



Review on Flood Hazard Mapping

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SUMMARY

The review on Flood Hazard Mapping deals mostly with technical and modelling aspects related to mapping in rivers and coasts and therefore is targeted to specialists (engineers, geographers etc.) working on the assessment and management of flood risks. Other initiatives (e.g. EXCIMAP 2008) provide good practices for flood mapping in Europe and more practical aspects (e.g. production, dissemination of flood maps).

In this review both riverine and coastal flood hazard mapping are presented with emphasis on data requirements and the “sources-pathway-receptor” model for estimating the flood risk. A separate section is devoted to Eastern European countries and the state of mapping since little is known in the open literature about it although flooding is a serious threat in most of these countries.

Modelling aspects are also presented which cover both flood inundation as well as erosion models, used in coastal flooding, and their data requirements. A major issue is the uncertainty, its sources and some guidelines how to deal with it are given.

Finally some key points for the production and dissemination of such maps are highlighted.

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1. Introduction

1.1. Definitions

Flood: a temporary covering by water of land normally not covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems.

Flood risk: the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment and economic activity associated with a flood event.

Flood plain maps indicate the geographical areas, which could be covered by a flood according to one or several probabilities: floods with a very low probability or extreme events scenarios; floods with a medium probability (likely return period ≥ 100 y); floods with a high probability.

Flood hazard maps are detailed flood plain maps complemented with: type of flood, the flood extent; water depths or water level, flow velocity or the relevant water flow direction.

Flood risk maps indicate potential adverse consequences associated with floods under several probabilities, expressed in terms of: the indicative number of inhabitants potentially affected; type of economic activity of the area potentially affected; installation which might cause accidental pollution in case of flooding; other information which the Member State considers useful.

Damage: the amount of destruction or damage, either in health, financial, environmental functional and/or other terms as a consequence of an occurred hazard.

Vulnerability: the degree of fragility of a (natural or socio-economic) community or a (natural socio-economic) system towards natural hazards. It is a set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of the impact and the consequences of natural hazards. Vulnerability is determined by the potential of a natural hazard, the resulting risk and the potential to react to and/or to withstand it, i.e. its adaptability, adaptive capacity and/or coping capacity.

1.2. Scope of the Report

The scope of the review is to highlight the most important technical and modelling aspects of flood hazard mapping in rivers and coasts with emphasis on data requirements, the “sources-pathway-receptor” model for estimating the flood risk and the sources of uncertainty in developing a flood hazard map..

1.3. Other Related Research Issues

There are several related research issues which are important but are out of the scope of this review. For example the determination of vulnerability and flood risk, the associated uncertainty and the development of flood risk maps are very important issues having in mind the European Flood Risk Directive 2007/60/EC on “The assessment and management of flood risks” endorsed by EU in 2007.

2. Official (national) Mapping

2.1. Overall Review

(a) Most European countries have flood plain extent maps. This flood extent should be related to a specified flood frequency. Frequencies used in the maps vary from 1/30 to 1/10000. Most countries use only 2 or 3 different frequencies (e.g. 1/100 and 1/1000, or the less accurate “frequent” and “exceptional”). England and Wales distinguish between flood originating from the sea (1/200) and flood from rivers (1/100).

□ Flood depth maps may be presented for one representative flood frequency, e.g. 1/100. An interesting example is from Japan, in which the flood depth intervals are such that it contains “danger/how to act” information for individuals. In France maps exist that also present flood duration

□ Information on historic floods is shown on maps from France and Finland. With this type of information one should be aware that since this flood event floodwave characteristics and floodplain topography may have changed considerably and that therefore this historic flood may not be representative for present conditions

(b) Flood hazard maps, indicating where the combination of current velocity and waterdepth may be dangerous, are published in England and Wales. Austria uses the more or less comparable dragforce parameter. In Rheinland-Pfalz (Germany) and Switzerland this velocity-depth information is related to frequency, expressing this hazard information in a more sophisticated way for professional users.

(c) In terms of flood risk maps, official maps indicating potential damage are rare. The only examples are from Germany (Rheinland-Pfalz, Sachsen). Italy, Spain and Switzerland have official risk zone maps. These maps are based on the probability of flooding in combination with the land use sensitivity/vulnerability to flooding. In Italy and Switzerland this risk zonation relates to spatial planning regulations and construction requirements. Specific vulnerability maps are available in England and Wales (social vulnerability of the population) and Sachsen (Germany) (vulnerable services, like hospitals).

In Austria two types of maps are produced in the Federal Ministry for Agriculture, Forestry Environment and Water Management (www.wassernet.at): (a) Flood plain maps and (b) Flood hazard maps. Flood plain maps are provided for about 5000 Km of river stretches on a scale between 1: 5000 and 1:10000. Flood hazard maps are produced for limited areas on scales between 1:1000 and 1:5000 with an accompanying text. They show expected flood extension for a return period of 1/100 years. For both types of maps, information is provided on methodology, accuracy etc. Hazard is expressed in two classes (yellow and red) which are determined by a combination of flood depth and flow velocity. No flood risk or flood damage maps are available.

For the Province of Flanders in Belgium, three types of flood plain maps are developed:

□ The NOG-maps (Naturally flooded) contain the areas that are known as being flooded through soil-mapping. These maps show the river sediments (alluvium) and slope (gravity-caused) sediments (colluvium) zones in the soilmap that has been constructed on a scale 1:20000

□ The ROG-map shows the recently flooded areas in the period 1988-2006 based upon manual cartography, local terrain knowledge, photographs, (areal) movies. Water authorities, Provinces, municipalities, consultants and others on topographical maps with scale 1:10000. An automatic correction of the ROG-map has been performed using the DTM-Flanders (5*5m) and GIS-techniques. This side-product is called the ROG-DHM map

□ The MOG-maps shows the flooded areas for about 2000 Km of rivers that have been modeled hydrological and hydrodynamical. The maps show flood extent, flood depth, flood time, flood frequency (2, 5, 10, 15, 20, 25, 30, 40, 50, 75, 100, 150, 200, 250, 300, 500 and 1000 years). The MOG-map can be used till a scale of 1:2500.

The flood extension maps are available from an interactive internet site called the “Geo-loket Overstromingen”; the same site is also used for the other map purposes, e.g. soil maps, color orthophotos, satellite images, water quality, etc. Only NOG and ROG maps are shown at present. Explanation on the interactive information, and how the flood extensions have been calculated, are given in an accompanying digital document (“Risicozones overstrooming-Begeleidende Nota”).

In England and Wales the Environment Agency (EA) publishes flood maps. On the internet site of the EA (www.environment-agency.gov.uk/) the following map layers are mentioned:

- Flooding from rivers or sea without defences- the natural flood plain area that could be affected in the event of flooding from rivers and the sea:
 - for flooding from rivers events with a return period of 1/100yr
 - for flooding from the sea with a return period of 1/200 yr
- Extent of an extreme flood (1/1000yr)
- Flood defences- flood defences such as embankments and walls, and flood storage areas
- Areas benefiting from flood defences- where possible the areas that benefit from the flood defences are shown. However, not all areas that benefit from flood defences are shown.

Flood hazard maps are available in Finland with scales ranging from 1:20000 to 1:250000 and various return periods. The spatial accuracy may range from 5-20m to 50-250m. Historical flood maps are also available which show the extent of historical floods.

France has interactive flood maps for various regions in the internet (www.geomapguide.com/diren/Risques/Dynamap_risques.htm).

In Germany each “Länder” makes its own maps, but recently (2006) recommendations have been published for the production of flood maps. More details are presented in Section 2.2.

In Hungary, flood maps have been produced for the major rivers but most of them are rather old and have not been updated since 1972. Flood extension and depth are indicated.

Interactive flood maps are available in the Netherlands (www.risicokaarten.nl).

A recent report edited by van Alphen and Passchier (2007) summarizes the works done within the Excimap EU initiative to compile examples of flood hazard maps in 19 European countries, Japan and USA. This report presents different types of maps with most of them related to river flooding. After a brief overview on different aspects related to cartographic issues and map contents, there are four chapters dealing with different maps (flood risk maps, transboundary flood hazard maps, insurance maps and evacuation maps).

For each map type a collection of examples are given that in the case of Flood risk maps are organized by countries. In this chapter maps from 19 European countries are presented. Each case is described in two main sections: one dedicated to “general information” about the existing maps for the country and, the other one dedicated to provide comments on the maps included in the report. This is completed with the inclusion of different flood risk maps (e.g. flood extension and water depths, flood velocities, flood hazard map, vulnerabilities, etc.). When available, the electronic address to access these maps is included.

The report includes a specific chapter dealing with transboundary flood hazard mapping. This chapter only includes EU-funded projects related to the topic where different countries collaborate and, not all of them refer to mapping efforts for drainage basins belonging to different countries. This chapter includes 7 examples ranging from research projects such as *Comrisk*¹ to real transnational flood hazard mapping such as *TIMIS*².

¹ *Comrisk*: Common strategies to reduce the risk of storm floods in coastal lowlands.

² *TIMIS*: Transnational Internet Map Information System flood project.

The report ends with two additional map types: insurance and evacuation maps. In the first case, seven examples are given, one developed by a private company with the aim of provide information in a quasi-worldwide basis and the rest ones which are developed mainly to be used at national scale. Here, an example from outside Europe is briefly introduced, the National Flood Insurance Program in USA. Finally, the last chapter includes different examples of evacuation maps (for four countries, including Japan and USA).

This report is a good inventory of flood risk/hazard maps in the different European countries and it serves to illustrate the different approaches followed to produce the maps from the selection of the flood frequency to be mapped to the information included (depth, velocities, drags, damages, vulnerabilities, etc). The report also stresses the use of different methodologies to produce the maps by the responsible agencies.

2.2. Flood Hazard Mapping in River Domains - Technical Aspects

2.2.1. Overview

River flood defence in Germany is the responsibility of the federal states. Therefore, a number of different approaches for creating flood hazard maps were developed by different states. In 2006 the German working group on water issues (LAWA) published a recommendation for creating flood hazard maps which outlines the creation process and contains recommendations on map content, requirements for creating maps, quality management and publishing maps. Some federal states had already made flood hazard maps before the recommendation was published. While the official guideline is discussed in chapter 3, the following overview of creating flood hazard maps in river domains is based on the workflow used in Baden-Württemberg (Ministry of the Environment Baden-Württemberg, 2005).

The first point to clarify is the content of the map that is produced. In Germany water levels and inundations are the most commonly displayed features. Therefore, German flood risk maps indicate where overflow might occur in a floodplain.

The second point to note is for which waterbodies calculations should be made. In Baden-Württemberg all waterbodies with a catchment area of greater than 10 km² were taken into consideration.

2.2.2. Data collection

The first step of building flood hazard maps should be the collection of necessary data. The general way to provide all required data is to build a *digital terrain model*. A digital terrain model is usually built from a data collection that contains laser scan data as well as geographical survey data. Laser scan data are collected by flying a plane over the territories which are at risk to be flooded. The plane contains a rotating laser that scans the land at right angles to the direction of flight. The scan should be made during the winter month, when vegetation is sparse. Afterwards, the scanned data have to be processed with the assistance of, for example orthophotos, in order to eliminate vegetation or man-made objects like cars, bridges or buildings. This is used to calculate regular, comprehensive dot grids with grid spacing of for example 1 m or 5 m. Any gaps in the terrain point data set (e.g. due to buildings) are filled in using interpolation.

To increase accuracy of the details with respect to buildings and terrain structures near to water bodies, the laser-derived digital terrain model is combined with geographical survey data. This process is especially important for adding cross section data for water bodies. Due to the lack of the existence of detailed geographical survey data it could be necessary to acquire data by an on-site survey. All buildings in and around a water body should be surveyed. Furthermore, cross sections of the water bodies should be surveyed at appropriate intervals for hydraulic requirements.

In the end the laser-scan data can be combined with the geographical survey data to produce a digital terrain model which, in this case, reach an accuracy of about +/- 50 cm in position and +/-25 cm in elevation for laser-scan data and about +/- 5 cm elevation accuracy for surveyed data. The combination of the data is shown in Figure 1.

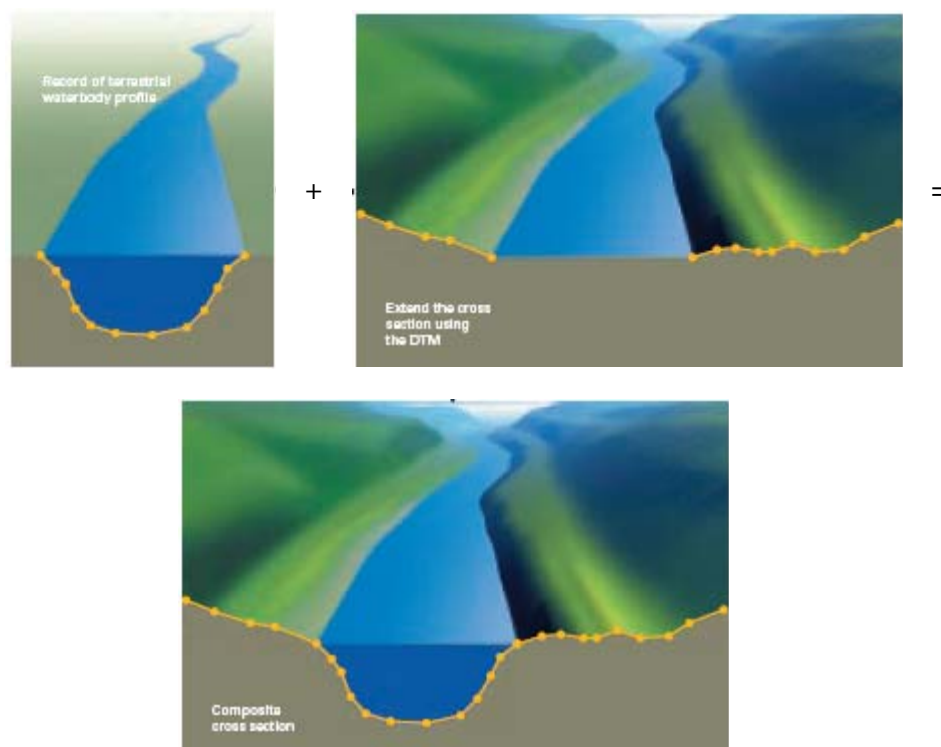


Figure 1: Combination of geographical survey data and laser scan data for extracting cross section data along the water bodies (Ministry of the Environment Baden-Württemberg, 2005)

2.2.3. Sources

Hydrology

The main input data for calculating flood hazard maps is the occurrence probability and the amount of high water discharge in rivers. High water discharge for particular annualities can be calculated by a regionalisation approach for water levels measured by gauges. In individual cases river basin studies need to be carried out. The application of a rainfall runoff model can also be helpful for considering water body system characteristics such as retention reservoirs or long term calculations. The following annualities are considered:

- HQ_{10}
- HQ_{50}
- HQ_{100}
- HQ_{EXTREM}

The results of the hydrologic calculation are *high water discharges* for certain annualities at certain locations along the water body.

Hydraulic

Based on the hydrologic output data and the cross sections derived from the digital terrain model, as shown in Figure 2, a hydraulic calculation can be made. In so doing, the choice of an appropriate model is essential for getting good results. Whereas for the vast majority of water bodies a 1D model is sufficient there are some areas which can not be correctly represented by the simplified numeric system of a 1D model. This is particular true for any kind of water body which does not satisfy the boundary conditions of a 1D model, e.g. estuaries or other areas where irregular flow occurs. In those cases a more complex calculation has to be done by a 2D model. Whereas 1D models can only be applied for assessing water levels along the axis of the water body, 2D models are able to assess extensive hydraulic dimensions such as flow depth, and speed of current in both directions along the axis of the water body.

The results of the hydraulic calculation show the different *water levels* along the length of the water bodies. The results from a 2D model and a 1D model differ in terms of resolution. Therefore an adaptation on cutting edges has to be done.

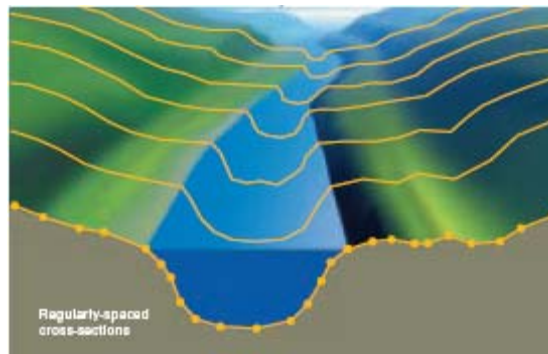


Figure 2: Input data for hydraulic calculation (Samuels and Burt, 2002)

2.2.4. Pathways - Inundation

With the results of the hydraulic calculations the flood outline can be calculated. The main step is to calculate the inundation area by subtracting the water level plane from the digital terrain model for results produced by a 1D model. The resulting map can be interpreted as a water depth map where negative values denote inundation areas as it is shown in Figure 3. Results of a 2D model bring out the water depth directly. Other hydraulic dimensions such as speed of current are also available for areas calculated by a 2D model.

The use of high resolution data in the digital terrain model can cause a so called “salt and pepper”- effect. This effect is caused by vegetation that adds a random noise to the elevation data. A classification of the map content might be necessary when the effect occurs heavily in the map. These classification leads to a corrected version of the map. Classifications are usually based on boundary criteria which depend on the water depth and noise area.

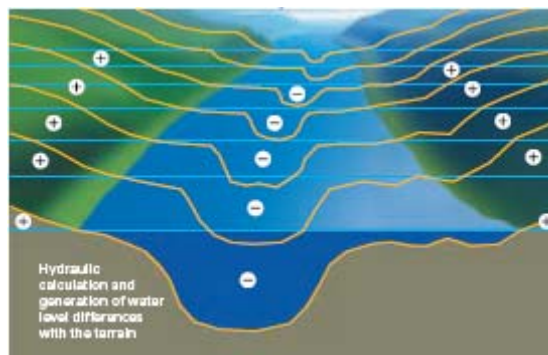


Figure 3: Intersection of hydraulic results with the digital terrain model (Samuels and Burt, 2002)

2.2.5. Maps

The calculated map of the water depth is the basis for further work. Another display option is the outline of the flooded area as it is shown in Figure 4. In Baden-Württemberg following maps are created by using the results from the hydraulic calculations:

- Flood extents (all annualities displayed in one map)
- Water depth for flooded areas HQ_{10} (uncorrected)
- Water depth for flooded areas HQ_{50} (uncorrected)
- Water depth for flooded areas HQ_{100} (uncorrected)
- Water depth for flooded areas HQ_{EXTREM} (uncorrected)
- Water depth for flooded areas HQ_{100} (corrected)

- Water depth for flooded areas HQ_{EXTREM} (corrected)

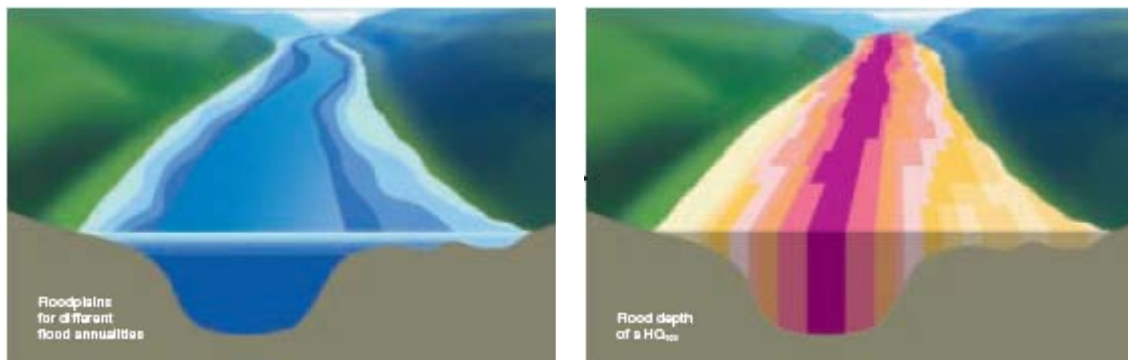


Figure 4: Possible map contents of flood hazard maps (Ministry of the Environment Baden-Württemberg, 2005)

Other maps can also be built from the water depth that is given by the hydraulic results. For example, an intersection of the water depth and the flood protection buildings can lead to a map in which the protected area is shown. Another example is the identification of bridges that can be used during the flood.

