Appendix 4 Germany

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1. General description

1.1 Flood-prone areas

The coastline of the four German North Sea coastal states Niedersachsen, Bremen, Hamburg and Schleswig-Holstein measures about 1,580 km, of which approximately 1,380 km are protected by coastal defence structures. Without coastal flood defence structures, an area of about 11,240 km^2 (17.5% of the total area of the four states) could become flooded during extreme storm surges (Figure l). Hence, coastal flood defence and protection has national priority.

Figure 1: Coastal flood prone areas in Germany (source: Ebehöh et al. 1997).

1.2 Main threats

The main threats in Germany are:

- flooding during storm surges of the coastal lowlands, and
- the long-term loss of land as a result of rising sea-level and storminess.

1.3 Types of sea defence

Along the North Sea coast of Germany, different types of sea defence are used to maintain security level against flooding:

- main dikes to protect coastal lowlands (mainly inhabited) from all flooding by storm surges. Either maintained by the state (Bremen, Hamburg, Schleswig-Holstein) or by dike boards (Niedersachsen),
- other dikes to protect coastal lowlands (mainly uninhabited) from flooding by storm surges,
- secondary dikes (middle) dikes to limit the flooded area after a breach in a primary dike,
- dunes at most of the barrier islands and small parts of the mainland.

2. Organisational framework

2.1 Organizations / authorities involved

The organisation and administration of coastal defence in Germany is in the responsibility of the coastal states Niedersachsen, Bremen, Hamburg, Schleswig-Holstein and Mecklenburg Vorpommern (Baltic Sea). Between the states, small differences in the organisational structures exists that are neglected in this contribution. The following organisations are involved in coastal defence:

- Federal Ministry of Food, Agriculture and Forests (co-financing and general framework);
- State Ministries (co-financing, state policy, general planning);
- regional coastal defence authorities (research, implementation of state plans);
- dike- and waterboards or municipalities where no boards exist (implementation of local plans).

2.2 Legislation

The state responsibility for coastal defence is defined in the "German Basic Law". The Federal (financial) commitment is described in the federal Act on the "Community Tasks Agriculture and Coastal Defence". Some States (e.g. Hamburg) have an own "State Coastal Defence Act". In other States coastal defence is regulated in "State Water Acts". Most states have a master plan coastal defence which describes the technical and financial concept (including safety standards) for coastal defence in the respective states. Public participation in coastal defence is regulated in "State Decrees on the Implementation of Public Plans".

2.3 Responsibilities

In principle, coastal defence devolves on the persons who profit. However, flood defence that is in the interest of the public, is a public obligation. Coastal protection that is in the interest of the public (i.c. protection of settlements against land loss) devolves on the state administration.

The responsibilities in public coastal defence are divided in three levels of government: Federal, State and municipal/board. At the federal level, a general framework and national co-financing of capital measures is established. The States are responsible for policies, general planning, financing, research and the implementation of state measures. In Niedersachsen, so-called dike and water boards are responsible for the implementation of state coastal defence measures. In the other states, dike and water boards are only responsible for local measures. Where no boards are formed, the municipalities are responsible.

2.4 Financing arrangements

As coastal defence has national consequences, capital measures are co-financed by the Federal government with 70% of total eligible costs (the other 30% are matched by the States). The maintenance of existing state coastal defence structures, on the other hand, is financed 100% by the States. Municipalities and/or local water boards that are responsible for coastal defence measures in their area normally have to contribute between 5 and 20% to the costs. The rest is financed by State (and Federal) government. Finally, a small but increasing financial contribution to coastal defence comes from the European Union.

