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3.1.12 Sea level rise and hydrological problems of coastal zones

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***SUMMARY:** IPCC estimates a sea level rise of 8 to 88 cm by the year 2100 due to global warming. Further impacts on the coastal zone result from regional tectonic subsidence, shore erosion, changes in freshwater discharge and intensified cyclones. Increased precipitation will enhance river floods and threaten coastal cities and densely populated deltas, e.g. London, Bangkok and the Ganges/Brahmaputra and Mekong deltas. As about 50% of the world's population live within coastal areas, their ecological functions, stability and benefits are rapidly deteriorating under anthropogenic pressure and climate change. Vulnerability assessments according to a Common Methodology proposed by IPCC are now being replaced by highly integrated regional risk assessments including natural and social sciences and public risk communication. Examples are given for the German island of Sylt and the Weser estuary region, for which the adaptation capacity is estimated as high, whereas in many coastal regions and islands outside Europe and North America adaptation will pose huge problems.*

According to IPCC, the presumed rise in the sea level of 8–88 cm by 2100 due to global climate change corresponds to an acceleration in the current rate of increase by a factor of 2.1–4.4 (CHURCH & GREGORY in IPCC 2001a). The factor of thermal expansion accounts for 11–43 cm, the melting of the mountain glaciers 1–23 cm, Greenland's contribution is –2 cm (negative sign means a drop in the sea level) to +9 cm and that of the Antarctic –17 cm to +2 cm. The figures indicate that the uncertainty margins are significant, as far as both the observation data (in most cases up to 1990) and the model-based studies of future development are concerned. In addition, the ranges described in the Third Assessment Report of the IPCC (IPCC 2001a) are based on different assumptions regarding the future social, economic and technical developments world-wide, formulated as a set of four different storylines (SRES). Altogether 40 different emission scenarios for greenhouse gases result from this and lead in turn to different changes in the composition of the atmosphere, corresponding rises in temperature and the above mentioned changes in the sea level.

Regionalisation or downscaling of assumptions on the future sea level is additionally made difficult by the varying impact of an increased freshwater supply to the coastal seas and by the geotectonic movements in coastal areas which may be significant in some regions. For the southern North Sea coast, for instance, a postglacial subsidence rate of around 10–15 cm per century (STREIF 1993) applies, which has to be added to the global rise in the sea level. Vulnerability analyses of »soft«, sediment-characterised coasts, furthermore, must take into account erosion or accumulation processes caused by changes in currents near the coasts and give consideration to subsidence and compaction processes in the diked and drained coastal marshes.

It is considerably more difficult to forecast the changes in the water balance of the atmosphere caused by climate change with the consequences for precipitation and continental runoff (see Chapter 3.1.2). The geographic location of the river catchment areas, their size, orographic features and also human intervention into surface features as well as the runoff regime play a great role here. The globally verified trend towards increased precipitation will continue according to the rise in temperature and water absorption capacity of the atmosphere. In accordance with the climate forecasts, there are already indications of a significant increase in winter precipitation and runoff for the moderate latitudes in Europe, while somewhat less rain falls in the summer, additionally resulting in even less runoff due to increased temperatures. According to the IPCC forecasts, an increasing number of extreme precipitation events may occur overall despite a decline in summer precipitation.

Thus, for rivers like the Rhine that obtain part of their water from Alpine regions there is a risk that the maximum summer runoff, induced by thaw, will occur earlier and earlier and, in conjunction with the also intensified winter / spring floods from the lower-lying sections of the catchment area, lead to extreme flooding events. KLIJN et al. (2004) quote forecasts of a rise in the 1,250-year design flood applying to the Dutch Rhine from currently 15,000 to as much as 18,000 m^3/s. In the Rhine delta this development, reinforced by the accelerated rise in the sea level, leads to an enormous increase in the risks facing the densely populated region.

