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European Flood Risk Management Research

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Flood Resilient Communities – Managing the Consequences of Flooding
"Guidelines for Novel Risk Quantification and Communication"

CRUE Research Report No 5.1:

Guidelines for Novel Risk Quantification and Communication

(Deliverable 5.1 of the DIANE-CM Project)

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Flood risk management strategies in European Member States: Flood resilient communities – managing the consequences of flooding

CRUE Research Report No 5.1

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ERA-Net CRUE was funded within the Sixth EU Framework Programme and introduced structure within the area of European research on flood risk management (FRM). Its vision was to support and develop an extensive co-ordination and integration of regional, national, and European research programmes, projects and policies in the field of Flood Risk Management. Within the CRUE ERA-Net two funding initiatives were introduced.

The second ERA-Net CRUE Research Funding Initiative**"Flood resilient communities – managing the consequences of flooding"** was launched in support of the EU Floods Directive 2007/60/EC, which was introduced as a result of several severe flood events causing loss of life and property. Within this initiative seven joint research projects with test sites all over Europe are funded and focus on a broad spectrum of issues related to the enhancement of resilience. Besides, the scientific coordination project CORE CRUE is funded within this second call, to support the implement of the call and to disseminate its results.

Decentralised Integrated ANalysis and Enhancement of Awareness through Collaborative Modelling and Management of Flood Risk (DIANE-CM)

Work Package 5: Enhancing Resilience through Training, Awareness Rising and Dissemination

Deliverable 5.1: Guidelines for novel risk quantification and communication

CRUE Research Final Report No 5. 1

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Contents

1 INTRODUCTION

The kernel of the DIANE-CM project is the **collaborative modelling**[1], which aims at bringing stakeholders together to jointly select the most appropriate alternatives for managing flood risk in a certain area. The participatory nature of the proposed approach enhances learning, transparency of information and results, confidence in the process and acceptance of selected negotiated measures.

One of the key tools for successful collaborative modelling is the appropriate estimation and communication of flood risk, as this constitutes the basis for assessing and ranking the different alternatives for flood risk management in a certain area.

The present guidelines describe the way in which **flood hazard and risk** were estimated and communicated in each of the project case studies (i.e. the Cranbrook catchment in the UK and the river Alster catchment in Germany). Furthermore, the reasons and concepts behind the implemented methodologies are also explained. In addition to this, a short summary of the main inputs required to estimate and map flood hazard and risk is provided in Appendix 1 and a summary of the maps developed for the two case studies of the DIANE-CM project is presented in Appendix 2.

[1] The *Collaborative Modelling Exercise* (*CME*) constitutes the final stage of the collaborative modelling approach implemented throughout the DIANE-CM project. The purpose of the *CME* was to jointly rank the alternatives for flood risk management in each case study area according to a set of objectives defined through guided discussion and negotiation amongst stakeholders. The web platforms implemented to carry out the CME in each case study can be accessed in the following links:

- UK case study (Cranbrook catchment): http://hikm.ihe.nl/diane_cm/internal/cranbrook/exercise/
- Germany case study (river Alster catchment): http://hikm.ihe.nl/diane_cm/internal/alster/exercise/

2 BASIC CONCEPTS RELATED TO FLOOD RISK

Risk is a complex concept that is difficult to quantify, understand and communicate. Part of its complexity lies on the fact that it involves different components, such as hazard, vulnerability, exposure and consequences. It is often mistaken for hazard and there is not a standard manner of estimating and communicating it in a way that is clear and convincing.

In order to clarify the above mentioned terms and avoid confusion, a brief definition of each of them is next provided.

2.1 HAZARD

A hazard is aphysical event, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (ISDR, 2009). In the DIANE-CM project the hazard dealt with is **flooding** and hazard assessment includes determining the **likelihood or probability of occurrence of a flood event of a certain magnitude**.

The flood hazard maps shall cover the geographical area which could be inundated by floods which have a low, medium or high likelihood of occurrence. For each of these scenarios the flood hazard maps shall show the likely extent of the flood, the water depth or level and, where appropriate, the likely direction and velocity of flow of possible floods. For the purposes of the UK Flood Risk Regulations of 2009, the following categories are used for determining whether the likelihood of occurrence is low, medium or high:

a) the probability of a flood occurring is **low** if the chances of it occurring in any 12 month period are 0.1% or less (above 1 in 1000 years),

b) the probability of a flood occurring is **medium** if the chances of it occurring in any 12 month period are more than 0.1% (1 in 1000 years) but not more than 1% (1 in 100 years) –it applies for fluvial flooding and no reference was found with regard to pluvial flooding–, and

c) the probability of a flood occurring is **high** if the chances of it occurring in any 12 month period are more than 1%.

2.2 VULNERABILITY

The term vulnerability refers to the characteristics and circumstances of a community, system or asset that make it **susceptible to the damaging effects of a hazard** (ISDR, 2009); **in the case of the DIANE-CM project, to the damaging effects of flooding**. It can be considered as a combination of susceptibility and value.

There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited social recognition of risks and

preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time.

In the UK, based on the Defra/Environment Agency research on Flood Risks to People and also on the need of some assets to keep functioning during flooding, PPS25 (Planning Policy Statement 25) has classified infrastructure in terms of its vulnerability to flood risk as follows:

- **Essential infrastructure:** essential transport infrastructure (including mass evacuation routes) that has to cross the area at risk, and strategic utility infrastructure, including electricity generating power stations and grid and primary substations.

- **Highly Vulnerable:** police stations, ambulance stations, fire stations and command centres and telecommunications installations required to be operational during flooding; emergency dispersal points; basement dwellings; caravans, mobile homes and park homes intended for permanent residential use; and installations requiring hazardous substances consent.

- **More Vulnerable:** Hospitals; residential institutions such as residential care homes, children's homes, social services homes, prisons and hostels; buildings used for dwelling houses, student halls of residence, drinking establishments, nightclubs and hotels; non-residential uses for health services, nurseries and educational establishments; landfill and sites used for waste management facilities for hazardous waste; and sites used for holiday or short-let caravans and camping, subject to a specific warning and evacuation plan.

- **Less Vulnerable:** buildings used for shops, financial, professional and other services, restaurants and cafes, hot food takeaways, offices, general industry, storage and distribution, non-residential institutions not included in 'more vulnerable', and assembly and leisure buildings; land and buildings used for agriculture and forestry; waste treatment (except landfill and hazardous waste facilities); minerals working and processing (except for sand and gravel working); water treatment plants; and ewage treatment plants (if adequate pollution control measures are in place).

- **Water-compatible Development:** flood control infrastructure; water transmission infrastructure and pumping stations; sewage transmission infrastructure and pumping stations; sand and gravel workings; docks, marinas and wharves; navigation facilities; MoD defence installations; ship building, repairing and dismantling, dockside fish processing and refrigeration and compatible activities requiring a waterside location; water-based recreation (excluding sleeping accommodation); lifeguard and coastguard stations; amenity open space, nature conservation and biodiversity, outdoor sports and recreation and essential facilities such as changing rooms; and essential ancillary sleeping or residential accommodation for staff required by uses in this category, subject to a specific warning and evacuation plan.

2.3 EXPOSURE

People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses (ISDR, 2009). It can be quantified in terms of the number of the receptors that may be influenced by a flood (FLOODsite, 2004). Measures of exposure can include number of people and their demographics, number of businesses or types of assets in an area, number and type of properties, etc.

2.4 CONSEQUENCE

A consequence is an impact such as economic, social or environmental damage/improvement that may result from a flood. It may be expressed quantitatively (e.g. monetary value), by category (e.g. high, medium, low) or descriptively (FLOODsite, 2004).

2.5 FLOOD RISK

Flood risk is the combination of the probability of occurrence of a flood event and its potential negative consequences. Flood risk can be mathematically calculated as:

$$Hazard\ (i.e. probbaility) * Exposure\ * Vulnerability$$

Or

$$Hazard\ * Exposure\ * Consequence$$

The flood risk maps must show the potential consequences associated with a certain flood scenario. According to the UK Flood Risk Regulations of 2009, a flood risk map must show:

- the number of people living in the area who are likely to be affected in the event of flooding (this has to be linked to a certain return period),
- the type of economic activity likely to be affected in the event of flooding,
- any industrial activities in the area that may increase the risk of pollution in the event of flooding,
- any relevant protected areas that may be affected in the event of flooding,
- any areas of water subject to specified measures or protection for the purpose of maintaining the water quality that may be affected in the event of flooding, and
- any other effect on human health, economic activity, or the environment (including cultural heritage).