2.2.6. Outreach

In Baden-Württemberg individual solutions are created for different user groups. The user groups which are given individual access are listed as following:

Maps for the public

Maps for the public are published to provide the public with access to flood risk information. The maps are provided as a web service. The maximum zoom factor can reach a scale up to 1:5000. Detailed information about house numbers is not disclosed. Figure 5 shows an example.

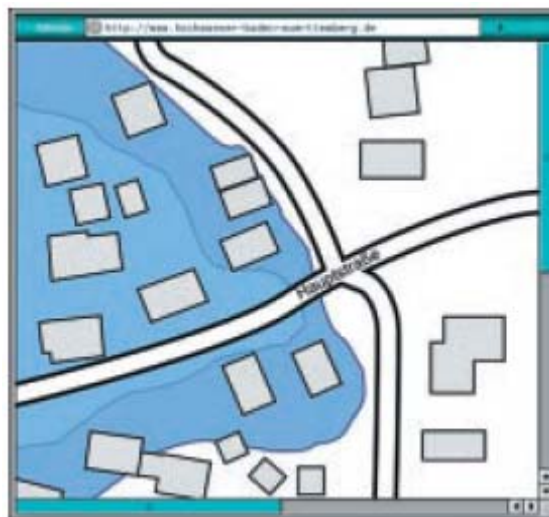


Figure 5: Sample map for public (Ministry of the Environment Baden-Württemberg, 2005)

Maps for local authorities

Local authorities are provided with hard copies of maps based on geographical information systems (GIS) as well as GIS accessible data. Maps can be zoomed down to plot level. The map information is supplemented within the boundaries of the municipality with data from the Automated Real Estate Map (ALK). Figure 6 shows an example of a map that is available for local authorities.



Figure 6: Sample map for local authorities (Ministry of the Environment Baden-Württemberg, 2005)

Maps for professional departments and regional associations

Professional departments have broader access to detailed supplement data for example orthophotos. The access to these additional data is granted to the departments.

Figure 7 shows an example of a map with detailed information.



Figure 7: Sample map for professional departments
(Ministry of the Environment Baden-Württemberg, 2005)

2.3. Flood Hazard Mapping in Coastal Domains - Technical Aspects

2.3.1 Overview

Coastal flood defence in most of the European countries are responsibility of the Central administration, e.g. federal state (see table 1). In Spain, this responsibility is taken by the Ministry of Environment who also has the duty of protecting the coast. In 1999 the Spanish Ministry of Environment through the Coastal General Directorate published the called *Inundation atlas of the Spanish littoral (Atlas de inundación del litoral español)*. In spite of the title, this document cannot be considered a real atlas because it mainly deals with the definition of the source, i.e. the definition of water levels along the

Spanish coast. Thus, it uses the existing data at that moment (wave and mean water level time series) to estimate the probability distribution of total water levels (considering astronomical tide, storm surges and wave-induced run-up). There are no specific recommendations on flood hazard mapping but some guidelines on how to use the estimated water level to delineate potential inundation areas in specific zones. In what follows a review on the main points to be considered in coastal flooding is presented. Although this is not followed by the Spanish case nor by all the countries (in its entirety), ideally all these points need to be considered to properly produce a good coastal inundation map.

2.3.2 Data collection

To properly build a flood hazard map in the coastal zone, different types of data to characterize the coastal domain are required. These are necessary to build a (i) digital terrain model, DTM, of the subaerial domain to be flooded (floodplain), (ii) to define the morphology of the coastal fringe where waves and surge will impact during the flood event and (iii) the bathymetry where waves and surge will propagate during their approach towards the coast.

In the first case, *DTM*, the requirements are similar to that already introduced for the river domain which essentially consists in accurate topographic data in both horizontal and vertical dimensions. Thus, this elevation data is the critical variable to produce the DTM, which is on the other hand, is the main factor (regarding the receptor) to control the reliability of the floodplain delineation.

The importance of the data quality on the quality of the final product (map) is underlined by the procedure implemented by the Federal Emergency Management Agency (FEMA) who has produced a series of guidelines and specifications on aerial mapping and surveying within the programme on Flood Map Modernization (FEMA, 2003). They provide guidelines on different practical aspects of surveying (e.g. ground surveys of control points, hydraulic structures, topographic mapping using photogrammetry, Lidar, etc.) and, also, they serve to specify the quality of the spatial data products to be produced which are later used as base maps to produce different Flood Maps. These guidelines have been developed for any flood map (riverine and coastal domains). Two additional reports deal with other aspects related to this topic such as “data capture standards” and data capture guidelines” (FEMA, 2004 a,b). In support of this activity, a study was launched to make a first assessment of the main issues involved in the use of new technologies for the FEMA Flood Map Modernization program. As a result of such study, a report was produced to provide a first focus on the framework information required to create a floodplain map (Committee on Floodplain Mapping Technologies, 2007). The report mainly deals with the following topics: (a) current mapping technologies being used by FEMA to develop flood hazard maps, (b) identify mapping technologies currently available, and (c) determine if newer technologies are appropriate and beneficial for floodplain mapping.

There exist different technologies to measure the elevation in the territory, ranging from remote sensing techniques (e.g. photogrammetry, Lidar, SAR, etc.) to ground-truth methods such as DGPS, each one with different limitations on accuracy, cost-effectiveness, time-consumption, feasibility, and applicability. One of the first main points to be considered is that the most frequent situation is that in which the area to be analysed for flooding purposes is large or very large (100s of km²). This makes that ground-truth methods are not practical since they are very costly in terms of time requirements and costs. As a consequence of this, data actually being used in most of the flood hazard mapping exercises are obtained by remote sensing based techniques.

As an example of many of existing comparative analyses on the accuracy of different techniques, Hodgson et al (2003) compared four different remote sensing-based methods to derive DTMs (LIDAR, IFSAR -interferometric synthetic aperture radar-, GPM -Gestalt Photomapper- and contour-to-grid, used by the U.S. Geological Survey). The analysis was done in a flood-prone watershed in North Carolina and, obtained results showed that the Lidar- and contour-to-grid (USGS level 2) derived DEMs presented the highest overall absolute elevation accuracies. This result has been also obtained in many other comparative studies in such a way that Lidar is becoming a standard to acquire high quality data to

produce topographic maps or DTM. In spite of this, it is absolute necessary to impose a series of requirements to know the accuracy of the data measured by using Lidar since a series of procedures during the data acquisition can condition it. Thus, there are cases where the responsible Mapping agency has produced a series of guidelines and/or specifications to be followed when Lidar is applied to get data for flood hazard maps. An example of this is the set of specifications imposed by Fema (FEMA, 2007).

Finally, it has to be stressed that if the quality of the data used to produce the DTM affects the accuracy of the flood map, the resolution of the generated DTM also affects the accuracy of the map (e.g. see Haile and Rientjes, 2005).

In addition to the topography of the floodplain, in coastal flooding analysis is necessary to characterize the morphology of the coastal fringe. This zone includes a subaerial and a subaqueous part and it will act on the one hand as a barrier for the flooding, i.e. the main element of protection for the hinterland and, on the other hand, it will control the intensity of the flood by modifying wave and surge propagation. Moreover, depending on the beach morphology the flooding intensity can be affected (e.g. run-up modification due to changes in beach slope; overtopping variation due to changes in dune and beach crest changes, etc.).

One of the main differences with respect to the floodplain is that the morphology of the coastal fringe is highly variable and it is continuously changing as a response to the marine energy supply. Due to this, the main problem in coastal flooding analysis is to have available a coastal fringe morphology representative of the pre-storm conditions. Thus, the ideal situation should be that in which the coastal fringe morphology is continuously updated at a “reasonable frequency” (e.g. yearly).

With respect to the methodology to gather topo-bathymetric data, traditional approaches measure topography and bathymetry in a separated manner by using different techniques, i.e. land surveying for the subaerial part and bathymetric surveys for the subaqueous one. Coastal topography can be efficiently measured in large areas by using real time kinematic GPS (RTK-GPS) which permit to sample the surface along a given path with selected density and 15cm vertical accuracy (see e.g. Morton et al., 1999). However, although dense data coverage is obtained along the paths, normally the distance between paths is relatively large (from to tens to hundred meters apart). As a result of this, when a large spatial coverage is required, the use of Lidar to measure beach and coastal topography is becoming more and more common worldwide. The capabilities of Lidar to characterize changes in coastal topography can be seen in Mason et al (2000) and Sallenger et al (2003) among others.

If we also consider that the characterization of this area also requires to measure underwater, additional problems may appear: a change in the type of measurement is required, a mismatch between topographic and bathymetric data could occur due to getting the data at different times and/or due to using different datums. Due to this, it should be highly convenient to have a technique able to measure both topography and bathymetry of the coastal zone. This technique is available and it is an evolution of the above mentioned topographic Lidar, the SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system. SHOALS uses an airborne, scanning, pulsing laser to deliver two frequencies of light, one reflects from the water surface and one passes through the water column and reflects from the sea bottom to give depths accurate to ± 15 cm (see e.g. Lillycrop et al., 1996). Technical characteristics and capabilities and limitations of the system to measure the bathymetry in shallow waters can be seen in Guenther et al. (2000). One of the main advantages with respect to “traditional” multi-beam surveys is that is much more efficient and that, at the same time, it is able to simultaneously measure the topography of the coastal fringe (see Figure 8).

Its most significant limitation is water clarity, which limits the maximum surveyable depths. Maximum surveyable depths range from around 50 meters in very clean offshore waters to less than 10 meters in murky near-shore waters. For extremely turbid conditions, surveying may not be possible (Guenther et al, 2000).

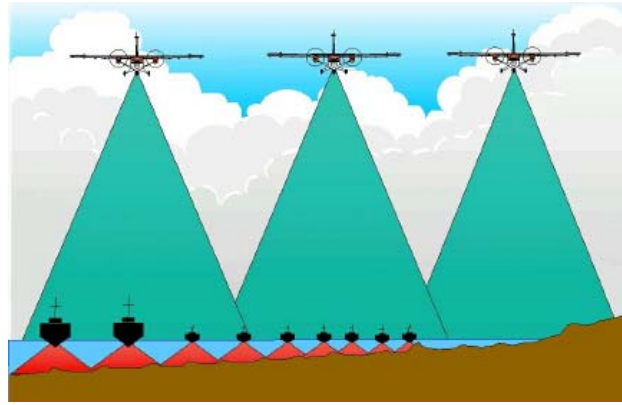


Figure 8: Comparison of Lidar and multi-beam sonar operation in shallow water (Guenther et al., 2000).

The remaining coastal domain to be covered is the nearshore zone. The bathymetry in this area will condition wave propagation towards the coast and, in this sense, can modulate the intensity of the flooding along the coast. With the exception of the relative rapid changes occurring in the shallowest part of this domain (already included in the previous zone), bathymetric changes in this area usually take place at long-term scales. Due to this, the requirements to update bathymetric data are relatively low. Presently, the most common used technology is the Multi-Beam Echosounder Surveying (MBES), which have demonstrated high quality with respect to meeting the IHO standards on depth accuracy (IHO, 1998). Moreover, they also provide additional info on processes taking place at sea bottom (e.g. Clarke et al, 1996).

Finally, Figure 9 shows a summary of the main characteristics of data collection in the different coastal domains in terms of frequency of coastal changes and updating requirements and the usual data surveying technologies.

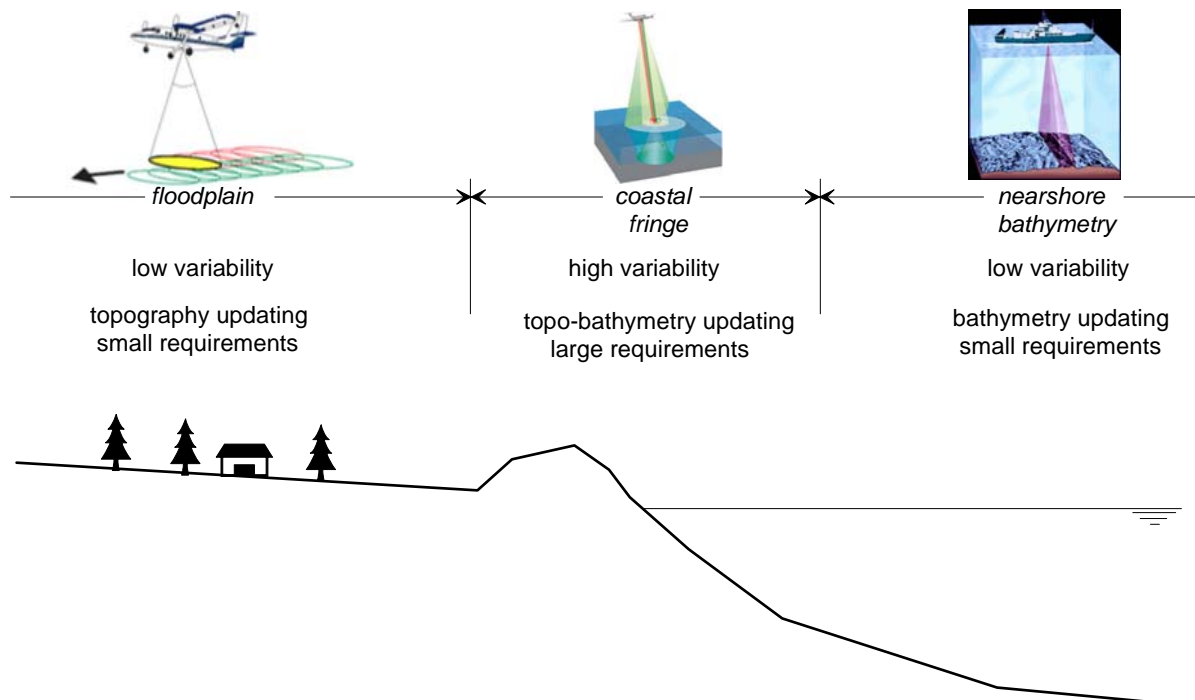


Figure 9: Domains in coastal flooding analysis.

2.3.3. Sources

Water levels

The main input data for calculating coastal flood hazard maps is a water level associated to a given probability. Following the *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks*, flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

- (a) floods with a low probability, or extreme event scenarios;
- (b) floods with a medium probability (likely return period ≥ 100 years);
- (c) floods with a high probability, where appropriate.

In addition to this, the directive also states that Member States may decide that, for coastal areas where an adequate level of protection is in place, the preparation of flood hazard maps shall be limited to the scenario (a).

Thus, with the exception of the scenario (b) where the probability is given (in terms of return period), the other two scenarios can be defined in function of the objective of the study. In cases where the coastal zone is protected by dikes, the probability to be used in the flood hazard mapping will be given by the safety level of the protective structures. As an example, Table 1 gives an overview of flood protection policies in countries along the North Sea where the considered safety levels are included.

| | Netherlands | United Kingdom | Denmark | Belgium (Flanders) | Germany |
|---------------------------------|---|---|--|--|---|
| flood-prone areas | The coastline is 350 km long. Two-thirds of the country (25,000 km ²) is at risk of coastal flooding. The flood-prone area comprises densely populated polders. The capital value at risk is estimated at 2,000 billion euros (1992). | The coastline is 4500 km long. 2,200 km ² (with 5% of the population), is at risk of coastal flooding: some large urban and agricultural areas, but also very many small areas. The capital value at risk is estimated at 250 billion euros (2000) | The coastline is 7,300 km long. A few towns and some agricultural areas are at risk of coastal flooding. | The coastline is 65 km long and about 3% of total area of Belgium is at risk of coastal flooding. | 11,240 km ² (17,5% of the area) of land at risk of coastal flooding in the coastal states Niedersachsen, Bremen, Hamburg, Schleswig-Holstein. |
| types of sea defence | <ul style="list-style-type: none"> • dunes (70%) • embankments • storm surge barriers | <ul style="list-style-type: none"> • sea walls • embankments • dunes, beaches, some shingle • gates and storm surge barriers | <ul style="list-style-type: none"> • embankments • beaches, some sandy | <ul style="list-style-type: none"> • embankments • dunes and beaches | <ul style="list-style-type: none"> • embankments • dunes • combination embankments and dunes |
| organisation / responsibilities | centralised policy framework, decision making and engineering, decentralised operational management | centralised policy framework, decentralised engineering and decision making | centralised | centralised (at the level of Flanders) | centralised (at the level of coastal states) |
| legislation | prescriptive legislation (Flood Protection Act, 1996) | permissive legislation | permissive legislation (Act of Reinforcement of Ribe dike, 1976; Fremskudt Dige, 1977) | permissive legislation (Regionalisation Act, 1988) | permissive legislation (State Water Act) |
| decision criteria | legal safety standards | economic efficiency, indicative standards | size of the population at risk | absolute standard | absolute standard |
| safety levels | Statutory standards by dike ring area. Standards are expressed as return periods of extreme water levels. Safety standards in the coastal area range from 2,000 to 10,000 years. | No target risk or flood defence standard; general aim of reducing risks to people and the environment, and requirement to achieve value for money spent. Indicative standards range from less than 200 to 1,000 years. | Safety levels are proposed by the DCA and approved by the Ministry. Safety levels are based on a cost/benefit analysis. Safety standards range from less than 50 to 1,000 years. | A minimum safety level of at least a 1,000 years is prescribed according to the Dutch methodology. | Safety levels expressed as a combination of design water level, design wave run-up and slope criteria. In practice this standard will exceed a 100 years. |

Table 1. Overview of flood protection policies in countries in the North Sea (Jorissen et al, 2000).

With independence of the probability chosen to define the water level to be used as the source for the flooding analysis, the water level is composed by different components associated to different agents varying at different time scales. Figure 10 schematizes the three main components contributing to the total water level: (i) astronomical tide; (ii) storm surge and (iii) run-up.

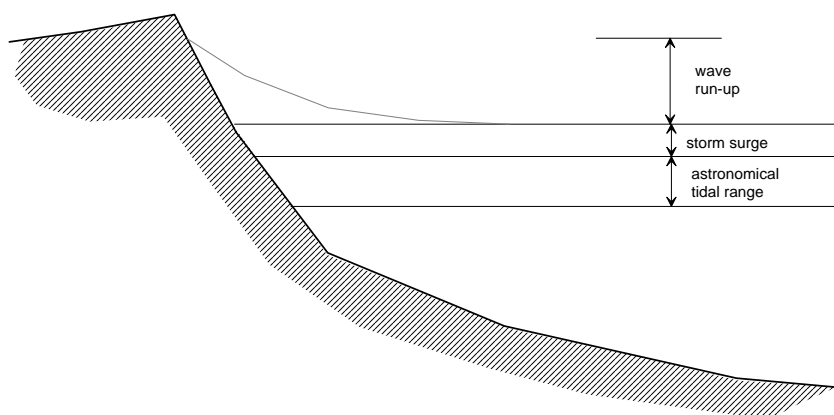


Figure 10: Domains in coastal flooding analysis.

The main problem associated to the right estimation of the water level associated to a given probability is to assess the contribution of each component. There are two main options to estimate such level:

- to directly estimate it from existing time series of water levels;
- to estimate it by analysing the integrated contribution of each component.

In the first case, the only procedure to follow is to analyse the water level time series to obtain the extreme distribution of water level and, to define the probabilities (or return period) where the water level are required. Extreme distributions to be used in fitting water levels can be seen in Sobey (2005) and Pirazzoli and Tomasin (2007) among others (see also Sánchez-Arcilla 2007). The main problem of this methodology is that water level records usually do not include wave-induced contributions. Thus, its use should only quantify the water level associated to astronomical and meteorological tides.

In the second case, the contribution of each component has to be estimated and the joint probability has to be calculated. Here two main approaches do exist: (i) response and (ii) event approaches (see e.g. Fema, 2005; Divoky and McDougal, 2006; Garrity et al, 2006).

The *event approach* is deterministic, it uses one or more combinations of water level and wave conditions (events) associated to a given probability and it computes the resulting flood level (response). The main problem is that, in many cases, a combination of events with a given probability will not generally result in a response of a different probability. Moreover, the flood associated to the given probability could be produced by many combinations of conditions. On the other hand, the *response approach* is that in which the water level of interest (associated to a given probability or return period) is directly calculated from a probability distribution of total water levels.