Similar developments with enlargement of the seasonal runoff amplitude can be expected in the large deltas of the Earth, particularly under the influence of monsoons (e.g. Ganges/Brahmaputra, see SCHIRMER 2001, Irawaddi, Menam, Mekong, Yangtsekiang, Huang-he), while the Mississippi and Nile deltas already display signs of disintegration due to a shortage of water and sediments (ARNELL & LIU provide an overview in IPCC 2001b). The disastrous impacts of hurricane Katrina on New Orleans

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and the US-Golf Coast were facilitated by this deterioration of the coastal transition zone. Furthermore, the unstable boundary between freshwater and seawater in coastal regions must be regarded as highly sensitive to climate change and a rise in the sea level. This applies primarily to the freshwater/brackish water boundary in river mouths and in the groundwater of river and sea marshes near the coast that are influenced anthropogenically at the same time by agricultural use and drinking water extraction world-wide. In addition, the IPCC feels that an increase in storms and storm tides is probable.

The overlapping of the above mentioned climate effects in the coastal regions of the world already poses substantial medium-term risks for the big cities and megacities concentrated there. Acute examples include the already badly hit New Orleans as well as Bangkok, Dacca, Calcutta and Rotterdam, while London, Mumbay and Shanghai, for example, have to be regarded as subject to medium-term risks as well. Another identifiable trend is a rise in heavy convection precipitation in connection with thunderstorms, which will increasingly overtax precipitation management, especially in rivers with a small catchment area and in cities with a high degree of surface sealing.

Direct and indirect consequences

Vulnerability of coastal regions

From a general point of view the oceans and coastal waters perform a wide variety of ecologically and economically important functions, which can be broken down into three groups: regulation functions, production / use functions as well as information functions (Sterr et al. 2003). Today around 50% of the world's population already lives in coastal regions, with an upward trend. For most of these people the coastal sea provides raw materials, food, living space and recreational areas or storage sites for wastes. It is often overlooked that, in addition to direct product extraction from the sea, the »self-running« processes of bio-regulation in an aquatic environment play a considerable economic role. However, coastal waters have already been destroyed in terms of their ecological balance in many places by such environmental impacts as intensive ground-water use, nutrient and pollutant inputs, artificial deepening of river mouths, etc. Besides this complex use pressure, a number of climate-related risks will also arise in the coming decades according to current findings and further aggravate the problems on many coasts (Schellnhuber & Sterr 1993, Beukenkamp 1993, Daschkeit & Sterr 2003). It is therefore feared that the functions of the coastal landscapes that are important for ecological stability and human use will be impaired on a long-term basis, at least regionally, by climate-related influences.

The impacts of the hydrographic and hydrological changes or scenarios described at the beginning will become noticeable within very different time and space scales. The more gradual, i.e. slow, developments, as those related to oceanic influences (currents, sea level), contrast with effects that take place suddenly and surprisingly – usually in the form of or accompanied by disastrous extreme events. The range of possible hydrological influences on low-lying coastal regions encompasses in particular:

a) as a consequence of the (accelerated) sea level rise and higher water temperatures

- changes in tidal range (gradual but already significant for the North Sea coast (Jensen & Mudersbach 2004), also depending on hydraulic engineering interventions)
- decline in sea ice cover and changes in salt concentration
- backflow of upstream water in estuaries and other river mouths
- rise in groundwater level with soil waterlogging
- higher statistical frequency of extreme levels due to rise in initial level as well as because of changes in regional ocean circulation pattern.

b) as a consequence of increasing weather extremes, particularly severe storm and heavy-rain events

- increase in large-scale flooding of insufficiently protected coastal lowlands during storm tides; thus a trend towards greater frequency of storm tides seems to be verified for the southern North Sea and Baltic Sea (Gönnert 2000, Hupfer et al. 2003)
- increase in erosion of beaches, dunes and cliffs, etc. due to storm tides as a global problem
- growing risk of flooding in lower reaches of rivers and in estuaries as a result of onshore flood waves (among other things, increase in probability of dike breach)
- this risk may be especially aggravated by a coincidence of runoff peaks in the catchment area and storm tide levels from the sea
- increased mobilisation of sediments (also nutrients and pollutants in some cases) both in the catchment area and in the coastal zone.

c) resulting from the effects indicated in a) and b)

- possible loss of seaward wetlands (especially Wadden Sea, salt meadows and marshes and mangroves, sandbars and lagoons)
- increase in salinity in estuary areas upstream as well as
- penetration of seawater into aquifers, sources of fresh-water, freshwater lenses and soils
- possible local enlargement of onshore wetlands due to backflow effects
- increasing stress for coral reefs (coral bleaching)
- massive increase in flood and erosion risks in flat island areas all the way to loss of entire atolls, etc.