3 FLOOD HAZARD AND RISK QUANTIFICATION AND COMMUNICATION IN THE CRANBROOK CATCHMENT (UK)

In what follows, a description of the UK case study is provided and the inputs and tools used to estimate and communicate flood hazard and risk in this area is also presented. As will be explained, the main purpose of quantifying and communicating flood hazard and risk in the DIANE-CM project was to support the *Collaborative Modelling Exercise* for ranking of alternatives in flood risk management. In the following sections information is provided about the way in which flood hazard and risk estimations were used to support the joint ranking of alternatives in the Cranbrook catchment.

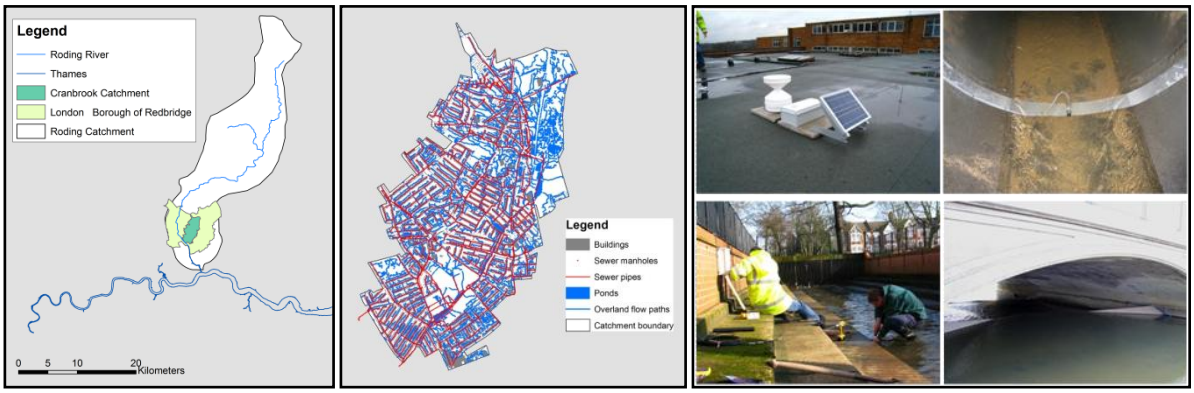
3.1 DESCRIPTION OF THE CRANBROOK CATCHMENT

Environmental Setting: the Cranbrook catchment is located within the London Borough of Redbridge. It is predominantly urbanised; the main water course is 5.75 km long, of which 5.69 km are culverted. The Cran Brook is a tributary of the Roding River, which in turn is a tributary of the River Thames.

Major type of flooding: pluvial and fluvial. Although the study area is subject to these two types of flooding, more attention has been given to fluvial flooding in the past and the associated models, forecasting and warning systems have been well established. In contrast, little attention has been given to pluvial flooding in this area and its management however has been identified as a missing gap both at the planning and at the emergency management stages. For this reason, the focus in the Cranbrook catchment case study was on pluvial flood risk management.

Size of catchment area: 9 km²

Past flood events: several flood events reported since 1926, most recent events in October 2000 and February 2009.



(a) (b) (c)

Figure 1.Cranbrook catchment. (a) location of Cranbrook catchment in relation to the Roding River catchment; (b) dual-drainage networks of the Cranbrook catchment; (c) monitoring system installed in the study area.

3.2 HYDRAULIC MODEL OF THE CRANBROOK CATCHMENT

As indicated in the previous section (Section 3.1), the Cranbrook catchment is prone to fluvial and pluvial/surface flooding. The DIANE-CM project focused on pluvial flood risk in this area, as the management of this type of flooding was identified as being a missing gap. Therefore, pluvial flood hydraulic models of the area were developed throughout the project and were used to generate pluvial/surface flood hazard and risk maps.

Pluvial flooding is caused by intense rainfall whose volume exceeds the capacity of the sewer network and of the surface drainage system. This type of flooding is typically localised and happens very quickly, making it necessary to have very detailed models. In fact, in order to reliably model urban pluvial flooding it is necessary to realistically represent the urban fabric in its complexity, taking into account the local topography and the interactions between the overland and sewer networks, as well as the boundary conditions that determine the performance of the system.

The models of the Cranbrook catchment developed throughout the DIANE-CM project are physically based[2] and take into account the interaction between the overland (surface) and the sewer network, which is known as the "dual-drainage concept" (Djordjevic *et al*., 2004).

In what follows, a description is given of the overland and sewer network models implemented for the Cranbrook catchment. In addition, the way in which these two models are coupled in order to account for the dual-drainage concept is also described.

3.2.1 Surface network model

In the last few years different approaches have been implemented to represent the flow on the urban surface (e.g. virtual reservoir, lost volume, rapid flood spreading models); however, none of these can realistically represent the hydraulic behaviour of the flow on the surface (Butler and Davies, 2011).

More recently, two ways of realistically modelling the surface or overland network of an urban catchment have been developed:

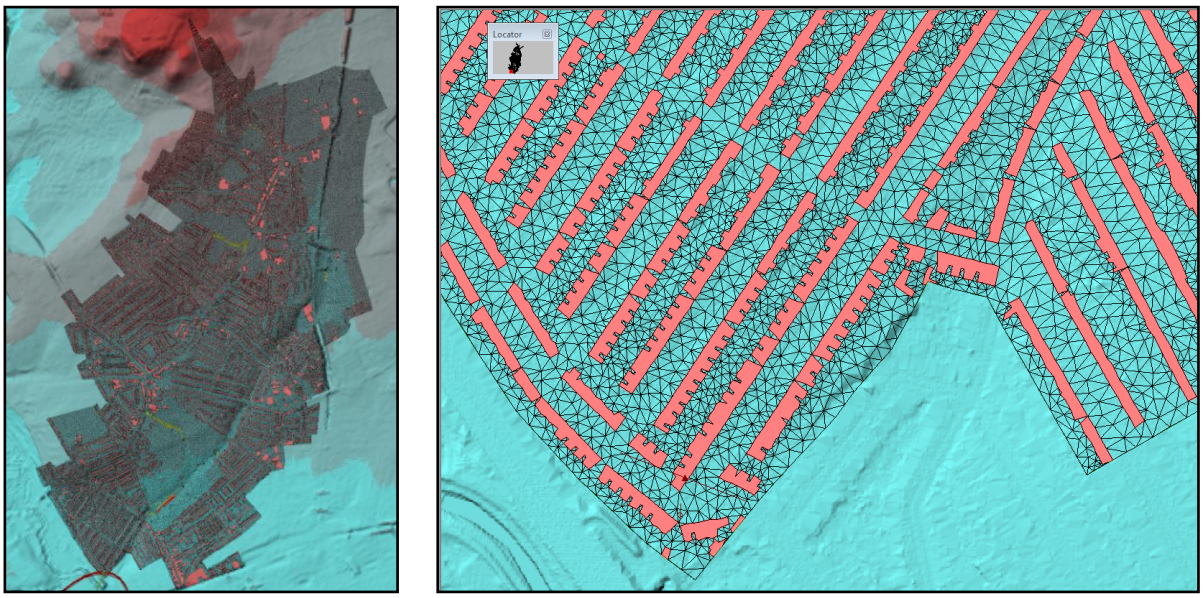
- As a 2-dimensional (2D) surface, using a mesh of triangular elements, or
- As a 1-dimensional (1D) system made up of ponds (modelled as storage nodes) and pathways (modelled as conduits with specific geometry computed from the Digital Terrain Model –DTM–).

Both models can reliably represent the overland network and the flow on it, but each of them has advantages and disadvantages. The 2D models provide a more detailed representation of the overland flow and allow for a better visualisation of the results; however, they are computationally demanding and their running time makes them unsuitable for short-term real-time forecasting of urban pluvial flooding

[2]In physically based models, water movement over the surface and in the sewers is modelled by solving the appropriate approximation of mass and momentum conservation equations. This enables simulating the features of urban areas more realistically. The main advantage of physically based approaches is that once the model has been calibrated, any changes in physical characteristics of the catchment (e.g. increased imperviousness due to urbanization), change of network topology, or addition / modification of pipes can be reliably described by updating the subcatchment characteristics but without the need for re-calibration of surface run-off model parameters as it would be necessary with conceptual models (Maksimović*et al*., 2009).

(given that short computational time is essential for this purpose). In contrast, the 1D models are significantly faster and therefore suitable for short-term real-time forecasting; however, they provide less detail and poorer visualisation of results, although they can still represent the overland flow reliably.
In the DIANE-CM project both kind of models were implemented for different purposes: the 1D model was used for forecasting purposes, whereas **the 2D model was used for the mapping and improved visualisation of flood scenarios (included in the *Collaborative Modelling Exercise*)**. Both models were implemented in *InfoWorks CS*.

