

Singer, E. and Endreny, P. (1993): Reporting on risk. How the mass media portray accidents, diseases, disasters, and other hazards. New York: Russel Sage Foundation.

Sinn, H.-W. (1986): Risiko als Produktionsfaktor. Jahrbuch für Nationalökonomie und Statistik 201 (6), 557–570.

Skinner, J. A., Lewis, K. A., Bardon, K. S., Tucker, P., Catt, J. A. and Chambers, B. J. (1997): An overview of the environmental impact of agriculture in the U. K. Journal of Environmental Management 50, 111–128.

Skorupinski, B. (1996): Gentechnik für die Schädlingsbekämpfung. Eine ethische Bewertung der Freisetzung gentechnisch veränderter Organismen in der Landwirtschaft. Stuttgart: Enke.

Slaper, H., Velders, G. J. M., Daniel, J. S., Degroijl, F. R. and van der Leun, J. C. (1996): Estimates of ozone depletion and skin cancer incidence to examine the Vienna-Convention achievements. Nature 384, 256–258.

Slotine, J. J. and Li, W. (1991): Applied nonlinear control. New Jersey: Prentice Hall.

Slovic, P. (1987): Perception of risk. Science 236 (4799), 280–285.

Slovic, P., Fischhoff, B. and Lichtenstein, S. (1985): Rating the risks: the structure of expert and lay perceptions. In: Covello, V. T., Mumpower, J. L., Stallen, P. J. M. and Uppuluri, V. R. R. (eds.): Environmental impact assessment, technology assessment, and risk analysis. Volume 4. Berlin, Heidelberg, New York: Springer, 131–156.

Slovic, P., Fischhoff, B. and Lichtenstein, S. (1986): The psychometric study of risk perception. In: Covello, V. T., Menkes, J. and Mumpower, J. (eds.): Risk evaluation and management. New York, London: Plenum Press, 3–24.

Smallwood, K. S. (1994): Site invasibility by exotic birds and mammals. Biological Conservation 69, 251–259.

Smayda, T. J. (1990): Novel and nuisance algal blooms in the sea: evidence for a global epidemic. In: Graneli, E. (ed.): Toxic marine phytoplankton. Proceedings of the 4th International Conference Lund, Sweden, June 26–30, 1989. Amsterdam: Elsevier, 29–40.

Smayda, T. J. (1997): What is a bloom? A commentary. Limnology and Oceanography 42 (5, Teil 2) 1132–1136.

Smith, V. K. (1986): A conceptual overview of the foundations of benefit-cost analysis. In: Bentkover, J. D., Covello, V. T. and Mumpower, J. (eds.): Benefits assessment: the state of the art. Dordrecht: Reidel, 13–34.

Snider, D. E. and Castro, K. G. (1998): The global threat of drug-resistant tuberculosis. The New England Journal of Medicine 338, 1689–1690.

Sojref, D. and Thamm, D. (1997): Gentechnik in Mittel- und Osteuropa. Analyse der gesetzlichen Regelungen, Forschungsschwerpunkte und Stand der Freisetzung in ausgewählten Ländern. Berlin: Umweltbundesamt (UBA).

Solow, R. M. (1971): The economist's approach to pollution control. Science 173, 498–503.

Sopolski, H. M. (1990): The politics of risk. Daedalus 119 (4), 83–96.

Soto A. M., Sonnenschein, C., Chung, K. L., Fernandez, M. F., Olea, N. and Serrano, F. O. (1995): The E-Screen Assay as a tool to identify estrogens: an update on estrogenic environmental pollutants. Environmental Health Perspectives 103, 113–122.

Spada, H. and Ernst, A. M. (1992): Wissen, Ziele und Verhalten in einem ökologisch-sozialen Dilemma. In: Pawlik, K. and Stapf, K. H. (eds.): Umwelt und Handeln. Bern: Huber, 83–106.

Spittler, G. (1989): Handeln in einer Hungerkrise: Tuaregnomaden und die große Dürre von 1984. Opladen: Leske und Budrich.

SRU – Sachverständigenrat für Umweltfragen (1988): Umweltgutachten 1987. Stuttgart: Kohlhammer.

SRU – Sachverständigenrat für Umweltfragen (1998): Umweltgutachten 1998. Stuttgart: Metzler-Poeschel.

Stahlschmidt-Allner, P., Allner, P., Römbke, J. and Knacker, T. (1997): Endocrine disruptors in the aquatic environment. Environmental Science and Pollution Research 4, 155–162.

Staudt, E., Auffermann, S., Schroll, M. and Interthal, J. (1997): Innovation trotz Regulation: Freiräume für Innovationen in bestehenden Gesetzen – Untersuchungen am Beispiel des Chemikaliengesetzes. Bochum: Institut für angewandte Innovationsforschung.

Steffen, E. (1990): Verschuldungshaftung und Gefährdungshaftung für Umweltschäden. Neue Juristische Wochenschrift 43 (30), 1817–1822.

Steger, U. (1995): Umwelt-Auditing. In: Junkernheinrich, M., Klemmer, P. and Wagner, G-R. (eds.): Handbuch zur Umweltökonomie. Berlin: Analytica, 245–250.

Stein, J. and Lotstein, R. (1995): Resistance management strategy for Ciba seeds' Transgenic Bt Corn. ISB News Report (December), 10–14.

Stocker, T. F. and Schmittner, A. (1997): Influence of CO_2 emission rates on the stability of the thermohaline circulation. Nature 388, 862–866.

Stommel, H. (1961): Thermohaline convection with two stable regimes of flow. Tellus 13, 224–230.

Stone, T. and Feldman, J. (1995): Development of a comprehensive resistance management plan for NewLeaf potatoes. ISB News Report (December), 7–10.

Streit, B. (1994): Lexikon Ökotoxikologie. Weinheim: VCH.

Swift, J. (1989): Why are rural people vulnerable to famine? IDS Bulletin 20, 8–15.