Numerous impacts for the coastal population and the settlement and use structures in the coastal zone result from the above mentioned processes and their consequences. Short-term flood events caused by meteorological conditions generally lead to more severe socio-economic consequences than a gradual rise in the sea level. In addition, depending on the location of the settlements and the type or distribution of uses, the risk of flooding varies from place to place along the coast while a gradually rising sea level becomes noticeable virtually everywhere in the form of a landward shift of the shoreline.

Thus, the impacts of the changes in water level are for the most part negative consequences compared to only a few positive effects. The climatic trend of the sea level rise is frequently reinforced locally by land subsidence tendencies (see above). To compare very different coastal regions, a methodological concept called Common Methodology (CM) was developed that was specially designed for a comparative investigation and evaluation of the risks for coastal regions expected from an accelerated rise in the sea level and an altered frequency of storm tides (IPCC 1992). The following vulnerability factors are indicated in the CM:

- Population affected: The population living in the risk zone and in an area that without protective measures would be affected by flooding and/or erosion at least once every 1,000 years.
- Capital values at loss, in particular the asset values of land areas, buildings and infrastructure that may be permanently lost due to flooding or erosion.
- Population at risk, i.e. the number of persons who are affected by the (future) hydrological scenarios multiplied by the probability of annual flooding of the region concerned. A distinction is made here between:
  a) the population in a region that is not secured by means of further flood protection measures (no measures),
  b) the population in a region in which additional protective measures against a rise in the sea level are planned (with measures).
- Values at risk, i.e. capital values and subsistence values, such as jobs, etc., in relation to the probability of flooding.
- Values at change, in particular restrictions in land use and indirect damage or costs.
- Area of land at loss, in particular loss or decimation of wetlands, Wadden Sea areas, dune areas and other intact coastal ecosystems that are permanently flooded or fundamentally altered in terms of their function.
- Loss of cultural monuments.
- Protection and adaptation costs, i.e. costs for coastal protection and other adaptation measures (against the background of an accelerated rise in the sea level and increasing occurrence of extreme water levels) that are necessary to comply with a standard of protection that at least corresponds to the present safety standard for the area concerned.

The course and management of flood events in recent years have indicated clearly that the only promising approach is that of an integrative strategy of analysis, evaluation and action. Both provisions for and management of extreme events must be structured along a chain of effects. One of the essential elements of a societal risk assessment and a derivation of possible courses of action based on that (solution scenarios, risk management, see *Fig. 3.1.12-1*) is a risk analysis primarily oriented to natural and engineering science (recording status quo conditions, forecasting precipitation events, etc.), including the determination of threats and expected damage (economic and ecological, among others). However, whereas vulnerability analyses to date have usually taken the meso-level and in some cases the macro-scale (large-scale) level as their starting point (e.g. IPCC 1992), a considerably more detailed (micro-scale) level of analysis is particularly relevant for the planning of measures. In the latest studies comparisons of meso- and micro-scale risk analyses have shown significant differences with respect to risks and potential damage (STERR et al. 2003).

The second step of an integrative approach to flood risk – risk assessment – is primarily of a normative nature. The large number of influencing factors at the individual and societal level (demographic factors, socio-economic parameters, legal framework, view of nature, etc.) is known to a certain extent from risk research. However, the very important aspect of risk perception and risk communication (between those affected and decision-makers) for effective risk management has been underestimated up to now and has thus often been neglected. Consequently an integrative risk assessment of flood events in coastal as well as river basin regions should be increasingly based on natural science and social science findings of risk analysis and risk assessment.