The 2D model of the surface network was created from the catchment DTM, using the tools provided in *InfoWorks CS* 11.0 to generate a 2D mesh of triangular elements, which is then used to model 2D flows. The DTM used for this purpose corresponds to 1 m resolution LiDAR data, obtained from Infoterra. In *InfoWorks CS* 11.0, the 2D mesh is generated using the Shewchuk Triangle meshing functionality. Heights at the vertices of the generated mesh elements are calculated by interpolation from the DTM. In order for meshing to be carried out, a bounding polygon must be defined (this generally corresponds to the catchment boundary). Furthermore, voids (i.e. regions that will not be meshed, such as buildings), break lines and areas of varying roughness and mesh resolution may also be defined (*InfoWorks CS* 11.0 help file, 2010). Figure 2 shows the 2D model of the surface network of the Cranbrook catchment (modelled in *InfoWorks CS 11.5*).

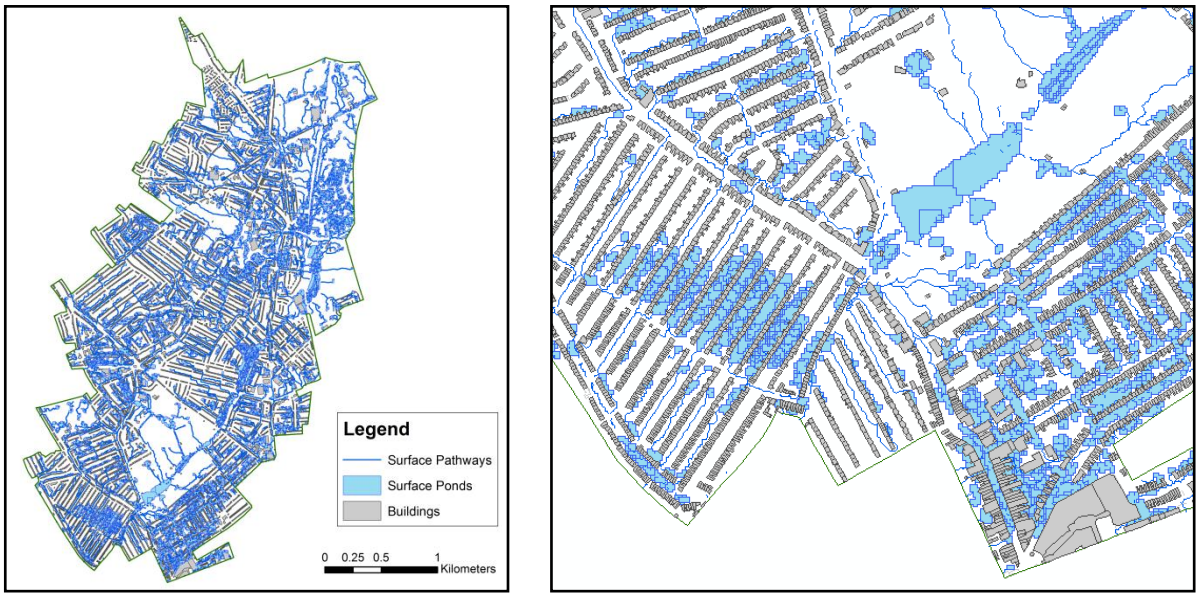


(a) (b)

Figure 2. 2D model of the overland network of the Cranbrook catchment: (a) entire catchment; (b) detail.

The 1D model of the surface was produced from the same set of 1 m resolution LiDAR data obtained from Infoterra. The tool used to create the 1D model of the overland network is the Automatic Overland Flow Delineation –*AOFD*– (Maksimovć et al., 2009). Based on the DTM of the area, the AOFD tool generates the overland network model and quantifies hydraulic parameters for simulation of pluvial urban flooding. The output of the *AOFD* tool is a series of shapefiles, which can be imported into *InfoWorks CS*(or also into SIPSON) in order to create the 1D model of the surface.Figure 3 shows the 1D model of the surface network of the Cranbrook catchment (map produced in ArcGIS using the shapefiles generated by the AOFD tool).

Both types of surface models (1D and 2D) can be coupled with the model of the sewer network, thus originating a dual drainage model. The connection between the two systems (i.e. overland and sewer network) takes place at the manholes, gullies or inlets.



(a) (b)

Figure 3. 1D model of the overland network of the Cranbrook catchment: (a) entire catchment; (b) detail.

3.2.2 *Sewer network model*

All sewer network models are made up of nodes and conduits. Given that in these elements the flow direction is very well defined and the section within each conduit is constant, 1-dimensional (1D) models can be used to represent its behaviour (in fact, sewer networks are always modelled as 1D models). An *InfoWorks CS* model of the sewer network of the Cranbrook catchment was obtained from Thames Water (the water company of the study area). However, this model was missing some details, which had to be completed from information provided by various local authorities of the London Borough of Redbridge or by means of different data mining tools. A map of the sewer network of Cranbrook is shown in Figure 4.

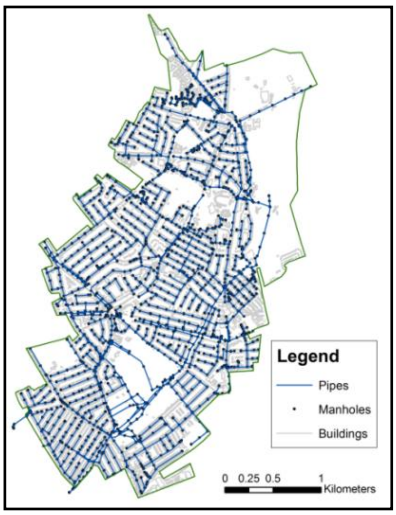


Figure 4.Sewer network of the Cranbrook catchment.

3.2.3 *Dual-drainage model: overland network model + sewer network model*

After coupling the overland and the sewer network models (in *InfoWorks CS*), a dual-drainage model of the study area is obtained. The interaction between these two systems takes place at the manholes, where water can either go in or out depending on the regime of flow in both systems.

According to the type of surface model used, the dual-drainage models can be of two types:

- **1D-2D:** 1D model of the sewer system + 2D model of the surface.
- **1D-1D:** 1D model of the sewer system + 1D model of the surface.

As previously explained, for flood hazard and risk quantification and mapping purposes a 2D model of the surface was developed and was coupled with a 1D model of the sewer network, thus generating a 1D-2D dual drainage model.

3.3 FLOOD SCENARIOS AND FLOOD RISK MANAGEMENT ALTERNATIVES SIMULATED FOR THE CRANBROOK CATCHMENT

3.3.1 *Flood scenarios considered in the Cranbrook catchment*

A scenario is a set of conditions that are out of the decision maker choice; it is something that could happen, but we cannot control.

In order to understand the effects of different flood events and conditions in the Cranbrook area, different flood scenarios were modelled and analysed. The scenarios that were considered are the following:

- Scenario 1: 30 years return period event + low level at the Roding River
- Scenario 2: 30 years return period event + high level at the Roding River
- Scenario 3: 200 years return period event + low level at the Roding River
- Scenario 4: 200 years return period event + high level at the Roding River

The design rainfall events were taken from the Flood Estimation Handbook (FEH). Furthermore, for all of the scenarios the summer rain profile specified in the FEH was used, given that the summer storms are more intense and are more likely to generate surface flooding, as compared to winter storms.

Scenario 4 was chosen as the base case in the *Collaborative Modelling Exercise*: i.e., it was used as reference to evaluate the performance of the different alternatives for flood risk management.

Table 1 provides a short explanation of the parameters chosen to create the above mentioned scenarios.

Table 1.Parameters chosen to create flood scenarios for the Cranbrook catchment.

PARAMETER	ADOPTED VALUE	RATIONALE
Return period or probability of occurrence	30 years (the probability of occurrence in any year is approximately 3 %) 200 years (the probability of occurrence in any year is approximately 3 %)	These are the return periods used for the "Flood Maps for Surface Water" (FMfSF), which have been recently produced by the Environment Agency. We wanted our scenarios to be comparable and compatible with the most recent UK regulations. The reason why these return periods were chosen to generate the new FMsSF is the following: The 30 year return period event is a more probable event, which is likely to produce inundation in the majority of urban areas of England and Wales. Furthermore, this return period is commonly used as standard for urban drainage design. The 200 year return period event corresponds to a rarer event, which enables testing a more critical condition.
Rain profile	Summer rain profile	Summer storms are more intense than winter storms and are more likely to generate surface flooding, which is the focus of this project.
Water level at the Roding River (at the downstream end of the Cranbrook catchment)	Low water level (0.00 m) High water level (5.86 m)	The Roding River is located in the downstream end of the Cranbrook catchment. When the water level at the Roding River is high, a backwater effect (water from the River entering the sewer system of the Cranbrook catchment) can take place, thus reducing the capacity of the drainage system and causing more critical surface flood events in Cranbrook. We picked two different water levels at the Roding River in order to understand the effect of the river on the behaviour of storm drainage system of the Cranbrook catchment. The high water level (5.86 m) was the level recorded during a major flood event in 2000.

