EXECUTIVE SUMMARY

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RELATED DOCUMENTS
The full reports to which this summary relates are available from the FLOODsite Project Website at http://www.floodsite.net/html/search_results.asp?documentType as Report Numbers T03-07-01 and T03-08-02.

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Executive Summary for Task 03

1. Scope of the research in Task 03

The main objective of Task 03 was to develop and test a general procedure for building a European Flood Hazard Atlas based upon the FLOODsite methodology mainly for coastal areas. This will be achieved through a series of partial objectives:

- Development of a framework to build a European Flood Hazard Atlas which will be based on the FLOODsite methodology.
- Assessment of the uncertainty in flood mapping, such that appropriate techniques can be determined as applicable to different flood area characteristics.

To achieve these objectives the work has been distributed in two main activities:

Activity 1. Review of existing approaches in Flood Hazard Mapping

This activity includes the review and identification of the steps to be followed for Flood Hazard Mapping. Since Flood Hazard Mapping has been mainly applied to riverine sites there exists much more experience in mapping this environment, whereas the mapping of coastal flood is significantly less developed. Due to this, although Flood Hazard Mapping is also considered for river floods, a large part of the effort has been devoted to close the existing gap in coastal flood hazard mapping.

Activity 2. Recommendations on Flood Hazard Mapping

This activity consists in the preparation of a set of recommendations to be followed for Flood Hazard Mapping with special emphasis on Coastal areas. This set of recommendations will include the results of the review process and will specify aspects to be included and how to deal with them in practice.

1.1 Flood Hazard Mapping in the European Flood Directive


1. Member States shall at the level of the river basin district, or unit of management, prepare flood hazard maps and flood risk maps, at the most appropriate scale for the areas identified under Article 5.1 [it refers to areas lying within their territory for which it is concluded that potential significant flood risks exist or might be considered likely to occur].

   …

3. The flood 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).

For each scenario set out in the first subparagraph the following elements shall be shown:

(a) the flood extent;
(b) projected water depths;
(c) where appropriate, the flow velocity or the relevant water flow.

According to the Directive the main characteristics of the maps to be produced are:

(1) Regarding probabilities, with the exception of the scenario (b) which is already given, the other two scenarios can be defined as a function of the objective of the study. In those cases in which the coastal zone is protected by dikes, the “extreme” probability to be employed in the flood hazard mapping should be derived from the safety level of the structures.

(2) Regarding the variables to be mapped, an adaptation to the characteristics of coastal floods should result in coastal flood hazard maps including the extension of the area to be inundated and projected water depths. In addition to this, areas along the coast sensitive to the event to be mapped (i.e. showing a projected erosion significant enough to affect/enhance inundation of the hinterland) should be indicated.

(3) Regarding the damages, the directive recommends to prepare maps including all the types of potential damages: inhabitants, economic and environmental affectations. These maps should be similar to those prepared for river basins although adapted to the specific characteristics of the coastal zone.

1.2 Links

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). It also 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\(^2\).

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.

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\(^1\) Comrisk: Common strategies to reduce the risk of storm floods in coastal lowlands.

\(^2\) TIMIS: Transnational Internet Map Information System flood project.
In addition to this, the work done within this Task obviously had different links with other Tasks. In what follows main links are identified:

- Task 2 dealing with data analysis, which provides methods to define the water level and wave conditions associated to a given return period, i.e. the definition of the source.
- Task 5 dealing with coastal morphodynamics, which provides methods and models to estimate the coastal response during a flood event to include feedbacks in the system, i.e. the definition of the pathways.
- Task 8 dealing with inundation models, which provides models to estimate the extent and properties of the inundation, i.e. the definition of the pathways.

In addition to these specific tasks, the remaining ones are also related to Hazard mapping in the sense that they cover topics that can be also required in the process of producing Hazard maps since all the project was created to solve/apply the model source-pathway-receptor (figure 2.1).

Finally, tasks 24 to 27 (field sites) were also important since they provide specific examples of flood hazard mapping to be analyzed and, in one specific case, Task 26 (Ebro delta), it serves to apply the recommendations developed in this task.

2. Principal results

2.1 Review on Flood Hazard Mapping

A review report on Flood Hazard mapping was been produced (FLOODsite, 2007). This report includes the following actions and will be summarised subsequently:

- Official Flood Hazard Mapping.
- Technical Aspects on Flood Hazard Mapping in River Domains.
- Technical Aspects on Flood Hazard Mapping in Coastal Domains.
- Modelling Aspects on Flood Hazard Mapping in Coastal Domains.