Tait, N. and Mead, G. (10.12.1997): Nature's errant child blows hot and cloud. London: Financial Times.

Tappeser, B. and Wurz, A. (1996): Freisetzungsrisiken gentechnisch manipulierter Organismen. Widersprüche und Diskrepanzen zu Deregulierungsabsichten des Gentechnikgesetzes und angestrebten Verfahrensvereinfachung bei gentechnischen Genehmigungsverfahren. Freiburg: Öko-Institut.

Taubenberger, J. K., Reid, A. H., Krafft, A. E., Bijwaard, K. E. and Fanning, T. G. (1997): Initial characterization of the 1918 'Spanish' influenza virus. Science 275, 1793–1796.

Tepfer, M. (1993): Viral genes and transgenic plants? What are the potential environmental risks? Bio/Technology 11, 1125–1129.

Tepfer, M. and Balázs, E. (1997a): Concluding remarks and recommendations. In: Tepfer, M. and Balázs, E. (eds.): Virus-resistant transgenic plants: potential ecological impact. Berlin, Heidelberg, New York: Springer, 121–123.

Tepfer, M. and Balázs, E. (1997b) (eds.): Virus-resistant transgenic plants: potential ecological impact. Berlin, Heidelberg, New York: Springer.

Tiedje, J. M., Colwell, R. K., Grossman, Y. L., Hodson, R. E., Lenski, R. E., Mack, R. N. and Regal, P. J. (1989): The planned introduction of genetically engineered organisms: Ecological considerations and recommendations. Ecology 70, 298–315.

Tietzel, M. (1985): Wirtschaftstheorie und Unwissen – Überlegungen zur Wirtschaftstheorie jenseits von Risiko und Unsicherheit. Tübingen: Mohr.

Tilman, D., Wedin, D. and Knops, J. (1996): Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379, 718–720.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M. and Sieman, E. (1997): The influence of functional diversity and composition on ecosystem processes. Science 277, 1300–1302.

Timmermann, P. and White, R. (1997): Megahydropolis: coastal cities in the context of global environmental change. Global Environmental Change 7 (3), 205–234.

Tittes, E. (1986): Zur Problematik der Wahrscheinlichkeitsrechnung bei seltenen Ereignissen. In: Kompes, P. C. (ed.): Technische Risiken in der Industriegesellschaft. Erfassung, Bewertung, Kontrolle. Wuppertal: GfS, 345–372.

Toon, O. B., Zahnle, K., Turco, R. P. and Covey, C. (1994): Environmental impact perturbations caused by asteroid impacts. In: Gehrels, T. (ed.): Hazards due to comets and asteroids. Tuscon: University of Arizona Press, 791–826.

Torsello, L. and Vercelli, A. (1994): Environmental bonds: A critical assessment. Siena: University of Siena.

Toth, F. L., Bruckner, T., Füssel, H.-M., Leimbach, M., Petschel-Held, G. and Schellnhuber, H.-J. (1997): The tolerable windows approach to integrated assessments. Proceedings of the IPCC Asia-Pacific Workshop on Integrated Assessment Models, Tokyo, Japan, 10–12th March 1997. Geneva: IPCC Secretariat.

Turco, R. P., Toon, O. B., Ackerman, T. P., Pollack, J. P. and Sagan, C. (1982): Nuclear winter: consequences of multiple nuclear explosions. Science 222, 1283–1292.

Turner, K., O'Riordan, T. and Kemp, R. (1991): Climate change and risk management. In: Jäger, R. and Ferguson, H. L. (eds.): Climate change: science, impacts and policy. Proceedings of the Second World Climate Conference. Cambridge, New York: Cambridge University Press, 397–409.

Turner II, B. L., Kasperson, J. X., Kasperson, R. E., Dow, K. and Meyer, W. B. (1995): Comparisons and conclusions. In: Kasperson, J., Kasperson, R. E. and Turner, B. L. (eds.): Regions at risk – comparisons of threatened environments. Tokyo: United Nations University Press, 519–588.

Turner, G. and Wynne, B. (1992): Risk communication – a literature review and some implications for biotechnology. In: Durant, J. (ed.): Biotechnology in public – a review of recent research. London: Science Museum, 109–141.

UBA – Umweltbundesamt (1996): Langzeitmonitoring von Umwelteffekten transgener Organismen. Arbeitstagung am 5./6. Oktober 1995. Berlin: UBA.

UBA – Umweltbundesamt (1998): Ursachen der Hochwasserentstehung and ihre anthropogene Beeinflussung. UBA-Texte 18/98. Berlin: UBA.

Ulrich, B. and Sumner, M. E. (eds.) (1991): Soil acidity. Berlin, Heidelberg, New York: Springer.

UN – United Nations (1992): Erklärung zur 'Verantwortung des Sicherheitsrates im Hinblick auf die Wahrung des Weltfriedens und der internationalen Sicherheit' vom 31.1.1992, S/23500. Geneva: UN.

UNAIDS – The Joint United Nations Programme on HIV/AIDS (1997): 1997 report on the global HIV/AIDS epidemic. Geneva: UNAIDS.

UNCHS – United Nations Centre for Human Settlements (1996): An urbanizing world – global report on human settlements. Oxford, N.Y.: Oxford University Press.

UNCTAD – United Nations Conference on Trade and Development (1997): Trade and Development Report 1997 – globalization, distribution and growth. New York, Geneva: UNCTAD.

UNDP – United Nations Development Programme (1992): Human Development Report 1992. Oxford, New York: Oxford University Press.

UNDP – United Nations Development Programme (1997): Bericht über die Menschliche Entwicklung. Human Development Report. Bonn: UNO Verlag.

UN-ECE – United Nations Economic Commission for Europe (1997): Workshop on critical limits and effect based approaches for heavy metals and persistent organic pollutants. Background Documents. Geneva: UN-ECE.

UN-ECE – United Nations Economic Commission for Europe und EC – European Commission (1997): Forest condition in Europe. 1997 Executive Report. Geneva: UN-ECE .