3.3.2 Pluvial flood management measures considered in the Cranbrook catchment

The final aim of the *Collaborative Modelling Exercise* developed throughout the DIANE-CM project was to jointly select the most appropriate alternatives for managing flood risk in the study areas. In order to do this, a decision support system was implemented but, before carrying out the exercise, a set of possible measures for managing flood risk in the Cranbrook catchment was defined. A preliminary set of alternatives was initially proposed based on its feasibility of implementation and the potential benefits they could bring to the Cranbrook area. The proposed alternatives were discussed amongst stakeholders during a collaborative workshop; based on the discussion the final set of alternatives to be considered in the *Collaborative Modelling Exercise* was defined. The total number of alternatives was kept to 5, in order to facilitate the execution of the *Collaborative Modelling Exercise*. It is worth mentioning that this is a first approach to the problem and that there are many more possible alternatives that could be implemented in the Cranbrook catchment. An overview of all the different measures that can be implemented to mitigate pluvial flood risk can be found in Annex F of the Surface Water Management Plan Technical Guidance (Defra, 2010).

The selected alternatives for the Cranbrook catchment are summarised in Table 2. In addition, more details about the modelling aspects of each of the alternatives can be seen in Figure 5 (a) to (e).

Table 2. Proposed alternatives for flood risk management in the Cranbrook catchment.

RISK MANAGEMENT MEASURE	TYPE OF MEASURE	DESCRIPTION
1- Do nothing	• Base case	Current situation. This will be used as base point for comparing and assessing the performance of the proposed measures.
2- Rainwater harvesting	• Mitigation measure at source level • Structural measure	It reduces runoff or flow entering the system. Rainwater harvesting has been selected as one of the few SUDS that can be retrofitted into the existing built-up area.
3- Improved and targeted maintenance regimes for the sewer system	• Mitigation measure at pathway level • Non-structural measure	After identifying locations which are at greatest risk of flooding, targeted maintenance at the critical points can be carried out.
4- Improved resistance for preventing water from entering properties	• Mitigation measure at receptor level • Non-structural measure	Resistance measures prevent water from entering the property. It is useful for managing residual risk. In this case, the effect of sandbags or *floodsaxs* placed at the household level was modelled and analysed.
5- Improved rainfall and flood forecasting and warning	• Mitigation measure at receptor level • Non-structural measure	With the technology we are currently developing, it will be possible to provide site-specific real-time rainfall and surface water flood forecast. This could be integrated with the Environment Agency warning system, so that improved warnings for surface flooding can be timely issued.

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Alternative 1: Do Nothing

(this alternative is considered to be the base case, against which the performance of the other alternatives will be compared and assessed)

The base alternative corresponds to the current conditions of the study area. The scenario that will be used as basis for testing the performance of the proposed alternatives has the following characteristics:

- Flood Estimation Handbook (FEH) Design Storm
- Return Period: 200 yr
- Storm Duration: 60 min (determined by running the model for 5 different durations ranging from 40 min to 90 min)
- Summer profile
- High level at the Roding River (downstream boundary condition of the model. This causes backwater effect)

(a). Alternative 1 – Base Case

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Alternative 2: Rainwater harvesting

(equivalent to reduction of runoff through either storage or increased infiltration)

It is assumed that in a roofed area of 10 m x 10 m (100 m^2), 5 m^3 (average) could be stored (either through storage tanks, infiltration trenches, small detention basins at the household level, etc.).

This storage rate (5 m^3 / 100 m^2) was applied to all roofed areas throughout the catchment. In the InfoWorks CS model this volume of water was subtracted from the rainfall profile.

(b). Alternative 2 – Rainwater harvesting

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Alternative 3: Improved and targeted maintenance regimes for the sewer system

An effective maintenance regime ensures that the sewer system works at its maximum capacity. Any blockage or damage could significantly reduce the capacity of the system, leading to increased surface flooding in certain areas.

To analyse the benefits that could be obtained from improved maintenance, the opposite situation was simulated: the effect of having a strategic pipe clogged was modelled.

Clogged pipe

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(c). Alternative 3 – Improved maintenance

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Alternative 4: Improved resistance for preventing water from entering properties

It is assumed that properties surrounded by floodwater with less than 50 cm depth could potentially be protected with sandbags, floodsax or other resistance measures (e.g. raising sidewalks) .

Based on this assumption, the number of properties protected and the number of properties that remain unprotected was estimated and mapped.

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(d). Alternative 4 – Improved resistance at properties

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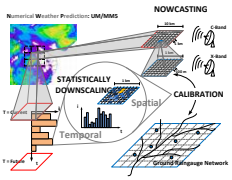
Alternative 5: Improved rainfall and pluvial flood forecasting and warning



With the methodologies currently under development, it will soon be possible to forecast surface flooding with at least 30 min lead time. This alternative does not change the extent of flooding, but allows triggering actions on time to protect critical infrastructure, belongings and population.

(e). Alternative 5 – Improved pluvial rainfall forecasting and warning

Figure 5.Description of proposed alternatives for flood risk management in the Cranbrook catchment.

3.3.3 Criteria considered for evaluation and ranking of flood risk management alternatives as a way of evaluating and quantifying flood hazard and risk (Cranbrook catchment)

As has been indicated previously, the *Collaborative Modelling Exercise* (*CME*) constitutes the final stage of the collaborative modelling approach implemented throughout the DIANE-CM project. The purpose of the *CME* was to jointly rank the alternatives for flood risk management in each case study area according to a set of objectives defined through guided discussion and negotiation amongst stakeholders. For each objective a measurable indicator was defined, in order to enable evaluation and ranking of the proposed flood risk management alternatives. Table 3 summarises the objectives and the corresponding indicators considered in the *CME* for the Cranbrook catchment. In addition, it specifies whether the indicator is quantitative or qualitative.

In the *CME* each participant developed an individual ranking of alternatives based on his/her preferences or interests. Participants were asked to give a weight to each objective and assess each flood risk management alternative in terms of each objective. In the case of quantitative indicators, the performance of each alternative was directly estimated from the hydraulic model (e.g. flood extent and number of flooded properties can be estimated from the results of the hydraulic simulations) and flood hazard and risk maps were created to illustrate the results obtained from the models. In the case of qualitative indicators, participants were asked to evaluate the performance of each alternative according to his/her own criteria and using the linguistic scale indicated in each case. For this purpose especial flood hazard and risk maps were developed and/or additional information was provided in order to support the subjective evaluation required from the participants. Afterwards, the linguistic values corresponding to qualitative indicators were transformed to numerical values by means of a fuzzy logic algorithm. Lastly, the TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution), developed by Hwang and Yoon (1981), was employed to obtain the ranking of alternatives based on the assessment and weights given by the participants.

After each participant developed an individual ranking of alternatives, a “joint” ranking was estimated for the entire group of stakeholders taking part in the exercise.

As can be seen, the objectives and the corresponding indicators (especially objectives/indicators 1, 2 and 3) are, in general, ways of evaluating and quantifying flood hazard and flood risk. In the following section a description is provided of the flood hazard and risk maps created to illustrate and support the evaluation and ranking of alternatives for improved flood risk management in the Cranbrook catchment.

Table 3. Summary of flood risk management objectives to be considered in the CME of the Cranbrook catchment

	Obj_1	Obj_2	Obj_3	Obj_4	Obj_5
Objective	To reduce the magnitude of surface flooding	To minimise the damage to properties	To minimise damage to critical infrastructure	To maximise the opportunity of salvaging belongings	To maximise ease and feasibility of implementation
Indicator	Flooded area where flood depth is above 30 cm. (Units: flooded hectares)	Number of properties flooded	How would you rate the flood damage to critical infrastructure?	How would you rate the opportunity to salvage valuables inside properties and businesses from flood damage?	How would you assess the ease and feasibility of implementing this measure in Redbridge**?**
Type of indicator / scale for evaluation	Quantitative indicator, the evaluation is based on the results of the flood model and the user cannot modify these results.	Quantitative indicator, the evaluation is based on the results of the flood model and the user cannot modify these results.	Qualitative Scale for evaluation: - Very Low damage - Low damage - Medium damage - High damage - Very High damage	Qualitative Scale for evaluation: - Very Low opportunity - Low opportunity - Medium opportunity - High opportunity - Very High opportunity	Qualitative Scale for evaluation: - Very Low feasibility - Low feasibility - Medium feasibility - High feasibility - Very High feasibility

3.4 RESULTING FLOOD HAZARD AND RISK MAPS FOR THE CRANBROOK CATCHMENT

The 1D-2D urban pluvial flood model of the Cranbrook catchment (set up in InfoWorks CS) was used to simulate the flood scenarios and flood risk management alternatives described in Sections 3.3.1 and 3.3.2.