Response method

It is based directly on measured or simulated water levels and waves as they occurred in nature and, the water level of interest (associated to a given probability or return period) is directly calculated from a probability distribution of total water levels. It is specially recommended when the variables (events) determining the flood level (response) are partially correlated, i.e. when surge and large waves are uncoupled and, for areas where wave height and periods during storms (both will determine the wave run-up) are poorly correlated and, at present, it is the recommended by Fema guidelines for flood studies (Divoky and McDougal, 2006).

If simultaneous water level and wave records do exist, the best option should be to estimate the induced run-up for each wave condition and to add it to the instantaneous water level. This will produce a time series of total water levels in the shoreline which can be later analysed as in the previous case, i.e. fitting to an extreme distribution. From that distribution the water level associated to any probability or return period can be estimated. Because run-up depends on the beach slope, the calculations have to be done for representative beaches in the area to cover the different slopes. Moreover, the run-up formula to be used will depend on the morphology of the coastal fringe (beaches, dikes, etc.). As an example, Stockdon et al. (2006) have proposed a formula to estimate the run-up in beaches based on field data analysis and in US Army Corps of Engineers (2002) an overview of existing methods to estimate run-up in coastal structures of different typologies can be found. The main restriction to apply this method is that long-time series of simultaneous measured relevant variables (water level, waves) are required to calculate reliable estimates of total water level associated to low probabilities (e.g. 100 years or longer).

When these simultaneous time series do not exist or they are too short to be used to estimate a reliable extreme distribution, an alternative technique has to be used. In these conditions, the measurements have to be substituted by simulations. The idea is to simulate all the conditions acting on the site and from the simulated combinations to obtain the desired probability distribution. Figure 11 shows an example of applying such statistical approach. The application of this approach using the Monte Carlo method for the simulation of time series to estimate the 100-year coastal flood for the US Pacific coast can be seen in Garrity et al (2006).

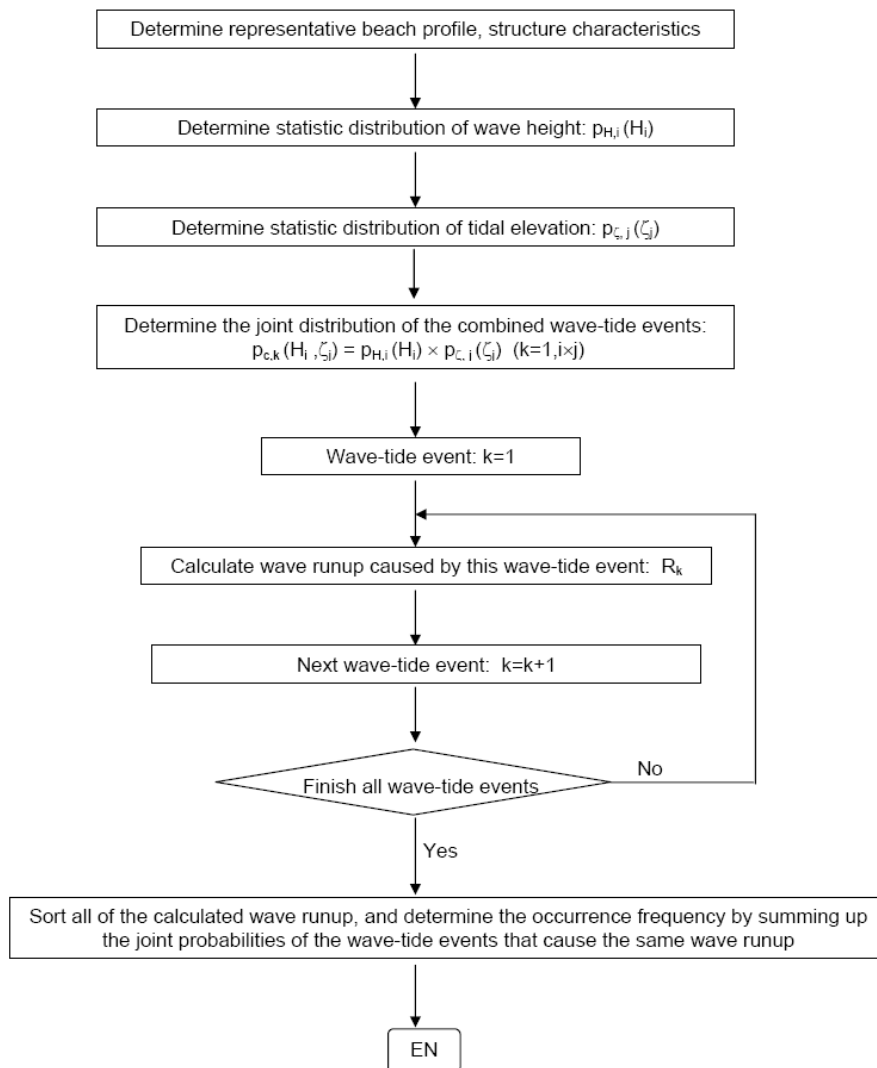


Figure 11: Flow chart for statistical approach (Fema, 2005).

Event method

As it was mentioned before, the main difficulty of this approach is that different combinations of forcing parameters can produce the same flood level. The objective is to define the conditions associated to the probability of interest and, from them, to calculate the corresponding flood level. Due to the combination of agents contributing to the response, the joint probability of involved agents has to be estimated. The application of this approach to estimate the 100-year coastal flood for the US Pacific coast and its comparison with the response approach can be seen in Garrity et al (2006). The event approach has been used in Spain to generate characteristic inundation levels along the Spanish coast (GIOC, 1998).

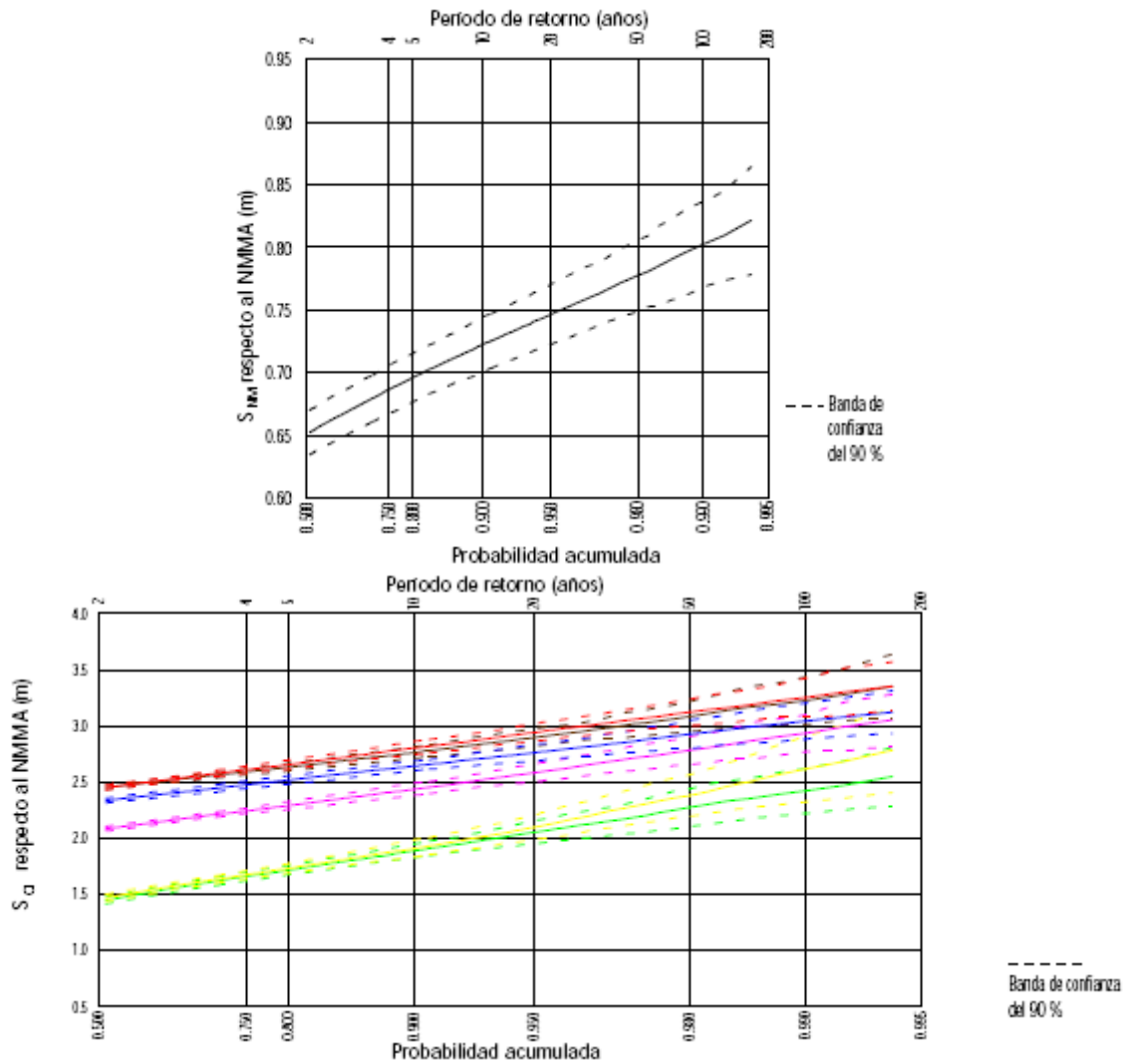


Figure 12: Example of extreme distribution of mean water level (up) and total water level in an open beach (down) in the Spanish Southern Mediterranean coast (GIOC, 1998).

Figure 12 shows an example of the estimation of the extreme distribution of total water level (with astronomical tide, meteorological tide and runup contributions) for a sector of the Spanish Mediterranean coast. First, the distribution of water level associated to the astronomical tide and storm surge are calculated. Later, the wave-induced run-up is calculated for the main directions (to take into account the orientation of each beach within the sector) and added to the other components. Main hypotheses are that storm surge and wave-induced run-up are correlated and, similarly, it is assumed that wave heights and periods are also correlated.

Results are presented for a dissipative beach which for the employed formula (Nielsen and Hanslow, 1991) means that it is independent of beach slope. This value can be later modified for a specific beach by including a correction factor that takes into account the actual beach slope. Additional factors to account percolation and roughness can also be considered.

2.3.4. Pathways

Once the storm impacts on the coast, two situations can occur: (i) the coast is rigid (e.g. protected by coastal structures) and will be inundated if total water level exceeds the crest of the structure and (ii) the coast is dynamic and reacts to the impact of the coast by being eroded. In the second case the inundation will not be controlled by the initial beach/dune height but by its evolution during the event. Due to this, the pathways in the case of coastal flooding include not only the inundation but the induced coastal changes.

Coastal changes

The impact of extreme storms on sedimentary coast produces different morphodynamic processes and responses that can significantly affect coastal flooding and with an intensity depending on the intensity of the storm. As an example, Figure 13 shows a qualitative hazard scale of coastal changes during storm impacts on barriers (applicable to any low-lying coast) with serves to illustrate the different regimes of functioning as a function of the water level. These regimes have been formalized in a conceptual model by Sallenger (2000) in: swash, collision-dune erosion, overwash and inundation regimes.

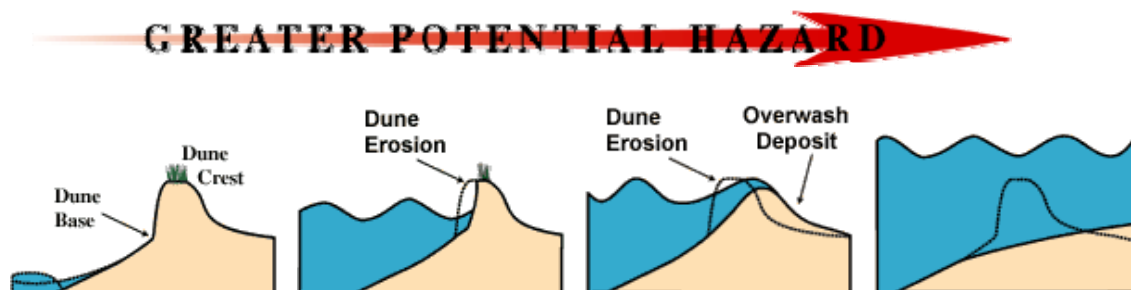


Figure 13. Qualitative hazard scale of coastal changes during storms as a function of water level (USGS, 2001).

Figure 14 illustrates the changes suffered by a dune under the impact of a storm where the changes in the morphology during the event would modulate the magnitude of the inundation with respect to the initial configuration. Thus, in this case the dune is lowered by overwash and, the representative slope becomes milder. Under this scenario, there are two sources affecting the changes in wave overtopping and, in consequence, in the volume of water flowing to the hinterland which contributes in an opposite way.

The decrease in D during the storm will produce a progressive increase in the freeboard ($Ru-D$) and, in consequence, will induce larger overtopping. The second one will be due to the change in the beach slope, that it will influence the run-up, Ru . In this case, the decrease in the beach slope during the erosion process will induce a lower run-up and, if this factor is solely considered should induce a decrease in the freeboard and would induce a lower overtopping. The final effect of the beach/dune changes during the event on the volume of water flowing landward with respect to the initial beach configuration will depend on which will be the dominant factor.

Section 3.4 presents different models able to simulate the response of beaches and dunes to the impact of a storm that can be used to estimate the morphology changes and to assess the changes in overtopping during the inundation event.

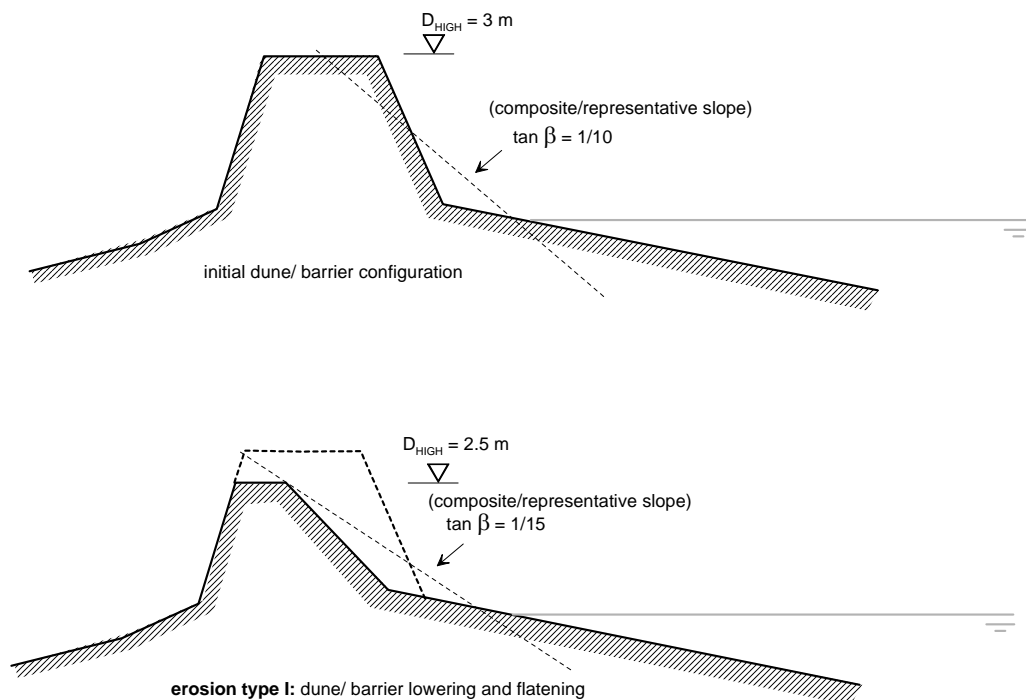


Figure 14: Example of extreme distribution of mean water level (up) and total water level in an open beach (down) in the Spanish Southern Mediterranean coast.

Inundation

If the total potential water level at the beach (considering tide, storm surge and run-up) exceeds the crest of the dune/beach, overtopping will occur. This overtopping will determine the total volume of water contributing to the inundation of the hinterland. Thus, once the total water level at the shoreline has been calculated for the storm, the next step is to calculate the wave-induced overtopping.

One of the main problems related to the estimation of overtopping is that existing methods are empirical and most of them have been derived for coastal structures. In the recently published Overtopping Manual (EurOtop, 2007) the approaches to be followed to calculate overtopping in the main types of coastal structures are presented in detail. Existing methods to estimate overtopping in beaches and dunes are much more limited. An example is the method developed by Delft Hydraulics (1983) to estimate the overtopping in dunes. In section 3.4 models able to reproduce overwash and overtopping in beaches and dunes are presented. These models jointly evaluate morphological changes and the overtopping rates during the storm.

If during the event the mean water level is very high during the event with respect to the land elevation, a full inundation of the coastal fringe can occur. Under these conditions, reformed waves after breaking will propagated overland. In some occasions, it is necessary to estimate this propagation to correctly delineate the inland extension of the inundation.

This is specifically considered by the analysis performed by Fema (2003) for selected transects along the coast (see scheme in Figure 15). Fema (2003) has developed a simple model –WHAFIS- to account the wave propagation overland taking into account the different elements that the wave can find during its propagation that will determine the bottom roughness.

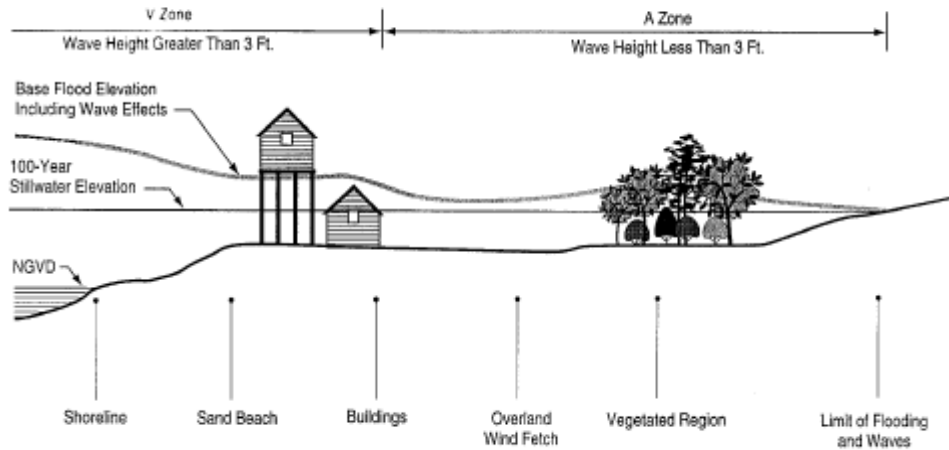


Figure 15. Schematic wave effects on a transect (Fema, 2003).

2.3.5. Maps

Once the total water levels have been determined as well as the potential coastal response, the coastal flood hazard map area produced. The information included in these maps normally includes the extension of the area to be inundated for a water level associated to a given probability.

In the case of Spain, there is not a specific program to produce such maps for the entire coastal zone. However, the methodology before mentioned to estimate the total water level associated to different probabilities (or return periods) also specifies the way to map the area to be potentially inundated by such levels. Figure 16 shows an example of the mapping of the flood hazard area associated to a return period of 50 years in an area with and without a protective coastal dune. It has to be considered that in this case, the delineation of the hazard area has been done by only considering the land surface with an elevation lower than the estimated water level (static approach) without considering the potential coastal response.

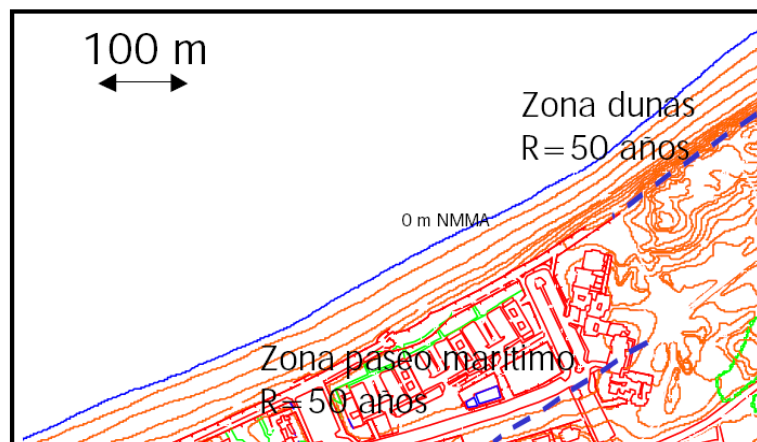


Figure 16. Delineation of flood hazard areas to a water level associated to a 50 years return period (dashed blue lines, GIOC 1998).