To be able to assess the specific risk situation along individual coastal sections, these basic parameters must be recorded in a general assessment of the current situation. A geographic information system (GIS) would appear to be a key tool in this connection. By means of GIS, it is possible to link physiographic and socio-economic characteristics to each other, define regions at risk with the help of elevation data and in this way work up a quantitative vulnerability analysis. In German coastal zones GIS-aided risk studies were conducted at all three scale levels: macro-scale for the entire German coastal region (BEHNEN 2000); meso-scale for the North Sea and Baltic Sea coasts in Schleswig-Holstein (HAMANN & KLUG 1998) and micro-scale for the municipalities of St. Peter-Ording, Fehmarn, Timmendorfer Strand and the city of Kiel (REESE & MARKAU 2004) as well as for the Weser estuary and the island of Sylt (see below).

Specific problems and risks: case examples from the German North Sea area

The possible consequences of climate change and especially an accelerated sea level rise for the German North Sea coast have been investigated within the framework of two cross-section-oriented case studies funded by the Federal German Ministry of Education and Research (BMBF) (DASCHKEIT & SCHOTTES 2002, SCHUCHARDT & SCHIRMER 2005). The impacts of similar climate scenarios for the year 2050 were examined in both studies: an accelerated mean sea level rise of +55 cm (10 cm isostatic, 45 cm due to climate change); an increase in the tidal range of +30 cm; an increase in the ground surface temperature of +2.7 °C (2.5 °C in the Sylt case study) as well as an increase in winter precipitation and wind intensity (in Weser estuary case study also doubling of CO_2).

The Sylt case study examined the impacts on the island of Sylt as well as the foreshore and the tidal area behind the island while the Weser estuary case studies analysed the Lower Weser region between Bremen and Bremerhaven. The major results were:

Natural sphere

- A concomitant growth of the Wadden Sea areas is not presumed in the Wadden Sea around Sylt; erosion and a decline in the Wadden Sea areas will occur locally.
- Changes, but no severe impacts on the marine Wadden Sea ecosystem are expected due to the temperature increase; this also applies to the ecological situation in the Lower Weser region.
- The proportion of virtually natural habitats in the foreshore of the Lower Weser will increase due to the flood-related discontinuation of agricultural use of sections.
- A significant extension or increase of the existing salinisation of the groundwater in the Lower Weser marsh is not expected.

Coastal protection

- For the Lower Weser region a reduction in dike security takes place due to the accelerated sea level rise and in the medium term there is a need for action to ensure dike security and therefore secure the utilisability of the region on a long-term basis; various adaptation strategies are conceivable, on a medium-term basis reinforcement of the dikes on the existing line is the most feasible and inexpensive.
- Even today it is only possible to preserve Sylt as an exposed North Sea island jeopardised by erosion by means of extensive beach nourishment. No significant changes in the sediment transport capacity seaward of the island are expected due to the climate scenario and the coastal protection situation must continue to be