The report starts by including a section on review of existing “official” approaches to Flood Hazard Mapping to document how this mapping is being done by national agencies. To do not duplicate the work already done within EXCIMAP, this part just briefly cites the existing experiences (including the main results from EXCIMAP initiative). A specific chapter on flood hazard mapping in Eastern European countries was also included. As a result of this, the review was focussed on the technical aspects required for Flood Hazard Mapping.

Moreover, since most of the hazard mapping has been done in river domains, it was decided to complement the existing information by focussing on the less covered coastal floods. In spite of this, technical aspects on river floods were also covered although at a lesser extent.

The work started by reviewing and identifying the steps to be followed for Flood Hazard Mapping, using the approach outlined in Figure 2.1, i.e. source-pathway-receptor model.
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The sequence followed to cover the technical aspects on hazard mapping was: (i) review on data collection required to launch the process; (ii) definition of the sources; (iii) definition of the pathways – inundation and (iv) production of the maps. In the case of the river domain, this scheme was covered using the example of hazard mapping done in Germany.

In the case of coastal domains, each aspect of the approach was intensively reviewed with emphasis on practical issues and in the advantages and/or disadvantages of each method.

As an example, figure 2.2 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 to be used to obtain the basic data required for flood hazard mapping, the topography and bathymetry of the coastal zone.
In the definition of sources, two different approaches were analyzed (event and response methods), which differ in how to define the flood event associated to a given probability. In terms of pathways, the main variables and processes controlling coastal flooding were covered from the ones associated to the water level (storm surge, wave run-up and overtopping) to those related to the coastal response.

Since flooding takes place under storm impacts and, most of coasts usually impulsively react to storm impacts, main coastal morphodynamic processes and responses affecting Flood Hazard Mapping were specifically considered. As an example figure 2.3 schematizes some possible changes in dune morphology during the impact of a storm. The induced change in beach morphology, i.e. beach lowering (decrease in the beach or dune height) and/or profile flattening (decrease in the beach slope) will affect the magnitude of the inundation in opposite terms when they are separately considered (see e.g. Jiménez et al., 2006). Thus, beach lowering will tend to increase the water discharge towards the hinterland because for a given water level the lowering of the beach/dune height will increase the freeboard. On the other hand, profile flattening will tend to reduce inundation because for given wave characteristics during the induced run-up will decrease due to the decrease in beach slope. The dominant effect (inundation increase or decrease) will depend on the type and magnitude of beach changes during the storm.

![Diagram](image)

**Figure 2.3.** Schematization of morphodynamic changes in dune erosion during storms affecting the magnitude of flooding.

Existing models able to reproduce/simulate the different processes (figure 2.4) involved in the definition of sources and pathways have been reviewed and compared, to identify their capabilities and limitations.
A detailed review on (identification and quantification) the different sources of uncertainty involved in Flood Hazard Mapping has been performed. This covers from sources inherent to the data to those related to techniques used in data analysis. As an example, Figure 2.5 provides a general guidance of which method to assess uncertainty can be used depending on the existent evaluation data.

![Figure 2.4. Main physical processes in coastal flooding (DEFRA, 2003).](image)

![Figure 2.5. Decision tree for uncertainty analysis tools (Pappenberger et al. 2005).](image)

### 2.2 Guidelines and Recommendations on Flood Hazard Mapping

After the review process, main factors and elements to be considered to cover each step in Flood Hazard Mapping were identified and, recommendations and guidelines on the best way to describe them and including in Coastal Flood Hazard Mapping were given. Thus, the main steps to produce a flood hazard maps are summarized in figure 2.6. They are:
**Characterization of the source.** This is primarily done by specifying wave and water level conditions associated to a given probability to be used in the analysis (which should be the one characterising the flood hazard map to be produced). There are two main approaches: event and response. The *event approach* is deterministic and 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 *response method* consists in directly calculate the water level of interest (associated to a given probability or return period) from a probability distribution of total water levels. This is especially recommendable when the variables (events) determining the flood level (response) are partially or poorly correlated.