The flood depths estimated for each flood scenario were exported as shapefiles and were afterwards post-processed in ArcGIS in order to create the corresponding flood hazard maps (on which flood extent was indicated and different flood depths were assigned different colours). In addition, layers containing information about location and type of properties (i.e. commercial and residential), roads and critical infrastructure (e.g. schools, hospitals, transport infrastructure, fire brigade, police stations, etc.) were added to the maps; these elements represent “Exposure” (as defined in Section 2.3) and when mapped together with the flood extent, they can convey an idea of flood risk (i.e. an idea of the potential consequences of the flood event on the properties and other infrastructure of the area). In this way, both flood hazard and risk were represented in a single map. The resulting **hazard + risk maps** were included in the Collaborative Platform and Google maps were used as background (therefore, the functionalities of Google maps can be used when visualising the generated maps; e.g. zooming, satellite view, map view, etc.). In addition, several tools were provided so that the user can choose the information that he/she wants to display in the map (e.g. flood extent, flood risk management alternative, location of properties and critical infrastructure, etc.).

As described in Section 3.3.3, the flood hazard + risk maps were tailored to support the evaluation of the different flood risk management alternatives in terms of each objective (see Table 3). Next, a detailed description is given of the maps created to support the evaluation of objectives 1, 2 and 3, which are direct ways of estimating and quantifying flood hazard and risk.

3.4.1 Maps created to illustrate the results of the evaluation of flood risk management alternatives in terms of Objective 1

- **Objective 1:** To reduce the magnitude of surface flooding
- **Indicator:** Flooded area where flood depth is above 30 cm (Units: flooded hectares)
- **Type of indicator:** Quantitative - the evaluation is based on the results of the flood model and the user cannot modify these results
- **Main information displayed on the map:**
  - Flood hazard, as represented by flood extent and depth: three ranges of flood hazard (i.e. low, medium and high) were defined following international as well as UK standards and each of them was assigned a different colour code. The established ranges can be seen on the top left corner of Figure 6. By checking or unchecking this option the used can choose whether or not to display the flood extent and depth on the maps.
- **Complementary information displayed on the map:**
  - Polygon of the Cranbrook catchment: the user can choose whether or not to display a polygon which shows the area comprised by the Cranbrook catchment. This can be done by checking or unchecking the option shown in the top left corner of Figure 6.
  - Polyline indicating the trajectory of the Roding River: same as the polygon of the Cranbrook catchment, the user can choose whether or not to display the trajectory of the Roding River.
  - Background map: Google maps were used as background maps, making it possible to use the tools inherent to these interactive maps (e.g. display of satellite, map and hybrid view, zooming and navigation options).
- **Additional visualisation tools provided:**
  - A special layout was designed which enables simultaneously and adjacently visualising the resulting flood hazard maps for two different alternatives. This enables direct visual comparison of the flood hazard and risk corresponding to two different flood risk management alternatives, thus helping the user in the evaluation and ranking of the alternatives.
  - For each of the two adjacent maps the user can chose (using a drop-down menu) the flood risk management alternative for which to display the flood hazard map.
  - For some of the flood risk management alternatives, the user can choose the return period for which to display the flood hazard map.
  - As the user explores one of the two displayed maps (by zooming in or out and navigating), the adjacent map is automatically updated to show the same location and zoom. This enables better comparison of the two flood risk management alternatives for which the hazard maps are being displayed.

Figure 6 shows an example of the flood hazard maps created to illustrate the impact of each flood risk management alternative on the flood extent.

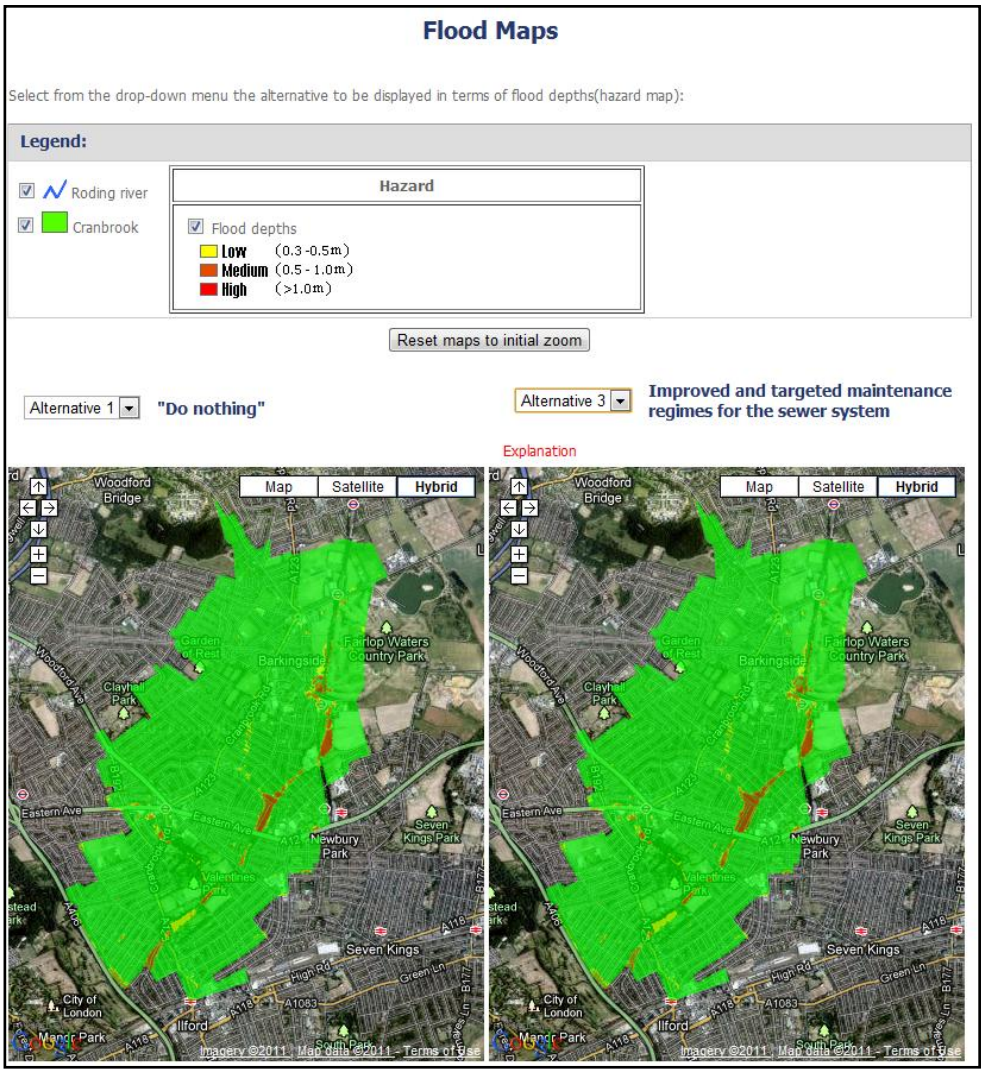


Figure 6. Example of flood maps created to support assessment of Objective 1 (i.e. Ability of the flood risk management alternative to reduce the magnitude of surface flooding)

3.4.2 *Maps created to illustrate the results of the evaluation of flood risk management alternatives in terms of Objective 2*

- **Objective 2:** To minimise the damage to properties
- **Indicator:** Number of properties flooded
- **Type of indicator:** Quantitative - the evaluation is based on the results of the flood model and the user cannot modify these results
- **Main information displayed on the map:**
  - Flood hazard, as represented by flood extent and depth (using the flood hazard ranges described in Section 3.4.1 and which can be seen on the top left corner of Figure 7).
  - Exposure, as represented by the location and type of properties (i.e. commercial or residential) affected by flooding. A threshold of 30 cm was used to determine the properties at risk of flooding. This threshold was adopted following the recommendations set in recent

documents published by the UK Environment Agency, according to which the 30 cm threshold represents a typical value for the onset of significant property damages when property flooding may start (above doorstep level).