UNEP – United Nations Environment Programme (1996): Survey on sources of POPs, report prepared for an IFCS expert meeting on persistent organic pollutants, Manila, 17.–19.6.1996. Nairobi: UNEP.

UNPD – United Nations Population Division (1998): World population prospects. The 1998 revision. Geneva: UNPD.

van den Daele, W. (1993): Hintergründe der Wahrnehmung von Risiken der Gentechnik: Naturkonzepte und Risikosemantik. In: Bayerische Rückversicherung (ed.): Risiko ist ein Konstrukt – Wahrnehmungen zur Risikowahrnehmung. Munich: Knesebeck, 169–189.

van den Daele, W., Pühler, A. and Sukopp, H. (1996): Grüne Gentechnik im Widerstreit: Modell einer partizipativen Technikfolgenabschätzung zum Einsatz transgener herbizidresistenter Pflanzen. Weinheim: VCH.

van den Daele, W., Pühler, A. and Sukopp, H. (1997): Transgenic herbicide-resistant crops. A participatory technology assessment. Summary report. Berlin: Wissenschaftzentrum Berlin (WZB).

van der Ploeg, R. R., Ringe, H., Machulla, G. and Hermsmeyer, F. (1997): Postwar nitrogen use efficiency in West German agriculture and groundwater quality. Journal of Environmental Quality 26, 1203–1212.

van der Voet, E., Kleijn, R. and de Haes, U. H. A. (1996): Nitrogen pollution in the European Union – origins und proposed solutions. Environmental Conservation 23 (2), 120–132.

van Loveren, H., Steerenberg, P. A., Garssen, J. and van Bree, L. (1996): Interaction of environmental chemicals with respiratory sensitization. Toxicology Letters 86, 163–167.

Vaughan, E. (1993): Individual and cultural differences in adaption to environmental risks. American Psychologist 48 (6), 673–680.

Vaughan, M. (1987): The story of an African famine: gender and famine in twentieth-century Malawi. Cambridge, New York: Port.

Veerhoff, M., Roscher, S. and Brümmer, G. W. (1996): Ausmaß und ökologische Gefahren der Versauerung von Böden unter Wald. Berlin: Umweltbundesamt (UBA).

Vitousek, P. M. (1986): Biological invasions and ecosystem properties: Can species make a difference? In: Mooney, H. A. and Drake, J. A. (eds.): Ecology of biological invasions of North America and Hawaii. Ecological Studies 58. Berlin, Heidelberg, New York: Springer, 163–176.

Vitousek, P. M. (1990): Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos 57, 7–13.

Vitousek, P. M. (1994): Beyond global warming: Ecology and global change. Ecology 75 (7), 1861–1876.

Vitousek, P. M., Mooney, H. A., Lubchenco, J. and Melillo, J. M. (1997): Human domination of Earth's ecosystems. Science 277, 494–499.

Vlek, C. A. (1996): A multi-level, multi-stage and multi-attribute perspective on risk assessment, decision-making, and risk control. Risk, Decision, and Policy 1 (1), 9–31.

von Bar, C. (1995) (ed.): Internationales Umwelthaftungsrecht – Auf dem Weg zu einer Konvention über Fragen des Internationalen Umwelthaftungsrechts. Volume 1. Köln: Heymann, 15–29.

von Gleich, A. (1997): Beurteilungskriterien beim Einsatz gentechnischer Verfahren in der Lebensmittelindustrie. In: Bender, W., Gassen, H. G., Platzer, K. and Sinemus, K. (eds.): Gentechnik in der Lebensmittelproduktion. Wege zum interaktiven Dialog. Darmstadt: TH Darmstadt, 177–214.

von Hayek, F. A. (1991): Die Verfassung der Freiheit. Tübingen: Mohr.

von Hoffmann, B. (1998): Art. 38 EGBGB. Kommentar zum Bürgerlichen Gesetzbuch. Berlin: deGruyter.

von Mehren, A. (1997): The case for a convention-mixed approach to jurisdiction to adjudicate and recognition and enforcement of foreign judgements. Rabels Zeitschrift 61, 86–92.

von Mutius, E., Fritzsch, C., Weiland, S. K., Röll, G. and Magnussen, H. (1992): Prevalence of asthma and allergic disorders among children in united Germany: a descriptive comparison. British Medical Journal 305, 1395–1399.

von Piechowski, M. (1994): Risikobewertung in der Schweiz. Neue Entwicklungen und Erkenntnisse. Mimeo.

von Schell, T. (1994): Die Freisetzung gentechnisch veränderter Mikroorganismen. Ein Versuch interdisziplinärer Urteilsbildung. Tübingen: Attempto.

von Schell, T. (1998): Zur Freisetzung gentechnisch veränderter Pflanzen. In: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland GmbH (ed.): Gen-Welten. Bonn: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland GmbH, 109–116.

von Schomberg, R. (1998): An appraisal of the working in practice of Directive 90/220/EEC on the deliberate release of genetically modified organisms. Luxembourg: European Parliament. Directorate General for Research.

von Winterfeld, D. and Edwards, W. (1984): Patterns of conflict about risky technologies. Risk Analysis 1, 277–287.

von Winterfeldt, D. and Edwards, W. (1986): Decision analysis and behavioral research. Cambridge, New York: Cambridge University Press.

Wadman, M. (1997): Dispute over insect resistance to crops. Nature 388, 817.

Wätzold, F. (1997): Anwendbarkeit und Effizienz umweltökonomischer Konzeptionen bei ökologischer Unsicherheit. In: Feser, H.-D. and von Hauff, M. (eds.): Neuere Entwicklungen in der Umweltökonomie und -politik. Regensburg: Transfer, 59–88.

Wätzold, F. and Simonis, U. E. (1997): Ökologische Unsicherheit: Über Möglichkeiten und Grenzen von Umweltpolitik. Aus Politik und Zeitgeschichte – Beilage zur Wochenzeitung 'Das Parlament' vom 27.6.1997, 3–14.