An example of advanced flood hazard mapping is the approach of Fema. This agency has developed a program to produce digital flood hazard maps where the population can access very detailed flood hazard maps for the area of interest via web. Figure 17 is an example of this kind of maps where in addition to flood hazard zoning, the user can select the type of information to be included.

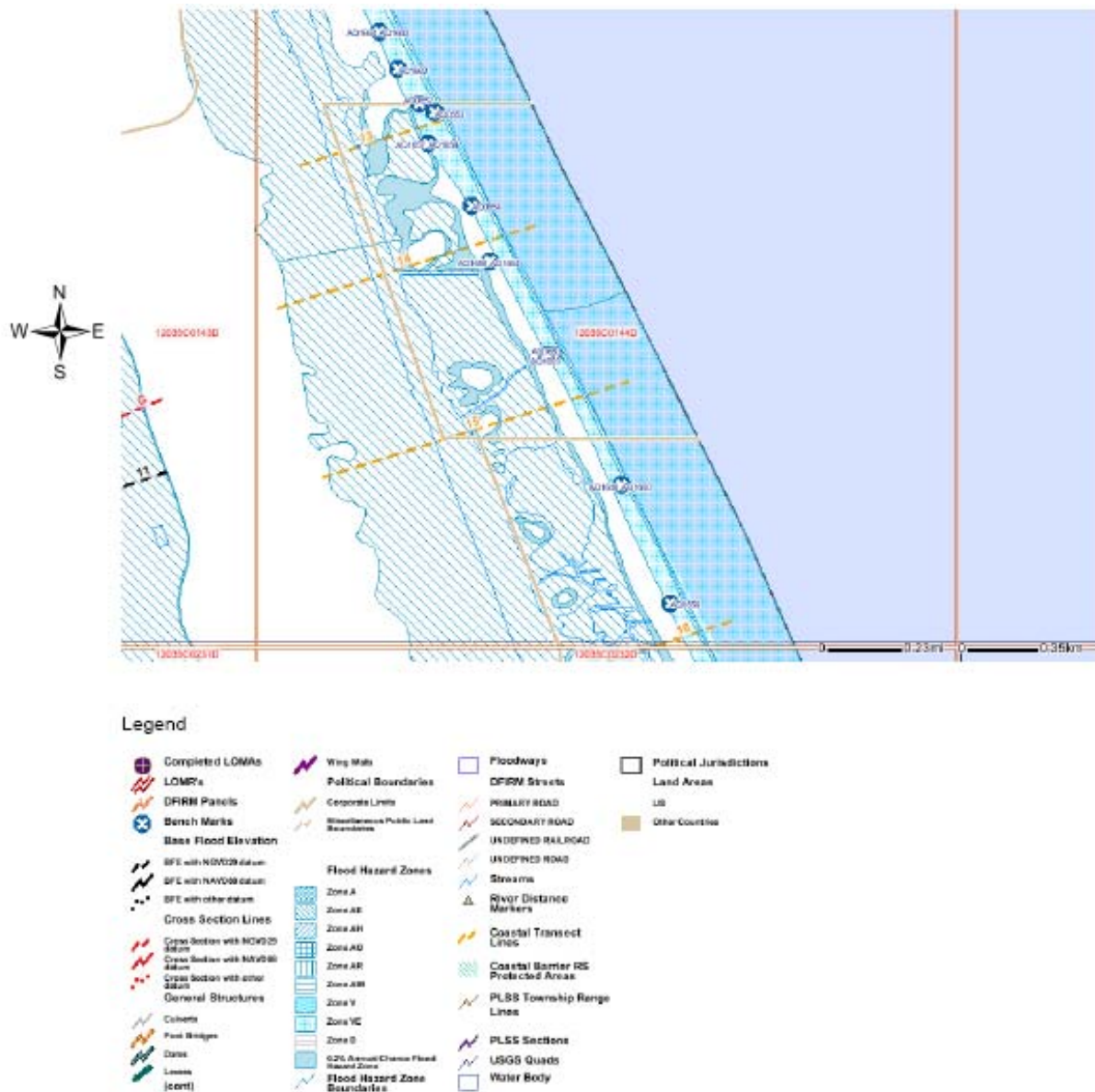


Figure 17. Example of digital flood hazard map generated through the Fema web application.

2.4 Eastern European countries

2.4.1 Overview

A general information regarding flood hazard mapping in Eastern European countries can be found in the final report of the EU JRC Enlargement project, “Management of Natural and Technological Hazards”. The project addressed the management and mitigation of risk from technological and natural hazards including floods. The work plan covered collection and analysis of existing data and information. The final report of the project, published in 1993, contains, among other things, information regarding flood risk management plans and flood risk maps.

In Bulgaria there exist flood hazard maps, but there are no information of flood risk management plans. Flood hazard maps are available at a scale of 1:500000.

In Czech Republic there are flood risk management plans and flood hazard maps. The flood protection plans contain available data and information for flood protection of a structure, municipality, watercourse, river basin or other territorial unit. Individual bodies or organisations prepare the flood protection plans in the extent and structure relevant to their needs or in accordance with requirements specified by a flood protection authority. The basic hierarchical structure of the flood protection plans is formed by municipal flood protection plans (of municipalities whose territories are exposed to flood danger), district flood protection plans, river basin flood protection plans, and Flood Protection Plan of the Czech Republic, which is prepared by Ministry of Environment. If required by a flood protection authority or needed, the flood protection plans can also be prepared for individual properties that are exposed to flood danger. The plans contain factual and graphical parts, which include relatively unchangeable information on sources of the flood danger, flood plain areas and flood protection measures. The operational part of the flood protection plans includes mainly contact information for individuals and organisations of the flood protection service.

The flood protection plans are annually examined and if needed also amended. The factual parts of the flood protection plans are submitted for approval to pertinent flood protection authority or the authority at higher level. The operational parts are continuously updated and forwarded to flood protection authorities and other participants of the flood protection system. Digital flood risk maps are available.

In Estonia there exist flood risk management plans and flood hazard maps. They can be accessed at the Estonian Meteorological and Hydrological Institute. They are not available in electronic format.

In Hungary there exist flood risk management plans and flood hazard maps. They can be accessed via the Internet. They are available as DTA-50 base map scale, are mainly available in electronic format (ArcView and ArcInfo) and are regionally divided and stored in Oracle or MS SQL database.

In Latvia there is no information available.

In Lithuania, flood risk management plans and flood hazard maps are under development. They will be available in electronic format in the future.

In Poland flood risk management plans and flood hazard maps can be accessed at the Regional Boards of Water Management and State Fire Service Headquarters. Flood hazard maps are available at a scale of 1:25000 to 1:100000. They are mainly available in traditional paper maps.

In Romania there exist flood risk management plan and flood hazard maps. In the Official Journal of Romania no. 726 (Monitorul Oficial al. Romaniei) pag. No. 1 – 32, Bucharest, the Law regarding the “Plan of the national territory development, the Fifth Section – Areas of Natural Hazards”, which includes risk maps of Romania for the areas prone to natural hazards (floods, landslides and earthquakes) and the exact geographical and administrative localisation of these areas including the indication of the risk level

of producing the specific hazards.) (Law no. 575/2001). Flood hazard maps are available at a scale of 1:1000000. They are available in *.pdf format. However, the Project “DESTRUCTIVE WATER (DESWAT) – Abatement and Control of Water Disasters, an “Integrated Decisional – Informational System for Waters Emergencies” has been conceived to facilitate the production of detailed risk maps for areas prone to flooding, using GIS.

In Slovak Republic flood hazard maps can be accessed at the following URLs:

<http://www.shmu.sk>, <http://www.enviro.gov.sk>, <http://www.uco.sk>, <http://www.minv.sk>. They are available at a scale of 1:50000. Competent authorities are investigating whether maps are available in electronic format (ArcView or ArcInfo).

In Slovenia there are flood risk management plans and flood hazard maps. They can be accessed at the Administration for Civil Protection and Disaster Relief (<http://www.mo-rs.si/urszr>). They are available at a scale of 1:50000 with flood lines:

- T = 5 yrs (frequent floods)
- T = 5-10 yrs floods every 10-20 yrs)
- T = 50 yrs (catastrophic floods)

They are available in electronic format, i.e., in ArcView

Most countries that provided information have flood risk management plans. Furthermore, all countries have flood hazard maps. In some cases, flood hazard maps can even be accessed on the Internet, as explained by the questionnaire compilers from the Slovak Republic and Slovenia. It can also be seen that most countries have flood hazard maps in electronic format.

In the next section a flood hazard mapping approach in national agencies in Poland is described. The review is based on the information already published in professional journals and also in Internet, as well as on the private communication with professionals involved in flood hazard mapping. The review concerns river flood hazard mapping.

2.4.2 Flood Hazard Mapping in Poland

Overview

The main authorities in water resources management in Poland are as follows: Minister of the Environment, President of the National Board for Water Resources Management, Director of the Regional Board for Water Resources Management, Voivode and Organs of territorial autonomy. Obligations and responsibilities of these authorities are clearly defined in the Polish Water Law.

The whole territory of Poland is divided into seven Regional Boards of Water Resources Management (RZGW) (Figure 18) (Majewski, 2005).



Figure 18. Territorial extent of the Regional Boards of Water Resources Management in Poland

Regional Boards of Water Resources Management are the basic units of water administration. Their duties are defined in Article 92 of the Water Law. Each area of RZGW has its own specific character. E.g. RZGW in Gdansk and Szczecin deal with inland waters, but also with coastal and transitional waters. Regional Boards of Krakow, Wroclaw and Gliwice cover mountain areas, where high precipitation very often results in flash floods. Regional Boards of Warsaw and Poznań deal with lowland sections of rivers, where low precipitation appears, thus causing problems of drought. The RZGW, among other things, develop the general strategy of flood control. Coordination-Information Centres (OKI) of flood protection in Regional Water Management Boards set up within the framework of a World Bank project, deal among others with mapping of flood hazard (<http://oki.krakow.rzgw.gov.pl>). Areas of flood hazard, also called flooding areas, and their reach, are outlined based on historical or hypothetical data (assuming determined probability of a given water level, e.g. for water 1%, or water level probable to appear once in 100 years). Two types of flood risks areas are distinguished: direct risk areas and potential risk areas. Direct flood risk areas are adjacent to water flow and cover terrain flooded when the river overflows flood banks. Potential flood risk areas are the areas in danger of floods when there is a damage of flood banks.

The Guidelines for flood hazard mapping were developed in frame of World Bank project in 2000 (Nachlik et. al., 2000). According to definition used in the above publication, the term ‘flood hazard map’ denotes the study presenting spatial range of flood hazard zones (inundation zones), marked on the topographic map or orthophotomap. Coastal regions are not included in the guidelines.

Data Collection

The State Hydrological and Meteorological Service (PSHM) carried out by the Institute of Meteorology and Water Management (IMGW) provides continuously the state authorities, general public and national economy with current information on the state of the atmosphere and hydrosphere, forecasts and warnings both in normal as well as in emergency situations. The system of the Polish Hydrological and Meteorological Service includes three sub-systems: observing-measurement, teleinformation and communication, data processing, forecasting and warning (Skapski, 2006).

Table 2. Measurements and Observation System

| | | |
|------------|--|--------------|
| 1. | Network of synoptic stations | 61 |
| 2. | Network of hydrological and meteorological stations | 2 230 |
| 2a. | Network of hydrological and meteorological stations (with signalling functionality) | 734 |
| 2b. | Network of hydrological and meteorological stations (with telemetry functionality) | 1 044 |
| 3. | Weather Radar Network POLRAD | 8 |
| 4. | Lighting Detection and Location Network PERUN | 9 |
| 5. | Network of aerological stations | 3 |
| 6. | Satellite data reception station | 1 |

Table 3. Network of hydrological and meteorological stations

| Ref. | Stations and sites | Total |
|----------|------------------------------------|------------|
| 1 | 3rd Order: climatological stations | 61 |
| 2 | 4th Order: meteorological sites | 149 |
| 3 | 5th Order: precipitation sites | 1 027 |
| 4 | Water gauge sites | 893 |
| 5 | Groundwater gauges | 100 |
| | Total | 2 230 |

At water gauge sites the following standard range of measurement and observations are routinely taken at 6 UTC by contracted staff: Water level

- Ice phenomena and ice cover thickness
- River bed growing over with plants

- Recording daily changes of water level [limnigraph], if needed
- Water temperature, if needed

At certain stations **water levels** are measured also at 12 UTC and 18 UTC. Upon the water rising above the alert level, emergency measurements are taken every 6 hours, and every 3 hours, if the water has risen over the alarm level.

Water gauge sites are all referenced to the National Levelling Network, with up to 1 mm accuracy.

River and river valley **cross-sections** are routinely made at water gauge sites, to facilitate drawing of rating curves: water gauge cross-section, three cross-sections in rating curve check profiles

In order to determine the dependence between the water level and the volume of discharge at water gauge stations it is necessary to continually take hydrometric measurements [**measure the volume of discharge**]. Typically, between 7 and 10 measurements p.a. are taken in each measurement cross-section, at different water levels. It is crucial to take measurements when water levels are very low, i.e. at the times of low water flow, and when the water table is at its highest [high water levels, or flood]. Following measuring equipment is used: hydrometric drum, electromagnetic flow meter, Acoustic Doppler Current Profiler (ADCP).

Table 4. Network of hydrological and meteorological stations (with signalling functionality)

| Ref. | Stations and sites (with signalling functionality) | Total |
|------|---|-------|
| 1 | 3rd and 4th Order: climatological stations and meteorological sites | 77 |
| 2 | 5th Order: Precipitation sites | 166 |
| 3 | Water gauge sites | 404 |
| 4 | Groundwater gauges | 54 |
| | Total | 734 |

Contracted observers at some station and sites on-line inform on results of their measurements and observations. Results of measurements and observations are transmitted mostly between 6:30 UTC and 7:00 UTC. When requested to take extra measurements (in flood alert, or alarm circumstances), observers provide information every 6, or 3 hours, as needed.

The main telecommunications medium in southern Poland is the radio network using the frequency leased by IMGW, whereas in the central and northern Poland we base our telecommunications on PSTN and mobile networks. Upon the launch of the telemetry functionality over the stations network, observers provide benchmarking information and use signalling as a redundant measure that enables communication when the automatic and telemetry equipment break, and as the source of information on station damage, or destruction.

Network of hydrological and meteorological stations with telemetry functionality covers the measurements listed below:

- Meteorological stations-temperature, relative humidity, wind speed and direction and volume of precipitation.
- Precipitation sites-volume of precipitation
- **Water gauge in a river, or lake-water level**
- **Macrograph sites-sea level**

The station communicates with IMGW ICT network through radio modems and re-transmitters, operating at the radio frequency leased by IMGW, GPRS modem, Inmarsat C modem.

Definitions of Flood Hazard Zones

Key elements of the flood hazard maps are the flood hazard zones. In Nachlik et. al. (2000) the following flood hazard zones are defined (see Figure 19):

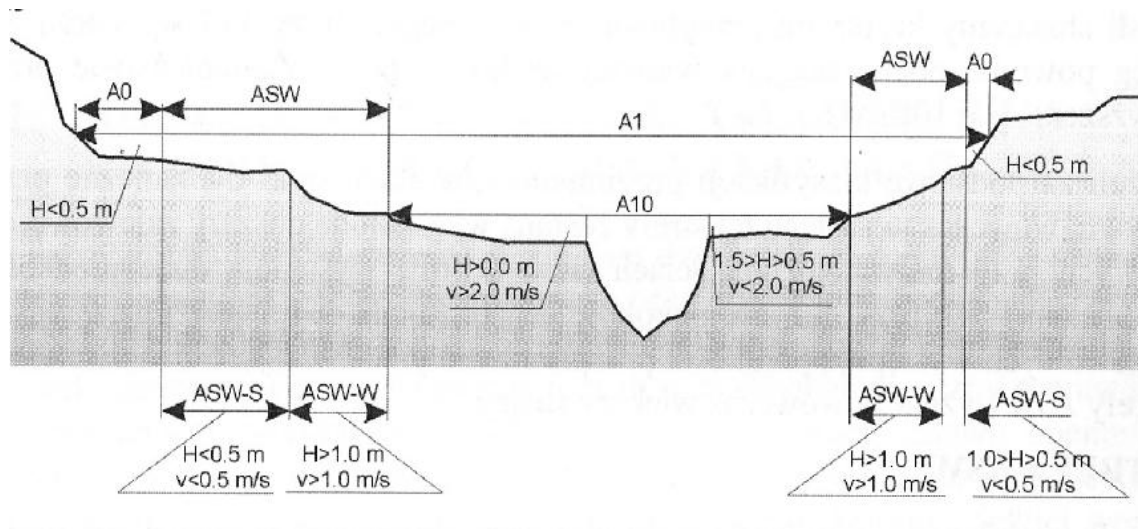


Figure 19. A range of flood hazard zones in a cross section of the river (according to Nachlik et. al. 2000).

Zone A1

It is defined as the area flooded by the highest floodwater flow volume Q at 1% exceedence probability. It includes flooding adjacent to rivers and streams, periodic catchments runoff (surface discharge) and stationary water bodies, as well as through-flowing ponds and lakes with certain surface levels.

Zone A0

A part (typically outer) of the A1 zone with the lowest risk level. The water depth lower than 0.5 m defines it. It covers flooded areas adjacent to rivers, streams, and water in local depressions. The flow speed is negligible. The zone excludes intensive surface discharge areas, typically featuring less than 0.5 m depth but high water speed and often causing landslides and erosion as a result of higher than the threshold (permissible) mean water speed or the rate tangent to a given ground surface type.

Zone A10

Defined as the part of the A1 zone with the greatest exposure to flooding. There are two definitions of the zone, depending on the level of input data and local conditions:

1. It is defined flood extent at high floodwater flow and exceedence probability 10%; or
2. It is defined by the following conditions:
 - Water depth ≥ 1.5 m adjacent to watercourses and bodies; excluding intensive surface discharge in steep terrain prone to develop periodic very shallow streams.
 - Water depth and mean local flow speed fulfil the following conditions

| | | |
|---------------------------------------|----|------------------|
| $h > 0$ m | at | $v > 2.0$ m/s |
| $0.5\text{m} \geq h \geq 1.5\text{m}$ | at | $v \leq 2.0$ m/s |

The higher calculated value of the zone range should be chosen. In case of questionable available data it is permissible to define this zone as covered by water with discharge $Q_{10\%}$.

Zone ASW

This is a medium and high exposure zone between zones A0 and A10.

Depending on local conditions and needs, the different levels of flood risk can be defined on the basis of:

1. Analysis of a river flow depth and speed:
 - Depth h :
 - Great: $h > 1.0$ m
 - Medium: $h = 0.5 - 1.0$ m
 - Small: $h < 0.5$ m

- Mean speed v of a local flow
 - Great: $v > 1.0$ m/s
 - Medium: $v = 0.5 - 1.0$ m/s
 - Low: $v < 0.5$ m/s
- 2. A determination of supplementary boundaries dividing the AWS zone into high and medium risk zones depending on discharge probability of occurrence equal Q2% or Q-5%.

The more hazardous values should be selected from those two.

In general the AWS zone is divided into two zones:

- AWS_W – high risk flood zone
- AWS_S – medium risk flood zone.

Nachlik et. al. (2000) in the book 484 pages long, give a detailed description how to delimit flood hazard zones.

Flood Hazard Mapping in Practice

In practical applications, the extensions of flood hazard zones are taken according to the definition of A1 and A10 zones. The zones A1 and A10 are defined as the zones covered by water flow with probability of occurrence equal Q1% and Q10% respectively.