- The combination of flood hazard and potentially affected properties gives an indication of the potential consequences of a given flood event; therefore, **the created maps represent flood risk in addition to flood hazard**.

- **Complementary information displayed on the map:** same as the one described for the maps created to support assessment of Objective 1 (see Section 3.4.1).
- **Additional visualisation tools provided:** same as the ones described for the maps created to support assessment of Objective 1 (see Section 3.4.1).

Figure 7 shows an example of the maps created to illustrate the impact of each flood risk management alternative on the number of properties affected by flooding.

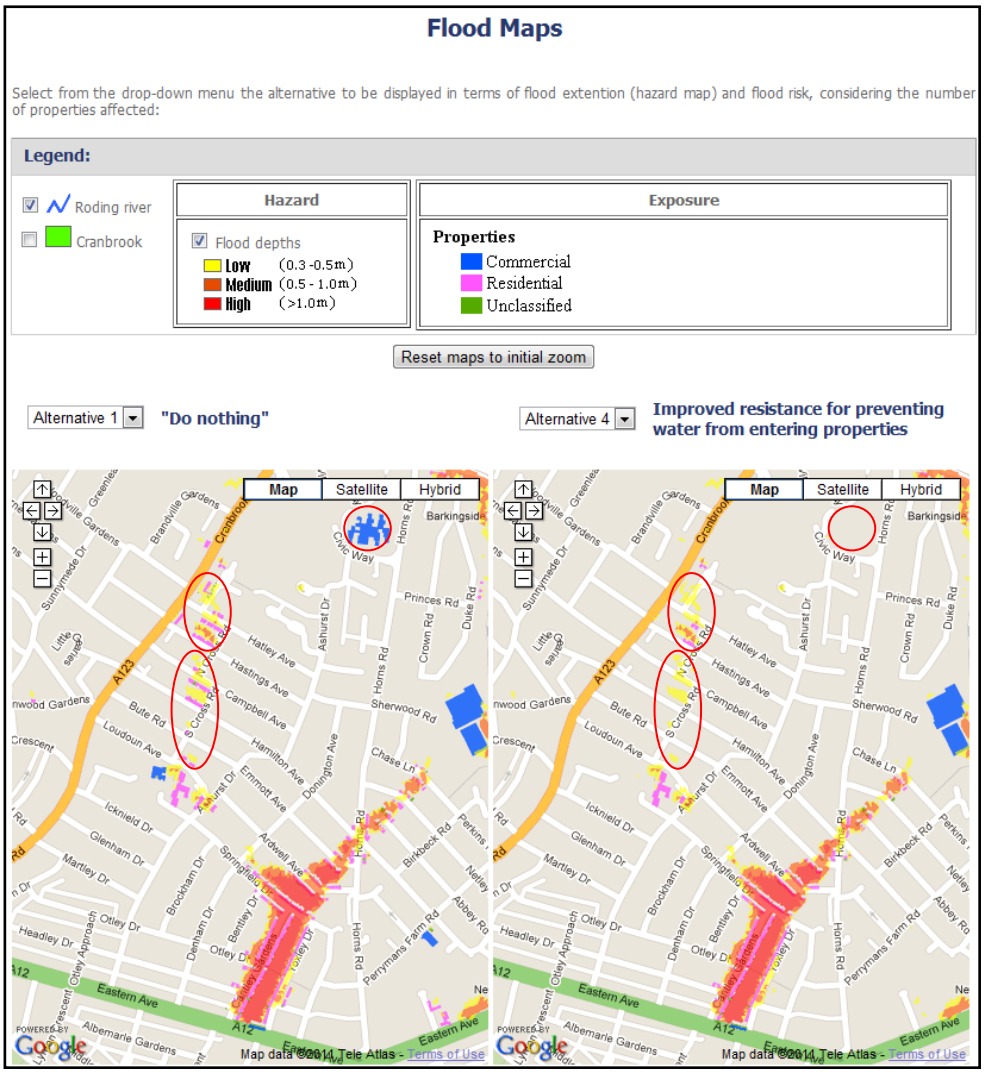


Figure 7. Example of flood maps created to support assessment of Objective 2 (i.e. Ability of the flood risk management alternative to minimise the damage to properties). The red circles point out some of the areas where Alternative 4 (shown on the right window) significantly reduces the number of properties affected by flooding.

3.4.3 *Maps created to support the evaluation of flood risk management alternatives in terms of Objective 3*

- **Objective 3:** To minimise damage to critical infrastructure
- **Indicator:** How would you rate the flood damage to critical infrastructure?
- **Type of indicator:** Qualitative – participants are required to use the following scale for answering the question above, based on the information provided by the **flood hazard + risk map:**
    - Very Low damage
    - Low damage
    - Medium damage
    - High damage
    - Very High damage
- **Main information displayed on the map:**
    - Flood hazard, as represented by flood extent and depth (using the flood hazard ranges described in Section 3.4.1 and which can be seen on the top left corner of Figure 7).
    - Exposure, as represented by the location of critical infrastructure in the study area, including location of hospitals, train and tube stations, schools, post offices, community centres, roads, amongst others. By checking or unchecking the tick box adjacent to each type of infrastructure, the user can choose which infrastructure to display on the maps.
    - By overlaying flood extent and location of critical infrastructure on the same map, the user is provided with enough information to carry out a subjective assessment of the potential effect of a given flood scenario on the critical infrastructure of the area. Thus, he/she can carry out a subjective estimation of flood risk (which might vary from person to person, as the perception of the importance of the infrastructure and its degree of affectation is different for each person).
- **Complementary information displayed on the map:** same as the one described for the maps created to support assessment of Objective 1 (see Section 3.4.1).
- **Additional visualisation tools provided:** same as the ones described for the maps created to support assessment of Objective 1 (see Section 3.4.1).

Figure 8 shows an example of the maps created to support the assessment of Objective 3 (i.e. To minimise damage to critical infrastructure).

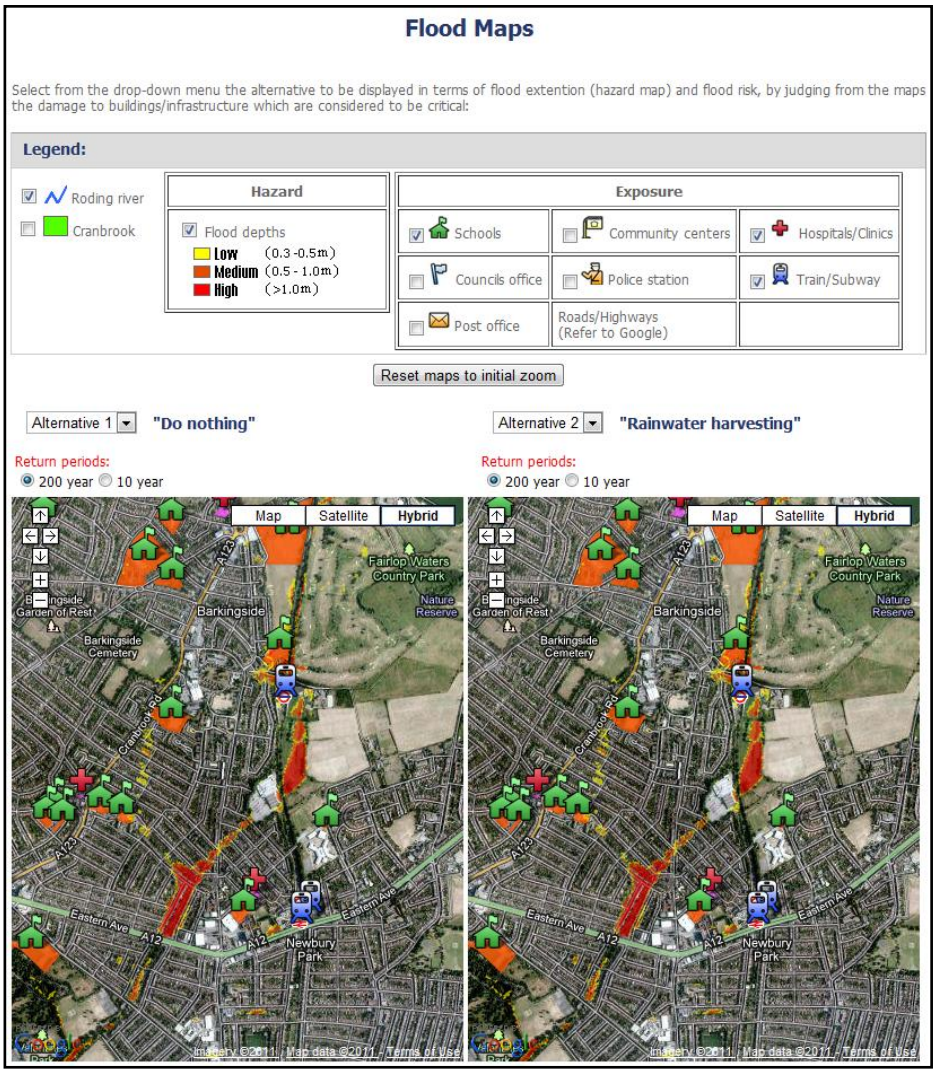


Figure 8. Example of flood maps created to support assessment of Objective 3 (i.e. Ability of the flood risk management alternative to minimise damage to critical infrastructure)