2.5 Flood and coastal defence policy

The old philosophy of executing coastal defence (building sea walls) in order to reclaim fertile land already ceased in the early fifties. In Schleswig-Holstein, the last sea wall aiming at this purpose was constructed in 1954 (Friedrich-Wilhelm-Lübke-Koog). Afterwards, the policy for coastal defence turned into achieving the same level of security for all main dikes (i.e., each sea wall has the same probability of breaching). The sixties, seventies and early eighties were characterised by a strong belief in engineering (hard) solutions for coastal defence. However, this attitude changed into trying to use more natural techniques and material, e.g. sand nourishment to combat coastal retreat. In 1995, in Schleswig-Holstein a common salt marsh management plan was established by coastal defence and environmental authorities that aims at an ecologically sound protection and management of salt marshes. Salt marshes being both an important (natural) coastal defence structure as well as an ecologically sensible and valuable area.

For Schleswig-Holstein, the following vision for coastal defence was established:

> *Secured against catastrophic flooding by storm surges, and protected against the destructive forces of the sea, the people of Schleswig-Holstein live, work, and relax in the coastal lowlands, today and in the future!*

Under this general vision, the following key objectives were formulated:

- The safety of people and their houses through sea walls and security measures has highest priority.
- The protection of land and economic values, as an important condition for the vitalisation of the rural areas, has a high priority.
- Dike relocation or abandonment remains the exception.
- Coastlines without sea walls are protected where settlements or important infrastructure facilities are threatened by coastal retreat.
- Islands and "halligen" are protected as a physical unit.
- Salt marshes in front of sea walls are maintained on the basis of coastal defence criteria. Other salt marshes are preserved according to the common interests of nature protection and coastal defence.
- The long-term stability of the Wadden Sea is aimed at.
- Hydrographic and geomorphologic developments and climate changes as well as their possible consequences are monitored and evaluated carefully. Early planning of scenarios will allow a fast response.
- Nature and the environment are preserved in the best possible way. The development and implementation of other demands/uses in the coastal zone are enabled.

In future (see also Chapter 7), the coastal defence policy will probably increasingly include risk management for single flood units. Further, more attention will be paid to public participation and the integration of other interests in coastal defence policy (integrated coastal defence management).

3. Risk assessment

3.1 Risk assessment methods

Risk in coastal (flood) defence is defined as the product of the probability of dike breaching and the damage potential (not the actual damage) in the flood unit. Considering the probability of dike breaching, in Germany, the concept of achieving the same level of safety for all state dikes (regardless the protected values) is still valid. Hence, until today risk management is not a formalised concept in coastal defence in Germany. However, due to financial constraints, ecological considerations and an the possibility of a strong increase in external (storm) stresses, future policy may include risk management.

3.2 Application of risk assessment methods

For Schleswig-Holstein, between 1995 and 2000 a meso-scale valuation study of the coastal lowlands (Figure 2) was carried out. The main objective of this GIS-based study was the determination of the consequences of a possible flooding of coastal lowlands, especially the assessment of the possible damages and depreciation in value. On the basis of this study it will be possible to conduct benefit-cost analyses for coastal defence works.

Figure 2: Schleswig-Holstein with the study area of the valuation study

The valuation study was restricted to the establishment of a geographical framework of the coastal lowlands (including a digital terrain model - DTM) and an assessment of economic values in these lowlands. Different studies were used as a methodological basis (Ball et al., 199 1, Karas et al., 199 1, Penning-Rowsell et al., 1992, Klaus & Schmidtke, 1990). They differ in their scales of interest and detail, in their database as well as in their methodology. Gewalt et al. (1996) differentiate between micro-, meso-, and macro-scale studies. The micro-scale approach is applied mostly in local studies. The meso-scale approach is used when larger areas are investigated, as for instance coastal zones (Schmidtke, 1995). The macro-scale approach is applied at a national or international level. Micro-scale studies can normally use detailed enumerations on damage-potential. Meso-scale studies on the other hand must rely on aggregated data sets. As a result of the larger study areas a detailed assessment of all economic values normally is not practicable.