The following activities are always carried out:

1. Field, tachymetric surveying of mileage and cross-sections of the river channel and valley.
2. Calculation of the characteristic water flow (mean SSQ [m³/s] and low-mean SNQ [m³/s]) and water levels (SSW and SNW) at water level measurement sites (controlled profiles).
3. Calculation of water flow and water levels with probability of exceedence $p=1\%$ and $p=10\%$ at measurement sites (controlled profiles). For the calculation of water flow the Weibull distribution is used.
4. Calculation of water flow and water levels with probability of exceedence $p=1\%$ and $p=10\%$ at measured cross-sections of the river (non-controlled profiles). The following equations can be used:

$$Q_o = Q_w * \left(\frac{A_o}{A_w} \right)^n \quad (1)$$

$$Q_o = Q_{w1} + \frac{Q_{w2} - Q_{w1}}{A_{w2} - A_{w1}} (A_o - A_{w1}) \quad (2)$$

where

Q_o - Water flow in a calculated cross-section,

Q_w - Water flow in a controlled profile,

A_o - Catchment area in a calculated cross-section

A_w - Catchment area in a controlled cross-section

n - Empirical parameter, $n = 2/3$

5. Calibration of a hydrological model and calculation of coordinates of water levels for discharges with probability of exceedence $p=1\%$ and $p=10\%$.
6. Mapping the inundation zones corresponding to the calculated coordinates of water levels on the topographic maps at a scale 1:10000.

According to Coordination-Information Centres (OKI) of flood protection in Regional Water Management Board of Krakow region [<http://oki.krakow.rzgw.gov.pl>], the following data are utilized in production process of flood hazard maps :

1. **River valley cross-sections** – results of field, tachymetric surveying of mileage and cross-sections of the river channel and valley. A distance between cross-sections amounts 0.5-2 km, depends on the river.
2. **Raster maps.** Raster map should be homogeneous, with continuous area. The map is based on the topographic maps at a scale 1:10000.
3. **Digital Terrain Model.** (DTM). Spatial reach of the inundation zones is outlined as a result of GIS analysis of intersection of the surface of water table with Digital Terrain Model. Aerial photographs at a scale 1:26000 taken during the period 1995-1998 were utilized as a data for DTM But 10% of the photographs were taken recently in years 2001-2002. Topographic maps at a scale 1:10000 were also used as an additional source of hypsometric data. Objects of great management significance during the flood (flood banks) were additionally measured with GPS. Data below the water table are not included in the DTM.
 The accuracy of DTM is varies from +/-0.2m for flood banks to +/-2.5m in the area with diversified lie of the land (gradient higher than 6 degrees) and is less then +/-1m if the gradient is less then 6 degrees.
4. **Hydraulic model** of the river based on **MIKE11** software (DHI Water & Environment) or **HEC-RAS** system (US Army Corps of Engineers, Hydrologic Engineering Centre-River Analysis System).

MIKE11 is an industry standard for simulating flow and water level, water quality and sediment transport in rivers, irrigation canals, reservoirs and other inland water bodies. The hydrodynamic module (HD) is used in the process of data preparation. HD module is the core of MIKE 11. It provides a library of computational methods for steady and unsteady flow in branched and looped channel networks as well as quasi two-dimensional flow simulation flood plains. A hydraulic model of Upper Vistula and Odra rivers were developed applying MIKE11 software. For example, a hydraulic model of upper Vistula river catchment area consists of seven independent sections, but also all section can be integrated in one model. An example of the section diagram is shown in the Figure 20.

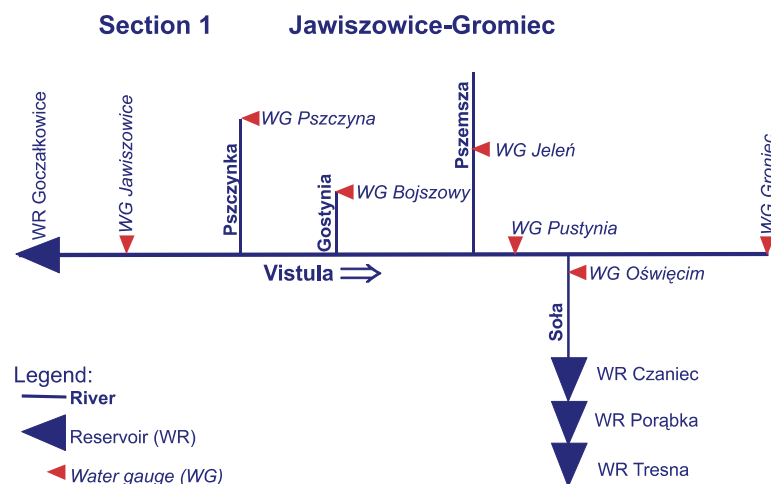


Figure 20. A hydraulic model of upper Vistula river catchment area – an example of river section diagram.

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that flow is considered to move uniformly from point to point upstream to downstream. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities.

5. Decision and informational system IT-GIS OKI supporting Regional Boards for Water Resources Management, which is based on the following software: Intergraph Geomedia Professional 5.1, Oracle Enterprise 9.2 and Oracle Spatial.

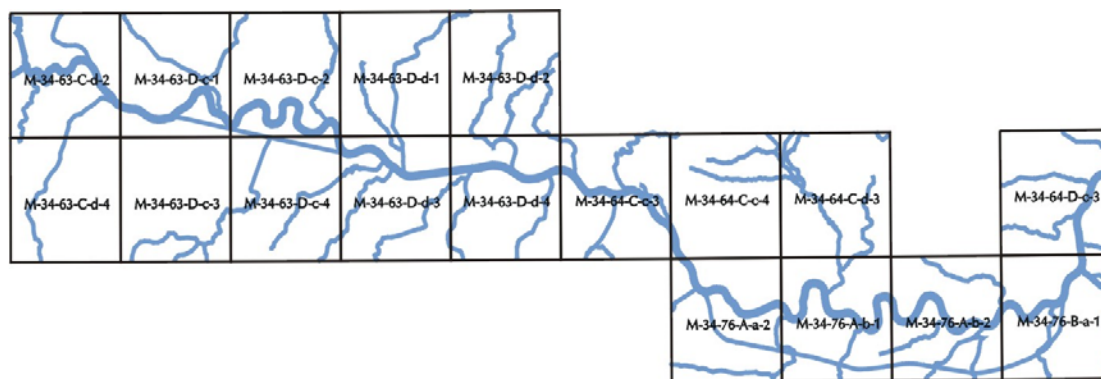


Figure 21. An index of flood hazard maps of upper Vistula river –Section 1.

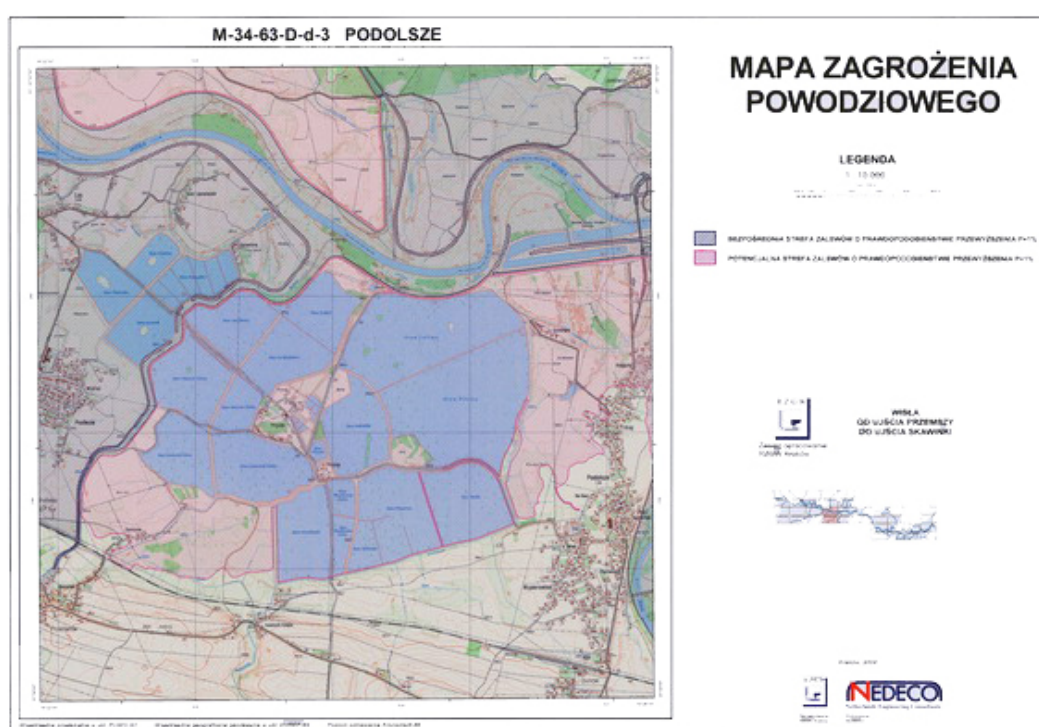


Figure 22. Flood hazard map presented by Coordination-Information Centres (OKI) of flood protection in Regional Water Management Board of Krakow region (<http://oki.krakow.rzgw.gov.pl>).

The risk of flood is usually associated with probability of a certain water level. However, there is other kind of risk, connected with analytical side of outlining flood areas, including first of all the quality of source data. When data is complete and up to date, the main parameter featuring the quality of data is their accuracy. In this case accuracy of source data may be understood as the accuracy of DTM and the accuracy of outlining the level of water table (e.g. based on hydrological modelling). It is important to estimate the risk connected with not taking into account the quality of source data in modelling flood areas. The method of the risk estimation is discussed in Hejmanowska (2006)

3 Modeling Aspects in Flood Hazard Mapping (FHM)

3.1 The Categorization System

As there are many models that have a similar primary function, but differ in the basic manner in which the processes are represented, it is sometimes difficult to determine the most appropriate modeling solution. It can therefore be useful to define categories of models. Carried out in a meaningful manner, categorization can relieve the burden of memorizing the purpose and function of every available model and assist in the selection of the most appropriate approach.

The underlying basis for the categorization system described here is the level of complexity of the model. The level of complexity has been defined to be dependent on: (a) Data Requirements, b) Resolution, c) Physical Processes and d) Characteristics of the underlying equations.

A form of categorization is performed by using the information regarding model properties to arrange a series of categories of increasing complexity. To aid understanding, a common and consistent terminology has been used to describe the range of categories for each physical zone. In order of increasing complexity these categories are:

- **Judgment-** Defined as a non-mathematical approach relying on intuition and experience
- **Empirical-** Defined as a model that does not attempt to simulate physical processes but relates observations or measurements of inputs such as wave conditions and water levels directly to outcomes such as overtopping rates
- **First Generation-** Attempts to model explicitly the physical processes, usually involving a number of simplified assumptions
- **Second Generation-** More sophisticated attempts to model the physical processes, involving more advanced (less simplified) methods than First Generation methods
- **Third Generation-** Advanced methods that attempt to model the physical processes that include few simplifying assumptions.

As for the spatial aspect of the field characteristics and the equations used, there can be identified: **one-dimensional (1D) models** (e.g. beach profile models), **two-dimensional (2D) models** which describe the phenomena either in the two horizontal dimensions assuming condition uniformity in the vertical one (two-dimensional horizontal models “2DH”), or in one horizontal and the vertical dimension assuming condition uniformity in the second horizontal (two-dimensional vertical models “2DV”) and **three-dimensional (3D) models** which are more accurate but also more complicated, and for this reason being confined to the study of smaller areas.

Further model classification can be made according to the implemented solution techniques/methods. In particular, there exist:

- **linear models**, in which the phenomena are represented by simplified first-order forms of the basic equations used (e.g. equation of forces equilibrium or mass conservation) and **non linear models** which comprise second or higher order terms and correlation between the variables
- models based on **finite element**, **finite difference** and **finite volume** schemes
- **phase-averaging models** through which the time-averaged effect of a process can be found (e.g. offshore and coastal wave models) and **phase-resolving models** which provide a simulation of the instantaneous environment for every model time step (e.g. swash zone and wave overtopping models)
- **coupled models** with one-way or two-way data transfer between two different models
- **nested models** with one-way data transfer from large area to small area models. In particular, the first model’s output is used as an input for the second model, which has a finer spatial discretization.

3.2. Data Requirements

The data requirements for building flood hazard maps in river domains can be divided into two parts. Firstly, the hydrological input data must be available. Secondly, the data that are needed for hydraulic calculations must be available. The hydrological input data can be described as flood estimation. There are two basic approaches to gain flood estimation for a particular return period:

- Statistical methods
- Rainfall run-off modelling

Statistical methods provide a single value of the flood peak discharge for a selected return period at a specific point. Rainfall run-off models provide a full flood hydrograph with both, peak discharge and flood volume.

Hydrology:

Statistical methods

Water levels and corresponding water discharges are recorded by the most countries for a long time. In the UK, for example, the Flood Estimation Handbook (FEH) exists, where such values can be found and required values can be calculated. In Germany such data are published for every gauge in a river domain by federal states.

Bases on these records, calculations can be done to estimate discharges at ungauged locations where data are needed. These are usually done by a regionalisation approach. Another assess has to be done in order to find a flood growth factor to produce particular recurrent values.

Rainfall run-off models

The use of a rainfall run-off model leads to full hydrographs which make it possible to examine the effects of storage and overspill in floodplains.

There are essentially three types of rainfall-runoff model:

- Unit Hydrograph models
- Physically based models
- Conceptual models

Whereas Unit Hydrograph models are most commonly used in the UK (Scottish Executive Environment Group, 2004), in Germany the most commonly used models are conceptual models.

A conceptual model seeks to describe the hydrology of a drainage basin from rainfall to stream discharge as a sequence of interlinked processes and storages (Scottish Executive Environment Group, 2004). The processes and storages a conceptual model contains are bases on underlying physical equations without solving them explicit.

In contrast to the conceptual model, the physical model is based on the exact underlying equations and solves them in a precise way. This process is very data and time intensive. Therefore, the use of physical based models is not (yet) applicable for huge areas.

The unit hydrograph model is a black box model which links the input data to the output data. The model has to be calibrated with some parameters that can be derived from historical time series.

Topographical requirements for hydraulic calculations:

The hydraulic calculation is based on topological data. Therefore the need for accurate topological data is essential for building flood hazard maps. The most commonly way to provide topological data is to build a digital terrain model on the basis of aerial taken data. Careful manual checking is required. In general high resolution data requires more post processing than low resolution data. Laser scan data can only provide terrain elevations above the water level. For a subsurface terrain model cross sections have to be surveyed. The surveyed data, extended with data from the digital terrain model, can be used a basis for further hydraulic calculations.

Another important point is the data management. The huge amount of data which is considered during the calculation process needs a powerful data and quality management Data should be edited and stored by using a geographical information system which is capable to manage data within a database. User

restriction, data integrity due to field domains and a unified data model are the most highlighting advantages of using a geodatabase. More advanced systems are also capable of building versions during the working steps. This gives the user the ability to recover any version that was made during the working history. A detailed workflow can also help to reduce errors and data confusion.

The amount of data is also a problem. Huge amount of data is not easy to handle. It slows down the computer and can be the cause for storage problems. Therefore, it is preferable to convert the raster data to a TIN format as soon as the digital terrain model is build.

3.3. Sources

Prediction of the Source variables is a logical start and a necessary prerequisite for all detection and flood forecasting methods in coastal areas. For coastal areas offshore models, which describe wave generation and water level setup under wind, current and tidal (astronomical and meteorological) action and nearshore models, which describe wave shoaling, refraction, diffraction and breaking are necessary for water level prediction in coastal waters. The assessment of the wave and water level conditions near the coast – wave heights, wave periods, wave directions and water levels near the shoreline – is essential for the estimation of flood characteristics. Using the output of offshore as input to nearshore wave and water level models, the wave climate next to the coastline is produced. This is used from shoreline response and flood inundation models to describe the pathways of erosion and flooding.

3.3.1. Water Level

For offshore wave prediction, First Generation models provide predictions at a single point. They consider wave generation and energy dissipation by white capping. The Second Generation models are 2DH models providing results over the grid area. They solve the energy balance equation and their distinguishing feature is the parametric description of the wave spectrum. The Third Generation models are like the Second Generation ones, but include an explicit presentation of the primary wave-wave interactions.

The global ocean Wave prediction Model called WAM is a Third Generation finite difference wave model. WAM predicts directional spectra as well as wave properties such as significant wave height, mean wave direction and frequency, swell wave height and mean direction, and wind stress fields corrected by including the wave induced stress and the drag coefficient at each grid point at chosen output times. It requires input of bathymetry and wind field. WAM solves the wave transport equation explicitly without any presumptions on the shape of the wave spectrum. It represents the physics of the wave evolution in accordance with our knowledge for the full set of degrees of freedom of a 2D wave spectrum. The model runs for any given regional or global grid with a prescribed topographic dataset. The grid resolution can be arbitrary in space and time. It simulates all processes described for the aforementioned models. It is a model of high accuracy, cost and run-time.

WAM runs for deep and shallow water and includes depth and current refraction. The integration can be interrupted and restarted at arbitrary times. The source terms and the propagation are computed with different methods and time steps. The source term integration is done with an implicit integration scheme while the propagation scheme is a first order upwind flux scheme. The wind time step can be chosen arbitrarily.

WAVEWATCH III is a Third Generation wave finite difference model developed at NOAA/NCEP in the spirit of the WAM model. WAVEWATCH III, however, differs from its predecessors in many important points such as the governing equations, the model structure, the numerical methods and the physical parameterizations. It solves the spectral action density balance equation for wavenumber-direction spectra. The model can generally be applied on spatial scales (grid increments) larger than 1 to 10 km, and outside the surf zone. The governing equations of WAVEWATCH III include refraction and straining of the wave field due to temporal and spatial variations of the mean water depth and of the mean current (tides, surges etc.), when applicable. Parameterizations of physical processes (source terms) include wave growth and decay due to the actions of wind, nonlinear resonant interactions, dissipation ('whitecapping')

and bottom friction. Wave propagation is considered to be linear. Relevant nonlinear effects such as resonant interactions are, therefore, included in the source terms (physics). Wave-wave interaction and wave-current interaction are also considered in the model. The model is prepared for data assimilation, but no data assimilation package is provided. Model outputs include gridded fields of 18 input and mean wave parameters such as the significant wave height, directions, frequencies etc, wave spectra at selected locations and wave spectra along arbitrary tracks. It is a model of high accuracy, run-time and cost.

For offshore/ nearshore water level predictions (tide and surge), the First Generation models are 2DH models providing results of tide and surge components across a given area. They solve the non linear shallow water equations and use inputs of wind fields and atmospheric pressure over the modelled area. More advanced models include the effects of breaking waves, causing set-up of water levels in nearshore areas. The Second Generation models are 3D models that include the effects of temperature and salinity, in addition to the characteristics of First Generation models. For nearshore water level prediction the models include all the fundamental processes included in the models for predicting offshore water levels. The distinguishing feature is the increased spatial resolution required to resolve coastline features.

Advanced Circulation Model (ADCIRC) is a finite element 2D hydrodynamic model. It is a First Generation model for water level prediction. The version 2DDI is vertically-integrated and solves a vertically-integrated continuity equation for water surface elevation. No storm or hurricane windfield models or statistical analysis tools are included in the model, they must be acquired separately. Statistical analyses using ADCIRC model storm surge simulations are compatible with the USACE Empirical Simulation Technique (EST) as well as joint probability methods.

MECO and MIKE21 HD/NHD are also First Generation 2D finite difference surge models. MECO is real time operational and a model which assimilates measured data. Both models need data of bathymetry and wind field and give output of surge and tide level. MIKE21 HD/NHD is an available software with full support. It solves the non-linear depth-averaged equations of continuity and conservation of momentum. It computes water levels and flows based on a variety of forcing functions as well as wave-driven currents and wave setup. MIKE21 HD/NHD uses a finite difference grid with dynamic nesting grid capabilities. Resolving small scale features such as narrow inland channels, culverts and control structures can be accomplished using the DHI MIKE FLOOD interface which allows for dynamic coupling between MIKE 21 and the DHI MIKE 11 model.

POLCOMS is the Proudman Oceanographic Laboratory Coastal Ocean Modelling System. It's a Second Generation 3D offshore/nearshore surge model. It is a real time operational finite difference system. Inputs needed and outputs produced are the same as the UKMO/POL First Generation models. Its accuracy and run-time are medium and its cost is low. Just like the models UKMO/POL, POLCOMS is not publicly available. The central core of the model is a sophisticated 3D hydrodynamic model that provides realistic physical forcing to interact with, and transport environmental parameters. POLCOMS comprises a baroclinic 3D model with the ability to run in regions which include both the deep ocean and the continental shelf, together with linked sediment and ecosystem models. It can take various forms of forcing boundary input.