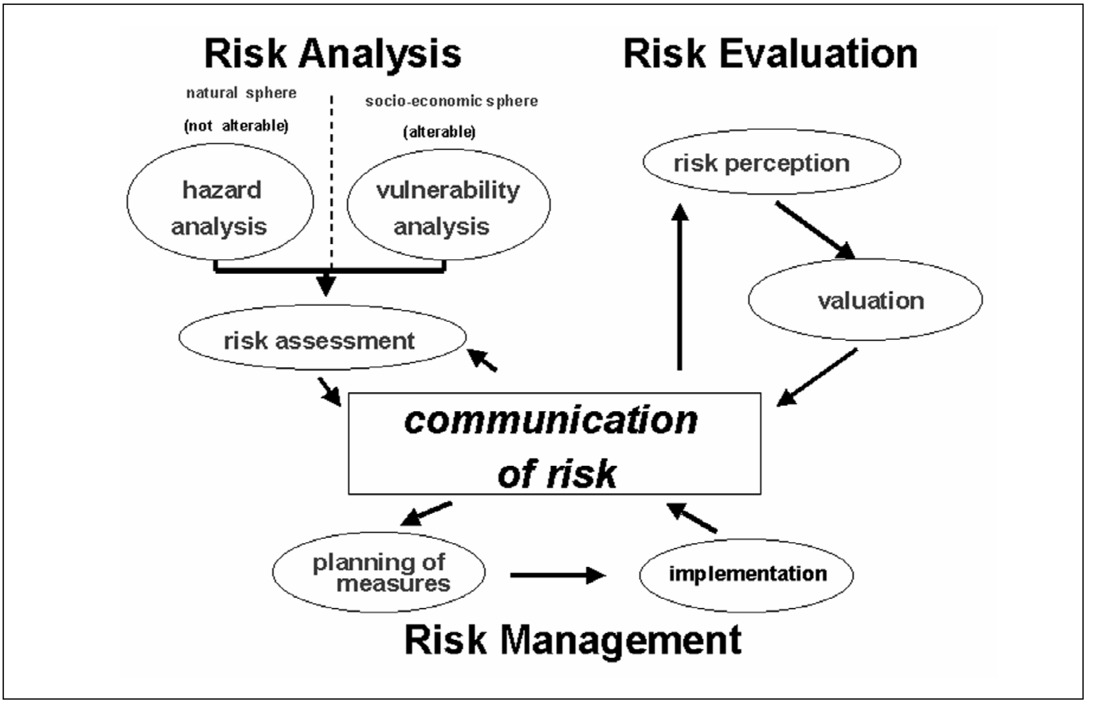

Fig. 3.1.12-1: Risk analysis and evaluation as bases of risk management (REESE & MARKAU 2004).

secured by means of beach nourishment at increasing expense (on average approx. 1% increase in beach nourishment quantities required every year).

Socio-economics

- To secure Sylt, significant additional costs are incurred, but on the other hand a great deal of damage can be avoided.
- There is no fear of a decline in Sylt's attraction for tourists due to the climate change.
- The costs of dike reinforcement in the Lower Weser region are substantial, but they only represent a relatively small impulse for the regional economic system given retention of the current form of funding (the federal government pays 70%, the rest is covered by the respective province).
- The climate scenario only leads to minor impairment in economic terms for the Lower Weser region: impacts of the altered hydrological situation on agriculture in the marsh can be extensively avoided by using the historically developed water management system.

Although two very different sections of the German North Sea coast were examined in the two studies, they arrive at a similar assessment. The foreseeable direct and indirect impacts of climate change for both regions studied seem manageable. The established techniques of coastal protection and social organisation are also suitable for increasing demands; the ecological consequences are not expected to be dramatic and coping with the challenges is also viewed as feasible by local experts and the population (DASCHKEIT & SCHOTTES 2002, SCHUCHARDT & SCHIRMER 2005). The adaptation potential can be designated as high. In the context of the key issue for the Wadden Sea, i.e. concomitant growth of the eulittoral zones and of the foreshore, CSPL (2001) does not rule out significant morphological and subsequent ecological changes in the tidal areas behind the Wadden Sea islands due to deficits in the sediment budget. In particular, increased edge erosion of the mainland salt meadows is of importance here. There is need for research.

For many other coastal sections in the world the vulnerability to a rise in the sea level has be assessed as significantly higher, especially because of a low adaptation capacity, for economic reasons (an overview is provided by STERR et al. 2003, KLEIN et al. 2001). The current vulnerability of the northern coast of Brazil (state of Parà; length of coast approx. 2,600 km) to storm tides and erosion processes (reinforced by a sea level rise), for example, is regarded as very high (SZLAFSZTEIN 2003). The problems there, which occur in a similar manner in other regions outside Europe and North America, are aggravated, however, by the fact that the aspiring coastal tourism industry is squeezing out the previously traditional (quite sustainable) subsistence economy in the mangrove zone more and more. The results of this and other studies show that the vulnerability regionally varies a great deal for two reasons: on the one hand, it is due to the specific situation in the natural sphere and, on the other hand, the adaptation capacity is also influenced by the natural sphere, but above all by social and economic parameters. Both the analysis of vulnerability and the derivation of possible adaptation measures must therefore take place on a regional scale.

Two things will be decisive in the medium term: preserving and/or developing the adaptation capacity and starting the planning phase at an early date, i.e. today, and also consistently minimising the scope of climate change and the sea level rise through climate protection measures as far as possible ♦