For Germany, Klaus & Schmidtke (1990) delivered a meso-scale expert opinion (cost-benefit analysis) for coastal defence works in the "Weserinarsch-area", Lower Saxony. This pilot study functioned as a methodological guide for a coastal defence valuation study that was conducted in the German Federal State of Mecklenburg-Vorpommem. For reasons of comparison, the same expert opinion was used in Schleswig-Holstein.
Being a meso-scale study, the valuation is based on aggregated data sets. With a GIS, the following data from different sources were compiled and processed to create a homogeneous database:

- physical geographical data
  - elevation information from a DTM topographical structures from maps, scale 1:50,000 (roads, settlements etc.)
  - land-use data (Landsat-TM images)
- socio-economic data (municipal and district statistics)
  - inhabitants
  - houses
  - roads/infrastructure
  - motor vehicles
  - livestock
  - quality of agricultural soils
  - touristic capacity (number of beds)
  - places of work and employees for 10 different sectors of economy
  - gross increment value and tax yield (running economic results)

Figure 3: Data sources and data flow of the valuation study

The integration of these data with statistical key values results in the entirety of all protected values per municipality. For instance, the multiplication of the number of inhabitants by the average housing capital per inhabitant (key value) results in the housing capital per municipality.

In a next step, the study area was divided into so called flood units (Figure 4). Each flood unit represents the area that becomes flooded when a single dike is breached during a storm surge. Each unit is separated from other flood units by other dikes or higher grounds. Normally, the flood units do not fit with the municipalities. However, for coastal defence planning purposes it is important to know what potential damages exist in each flood unit. Hence, the values per municipality were broken down to these units. For this, the method used in the "Weserinarsch-study" was modified to local circumstances. Assuming that economic values and inhabitants are primarily located in the residential sites, the proportion (%) of residential sites per municipality within each flood unit was established. Similar the proportion (%) of agricultural area or rather agricultural values per municipality for each flood unit was determined. With the established percentages the total values per flood unit could than be calculated. Furthermore, with the DTM the values for different height intervals within each flood unit could be appraised. These calculations could be performed by applying the concept of REGIONS, which is implemented in the used GIS software.

Figure 4: Municipalities and flood units in the district of Nordfriesland

The valuation study delivered the following results for the North Sea coast of Schleswig-Holstein. Along the west coast, an area of about 2,400 km^2 is situated less than 5 m above German Ordnance Level and could become flooded during extreme storm surges. In these coastal lowlands, about 250,000 people live, and 31.5 billion euros of economic values are concentrated. Further, 85,000 people work here, producing a yearly gross added value of 4.4 billion euros.

The use of GIS for the valuation study turned out to be very time consuming. Almost 90% of total project time was used to compile and process the raw data into a homogeneous database. However, once this database had been established, the powerful analysis-functionality of GIS allowed for an accurate, high-resolution calculation of total protected values per flood unit and height interval.

4. Safety levels

4.1 Background

For the main dikes, each state has defined a safety standard. The regulatory status and the definition vary among the states. As stated before, all main dikes have the same design standards, regardless of damage potential (the number of inhabitants and economic values) in the flood unit.

4.2 Definition

In some states, the present safety standards for state dikes are expressed as return periods (e.g. in Schleswig-Holstein 100 years) of extreme water levels, which the dike must be able to withstand (additive method). In other states, the safety standard is based on maximum observed values for the parameters contributing to a storm surge (single value method).

4.3 Application

For the state dikes, the respective safety standards are determined on a regional basis. As a result, dike heights may vary up to 1.5 meter. Further, dike profiles may vary depending on local circumstances, e.g. foreland topography, exposition to waves and/or infrastructure.

5. Technical models and criteria

As stated before, the method to establish the necessary dike dimensions differ from state to state. The principle for the main dikes is the same safety level regardless of the damage potential (people and economic values) in all flood units.

In Schleswig-Holstein, the design of the main dikes along the North Sea coast comprise the following components (Figure 5):

- design water level;
- wave run up;
- safety reserve;
- design slopes.