When the analysis is performed at a coast able to dynamically react to the impact of the storm, i.e. to be eroded, the most straightforward approach should be the *event* one. For this purpose, joint probability distributions of wave and water level conditions should be used to define the event assigned to a given probability or return period, which will be used to calculate the risk pathways. This is due to the fact that erosion and inundation are not necessarily correlated and, in consequence, hydrodynamic conditions resulting in a water level of a given probability and an erosion of the same probability should be different.

If the analysis is applied to a coast where one of the two processes (erosion and/or inundation) clearly dominates, the recommended approach should be the *response* one. For this purpose, joint probability distributions of wave and water level conditions should be used to built a probability distribution of the target variable (e.g. total water level by estimating the contribution of the different components), from which the value associated to a given return period is directly obtained. This should be the usual approach for static flooding analysis, i.e. when the coastal response is not included.

An additional element to be considered is that to fully define this transient wave-induced plus storm surge flood event we have to assign a duration to it. This means that is not enough to define a water level associated to a given probability but we have also to give information about the duration of such event. This variable is very important since it will control the amount of water to flow landwards and, in consequence, will control the extension of the affected area as well as the water depth in that area. Thus, once the events are identified to be subjected to extreme distribution fitting, their duration must also be recorded to obtain the relationship between a given level and the duration of the event. This can be done in probabilistic terms (by estimating the joint probability of water level-duration) or in deterministic ones (by obtaining a relationship between event duration for given water levels).

**Characterization of the pathway.** This is done by estimating the main quantification of the two main coastal processes taking place during the impact of a storm in the coast, inundation and erosion.

Thus, the first variable to be calculated is the total water level at the beach during the storm, which is composed by the storm surge plus the wave-induced run-up. Whereas the first component is directly defined from its probabilistic distribution, the run-up has to be calculated from wave conditions during the storm. Although there are many formulas to calculate wave run-up, we recommend the use of the recently proposed by Stockdon *et al.* (2006) because it is specific for beaches and it was derived from data obtained in field experiments and large scale laboratories.

Once the target total water level has been estimated, the following step is to calculate overtopping rates ($Q$) for those cases in which the run-up exceeds the beach/barrier crest. This will determine the volume of floodwater penetrating the hinterland and, in consequence, determining the extension of the flood hazard area.

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 or the structure fails 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 only be controlled by the initial beach/dune height but by its evolution during the event. Due to this, risk pathways in the case of coastal flooding analysis must
include not only the inundation but the induced coastal changes. Thus, a critical issue of mapping coastal areas prone to be inundated during storms is how to properly characterize the beach configuration. Beach configuration takes part in the process by controlling the magnitude of the run-up (via beach slope) and, by controlling the overtopping (via beach/dune crest height).

As a result of this, we recommend to characterize the beach morphology in a dynamic way by simulating the beach profile response during the storm action recovering all the intermediate configurations from the pre-storm situation to the post-storm one. These intermediate configurations will allow updating the wave-induced run-up and overtopping rates according to the time-dependent beach slope and crest height. This uncoupled way of updating floodwaters can be superseded when using a model able to properly take into account the modifications of such processes. However this is an easy solution to account morphodynamic feedback on coastal flooding.

![Figure 2.6: Sketch of the methodology to generate a coastal flood hazard map.](image)

**Characterization of the receptor.** Finally, the estimated overtopping discharges to the hinterland are “propagated” landwards over a Digital Elevation Model of the floodplain, from which the flood hazard areas are delineated in terms of extension and depth. For this purpose, flood inundation models combined with Digital Terrain Models are used to describe the processes taking place in the flood plain.

The simplest option is the use of the so called empirical models, which are often described as pure mapping. No physical laws are involved in the simulations performed. They are rather simple methods and of low cost, but they provide only poor estimates of flood hazard 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 on a broad scale. This option should be acceptable when analyzing the flooding associated with the relative sea level rise (RSLR)-induced water level scenarios and/or when the shoreward extension of the area to be inundated is relatively small.
The second option should be applicable in situations when the beach topography is not as simple and the event involves the overtopping of the beach/dune crest with a flow of water entering to a domain with a lower elevation than the beach crest and, it consists in inundation models. There is no general rule for accepting the advantage of the use of one specific model over a different one other than an ad-hoc analysis of the case study. The best model appears to be one including the processes and conditions of the specific case, for which the required data is available and which has been calibrated and validated.

Once the properties of the flood in the study area have been determined, the final step is to produce the Flood Hazard map. This map should provide information on the flood conditions that harm people during a flood. It can include the hazards associated with a single event or a combination of events.