4 FLOOD HAZARD AND RISK QUANTIFICATION AND COMMUNICATION IN THE RIVER ALSTER CATCHMENT (GE)

4.1 DESCRIPTION OF ALSTER CATCHMENT

Environmental Setting: the Alster catchment is situated in Northern Germany. Approximately 47 % of the catchment is located within the Hamburg Metropolitan Region and the remaining 53 % lies within the state of Schleswig-Holstein. The upper part of the catchment (located in Schleswig-Holstein) is predominantly rural, whereas the lower part (located in Hamburg) is highly urbanised, with impervious surfaces covering approximately 80 % of the area. In the city centre of Hamburg the Alster River is dammed by a sluicegate (Rathausschleuse), forming two lakes (Binnenalster and Außenalster) which have the same water level, ranging from 2.85 m to 3.25 m. Another lock (Schaartorschleuse) is located 1 km downstream of the Rathausschleuse (see Figure 9), where the Alster joins the River Elbe. This sluice protects the inner city of Hamburg from high tides in the Elbe River. A pumping station at the Schaartorschleuse (with a pumping capacity of 36 l/s) protects the city centre from flooding. In the Hamburg city centre the Alster is famous for its charm and for the recreational activities that take place in it, rather than for its flooding history. Approximately 10 km upstream of the Rathausschleuse there is another sluice called Fuhlsbüttler Schleuse (see Figure 9), with an upstream-downstream water level difference of 3 m. Upstream of this sluice the Alster and its tributaries cause frequent flooding, with the most recent event in February 2011 (during the development of the DIANE-CM project). The focus in the Alster catchment case study was on long term planning for fluvial flood risk management.

Major type of flood: fluvial

Size of catchment area: 578 km²

Past flood events: several flood events during the last 10 years, with the most recent event on 6th February 2011

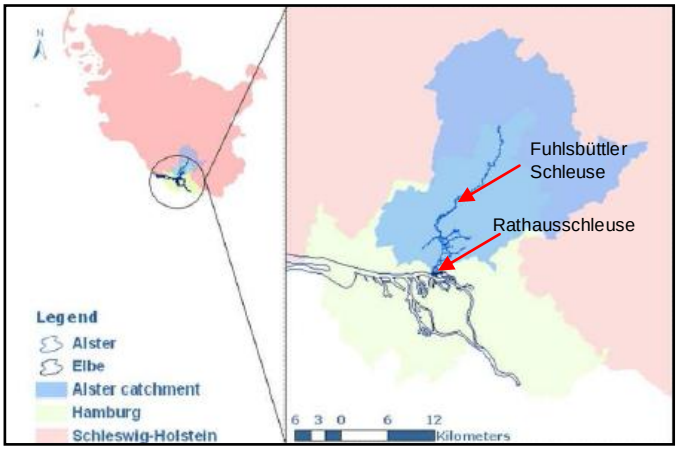


Figure 9. River Alster catchment

4.2 HYDROLOGICAL AND HYDRAULIC MODELLING OF THE ALSTER CATCHMENT

4.2.1 Existing models

A hydrological model of the river Alster catchment was built and calibrated by an engineering company using Calypso software. In addition to the hydrological model, a hydraulic model for the upper part of the river Alster (until Fuhlsbüttler sluice) was built and calibrated using MIKE 11. These models are owned by the LSBG (Agency for Streets, Bridge and Water), which was a technical partner in the DIANE-CM project. Simulations of different events, including extreme events, were carried out by the engineering company and these results were used in the DIANE-CM project as a boundary condition for the model that was built for the river section between Fuhlsbüttler sluice and Schaartorschleuse.

4.2.2 New models developed throughout the DIANE-CM project

Throughout the DIANE-CM project a model was built for the section of the river between Fuhlsbüttler sluice and Schaartorschleuse (point at which the Alster River flows into the Elbe); this part of the river had not been modelled before.

HEC-RAS software was used to build the 1D model of this section of the river Alster and the output from the MIKE 11 model (described in Section 4.2.1) was used as upstream boundary condition. Moreover, tidal data of the river Elbe was used as downstream boundary condition.

In what follows a description is provided of the information used for the construction of the model and also of the steps followed in the construction process.

Data used in the set-up of the 1D model of the river Alster (between Fuhlsbüttler sluice and Schaartorschleuse):

- High resolution elevation data: elevation data with at least 3 points in a 1 m grid was provided by LSBG. This dataset was used to determine the geometry of the river.
- River bed elevation data (bathymetry) of the river Alster and its tributaries was provided by LSBG.
- Flow output from MIKE 11 model (provided by LSG) was used as upstream boundary condition.
- Measurements from level gauges along the river Alster and its tributaries were provided by LSBG. These data were used for calibration of the model.
- Tidal data of the Elbe River, which was used as downstream boundary condition.

Steps followed for construction and calibration of the 1D river model with HEC-RAS:

i. ***Preparation of geometrical data:*** the high resolution elevation data and bathymetry data were processed in ArcGIS to create a Digital Elevation Model (DEM). Using the HEC-GeoRAS extension tool in ArcGIS river cross sections, bank lines and structures across the river were extracted. These geometrical data was exported to HEC-RAS afterwards. Figure 10 illustrates this process.

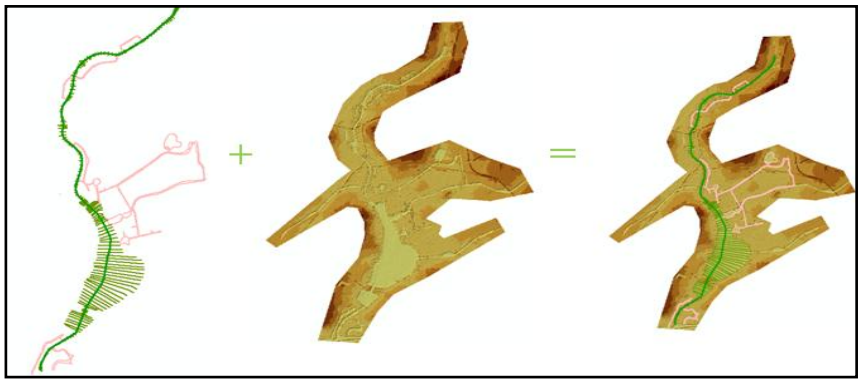


Figure 10. Extraction of geometrical data from DEM

ii. ***Import of geometrical data to HEC-RAS and setting of model parameters:*** after processing the geometrical data in ArcGIS, it was imported to HEC-RAS. Afterwards, model parameters (e.g. manning, expansion and contraction coefficients) were set and information of bridges, pumps and inline structures was incorporated in the HEC-RAS model. An example of this process is shown in Figure 11.

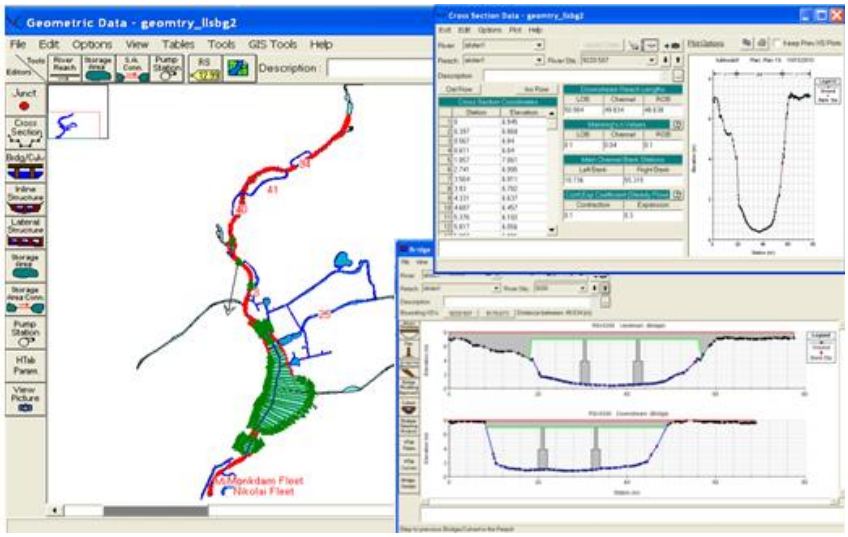


Figure 11. Example of cross section and bridges definition in HEC-RAS

iii. ***Calibration***: the model was calibrated using data from December 2007 to April 2010. During the calibration process the only parameter that was adjusted was the manning coefficient and the only data available for calibration was water level at different locations. Having flow data, in addition to level data, would have enabled having a more robust model; however, the quality of the model obtained after calibrating with level data only was enough for reliably simulating extreme events for flood mapping purposes. Some results of the calibration process are shown in Table 4. It can be observed that the results obtained from the model match with the observations.