TELEMAC, TABSRMA are 2D surge models. Bathymetry and wind field data are necessary to provide results of surge and tide elevation. TELEMAC is an available software of high accuracy, run-time and cost. TELEMAC-2D is used to simulate free-surface flows in two dimensions of horizontal space. At each point of the mesh, the program calculates the depth of water and the two velocity components. TELEMAC-2D solves the Saint-Venant equations using the finite-element or finite-volume method and a computation mesh of triangular elements. It can perform simulations in transient and permanent conditions. TABSRMA is a 2D steady/unsteady flow model, for water levels and velocities. It computes finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows.

FINEL 3D is a fully 3D numerical model for the computation of shallow water flow and transport processes in rivers and coastal waters. FINEL 3D is based on the complete Navier-Stokes equations. No

assumptions are made with respect to the vertical pressure distribution, hence the model is especially suited to compute currents which strongly vary in both horizontal and vertical directions. The numerical basis of FINEL 3D is the finite element method and uses the same grid as the 2D shallow water flow model FINEL 2D, which is extended in vertical direction with an arbitrary number of vertical gridpoints. This procedure makes the schematisation process quick and efficient as special features of the area of interest can be easily incorporated in the model.

WAQUA is one of the oldest and most commonly used computation models at the National Institute for Coastal and Marine Management (RIKZ) and is a SIMONA model. The 2D hydrodynamical model WAQUA computes water levels, currents and particle transport in open water. The RIKZ aims for model development regarding the North Sea, the coastal areas, and the Dutch estuaries. WAQUA considers a study area that can be characterised by curviform shaped, quadrangular grid of computation points. Gridsizes for coastal areas vary from 30 m to 16 km. The corresponding grid cells are attributed with linked information such as bathymetry and bed roughness. By means of applying specific modules, the information is being generated for the whole grid and converted to the required WAQUA format with the use of a GIS-oriented info-database (BASELINE). This database forms the basis for the development of specific area schematisations and supplies the physical boundary conditions and characterisations for both WAQUA and SOBEK.

For nearshore wave prediction there are phase resolving and phase averaging models. The First Generation models of the former category (e.g. "mild slope" models) are 2DH models which provide instantaneous surface elevations over a given area. They include a linear representation of refraction, mild shoaling and an approximate representation of diffraction. The Second Generation models (Boussinesq models) are 2DH models which include non-linear representation of diffraction, refraction and mild shoaling. The First Generation models of the latter category are 2DH wave tracing models that provide results at a point or in an area and they have a linear representation of refraction and shoaling. The Second Generation models are 2DH models which provide averaged results of tide and surge components across a given area. The Third Generation models are like the Second Generation ones but include an explicit representation of the non-linear transfer of energy resulting from the primary wave-wave interaction frequencies.

COSMOS is a First Generation 1D phase-averaging wave model. It simulates wave breaking and energy dissipation, refraction, shoaling and wave-current interaction. COSMOS is 1D wave model, which needs input and produces output in the form of time series or stationary data. Wind field and bathymetry are required. Random waves, wave spectra and wave parameters are provided and estimated as output. COSMOS is a model of low cost, run-time and accuracy.

MIKE21 NSW is a wind-wave Second Generation model that describes the propagation, growth and decay of short-period and short-crested waves in nearshore areas. The model takes into account the effects of refraction and shoaling due to varying depth, local wind generation and energy dissipation due to bottom friction and wave breaking. Also the effect of wave-current interaction is included. MIKE21 NSW is a stationary, directionally decoupled parametric model, and the effect of current is taken into account by deriving the basic equations in the model from the conservation equation for the spectral wave action density. The basic equations are solved using an Eulerian finite difference technique. The basic output from the model is integral wave parameters, such as significant wave height, mean wave period, mean wave direction, directional standard deviation and radiation stresses. In addition, spectral output data can be obtained in the form of the distribution of wave energy with direction at a number of user specified points. MIKE 21 NSW can be used to calculate the wave conditions and associated radiation stresses, which are important for the calculation of the sediment transport that, to a great extent, is determined by wave conditions and associated wave-induced currents. The wave-induced current is generated by the gradients in radiation stresses that occur in the surf zone. The US Federal Emergency Management Agency (FEMA) has officially approved MIKE 21 NSW for use in coastal Flood Insurance Studies.

STWAVE (STeady State spectral WAVE) is an easy-to-apply Second Generation, flexible, robust, half-plane model for nearshore wind-wave growth and propagation. STWAVE simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, parametric wave growth because of wind input, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field. STWAVE is being extended from a half-plane model to a full-plane model (including propagation and generation from all directions).

SWAN is a Third Generation finite difference 2D wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. SWAN accounts for the following physics: wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non-stationary depth, wave generation by wind, three- and four-wave interactions, white-capping, bottom friction and depth-induced breaking, wave-induced set-up, propagation from laboratory up to global scales, transmission through and reflection (specular and diffuse) against obstacles and diffraction. It is a phase averaging wave model, based on the discrete spectral action balance equation and is fully spectral in all directions and frequencies. The use of fully implicit propagation schemes in SWAN averts excessive model run times and promotes the robustness of the model. It is a model of high accuracy, medium run-time and medium cost. Input required and output produced are similar to the other models described above. The model is available and with full support.

3.3.2. Water flow & depth

The water level calculation can be done either by a 1D or by a 2D model. A 3D model has not been applied so far. The German LAWA (Länderarbeitsgemeinschaft Wasser, 2006) gives recommendations on which model should be used as follows: 1D models can be a good choice in mountain and low mountain range areas when the stream flow takes mainly one direction. 2D models should be used in plain areas or estuary areas or areas that are affected by tide. In these areas the assumption of one dimensional flow is false. There can also be made a distinction between steady and unsteady models. When the change over time is important for the distribution of the water volume in the area, an unsteady calculating model should be used.

3.4. Pathways

3.4.1. Flood Inundation Models

Flood inundation models, which combined with Digital Terrain Models, describe the processes taking place in the flood plain, have shown significant progress in the latest years. The basis for flood inundation models is a Digital Terrain Map (DTM) of the flood plain area. Digital Terrain Maps are often produced based on laser scan data and from joining survey and laser scan data. Basic characteristics of flood inundation models of Table 1 are shortly presented in the following.

Empirical methods are often described as pure mapping. No physical laws are involved in the simulations performed. They are rather simple methods compared to the others, with low cost, but they provide poor estimates of flood risk in large low lying or extensive areas where flows through a breach may be critical in determining the flood extent. They are usually applied to assess flood extents and flood depths in broad scale. ArcGIS and Delta mapper are example models which usually describe flow processes in compound channels. These models use Digital Elevation Maps (DEM), upstream water level and down stream water level as inputs and calculate inundation extent and water depth by intersecting planar water surface with Digital Elevation Maps. The time necessary for computations is measured in seconds.

First Generation models are essentially 1D models used with a 2DH grid. These models calculate water level in each flood cell at given output steps and therefore enable the duration of flood to be estimated. In cases where the flood plain is extensive, such models can give poor results, because they do not consider

the propagation of floodwater within each cell. Infoworks RS, Infoworks CS and ISIS are typical examples of this category of models. Infoworks RS and Infoworks CS are available softwares of medium cost, medium accuracy and medium run-time. They are 1D models with 2DH grids, which simulate flood volume propagation. They use Digital Terrain Maps (DTM), time series and overflow discharges as input and produce results of flood depth, flood extent and flood duration. ISIS is a software of similar characteristics to the previous models, but of lower accuracy. Models such as Infoworks RS, ISIS, as well as Mike 11, HEC-RAS and SOBEK-CF, which solve the one-dimensional St Venant equations are used to describe flow processes in compact channels. They are applied in the case of design scale modeling which can be of the order of 10s to 100s of km depending on catchment size. Surveyed cross sections of channel and floodplain, upstream discharge hydrographs and downstream stage hydrographs are provided as inputs to the models aforementioned. Water depth and average velocity at each cross section, inundation extent by intersecting predicted water depths with Digital Elevation Models and downstream outflow hydrograph are produced as outputs of the models. First Generation Models also include 1D⁺ models, which are 1D models plus a storage cell approach to the simulation of floodplain flow. Example models of this category are: Mike 11, HEC-RAS, Infoworks RS and ISIS. The computation time for 1D and 1D⁺ models is counted in minutes and minutes to hours, respectively.

Second Generation models are 1D/2DH hybrid models and fully 2D. The models of this category use the St Venant equations to model channel flow, however, a 2D continuity equation is used to approximate flow over the flood plain area. HYDROF and LISFLOOD-FP are Second Generation models of method 2D⁻, which means that they are 2D excluding the law of conservation of momentum for the floodplain flow. They are used in the case of broad scale modeling or urban inundation depending on dimension cells. HYDROF simulates the process of flood volume propagation. It is an available model of medium cost, accuracy and medium run-time. It uses Digital Terrain Maps (DTM), time series and overflow discharges as input and produces results of flood depth, flood extent and flood duration. LISFLOOD-FP is a 1D/2DH hybrid model of the same characteristics as HYDROF. When used to simulate flood inundation in compound channels it uses DEMs, upstream discharge hydrographs and downstream stage hydrographs as input and produces outputs of inundation extent, water depths and downstream outflow hydrographs. The computation time needed is measured in hours. Mike 21 and TELEMAC 2D are 2D models, which solve the two-dimensional shallow wave equations. Mike 21 is similar to the previously analysed models, while TELEMAC 2D is a finite element 2DH available software of high cost, medium accuracy and medium run-time (hours to days). Except from flood volume propagation, TELEMAC 2D simulates the processes of percolation and seepage. DTMs, time series and overflow discharges are used as inputs to the model, while flood extent, duration, flood depths and flood plain flow velocities are extracted from the model. 2D models such as Mike 21, TELEMAC, TUFLOW, SOBEC-OF and Delft-FLS are utilized for channel flow in the case of design scale modeling of the order of 10s km. They may have the potential for use in broad scale modeling if applied with very coarse grids. They make use of DEMs, upstream discharge hydrographs and downstream stage hydrographs as input and produce results of inundation extent, water depths, depth-averaged velocities at each computational node and downstream outflow hydrographs. The computational time varies from hours to days for the previously mentioned models. TELEMAC 3D is an available finite element 3D model included in the category of Second Generation models. It is a model of high cost, accuracy and high run-time. Except from flood volume propagation, TELEMAC 3D simulates the same physical processes and is characterized of the same input and output as TELEMAC 2D. TELEMAC 3D and Delft-3D are usually characterized as 2D⁺ models, 2D plus a solution for vertical velocities using continuity only, which are predominantly applied to coastal modeling where 3D velocity profiles are important. They have also been applied to reach scale river modeling problems in research problems. Inputs needed by the models are DEMs, upstream discharge hydrographs, inlet velocity distribution and downstream stage hydrographs. Outputs produced are inundation extent, water depths, u, v, w velocities for each computational cell and downstream outflow hydrographs. The time demanded for computation is in the range of days.

Third Generation models simulate breaching in 3D with the flood inundation in 2D. They provide better simulations of the flood inundation as the flow velocities at the boundary are accurately simulated. FINEL 2D is a 2DH finite element model of medium cost and run-time and high accuracy. Except from flood volume propagation, FINEL 2D simulates the processes of percolation and seepage. DTMs, time

series and overflow discharges are used as input to the model, while flood extent, duration, flood depths and flood plain flow velocities are extracted from the model. FINEL 3D is a 3D finite element model of high cost, accuracy and run-time. Simulated processes, inputs and outputs are similar to those of FINEL 2D. Third Generation models such as CFX, FLUENT and PHOENIX are usually applied for local predictions of three-dimensional velocity fields in main channels and floodplains. They provide a 3D solution of the three-dimensional Reynolds averaged Navier Stokes equations. Inputs necessary for these models are DEMs, upstream discharge hydrographs, inlet velocity and turbulent kinetic energy distribution and downstream stage hydrographs. Outputs produced are inundation extent, water depths, u, v, w velocities and turbulent kinetic energy for each computational cell and downstream outflow hydrographs. Computation time is estimated in days.

For river domains the inundation is calculated by intersecting the water level from the digital terrain model. This working step is pretty straightforward and is used by a wide range of users. In fact, all the commonly used models have a post-processor which is directly linked to a GIS environment and enables the user to build quickly an inundation map from the calculation results (Scottish Executive Environment Group, 2004).

Figure 23 presents the physical system for coastal areas with the four physical zones: offshore, nearshore, shoreline response and flood inundation zone. Table 5 presents some widely used models for coastal areas, classified for better supervision under the most important categories (Defra, 2003).

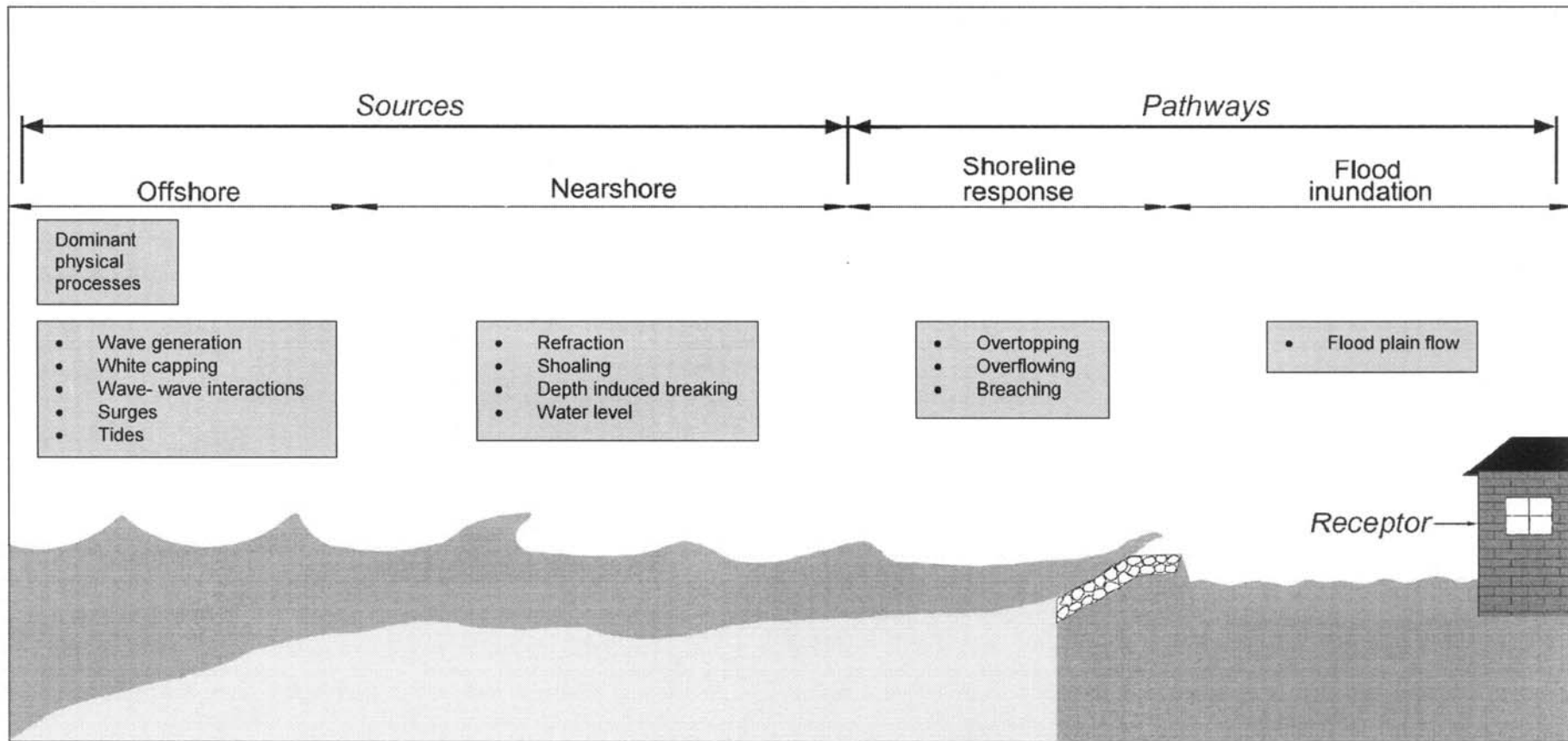


Figure 23. Characterization of the physical system for coastal areas

DEFRA/ Environment Agency Flood and Coastal Defence R&D Programme (2003) - Best practice in coastal flooding, *R&D Technical Report FD2206/TR1*, Workshop Version issued 24/09/03, HR Wallingford Report TR 132

Table 5. Numeric Models for prevision in coastal areas

| OFFSHORE | | NEARSHORE | | BEACH EVOLUTION | | SHORELINE | | FLOOD INUNDATION |
|---------------|---------------|-----------------|-----------------|-----------------|-----------|-------------|-------------|------------------|
| Waves | Water Levels | Waves | | Cross-shore | Longshore | Overtopping | Breaching | |
| | | Phase Resolving | Phase Averaging | | | | | |
| ADCIRC | ADCIRC | CGWAVE | AFDA | COSMOS | GENESIS | AMAZON-CC | SHINGLE | ArcGIS |
| UKMO | CS3 | HARES | COSMOS | CROSMOR | NMLong-CV | OTT | COSMOS | Delta mapper |
| UKMO UK | HYDROF | RCP-WAVE | ENDEC | DELFT 2D/3D | ONELINE | RUNUP 2.0 | HR BREACH | INFOWORKS RS |
| WISWAVE | FEMA surge | REF/DIF | RCPWAVE | LITCROSS SBEACH | | AMAZON-SC | NWS BREACH | INFOWORKS CS |
| WAVEWATCH III | FINEL2D | BOWAM 2D | REFRAC | SEDITEL | | FAVOR | BRDAM | ISIS |
| TOMAWAK | FLOW 2D | FUNWAVE | STORMS | UNIBEST-TC | | NEWMOTICS | FINEL 2D/3D | MIKE 11 |
| | MECO | MIKE21 BW | TELURAY | WATAN 3 | | SKYLLA | | HEC-RAS |
| | MIKE21 HD/HND | MIKE21 PMS | WENDIS | | | COBRAS | | SOBEK-CF |
| | TABS RMA | | BOUSS-2D | | | | | HYDROF |
| | TELEMAC-2D | | COWADIS | | | | | LISFLOOD-FP |
| | WAQUA | | HISWA | | | | | TUFLOW |
| | WIMF | | NTUA | | | | | MIKE 21 |
| | TELEMAC 3D | | STWAVE | | | | | TELEMAC 2D |
| | FINEL 3D | | MIKE21 EMS | | | | | SOBEK-OF |
| | FLOW 3D | | MIKE21 NSW | | | | | Delft-FLS |
| | POLCOMS | | SWAN | | | | | TELEMAC 3D |
| | UKMO/POL | | TOMAWAC | | | | | Delft-3D |
| | | | WAM | | | | | FINEL 2D |
| | | | | | | | | FINEL 3D |
| | | | | | | | | CFX |
| | | | | | | | | FLUENT |
| | | | | | | | | PHEONIX |

DEFRA/ Environment Agency Flood and Coastal Defence R&D Programme (2003) - Best practice in coastal flooding, *R&D Technical Report FD2206/TR1*, Workshop Version issued 24/09/03, HR Wallingford Report TR 132

3.4.2. Erosion Models

In this section, a review of the most used models (analytical and numerical) to describe the coastal response to storm impacts is presented. This initial response that can be described as erosive will range from simple dune/beach erosion to overwash and breaching depending on the intensity and magnitude of the event. Since in unprotected coasts, the beach is the main element protecting the hinterland from the direct impact of the waves and from inundation during extreme storms, it is absolutely necessary to include/simulate the induced response to properly estimate flood hazards.