Wagner, W. (1994): Alltagsdiskurs – Die Theorie sozialer Repräsentationen. Göttingen: Hogrefe.

Wagner, G. R. (1991): Entrepreneurship and innovation from an environmental risk perspective. In: Roberts, L. and Weale, A. (1991): Innovation and environmental risk. London, New York: Belhaven, 138–148.

Wagner, G. R. and Janzen, H. (1994): Umwelt-Auditing. Betriebswirtschaftliche Forschung und Praxis 6, 573–604.

Wahl, R. (1994): Erlaubnis. In: Kimminich, O., von Lersner, H. and Storm, P.-C. (eds.): Handwörterbuch des Umweltrechts. Volume I. Berlin: Schmidt, 528–542.

Walker, B. and Steffen, W. (eds.) (1996): Global change and terrestrial ecosystems. Cambridge, New York: Cambridge University Press.

Walker, E. and Christie, P. (1998): Chinese avian influenza. British Medical Journal 316, 325.

Walker, B., Steffen, W., Canadell, J. and Ingram, J. (1998): The terrestrial biosphere and global change: implications for natural and managed ecosystems – executive summary. In: Walker, B., Steffen, W., Canadell, J. and Ingram, J. (eds.): The terrestrial biosphere and global change. Cambridge, New York: Cambridge University Press (in print).

Walter, G. (1997): Neuere Entwicklungen im internationalen Zivilprozeßrecht. In: Prütting, H. (ed.): Festschrift für Lüke. Munich: Beck, 921–940.

Wartenberg, D. and Greenberg, M. (1998): EMF and the media: coverage by three major U.S. daily newspapers. In: Matthes, R., Bernhardt, J. H. and Repacholi, M. H. (eds.): Risk perception, risk communication and its application to EMF exposure. Proceedings International Seminar on Risk Perception, Risk Communication and its Application to EMF Exposure, Vienna, Austria, October 22 and 23, 1997. Vienna: International Commission on Non-Ionizing Radiation Protection and World Health Organization (WHO), 215–228.

Watts, M. J. and Bohle, H. G. (1993a): The space of vulnerability: the causal structure of hunger and famine. Progress in Human Geography 17 (1), 43–67.

Watts, M. J. and Bohle, H. G. (1993b): Hunger, famine and the space of vulnerability. GeoJournal 30, 117–125.

Watzlawick, P., Beavin, J. H. and Jackson, D. D. (1993): Menschliche Kommunikation – Formen, Störungen, Paradoxien. Bern, Stuttgart, Toronto: Huber.

WBGU – German Advisory Council on Global Change (1994): World in transition: basic structure of global human-environment interactions. 1993 Annual Report. Bonn: Economica.

WBGU – German Advisory Council on Global Change (1995a): World in transition: the threat to soils. 1994 Annual Report. Bonn: Economica.

WBGU – German Advisory Council on Global Change (1995b): Scenario for the derivation of global CO_2 reduction targets and implementation strategies. Statement on the occasion of the First Conference of the Parties to the Framework Convention on Climate Change in Berlin. Bremerhaven: WBGU.

WBGU – German Advisory Council on Global Change (1996): World in transition: ways towards global environmental solutions. 1995 Annual Report. Berlin, Heidelberg, New York: Springer.

WBGU – German Advisory Council on Global Change (1997a): World in transition: the research challenge. 1996 Annual Report. Berlin, Heidelberg, New York: Springer.

WBGU – German Advisory Council on Global Change (1997b): Targets for climate protection 1997. A study for the Third Conference of the Parties to the Framework Convention on Climate Change in Kyoto. Bremerhaven: WBGU.

WBGU – German Advisory Council on Global Change (1998a): World in transition: ways towards sustainable management of freshwater resources. Annual Report 1997. Berlin, Heidelberg, New York: Springer.

WBGU – German Advisory Council on Global Change (1998b): The accounting of biological sinks and sources under the Kyoto Protocol - a step forwards or backwards for global environmental protection? Special Report 1998. Bremerhaven: WBGU.

WCMC – World Conservation Monitoring Centre (1997): Generalized world forest map. Internet–Datei http://www.wcmc.org.uk/forest/data/wfm.html. Geneva: WCMC.

Weber, K. (1988): Forschungspolitische Früherkennung: zwei Jahre Projekterfahrung. In: Knoepfel, P. (ed.): Risiko und Risikomanagement. Basel, Frankfurt/M.: Helbing & Lichtenhahn, 111–121.

Webler T., Levine, D., Rakel, H. and Renn, O (1991): A novel approach to reducing uncertainty: the Group Delphi. Technological Forecasting and Social Change 39 (3), 253–263.

Webster, R. G. and Laver, W. G. (1972): The origin of pandemic influenza. Bull-World-Health-Organ, 47, 449–452.

Wegner, G. (1994): Marktkonforme Umweltpolitik zwischen Dezisionismus und Selbststeuerung. Walter Eucken Institut, Vorträge und Aufsätze 143. Tübingen: Mohr.

Weick, K. E. (1987): Organizational culture as a source of high reliability. California Management Review 29 (2), 112–127.

Weinrich, H. (1972): System, Diskurs, Didaktik und die Diktatur des Sitzfleisches. Merkur 8, 801–812.

Weissman, P. R. (1994): The comet and asteroid impact hazard in perspective. In: Gehrels, T. (ed.): Hazards due to comets and asteroids. Tuscon: University of Arizona Press, 1191–1212.

Wells, G. A., Wilesmith, J. W. and McGill, I. S. (1991): Bovine spongiform encephalopathy: a neuropathological perspective. Brain Pathology 1, 69–78.

Wenninger, G. and Graf Hoyos, C. (eds.) (1996): Arbeits-, Gesundheits- und Umweltschutz. Handwörterbuch verhaltenswissenschaftlicher Grundbegriffe. Heidelberg: Asanger.

WHO – World Health Organization (1996a): Melanoma cooperative group. Geneva: WHO.