Ideally, according to the EU Directive 2007/60/EC a Flood Hazard map should include the flood extent, projected water depths and, where appropriate, the flow velocity. Due to the characteristics of coastal floods, Flood Hazard maps will mainly include the extension of the area to be inundated and projected water depths. In addition to this, the areas along the coast sensitive to the event to be mapped (i.e. showing a projected erosion significant enough to affect/enhance inundation of the hinterland) should also be indicated. The most simple flood hazard map should be one just showing the extension of the area to be flooded during an event of a given probability or return period.

In coastal sedimentary environments where the coastal fringe is capable of responding to the impact of an event (a storm associated to a given probability), the hazard map can also include an indication of the areas prone to be eroded. This information can later be integrated into the flood hazard to obtain the integrated hazard of the zone.

For each of the mentioned steps, specific recommendations were specified in the guidelines (TR03-08-02) ranging from data acquisition, data analysis to modelling. These recommendations can be considered as general enough to be applied to most of coastal environments, although they need to be adapted to the specific conditions of the area of study, including the proper selection of techniques and models to be used throughout the process.

Finally, as an example of application of these recommendations, figure 2.7 shows the application of the methodology to the Ebro delta coast to delineate the flood hazard area associated to the impact of a storm with a $T_r$ of 100 years. This case was selected because is a clear example of the influence of the coastal morphodynamic feedback on the extension of flooding. Thus, the obtained results showed that the selection of a given initial beach profile from an existing dataset to characterize the coastal fringe, can result in variations of the duration of overtopping events of about 300%. When the beach evolution during the storm is included, the volume of floodwater entering the coastal plain is significantly larger than for any tested static scenario. This means that any flood hazard mapping in coastal sedimentary environments without including the beach response will significantly underestimate the hazard area.
3. Relevance to practice

The set of guidelines and recommendations for Coastal Flood Hazard Mapping will serve to better delineate coastal areas prone to be flooded by considering the main involved processes. In this way, and, as stated in the Introduction Flood Hazard Mapping is an issue directly covered in 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.

Thus, works done within this Task cover some of the main aspects needed to fulfil the requirements of the Directive to produce Flood Hazard Maps in the coastal zone:

(1) Regarding probabilities, guidelines discuss on the different approaches to define floods associated to a given probability (event vs. response). Since coastal floods are the result of a combination of different variables (H, T ξ), the use of the response approach to define such probabilities is strongly recommended.

(2) Regarding the variables to be mapped, the Directive mentions that coastal flood hazard maps should include the extension of the area to be inundated and projected water depths. Moreover, also specifies that areas along the coast sensitive to the event to be mapped should be indicated (i.e. showing a projected erosion significant enough to affect/enhance inundation of the hinterland). In this aspect, the guidelines directly propose a method to account the flood enhancement due to the coastal morphodynamic response.

In addition to these specific items, review report and guidelines cover most of the topic/issues required to produce flood hazard maps, especially in the coastal zone. Thus, main models
4. Remaining gaps in knowledge

In this section, further research needs are identified. These needs can also be considered a result of the project in the sense that the advances achieved in the project have served to identify remaining gaps not previously considered in the work programme.

In coastal domains, when defining the source, i.e. the flood event associated to a given probability, there is a difference (sometimes very significant) in its magnitude depending on the approach to be followed (event vs. response approaches). Since the EU Flood directive asks to delineate maps for flooding events associated to a given probability, more works have to be done in defining which should be used.

In defining the pathways for flooding in coastal domains, many (most) of the existing approaches use an offline coupling between coastal response and inundation, i.e. they are separately calculated to be later joined. It is important to work in obtaining a robust and simple method to jointly consider both processes since flooding in non-protected low-lying coasts is highly dependent on coastal response during the event.

Inundation models have been mainly derived to work in river environments. When working in coastal areas, the specific characteristics of the coastal floods are not generally well covered. More works have to be done to adapt existing models to this environment including wave/bore propagation over the inundated hinterland.

Also, it is important to work on how to incorporate the uncertainty associated to the definition of all the variables and processes in coastal flooding analysis. Although a general procedure is well established for areas protected by dikes and/or other coastal structures, this has to be extended for non-protected coastal areas, especially when coastal morphodynamics is assessed by using numerical modelling.

5. References


FLOODsite 2008. Guidelines on Flood Hazard Mapping, Technical report T03-08-02