Erosion models

One of the most well known and used analytical models to estimate the erosion induced by the impact of a storm on a beach profile is that to Vellinga (1986). This is an empirical model based on a series of dune erosion laboratory experiments. It uses the concept of equilibrium profile in such a way that it predicts the final erosion profile corresponding to a set of hydrodynamic forcing (defined in terms of wave height and storm surge-water level) acting on an initial beach profile (characterised by the sediment grain size). The final profile is independent of the storm duration and it is given by the relationship

$$\frac{7.6}{H_{0s}} \cdot y = 0.4714 \left[\left(\frac{7.6}{H_{0s}} \right)^{1.28} \cdot \left(\frac{w}{0.0268} \right)^{0.56} \cdot x + 18 \right]^{0.5} - 2.0$$

This model has been widely used even in sites with fully different characteristics (in terms of coastal morphology and wave and water level climate) to the ones of the Dutch coast where this empirical model was developed.

Recently, van Gent et al (2007) have proposed a modification of this erosion profile by including the wave period (T_p), to take into account the effect of this parameter in the final dune profile configuration, in such a way that the longer the wave period is, the larger the profile retreat will be (figure 24).

$$\frac{7.6}{H_{0s}} \cdot y = 0.4714 \cdot \left[\left(\frac{7.6}{H_{0s}} \right)^{1.28} \cdot \left(\frac{12}{T_p} \right)^{0.45} \cdot \left(\frac{w}{0.0268} \right)^{0.56} \cdot x + 18 \right]^{0.5} - 2.0$$

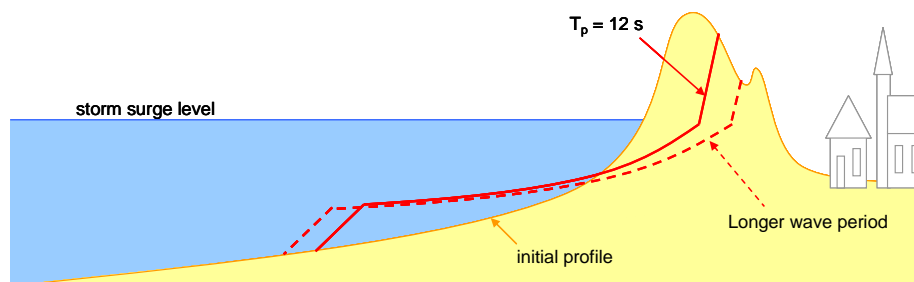


Figure 24. Effects of wave period in the erosion equilibrium profile (van Gent et al., 2007).

Komar et al (1999, 2001) have also developed a simple geometric model to predict the erosion (retreat) of beach foredunes induced by wave runup during extreme storm events. The model is similar to the Bruun’s rule but applied at a shorter time scale where the total water level during the storm is the driving force. The dune retreat, S_{dune} , is given by the relationship (Figure 25)

$$S_{dune} = \frac{(WL - H_j) + \Delta BL}{\tan \beta}$$

where S_{dune} is the maximum beach or dune recession due to total water level, WL , associated with an extreme storm (which is a combination of mean water level and wave runup); $\tan \beta$ is the average slope of beach face (which remains constant during the event), H_j is the elevation of the dune toe or beach/dune junction; and ΔBL is the vertical shift in the beach profile that results from the presence of a rip current (considered as a safety factor since it will imply an additional sand loss for the profile). This model was developed for the Oregon coast (Pacific) and it is used by the Oregon Department of Land Conservation and Development within a DSS tool to help coastal managers to identify coastal erosion-related risks.

As in the previous case, this is an “equilibrium model” in the sense that it should predict the maximum erosion induced by a given event without taking into account its duration (storm of unlimited duration). Since the model uses the maximum total water level, it includes the combined effects of wave height and period (which determine the wave run-up) and storm surge.

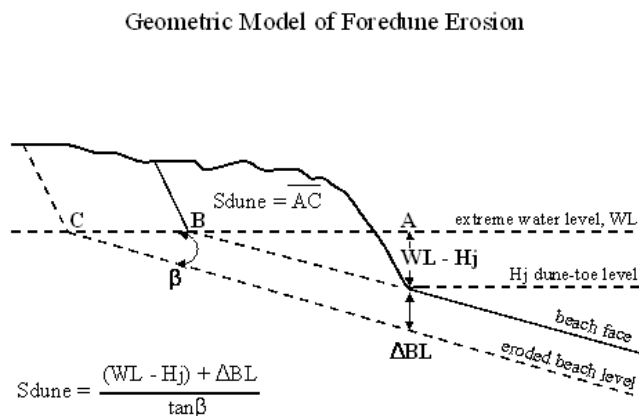


Figure 25. Geometric foredune erosion model of Komar et al (1999, 2001).

Kriebel and Dean (1993) developed an analytical model to simulate the beach profile erosion due to storm impacts. One of the major differences of this model with respect to the previous ones is that it is time dependent, it takes into account the storm duration. The model uses a time-varying erosion-forcing function which reflects the time evolution of the water level and wave height during the storm and an exponential erosion-response function whereas the coast is represented by a given initial beach geometry and sediment size. The maximum erosion potential at the equilibrium situation is determined by the peak water level and the breaking wave height. Due to the followed approach, beach response is found to lag the erosion forcing in time, and is damped relative to the maximum erosion potential such that only a fraction of the equilibrium response actually occurs. It has been widely used and in Ferreira et al (2006) a recent application in South Portugal can be seen.

Recently, Larson et al. (2004) presented an analytical model to simulate the impacts of storms on dunes. The model quantifies the erosion in terms of recession distance and eroded volume. It uses a transport relationship based on wave impact theory, where dune erosion is induced by individual swash waves impacting the duneface. The model was validated using different datasets obtained in laboratory and the

field. They conclude that the model produce reliable quantitative estimates of storm-induced dune erosion (retreat and volume loss), provided that the forcing conditions are known and that the geometry of the dune configuration is similar to the assumed in the model (plane-sloping foreshore backed by a vertical dune). Finally, authors recommended applying the model using a range of transport coefficient values (calibration parameter) to include some uncertainty estimate in the calculated variables.

Numerical beach/dune erosion models are more versatile than analytical ones because have no limitations to describe the initial beach profile and, in most of the cases, are able to include most of the variables characterising the forcing in a realistic manner. The major limitation will be the reliability of the sediment transport model included to simulate the process (see e.g. Schoones and Theron, 1995).

Among the existing beach erosion models, the *Sbeach* model (Larson and Kraus, 1989, Wise et al. 1994) is the most used one worldwide. It is an empirically based model originally developed using a large data set of cross-shore sand transport rates and geomorphic change obtained in large wave tanks. It includes a module for wave propagation across the beach profile which is used to estimate the cross-shore transport rates in different zones from outside the surf zone to the swash zone. These transport rates are included in the conservation equation to estimate beach profile changes. The model requires an initial beach profile and sediment grain size to characterize the receptor and, wave height, period and direction time series together the water level to characterize the forcing. The model has been largely validated with field cases (see Figure 26) and now it can be considered as a standard for beach/dune erosion calculations.

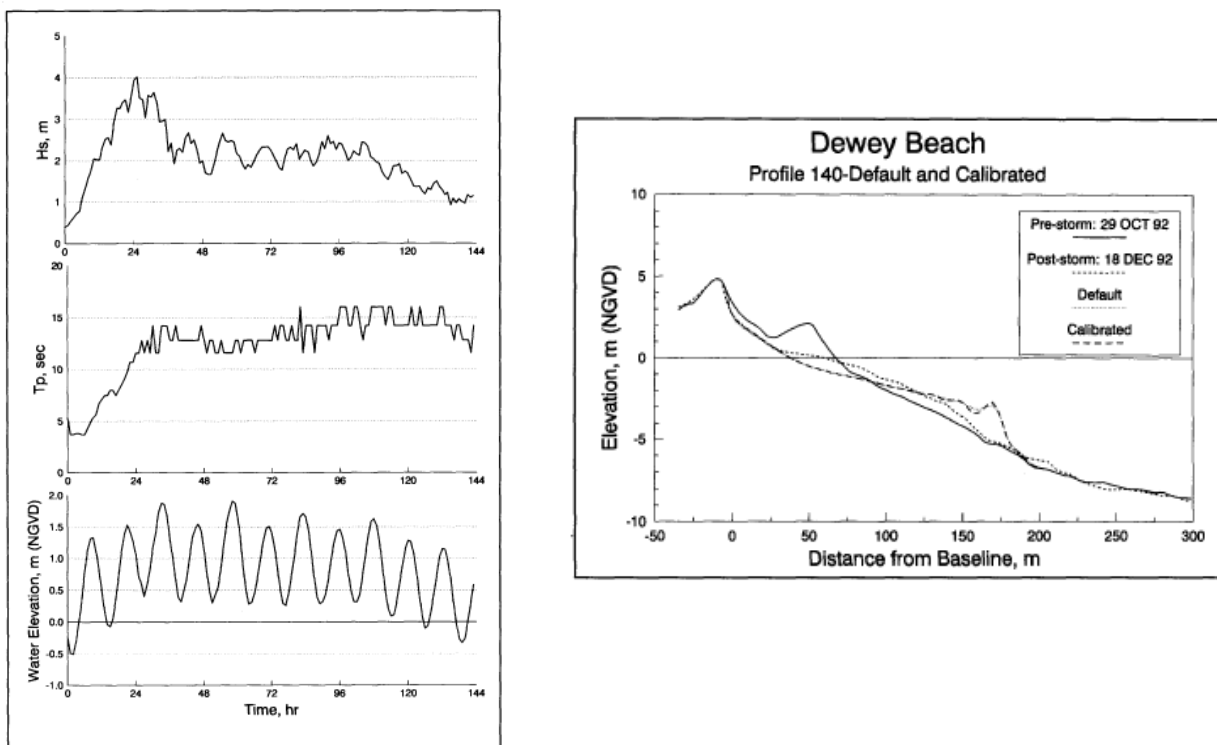


Figure 26. Field application of Sbeach (Wise et al., 1994).

Another example of numerical dune/beach erosion models is DUROSTA -DUne eROsion Time Averaged- (Stetzel 1993), which is mainly used in the Netherlands as a tool to check beach and dune safety. This is a cross-shore based profile erosion model where for a given beach/dune profile the erosion is calculated as a function of the maximum wave height and surge level. The incident wave height and the

sediment composing the beach determine the shape of the erosion profile, and the surge level determines the level of the erosion profile.

In addition to these two erosion models, different beach profile models do exist in the s-o-a, many of them using a very detailed description of processes taking place across the beach profile. However, the inclusion of a more detailed hydrodynamics not necessarily ends-up with a better description of induced beach changes during extreme events. At present, the use of such detailed models to simulate storm-induced changes is quite limited.

Overwash and breaching models

As storm magnitude increases, dune and beach are more frequently overtopped and overwash transport begin to be important. There are few models able to deal with these processes in a realistic manner. Thus, few transport models to describe overwash do exist. One of the last attempts to include this transport in a beach profile model is that due to Larson et al (2004) within the before introduced analytical model for dune erosion during extreme storms. It has to be also mentioned that the last version of Sbeach simulates the effect of overwash transport on the beach profile evolution. However, this is a topic under development and a realistic model is still required (e.g. Donnelly, 2008).

Under very intense storms, the ultimate coastal response specially in low-lying areas is breaching. A breach is a new opening in a narrow landmass such as a barrier beach that allows water to flow between the sea and the area behind the barrier -a water body or a low-lying area- (Kraus and Wamsley, 2003). They usually occur under extreme events and, in consequence, they are associated to the inundation stage in the scale of Sallenger (2000). In spite of the potential importance of this process, the number of existing models able to simulate breaching is quite limited (models dealing with dike breaching have been reviewed elsewhere, see e.g. Visser, 1998, Allsop et al., 2007).

One of the first serious attempts to model the breaching process in sandy barriers was due to Basco and Shin (1999). They developed a one-dimensional model for simulating storm-induced breaching in coastal barriers. The model considers the different (four) phases-stages of the process starting by the beach/dune erosion which is simulated by means of the Sbeach model (Larson and Kraus, 1989). This is followed by a series of hydrodynamic models used to simulate the water flow over the barrier and induced sediment transport.

Kraus (2003) presented an analytical model to predict the development of beaching in coastal barriers. The model solves the problem for idealized beach configurations by means of two coupled equations governing breach width and depth development. It was later extended to a numerical model by coupling a sediment transport model to 1D inlet flow equations to calculate breach growth (Kraus and Hayashi, 2004). It also included forcing by tidal hydrodynamics, longshore sediment transport and multiple breaches and inlets.

Roelvink et al (2003) assessed the feasibility of using a general morphodynamic model such as Delft3D to model barrier island breaching and storm surge. To do that, they first validated the model against laboratory and prototype experiments of breaching of a sand dike. They concluded that the model was able to predict the occurrence of breaches with a satisfactory level of accuracy. They proposed to use the model to identify weak spots in barrier islands and to identify conditions and locations where a breakthrough might occur.

A detailed process-based morphodynamic model (TIMOR3) was also used by Witting *et al* (2005) to simulate the breaching of Hiddensee Island in the Baltic Sea. It is coupled with the SWAN model to simulate hydrodynamics, sediment transport and bottom evolution at short-term scales. Since this approach is not efficient to calculate the initial impulsive response of the coast to the impact of a storm, they used Sbeach to simulate the initial phase of the breaching process.

Another process-modeling approach is that due to Tuan *et al* (2006, 2008) who presented a process-based model to simulate the overflow-induced growth of an erosional channel in noncohesive bodies such as sand-dikes and barriers. It includes an overwash model for barriers which makes use of the Unibest-TC approach (Tuan et al., 2006) and a model for the lateral growth and morphological development of erosional channels (Tuan et al., 2008).

In spite of all of these attempts, there is not yet a morphodynamic model able to accurately simulate the dynamic response of low-lying coast to the impact of extreme events. Due to this, the USACE-ERDC has launched a program to develop an open-source program to simulate effects of hurricanes on low-lying sandy coasts. The aim of this program, XBeach (Roelvink et al., 2007), is to simulate the different phases taking place during the impact of extreme storms in low-lying coasts, i.e. dune erosion, overwashing and breaching. A first version which has been tested against some laboratory experiments is already available. The main emphasis has been put up to date in numerical robustness and first order accuracy.

3.5. Sources of Uncertainty

3.5.1 Definition

According to Pappenberger et al. (2005) the term “uncertainty” is described as follows:

- **Uncertainty** - A general concept that reflects our lack of sureness about someone or something, ranging from just short of complete sureness to an almost complete lack of conviction about an outcome.
- **Uncertainty Analysis (Model)** - Assesses the uncertainty in model outputs that derives from uncertainty in structure, parameters, boundary conditions and evaluation data

3.5.2 Sources of uncertainty

Uncertainties arising from the creation of flood hazard maps can be divided into three types:

- data uncertainty,
- model uncertainty,
- Parameter uncertainty.

Each element, contributing to the flood disaster chain (*hydrological load -> flood routing -> potential failure of flood protection structures -> inundation -> property damage*) arises uncertainties, which can be assigned to at least one of the above types of uncertainty.

The following table displays the steps of creating flood hazard maps and shows likely sources of uncertainty and the assigned type:

Table 6: Sources and types of uncertainty (Source: FLOWS (Homepage), modified)

| Variable | Source of uncertainty | Type of uncertainty | |
|------------------|---|---|-------------------|
| Annual discharge | Rainfall runoff modelling | Model uncertainty | |
| | Wave modelling | Model uncertainty | |
| | Selection of distribution function | Model uncertainty | |
| | Parameters of the statistical distribution | Parameter uncertainty | |
| | Short or unavailable records | Data uncertainty | |
| Levee failure | Measurement errors | Data uncertainty | |
| | Measurement errors of levee geometry | Data uncertainty | |
| | Breach modelling | Model uncertainty | |
| | Levee parameters (geometry, substrate, breach width, turf) | Parameter uncertainty | |
| | Water stage | Model selection (1D or 2D model) | Model uncertainty |
| | Steady or unsteady calculation | Model uncertainty | |
| | Frictional resistance equation | Model uncertainty | |
| | Channel roughness | Parameter uncertainty | |
| | Channel geometry | Parameter uncertainty | |
| | Sediment transport and bed forms | Data uncertainty | |
| | Debris accumulation and ice effects | Data uncertainty | |
| | Flood damage | Dependence on water stage | Model uncertainty |
| | Dependence on water stage | Parameter uncertainty | |
| | Land/building use, value and location | Data uncertainty | |
| | Content value | Data uncertainty | |
| | Structure first-floor elevation | Data uncertainty | |
| | Flood warning time | Data uncertainty | |
| | Public response to a flood (flood evacuation effectiveness) | Data uncertainty | |
| | | Performance of the flood protection system (possibility of failure below the design standard) | Data uncertainty |

3.5.3 Dealing with uncertainty

Several approaches have been developed to assess uncertainty. They can be divided by their need for evaluation data. The following figure provides a general guidance of which method can be used, depending on the existent evaluation data:

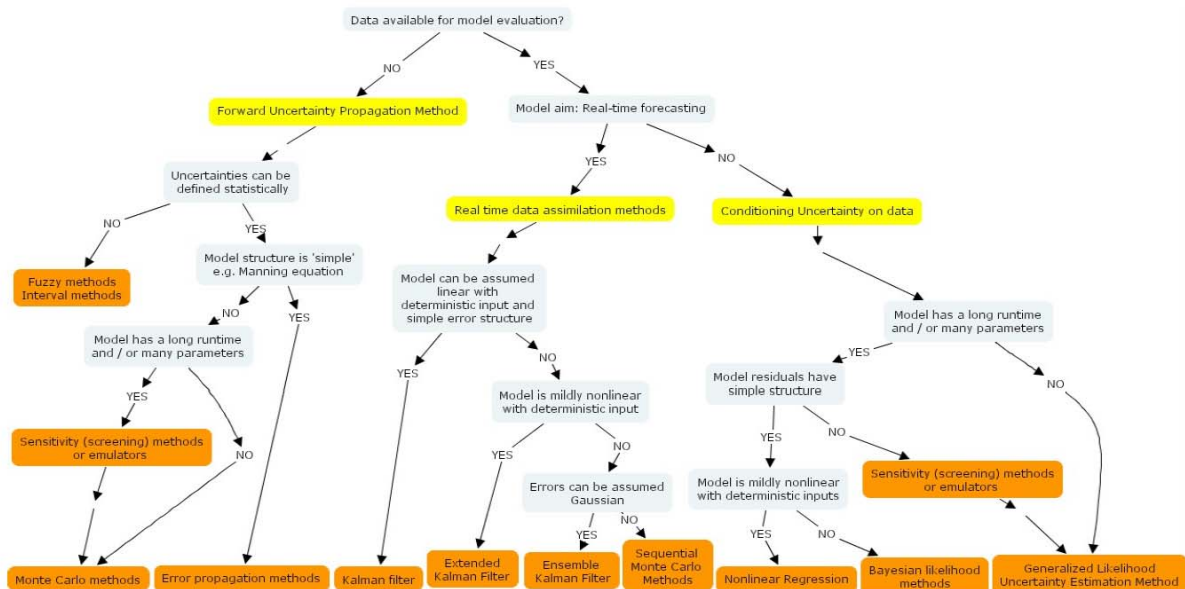


Figure 27: Decision tree for uncertainty analysis tools (blue boxes represent the questions to derive a decision for an uncertainty method, yellow boxes show the major classifications of several uncertainty methods and orange boxes stand for individual methods or small sub-groups of those) (from Pappenberger et al.(2005))

For the creation of flood hazard maps usually no evaluation data is available. Hence, regarding the diagram, the applications of Monte Carlo methods or error propagation methods seem to be reasonable. A short introduction of both methods is given as follows:

Error propagation equation

The Error propagation equation deals with the normal distributed errors of the underlying formula. The goal is to assess how the quantified uncertainties in model inputs propagate during the model calculations and how it affects the results. The following simple example shows how it works:

Regarding the following equation

$$z = x + y + \dots$$

With the appropriate deviation of the input parameter x and y the following equation leads to the deviation of z:

$$\sigma_z = \sqrt{(\sigma_x^2) + (\sigma_y^2) + \dots}$$

This method can be used to quickly evaluate simple calculations. However, this shows its strength and limitation at the same time. While simple calculations are easy to execute, it is hard to apply this method to complex calculations. For this reason the application of error propagation does not seem to be favourable to assess uncertainties in the run of flood hazard map creation.