WHO – World Health Organization (1996b): Climate change and human health. Geneva: WHO.

WHO – World Health Organization (1997a): Global AIDS surveillance. WHO Weekly Epidemiological Record (48), 357–360.

WHO – World Health Organization (1997b): HIV/AIDS: The global epidemic. WHO Weekly Epidemiological Record (4), 17–21.

WHO – World Health Organization (1997c): World Health Report 1997. Geneva: WHO.

Wicke, L. (1990): Der ökonomische Wert der Ökologie. In: Schüz, M. (ed.): Risiko und Wagnis: Die Herausforderung der industriellen Welt. Volume 1. Pfullingen: Neske, 210–227.

Wiedemann, P. M. and Schütz, H. (1996): Elektromagnetische Felder und Risikowahrnehmung. In: Preuss, V. (ed.): Risikoanalysen. Über den Umgang mit Gesundheits- und Umweltgefahren. Heidelberg: Asanger, 204–213.

Wiedemann, P. M., Rohrmann, B. and Jungermann, H. (1991): Das Forschungsgebiet 'Risiko-Kommunikation'. In: Jungermann, H., Rohrmann, B. and Wiedemann, P. (eds.): Risikokontroversen – Konzepte, Konflikte, Kommunikation. Berlin, Heidelberg, New York: Springer, 1–10.

Wiedemann, P. M., Bobis-Seidenschwanz, A. and Schütz, H. (1994): Elektrosmog – Ein Risiko? Bedeutungskonstitution von Risiken hochfrequenter elektromagnetischer Felder. Arbeiten zur Risikokommunikation Heft 44. Jülich: Programmgruppe Mensch, Umwelt, Technik (MUT) des Forschungszentrums Jülich.

Wiese, G. T. (1998): Wahrscheinlichkeitshaftung. Anmerkungen zu einem alternativen Haftungskonzept. Zeitschrift für die Rechtspraxis (1), 27–31.

Wildavsky, A. (1984): Die Suche nach einer fehlerlosen Risikominderungsstrategie. Lange, S. (ed.): Ermittlung und Bewertung industrieller Risiken. Berlin, Heidelberg, New York: Springer, 224–233.

Wildavsky, A. and Dake, K. (1990): Theories of risk perception: who fears what and why? Daedalus 119, 41–60.

Will, R. G., Ironside, J. W., Zeidler, M., Cousens, S. N., Estibeiro, K., Alperovitch, A., Poser, S., Pocchiari, M., Hofmann, A. and Smith, P. G. (1996): A new variant of Creutzfeldt-Jakob Disease in the UK. Lancet 347, 921–925.

Williams, C. H. (1998a): Global environment and human intelligence. The Globe 42, 11–13.

Williams, K. (1998b): Biological control of European rabbits in Australia. Expertise for WBGU. Mimeo.

Williams, G., Stretton, T. B. and Leonard, J. C. (1983): AIDS in 1959? [letter]. Lancet 2, 1136.

Wilson, R. and Crouch, E. A. C. (1987): Risk assessment and comparisons: an introduction. Science 236, 267–270.

Winkler, M. (1995): Ökologische Intervention im internationalen Recht? Natur und Recht 17 (2), 57–61.

WMO – World Meteorological Organization (1997): Global acid deposition assessment. In: Whelpdale, D. M. and Kaiser M. S. (eds.): WMO-TD No. 777. Geneva: WMO, 241ff.

Woodwell, G. and Mackenzie, F. T. (eds.) (1995): Biotic feedbacks in the global climatic system – will the warming feed the warming? Oxford, N.Y.: Oxford University Press.

Wüthrich, B. (1989): Epidemiology of allergic disease: are they really on the increase? International Archives of Allergy and Applied Immunology 90, 3–10.

Wynne, B. (1991): Public perception and communication of risks: what do we know? The Journal of NIH Research 3, 65–71.

Wynne, B. (1992): Risk and social learning: reification to engagement. In: Krimsky, S. and Golding, D. (eds.): Social theories of risk. Westport, CT., London: Praeger, 275–297.

Yemaneberhan, H., Berkele, Z., Venn, A., Lewis, S., Parry, E. and Britton, J. (1997): Prevalence of wheeze and asthma and relation to atopy in urban and rural Ethiopia. Lancet 350, 85–90.

Yuen, K. Y., Chan, P. K. S., Peiris, M., Tsang, D. N. C., Que, T. L., Shortridge, K. F., Cheung, P. T., To, W. K., Ho, E. T. F., Sung, R., Cheng, A. F. B. and members of the H5N1 Study Group (1998): Clinical features and rapid viral diagnosis of human disease associated with avian influenza A H5N1 virus. Lancet 351, 467–471.

Zaitsev, Y. P. (1993): Impacts of eutrophication on the Black Sea fauna. Fisheries and Environment Studies in the Black Sea System. Rome: Food and Agriculture Organization (FAO).

Zaslavsky, D. (1997): Solar energy without a collector for electricity and water in the 21st century. A lecture presented at the 150 years anniversary of the Austrian Academy of Sciences on May 1997. Haifa: Technion. Israel Institute of Technology.

Zhu, T. F., Korber, B. T., Nahmias, A. J., Hooper, E., Sharp, P. M. and Ho, D. D. (1998): An African HIV-1 sequence from 1959 and implications for the origin of the epidemic. Nature 391, 594–597.

Zilleßen, H. (1993): Die Modernisierung der Demokratie im Zeichen der Umweltpolitik. In: Zilleßen, H., Dienel P. C. and Strubelt, W. (eds.): Die Modernisierung der Demokratie. Opladen: Westdeutscher Verlag, 17–39.

Zimmermann, H. (1984): Ökonomische Anreizinstrumente in der Umweltpolitik – Einsatzbegründung, Formen sowie die Wirkung in verschiedenen Typen von Verdichtungsgebieten. Bochum: Ruhr-Forschungsinstitut für Innovations- und Strukturpolitik.