Figure 5: Design dike dimensions for the main dike at Westerhever (SchleswigHolstein)

The design water level has to meet the following three criteria:

- return period at least 100 years;
- not lower than the highest recorded storm surge including sea level rise since than;
- not lower than the sum of mean high water, spring tide set up and highest surge height recorded (single value method, see below).

For the west coast of Schleswig-Holstein, the design water level has a return period of 100 years, established through statistical analyses of the yearly highest high water levels registered at coastal gauge stations. The wave run up was determined by the formula of Hunt. This formula was validated by levelling of the floatsam level on outer dike slopes during extreme storm surges. A wave overtopping of about 3% was allowed for in the calculations. An additional safety reserve of 50 cm was defined in the original masterplan coastal defence to account for sea level rise and uncertainties in the design. The design dike heights were established for about 60 flood units, ranging between GOL +6.6 and GOL +8.8 m. On top of this, an individual margin for sagging and sinking after construction, depending on geotechnical analyses, is added.

Apart from dike height, a standard design slope was established in Schleswig-Holstein (as in the other states) with the following gradients (Figure 5):

- inner slope: 1:3
- outer slope
    - lower parts: 1:15 to 1:10
    - near design water level: 1:8
    - upper parts: 1:6

Sea walls that are fronted by salt marshes do not have stone revetments at their foot. Instead, the gradient in the lower parts is a bit flatter.

In Niedersachsen, a partly different approach to establish the necessary dike dimensions is used. Here, the design water level is established on the basis of the single value method, comprising the following components:

- Mean high water level (MHW) above GOL (German Ordnance Level);
- Height difference between MHW and the highest spring tide high water level;
- Height difference between MHW and the highest observed (storm surge) water level;
- Secular sea level rise (of 20 cm per century).

In all, the design of the main dikes comprise of three components:

- design water level;
- wave run up (similar to Schleswig-Holstein);
- design slope (similar to Schleswig-Holstein).

6. Probabilistic techniques

As described in Chapter 5, probabilistic methods are used only to establish the design water level in Schleswig-Holstein. For the original masterplan of 1963, the yearly highest water levels from different tidal gauges for the period 1901 - 1950 were ordered according to Weibull. Through this Weibull distribution a line was drawn and a IOO-year water level was extracted from the diagram. In the eighties, this very simple method was checked using different functions (Gumbel, Jenkinson, etc.) fitted through the Weibull distribution as well as updated time series. Values for wave run up were established deterministically using the formula of Hunt, validated with flotsarn data.

For the new masterplan, the validity of the existing design water levels was reconsidered using a time series from 1950 to 1999, and the same methods as in the eighties. For the establishment of the respective wave run up, the formula of Hunt was, again, used as a basis. However, the general formula of Hunt was modified with specific coefficients to fit local wave characteristics and dike geometry's. The coefficients were established on the basis of nature data and physical model results.

7. Future developments

In the old masterplan coastal defence in Schleswig-Holstein from 1963, it was assumed that the design water level is valid up to the year 2000. Hence, the yearly highest high water levels were homogenised (i.e., corrected for sea level rise) to the year 2000. In the new masterplan, the validity of design components will be checked every 10 years (2010, 2020, etc.) to accommodate sea level rise and new technical developments (especially for the calculation of wave run up). For Niedersachsen, pilot studies on joint probability distributions of flood level and wave parameter have been carried out. However, the results so far are not convincing. Momentarily, there are no considerations to introduce this joint probabilistic methods into planning practise.

Especially for Schleswig-Holstein, investigations on the actual damages that may result from coastal flooding will continue as a basis for benefit-cost analyses and risk management. The results will be used to inform the public more comprehensive about the (latent) risks of living in coastal lowlands. In general, the information and participation of the public in (integrated) coastal defence management will be intensified by the development of appropriate techniques and instruments.

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