Monte Carlo method

The Monte Carlo analysis can be used to gain information about the distribution of the output parameters. This can be achieved by applying random drawing of input parameters and examine the results. The variation of the input parameters and the repeated application of the model can be a very time consuming task. Therefore models should be simplified in order to reduce computation time. Apel et al. (2004)

describe an application of a Monte Carlo based framework, which is used by simple parameterised modules of the corresponding complex deterministic models. Each module refers to a specific step in the process chain. **Figure 28** shows an overview of the modules. As a result the Monte Carlo method leads to confidence bounds for each scenario.

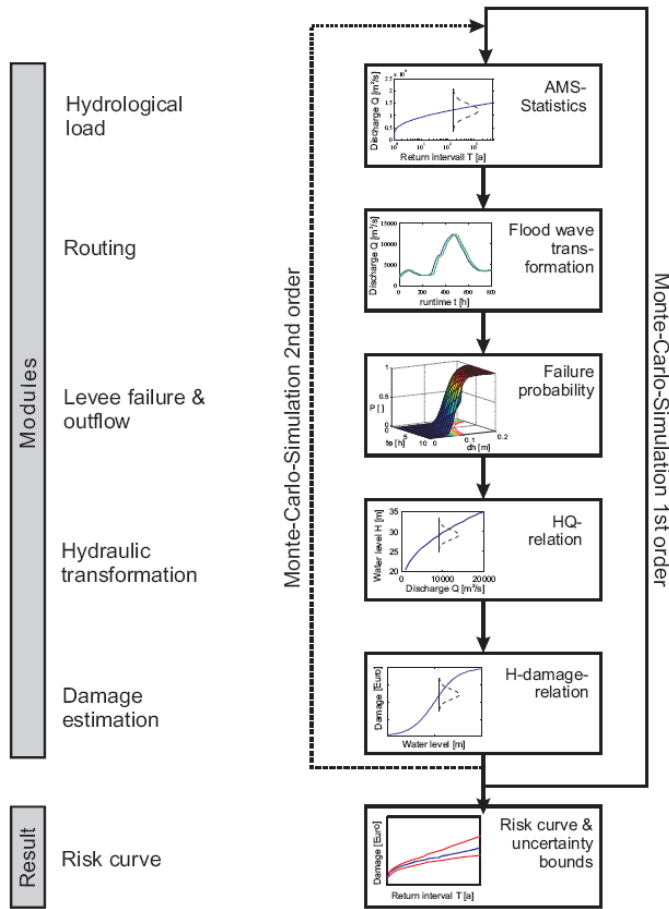


Figure 28: Scheme of risk and uncertainty calculations (from Apel et al. (2004))

Method suggested by the FLOWS Project

Another approach to consider uncertainty is shown by the FLOWS Project (2005). Instead of the examination of uncertainty after calculation FLOWS recommends as a “best practice” to determine a level of accuracy for which appropriate methods should be used to match the accuracy level. **Figure 29** shows a sample application for low lying areas which was originally published in the FLOWS Technical Report (2005). It shows the required accuracy depending on the location of the site and the vulnerability to floods.

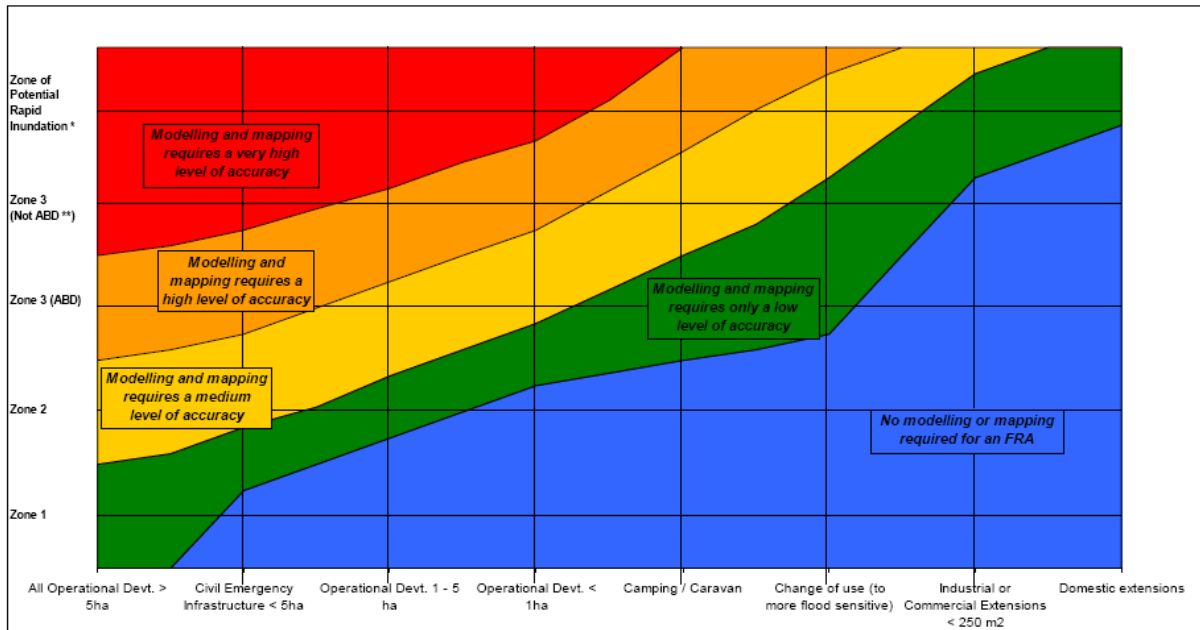


Figure 29: Required accuracy (for application to low-lying areas only) (from FLOW, 2005)

Together with the process chain shown in

Figure 30 and the investigated level of accuracy one is now able to determine appropriate methods regarding uncertainty assessment for each step in the process chain. **Table 7** shows an extraction of FLOWS (2005) which contains appropriate methods and parameter sets for each level of accuracy. Together with a textual guideline in the report this is a practical aid to gain confidence in flood hazard maps. However, the disadvantage of this method is the assumed availability of the listed method and data. If you don't have access to these methods and data, you might use other (maybe quantifying) techniques to assess the uncertainty.

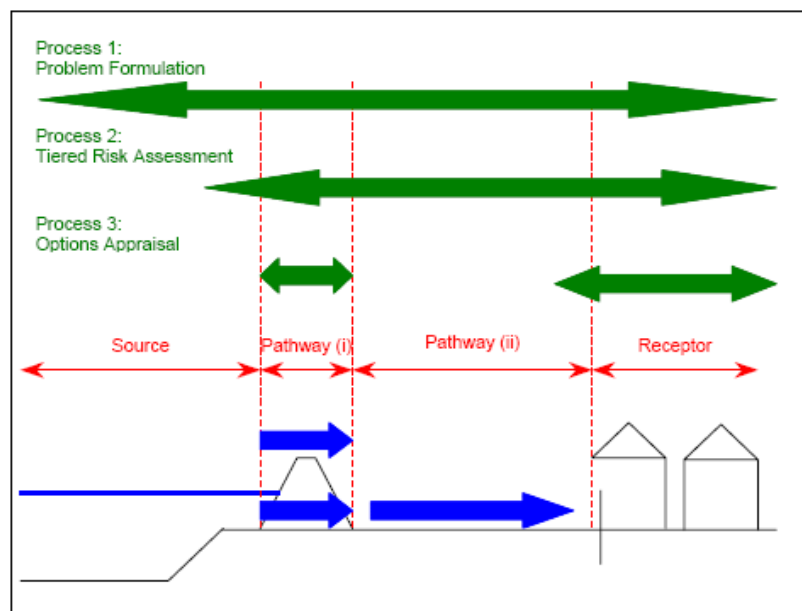


Figure 30: FLOWS process chain (from FLOWS (2005))

Table 7: Available techniques for pathway (ii) assessment (from FLOWS (2005))

| Location In schematic | Flooding Pathway (II) | | | | |
|--|--|-----------------------------|------|--------|-----|
| Process | <ul style="list-style-type: none"> Define the flood level for a given return period Define the flood extent for a given return period Define the flood depth for a given return period (across the study site) Define the flood velocity for a given return period (across the study site) | | | | |
| Tools | | Degree of Required Accuracy | | | |
| | Topographical Data | Very High | High | Medium | Low |
| | Local Surveys (using GPS) | ✓✓✓ | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| | Local Surveys (no GPS) | | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| | LIDAR data combined with local survey, manhole cover levels or landline spot height data | ✓✓ | ✓✓ | ✓✓ | |
| | OS Land-line | ✓✓ | ✓✓ | | |
| | Photogrammetry | ✓ | ✓✓ | ✓✓ | |
| | Lidar data only | | ✓ | ✓ | ✓✓ |
| | Nextmap DEM | | ✓ | ✓ | ✓ |
| | OS Profile | | | | ✓ |
| OS Panorama | | | | | |
| Tools | Flood Level / Depth / Velocity | Very High | High | Medium | Low |
| | Fully dynamic 2D model | ✓✓✓ | | | |
| | Raster spreading model (grid based) | ✓✓✓ | ✓✓✓ | | |
| | Raster spreading model (flood cell based) | ✓✓✓ | ✓✓✓ | | |
| | Existing 2D model (all types) | ✓✓✓ | | | |
| | Existing reservoir cell 1D model | ✓✓✓ | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| | Existing floodplain channel 1D model | ✓✓✓ | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| | New reservoir cell 1D model | ✓ | ✓ | ✓✓ | |
| | New floodplain channel 1D model | | ✓ | ✓✓ | |
| | Estimation method using decay factor | | | ✓ | ✓✓ |
| Existing extended cross-section 1D model | | | | ✓✓ | |
| New extended cross-section 1D model | | | | ✓ | |
| Tools | Flood Extent | Very High | High | Medium | Low |
| | Fully dynamic 2D model combined with re-projection of flood extent data onto smaller grid DEM | ✓✓✓ | | | |
| | Direct mapping of fully dynamic 2D model | ✓✓✓ | ✓✓✓ | | |
| | Direct mapping of raster spreading model | ✓✓✓ | ✓✓✓ | | |
| | Projection of existing 1D model level data onto DEM | ✓✓✓ | ✓✓✓ | ✓✓✓ | |
| | Projection of new 1D model level onto DEM | ✓ | ✓✓ | ✓✓✓ | |
| | Map estimated flood level onto DEM | | | ✓✓ | |
| | Map extended section 1D model onto DEM | | | | |
| | Projection of existing 1D model level data onto map data (no DEM available) | | ✓ | ✓ | ✓✓✓ |
| | Map estimated flood level onto map data (no DEM available) | | | ✓ | ✓✓ |
| Map extended section 1D model onto map data (no DEM available) | | | | ✓ | |

* = Provided review of model and results suggests sufficient accuracy of previous modelling

| | | | | |
|--|-----|-----|-----|-----|
| High Acceptability | ✓✓✓ | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| Medium Acceptability | ✓✓ | ✓✓ | ✓✓ | ✓✓ |
| Low Acceptability | ✓ | ✓ | ✓ | ✓ |
| Unacceptable approaches due to insufficient accuracy | | | | |
| Excessively complex approaches for degree of risk | | | | |

3.5.4 Presentation of uncertainty in flood hazard maps

Publication of flood hazard maps requires remarks to the confidence and the likely uncertainty. An easy way to do this is proposed in **Figure 31**, where the calculated uncertainty is demonstrated as an area of uncertain flooding. This can nowadays easily be done using GIS.

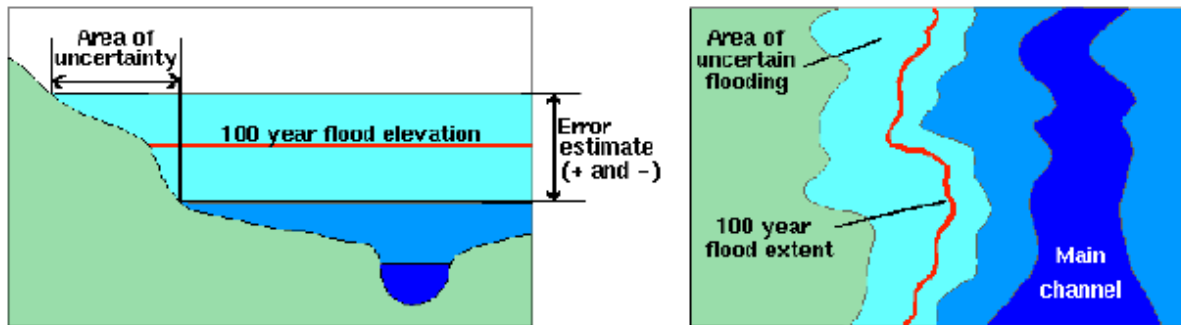


Figure 31: Scheme of cross section and overhead view showing application of error estimates (from Jones (1998))

3.6 Maps

Flood maps should include at least the following information: (a) Title (what kind of information on which location is presented), (b) Location of the map as part of the catchment or country, (c) North and scale (preferably scale pole as this allows for changes in page sizes), (d) Responsible authority or institute with address, website and or telephone number, (e) Date of publication and (f) Disclaimer, including remarks on the quality of information.

All maps should have consistent information (e.g., consistent extents for given event probability), although the content, format and dissemination may differ depending on the purpose and target audience. Explanations should always be given (directly onto the maps) for correct interpretation of maps (e.g. return period or probability, method of development, uncertainty, etc.), as appropriate for the target audience.

Public maps should be simple and self-explanatory and include a legend, such that as little supporting or explanatory information as possible is required for correct interpretation.

Organisational users (governments, local authorities, etc.) may require more detailed explanatory information to fully understand the development and limitations of the maps. Supporting information for organisational users should include: (a) GIS data available for download, emphasising the use of supporting information, (b) Meta-data information (e.g. quality, data sources, inventory of existing information, etc.)

The extent of potential flooding has to be presented as a surface covering the topography for a specified flood level /frequency. For reference, roads, railways, houses and permanent water bodies from which the floods originate may be included. Recently Google Earth has become a powerful tool to use as background layer for this kind of information. The more natural colour for this flood extent information is blue: dark blue for frequent floods, light blue for the areas covered during less frequent floods (suggesting here lower inundation depth than the more frequent flooded lower situated parts). An alternative could be red, as the colour representing danger.

The potential extent of flooding may be calculated with computer models or other methods. In any case it is important to include information about the accuracy of the result and the area covered by the results.

Water depth may be presented as different zones with different colours, colour banding, contours and numbers. Numerical presentation may be combined with other methods and it is possible for example to present water depth as zones with different colours and water levels as numbers.

The same methods can be used to present flow velocity information than water depth information. In addition arrows or other suitable symbols can be used to present flow direction and scalar value of flow velocity. In some cases it may be useful to combine presentation of water depth and flow velocity by showing depth as coloured zones and flow velocity as vectors (arrows). This requires very detailed flood mapping and topographical mapping that maps the location of buildings, road and rail embankments, trees etc.

More details can be found in the Atlas of Flood Maps in Europe (Ministry of Transport, Public Works and Water Management, The Netherlands, editors J. van Alphen, R. Passchier, V. Jetten, Dec. 2006)

The LAWA recommendation (Länderarbeitsgemeinschaft Wasser, 2006) proposes several types of content:

- Water depth
- Flow velocities
- Flood duration
- Rising rate

There are no further recommendations given about calculating flood duration or rising rates. This seems to be not applicable for large area calculations. However, water depth can be calculated by the workflow described above and should be displayed. In special cases the flow velocity may be an important dimension. It can be calculated by using a 2D model. Besides the content type the occurrence probability should be displayed, too. This leads to maps which show the water depths of a particular occurrence probability.

LAWA gives also a recommendation about the display style which can be found in Table 8. The classification of intensity and probability can be found in Table 9 and Table 10.

Table 8: Display style regarded to occurrence probability and intensity (Länderarbeitsgemeinschaft Wasser, 2006)

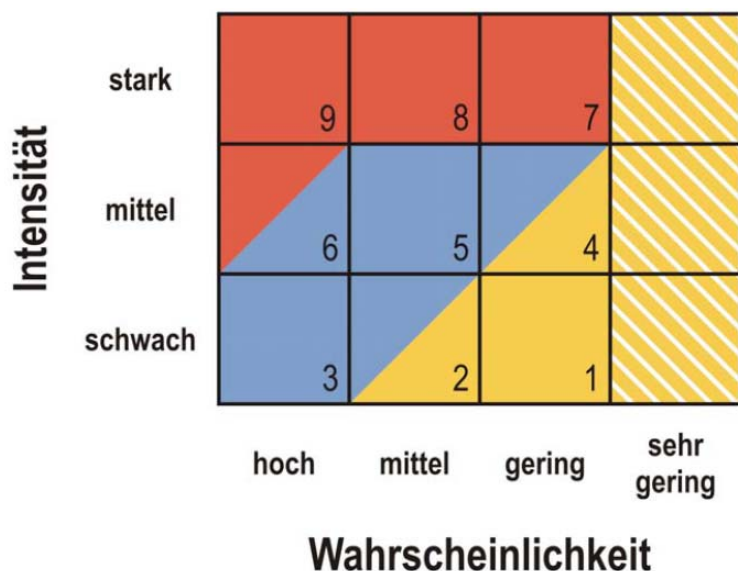


Table 9: Classification of intensity

| Intensity | Lowlands | Steep areas | |
|------------------|----------------------|--------------------|------------------------------|
| | Water depth h | Velocity v | v*h |
| High | > 2.0 m | > 2.0 m/s | > 2.0 m ² /s |
| Medium | 0.5 to 2.0 m | 0.5 to 2.0 m/s | 0.5 to 2.0 m ² /s |
| Low | < 0.5 m | < 0.5 m/s | < 0.5 m ² /s |

Table 10: Classification of probability

| Probability | Return Period |
|--------------------|----------------------|
| High | < 10 years |
| Medium | 10 to 50 years |
| Low | 50 to 200 years |
| Very low | > 200 years |

3.7 Outreach

The dissemination of maps and the information to be provided depends on the following two groups of users (a) Public (including general public that ought to be made aware of the risk) and (b) Professional users (public sector authorities, involved in planning, execution and maintenance of measures, and/or decision making in policy and/or crisis management, private companies)

The primary purpose of public dissemination of flood maps is to increase public awareness. This is to empower individuals for taking appropriate preparatory and response measures, and informing them about decisions such as the purchase or otherwise of a property, or the assignment of use, layout and design of an area of land.

The public dissemination via the Internet is essential (single-point update, low-cost dissemination, reducing risks of use of superseded (aged) data, etc.), although hard copies of maps should also be available in public offices (e. g. in libraries, municipalities) to make the information available to those who do not have Internet access.

The availability of maps via the internet is inadequate to meet public awareness objectives, A website and availability of information must be actively promoted (via insurance, flyers, billboards), and be supported (where possible) by teaching in schools and public meetings organised by municipalities.

Web based GIS technology is currently being developed very fast. Popular freeware tools such as Google Earth are increasingly capable of showing thematic maps from a variety of GIS systems (Arc/Info). This could mean that availability of flood information for the larger public could simply be a spin-off of the professional GI systems in the form of data layers made available in a format of these public tools. Separate development of public accessible web-GIS may not be necessary, and the emphasis can be on the cartographic content of the information.

The Internet, with restricted access where required, is also considered to be the most appropriate media for dissemination of flood maps to professional users. It is however noted that maps for these users should generally be downloadable in GIS (for integration into the existing GIS of the relevant organisation) or PDF format. Data format, data collection and data availability should have the following (<http://eu-geoportal.jrc.it/gos>): (a) Data should be collected once and maintained at the level where this can be done most effectively, (b) It must be possible to combine seamlessly spatial data from different sources across the EU and share it between many users and applications, (c) It must be possible for spatial data collected at one level of government to be shared between all levels of government, (d) Spatial data needed for good governance should be available on conditions that are not restricting its extensive use , (e) It should be easy to discover which spatial data are available, to evaluate their fitness for a particular purpose and to know which conditions apply for their use. Dedicated concentration and dissemination facilities of numeric flood maps might be recommended operational solutions, where needed, for integration of these specific data into data services, with appropriate references and various other sources and layers of data : (a) At appropriate administrative levels: national but also at Floodplain management authority, regional, county or municipal authority levels, through dedicated data management platforms and (b) For specific needs such as insurance/reinsurance, real estate, etc., in most cases through an umbrella association. The scope of the information made available will generally be determined by national legislation or agreements.

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