Zimmermann, H. and Henke, K.-D. (1994): Finanzwissenschaft – Eine Einführung in die Lehre von der öffentlichen Finanzwirtschaft. Munich: Vahlen.

Zimmermann, H., Wohltmann, M. and Hansjürgens, B. (1996): Umweltabgaben und Innovationen. Berlin: Analytica.

Zimmermann, P. H., Feichter, J., Rath, H. K., Crutzen, P. J. and Weiss, W. (1989): A global three-dimensional source-receptor model investigation using ^{85}Kr. Atmospheric Environment 23, 25–35.

ZKBS – Zentrale Kommission für die Biologische Sicherheit (1997): Stellungnahme der ZKBS zum Ampicillinresistenz-Gen in gentechnisch verändertem Mais. Internet location http://www.rki.de/gentec/zkbs/allgstell/stell.htm. Berlin: ZKBS.

Zschau, J. (1998): Geophysikalische Risiken mit dem Schwerpunkt Erdbeben. Expertise for WBGU. Mimeo.

Zuckerman, M. (1979): Sensation seeking and risk taking. In: Caroll, C. E. (ed.): Emotions in personality and psychopathology. New York: Plenum Press, 163–197.

Zürn, M. and Take, I. (1996): Weltrisikogesellschaft und öffentliche Wahrnehmung globaler Gefährdungen. Aus Politik und Zeitgeschichte (24–25), 3–13.

Zylicz, T. (1987): Environmental risk analysis and management. EKO-Series No. 8710. Warsaw: University of Warsaw.

➥ cross-reference within glossary

Cassandra refers to a class of risks of global change in which both the ➥ probability of occurrence and the ➥ damage potential are known and high. Despite this, there is little concern in the present because the damage will only occur after a long period.

Certainty of assessment is the degree of reliability with which the two prime components of risk can be determined, namely ➥ probability of occurrence and extent of damage. To state a specific certainty of assessment, these components must be identifiable. No statement is possible where ➥ ignorance or indeterminacy prevail. Where the distribution function of probabilities of occurrence and their corresponding ➥ damage potentials are known, certainty of assessment is high. Where the function has broad error corridors, certainty of assessment is low. We speak of statistical uncertainty in cases where the certainty of assessment can be quantified by statistical techniques (for instance by stating ➥ confidence intervals).

Compensability is the possibility of providing injured or aggrieved parties with compensation such that the utility to them represented by the compensation and the lost utility to them represented by the ➥ damage are roughly in balance, insofar as and to the extent that the original state cannot be reinstated or, for other reasons, should not be reinstated.

Confidence intervals indicate the range of variance of the two prime determinants of risk, namely extent of damage and ➥ probability of occurrence. They are thus a measure of statistical uncertainty. However, the latter can only be stated if the certainty of assessment can be quantified by means of statistical techniques.

Core problems of global change are, in syndrome analysis, the global change phenomena of central importance. In the syndrome approach, they appear either as particularly dominant trends of global change, such as climate change, or consist of several interrelated trends. One such 'megatrend' is the core problem of 'soil degradation'.

Critical area means, in the terminology of the Council, a category of risk in which the uncertainty of all risk parameters is high, the ➥ damage potential can be severe and the probability of occurrence is high. ➥ Persistency, ➥ ubiquity and ➥ irreversibility are high. Within the critical area, the Council distinguishes between the ➥ transitional area and the ➥ prohibited area.

Cyclops refers to a class of risks of global change in which the ➥ probability of occurrence is uncertain, while the maximum ➥ damage is largely known.

Damage means the destruction, diminution or impairment of concrete or abstract values. These include loss of goods that have money value (property loss), loss of opportunities in life (e.g. when having to flee from a natural disaster) and loss of quality of life (e.g. due to degradation of the natural environment). They further include forms of immaterial damage, such as loss of confidence in the integrity of policymakers. To perceive a damage as such, there must be an evaluating subject. The concept of damage is thus inherently anthropocentric. A distinction is made between effective or real damage, contingent damage and compensation damage.

Damage potential is the sum of all possible forms of damage that may be caused by an activity or event.

Damocles refers to a class of risks of global change in which the ➥ damage potential and the ➥ certainty of assessment are high, but the probability of occurrence is low.

Degradation of ecosystems means changes leading to the loss or impairment of ecosystem functions.

Delay effect is one of the risk evaluation criteria used by the Council. It expresses the possibility that there is large latency between the causative event and its consequential damage. Latency can be of physical, chemical or biological nature. It can also result from a long chain of variables.

Disposition means, in syndrome analysis, the structural susceptibility of a region to the syndrome in question.

Effective damage or real damage is a category of damage that involves the loss of real life values. This includes damage to property and bodily or mental harm – i.e. impairment of an object of legal protection, a right or a legally protected interest.

Environmental action is court action that can be taken without the plaintiff needing to demonstrate that his or her own rights or interests have been violated or impaired. Normally an impairment of own rights or interests must be demonstrated in order to seek remedies in court. In Germany, associations have standing to sue in some circumstances (this is termed 'Verbandsklage'). In the USA, environmental action has been introduced in the form of the 'citizen suit'. In other countries, too, there are moves towards allowing private persons to assert environmental interests as public interests in court.

Expected value of a risk means the expected extent of damage. It is determined by integrating over all possible instances of ➥ damage, weighted according to their ➥ probabilities of occurrence.

Exposition means, in syndrome analysis, natural or human-induced events or processes that are mostly of a short-term nature (e.g. sudden natural disasters, rapid changes in exchange rates) and that have the potential to trigger a syndrome in a vulnerable region – i.e. one with a ➥ disposition to the syndrome in question.

Expression means biosynthesis of the functioning product of a gene (e.g. an enzyme).

Global network of interrelations means, in syndrome analysis, a qualitative network embracing all trends of global change identified by the syndrome concept, as well as their interactions. The global network of interrelations provides a highly aggregated description of the global change system in terms of its specific phenomena.

Guard rails demarcate, in ➥ syndrome analysis, the domain of free action for the people-environment system from those domains which represent undesirable or even catastrophic developments and which therefore must be avoided. Pathways for sustainable development run within the corridor defined by these guard rails. The Council sees the guard rail model as an instrument which, by setting clear priorities, enables the dilemma between social, ecological and economic goals to be resolved.

Hazard is the circumstance of an objective threat posed by a future damaging event that will occur under certain conditions. In contrast, a ➥ risk is a mental construct by which to characterize hazards more precisely. Risk assessments must always remain approximations of the objective hazard, as the latter can only be known with certainty after the ➥ damage has occurred.

Ignorance means here the absence of knowledge about both the ➥ probability of occurrence of a damaging event and about its possible consequences.

Incertitude means the fundamental inability of a risk assessment to deliver a deterministic forecast of damaging events. The Council distinguishes between ➥ ignorance, ➥ indeterminacy and ➥ statistical uncertainty. Incertitude embraces ignorance and indeterminacy and is a fundamental property of risk, while the ➥ certainty of assessment may be anywhere between extremely high and extremely low values.

Indeterminacy means here a state of uncertainty in which the extent of damage is largely known, but no reliable statements can be made concerning the ➥ probability of occurrence.

Irreversibility is one of the risk evaluation criteria used by the Council. It expresses the degree of non-restorability of the state that prevailed prior to occurrence of damage. In the environmental context, this is primarily a matter of the restorability of types in processes of dynamic change, not of the individual restorability of an original state.

Medusa refers to a class of risks of global change in which the ➥ mobilization potential is high, but the possible threat is not statistically verifiable.

Mobilization potential refers to the violation of individual, social or cultural interests and values that leads to a corresponding reaction on the part of those affected. Such reactions can include open protest, the withdrawal of trust in decision makers, covert acts of sabotage or other forms of resistance. Psychosomatic consequences can also be included in this category.

Normal area means, in the terminology of the Council, the category of risk that is characterized by low uncertainties of ➥ probability of occurrence and of extent of damage, in all a rather low ➥ damage potential and a low to medium probability of occurrence. In addition, levels of ➥ persistency and ➥ ubiquity of risk generators or consequences are low and the reversibility of risk consequences tends to be high. Risks located in the normal area exhibit no substantial distortions between those who are exposed to the risk and those who benefit. In such a constellation, the ➥ objective risk is almost identical to the scientific risk assessment, so that the risk can be described adequately by means of a multiplicative weighting of extent and probability, with due regard to variances.

Objective risk is an ideal quantity that can be defined as a relative frequency of recognizable patterns of distribution of damaging events when looking back over the entire period of time during which the event can occur at all. The fit between the assessed risk and the objective risk will be all the closer the more accurately the system is understood, the more is known about the relative frequencies and the smaller system change is.

Pandora refers to a class of risks of global change in which there are high levels of ➥ persistency, ➥ ubiquity and ➥ irreversibility. The consequences of these risks are often still unknown or there are at best presumptions as to their possible adverse effects. The magnitude of damage does not approach the infinite, but is large enough to justify counteracting risk policies.

Persistency is one of the risk evaluation criteria used by the Council. It expresses the temporal scope of the damage or of the ➥ damage potential. The persistency of ➥ damage is an important criterion of intergenerational equity.

Probability of occurrence is one of the two prime categories of ➥ risk, the other being extent of damage, and means the probability that an event occurs which leads to ➥ damage.

Prohibited area means, in the terminology of the Council, a category of risk located in the critical area, where the risks are so severe that generally a ban should be imposed unless there is a consensus in society that these risks are to be accepted because of the associated opportunities.

Pythia refers to a class of risks of global change in which both the ➥ damage potential and the ➥ probability of occurrence are largely uncertain.

Resilience is the capability of a system to return after deflection or perturbation to a stable overall or local state of equilibrium (also termed elasticity).

Risk refers, in a technical perspective, primarily to two variables – the ➥ probability of occurrence of a specific instance of ➥ damage, and the extent of that damage. The social science perspective focuses on the aspects of societal and psychological risk experience and ➥ risk perception, while socio-economic approaches focus on risks to livelihood security and the satisfaction of basic needs. As opposed to ➥ hazard, risk is a mental construct by which to characterize hazards more precisely and to organize them according to the degree of threat that they pose, i.e. to image complex cause-effect chains of chance events that have no direct counterpart in reality.

Risk acceptance is a normative concept, indicating which undesirable consequences are still tolerable to a society and which are not, how much ➥ uncertainty is acceptable in cases where consequences can be catastrophic, and whether positive and negative consequences are distributed equitably.

Risk analysis is a term referring to efforts to ascertain on the basis of observation, modeling and scenario formation, using scientific methods and in a manner as true to reality as possible, the ➥ probability of occurrence of concrete damaging events or the probability function of magnitudes of damage. Risk analyses aim to determine the ➥ expected value of a risk.

Risk evaluation comprises a set of techniques used to arrive at rational judgments about a ➥ risk in terms of its acceptability for society as a whole or for certain groups or individuals. Scientific risk analysis and the risk perceptions ascertained by empirical studies provide inputs to risk evaluation.

Risk management is the sum of measures instituted by people or organizations in order to reduce, control and regulate risks. Such measures include politically stipulated limit values, economic incentives, liability regimes, planning techniques and educational schemes.

Risk perception refers to a risk assessment based largely upon personal experience, mediated information and intuitive appraisals that have emerged in the course of biological and later cultural evolution. In addition to the two prime categories of risk assessment – probability and magnitude of damage – it integrates other risk characteristics such as reversibility or distribution.

Risk vulnerability is an attribute of regions or of individual groups in society, referring to whether they are more or less vulnerable than others to a certain risk aggregate in terms of ➥ probability or magnitude of damage.

Statistical uncertainty is the quantifiable degree of uncertainty of the two risk categories, ➥ probability of occurrence and ➥ damage potential. It is determined using the tools of classical statistics, e.g. by stating a confidence interval. However, it can also be expressed by stating subjective estimates. Chance is expressed in two dimensions: in the probabilities for a certain event (first order uncertainty) and in the variance of damaging events for given probabilities (second order uncertainty).

Sustainable development is generally understood to be an environment and development policy concept, that was popularized by the 1987 Brundtland Report ("sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs") and further detailed by the 1992 Earth Summit in Rio de Janeiro. The German Advisory Council on Global Change has created, with its syndrome concept, an approach for operationalizing the concept of sustainable development.

Symptoms of global change (or 'global trends') are anthropospheric or ecospheric phenomena that are relevant for and characterize global change. They represent variable or processual factors that can be determined qualitatively. Examples include 'population growth', 'enhanced greenhouse effect', 'growing environmental awareness' or 'advances in medicine'.

Syndromes of global change are functional patterns of crisis-ridden people-environment relations. They are characteristic, globally relevant constellations of natural and anthropogenic trends of global change and their interactions. Each syndrome – or 'clinical profile', to use a medical analogy – represents an anthropogenic cause-effect complex involving specific environmental stresses, and thus forms a specific pattern of environmental degradation. Syndromes are trans-sectoral in nature, i.e. they affect several sectors (such as the economy, the biosphere or population) or environmental media (soils, water, air), yet they are always related, directly or indirectly, to natural resources. Syndromes can usually be identified in different forms in many regions of the world. Several syndromes may also occur simultaneously in one region.

Transitional area means, in the terminology of the Council, a category of ➥ risk located in a critical zone (i.e. not in the ➥ normal area), where implementation of risk-reducing measures promises movement towards the normal area.

Ubiquity is one of the risk evaluation criteria used by the Council. It expresses the spatial distribution of the ➥ damage or of the ➥ damage potential. It is thus an important criterion of intragenerational equity.

The German Advisory Council on Global Change

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Joint Decree on the Establishment of the German Advisory Council on Global Change (April 8, 1992)

Article 1

In order to periodically assess global environmental change and its consequences and to help all institutions responsible for environmental policy as well as the public to form an opinion on these issues, an Advisory Council on 'Global Environmental Change' reporting to the Federal Government shall be established.

Article 2

(1)

The Council shall submit a report to the Federal Government by the first of June each year, giving an updated description of the state of global environmental change and its consequences, specifying quality, size and range of possible changes and giving an analysis of the latest research findings. In addition, the report should contain indications on how to avoid or correct maldevelopments. The report shall be published by the Council.

(2)

While preparing the reports, the Council shall provide the Federal Government with the opportunity to state its position on central issues.

(3)

The Federal Government may ask the Council to prepare special reports and opinions on specified topics.

Article 3

(1)

The Council shall consist of up to twelve members with special knowledge and experience regarding the tasks assigned to the Council.

(2)

The members of the Council shall be jointly appointed for a period of 4 years by the two ministries in charge, the Federal Ministry for Research and Technology and the Federal Ministry for the Environment, Nature Conservation and Reactor Safety, in agreement with the departments concerned. Reappointment is possible.

(3)

Members may declare their resignation from the Council in writing at any time.

(4)

If a member resigns before the end of his or her term of office, a new member shall be appointed for the retired member's term of office.

Article 4

(1)

The Council is bound only to the brief defined by this Decree and is otherwise independent to determine its own activities.

(2)

Members of the Council may not be members either of the Government or a legislative body of the Federal Republic or of a Land or of the public service of the Federal Republic, of a Land or of any other juristic person under public law unless he or she is a university professor or a staff member of a scientific institute. Furthermore, they may not be representatives of an economic association or an employer's or employee's organisation, or be permanently attached to these through the performance of services and business acquisition. They must not have held any such position during the year preceding their appointment as member of the Council.

Article 5

(1)

The Council shall elect a Chairperson and a Vice-Chairperson from its midst for a term of 4 years by secret ballot.

(2)

The Council shall set up its own rules of procedure. These must be approved by the two ministries in charge.

(3)

If there is a differing minority with regard to individual topics of the report then this minority opinion can be expressed in the report.

Article 6

In the execution of its work the Council shall be supported by a Secretariat which shall initially be located at the Alfred Wegener Institut (AWI) in Bremerhaven.

Article 7

Members of the Council as well as the staff of the Secretariat are bound to secrecy with regard to meeting and conference papers considered confidential by the Council. This obligation to secrecy is also valid with regard to information given to the Council and considered confidential.

Article 8

(1)

Members of the Council shall receive all-inclusive compensation as well as reimbursement of their travel expenses. The amount of compensation shall be fixed by the two ministries in charge in agreement with the Federal Ministry of Finance.

(2)

The costs of the Council and its Secretariat shall be shared equally by the two ministries in charge.

Dr. Heinz Riesenhuber
Federal Minister for Research and Technology
Prof. Klaus Töpfer
Federal Minister for Environment, Nature Conservation and Reactor Safety
May 1992

— Appendix to the Council Mandate —

Tasks to be Performed by the Advisory Council Pursuant to Article 2, para 1

The tasks of the Council include:

(1)

Summarising and continuous reporting on current and acute problems in the field of global environmental change and its consequences, e.g. with regard to climate change, ozone depletion, tropical forests and fragile terrestrial ecosystems, aquatic ecosystems and the cryosphere, biological diversity and the socioeconomic consequences of global environmental change. Natural and anthropogenic causes (industrialisation, agriculture, overpopulation, urbanisation, etc.) should be considered, and special attention should be given to possible feedback effects (in order to avoid undesired reactions to measures taken).

(2)

Observation and evaluation of national and international research activities in the field of global environmental change (with special reference to monitoring programmes, the use and management of data, etc.).

(3)

Identification of deficiencies in research and coordination.

(4)

Recommendations regarding the avoidance and correction of maldevelopments.

In its reporting the Council should also consider ethical aspects of global environmental change.

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