Table 4. Calibration results (comparison of simulated and observed water level at different locations)

Location	Simulated	Measured
Krugkoppelbrücke	3.07 m	3.18 m
Upstream of Rathausschleuse	3.05 m	3.12 m
Downstream of Rathausschleuse	1.7 m	1.63 m

After calibration, the model was used for simulation of different flood scenarios and flood risk management alternatives. The scenarios and alternatives considered for the river Alster catchment are described in the next section (Section 4.3). In addition, the results of the model were used for generation of flood hazard maps, as explained in Section 4.4.

4.3 FLOOD SCENARIOS AND FLOOD RISK MANAGMENT ALTERNATIVES SIMULATED FOR THE ALSTER CATCHMENT

4.3.1 *Flood scenarios considered in the Alster catchment*

In order to estimate the effects of different flood events and conditions in the Alster catchment, the following flood scenarios were simulated and analysed:

- Scenario 1: 100 years return period event
- Scenario 2: 200 years return period event
- Scenario 3: 100 years return period event + pump failure at Schaartorschleuse
- Scenario 4: 100 years return period event + gate failure at Schaartorschleuse + high tide at river Elbe

Scenario 2 was chosen as the base case for the CME: it was used as reference to evaluate the performance of the different alternatives for flood risk management. Scenarios 3 and 4 are very extreme scenarios with very low probability of occurrence; that is why they were not considered as base case in the CME.

4.3.2 *Fluvial flood risk management measures considered in the Alster catchment*

As explained in Section 3.3.2, the main objective of the DIANE-CM project was to jointly select the best alternative for flood risk management in the study areas. In the Alster catchment the focus was on long-term planning, as opposed to the UK case study, where the focus was on event management (without neglecting long term management strategies).

The *Collaborative Modelling Exercise* was applied to the Alster case study in the same it was applied in the UK case study (see Section 3.3.2).

The flood risk management alternatives considered in the Alster catchment are summarised in Table 5. Some of the alternatives correspond to a combination of individual measures; this is also explained in the table below.

Table 5. Proposed alternatives for flood risk management in the Alster catchment

Alternative	Modelling example / Description of the alternative
Alternative 1: Doing nothing (base case)	Current situation, no measures are implemented
Alternative 2: Technical measures	
Modification of hydraulic structures	• Lowering crest level of weir at Fuhlsbüttler Schleuse • Lowering crest level of weir at Wohldorfer Scheuse
Construction of reservoirs	Building dike around Hoopwishen village
Alternative 3: Management of the catchment area	
Sustainable and careful maintenance of water systems	Clearing trees from Ammersbeck River, a tributary of the Alster
Alternative 4: Prevention	
Improved coordination	Coordination of responsibilities between authorities and other stakeholders
(Private) property protection	Flood protection measures at the household level
Forecast / Information	Installation / improvement of predictive mechanisms, information of local residents

The potential measures for flood risk management were defined through live discussion with workshop participants and also based on the feedback provided via the collaborative platform and e-mail.

4.3.3 Criteria considered for evaluation and ranking of flood risk management alternatives as a way of evaluating and quantifying flood hazard and risk (Alster catchment)

Following the same procedure applied in the Cranbrook catchment (described in Section 3.3.3), in the Alster case study three “criteria” for evaluation and ranking of alternatives were jointly identified with the stakeholders. Each of these criteria comprises a set of objectives, as indicated in Table 6.

Table 6. Summary of flood risk management "criteria" to be considered in the CME of the Alster catchment

	Cr_1	Cr_2	Cr_3
Criterion	Effectiveness in flood protection	Potential impact to the environment	Cost of implementation
Accounted objectives	- To reduce the magnitude of flooding - To minimise damage to properties	- To increase the protection and improvement of the floodplain	- To minimise the cost of implementation of the alternative under consideration
Indicator	How would you rate the effectiveness of the alternative in terms of flood protection to properties and infrastructure?	How would you rate the contribution of the alternative under consideration towards the protection and improvement of the floodplain?	How would you rate the total cost of implementation of the alternative under consideration? ***(This assessment was provided by LSGB and it cannot be modified by the users)***
Type of indicator / scale for evaluation	*Qualitative* - Very low effectiveness - Low effectiveness - Medium effectiveness - High effectiveness - Very high effectiveness	*Qualitative* - Very negative impact - Negative impact - Neutral impact - Positive impact - Very positive impact	*Qualitative* - Very low cost - Low cost - Medium cost - High cost - Very high cost

4.4 FLOOD HAZARD AND RISK QUATIFICATION AND COMMUNICATION IN THE RIVER ALSTER CATCHMENT

The river models described in Section 4.2 were used for simulation of the flood risk management alternatives presented in Table 5.

The results of the HEC-RAS 1D river model were exported to ArcGIS and were processed and analysed using the HEC-GeoRAS extension tool in order to produce flood hazard maps. The results of the MIKE 11 1D river model were also exported to ArcGIS and were post-processed using the FLOODAREA extension tool. The end products of this analysis are raster and shape files which were uploaded to the Collaborative Platform.

In the case of the Alster catchment, one single map was used to support the evaluation of the different flood risk management alternatives in terms of the 3 criteria defined for this purpose (see Table 6). Next, a detailed description is given of the map created to communicate flood risk and support the ranking of alternatives in the Alster catchment.

Map created support the evaluation and ranking of flood risk management alternatives in terms of the assessment criteria defined for the Alster catchment:

- **Criteria:** three evaluation criteria are considered and are summarised in Table 6
- **Indicator:** a different indicator was defined for each of the three criteria (see Table 6)
- **Type of indicator:** all indicators are **qualitative**. In each case participants were asked to use a particular qualitative scale to rate the performance of each alternative in terms of each criterion (these scales are shown in Table 6).
- **Main information displayed on the map:**
  - Flood hazard, as represented by flood extent, depth and number of properties affected by flooding. Three ranges of flood hazard (i.e. low, medium and high) were defined and each of them was assigned a different colour code. The established ranges can be seen on the top left corner of Figure 12. Furthermore, the flood extent (expressed in areal units) and the number of properties affected by flooding is also shown in the summary table located besides the map (see Figure 12).
  - Exposure, as represented by the location of critical infrastructure in the study area, including location of schools, sport centres, transport infrastructure, cultural centres, amongst others. By checking or unchecking the tick box adjacent to each type of infrastructure, the user can choose which infrastructure to display on the maps.
  - In the same way as in the UK case study, by overlaying flood extent and location of critical infrastructure on the same map, the user is provided with enough information to carry out a subjective assessment of the potential effect of a given flood scenario on the critical infrastructure of the area. Thus, he/she can carry out a subjective estimation of flood risk (which might vary from person to person, as the perception of the importance of the infrastructure and its degree of affectation is different for each person).
- **Complementary information displayed on the map:**
  - Polygon of the Alster catchment: the user can choose whether or not to display a polygon which shows the area comprised by the Alster catchment. This could be done by checking or unchecking the option shown in the top left corner of Figure 12.
  - Polyline indicating the trajectory of the Alster River: same as the polygon of the Alster catchment, the user can choose whether or not to display the trajectory of the Alster River.
  - Background map: Google maps were used as background maps, making it possible to use the tools inherent to these interactive maps (e.g. display of satellite, map and hybrid view, zooming and navigation options).
  - Wetspots: these correspond to areas prone to flooding (these areas were identified based on the results of the models).
- **Additional visualisation tools provided:**
  - Using a drop-down menu, the user can choose the flood risk management alternative for which to display the results.
  - For some of the flood risk management alternatives, the user can choose a different measure to be displayed (given that some of the alternatives comprise different measures).

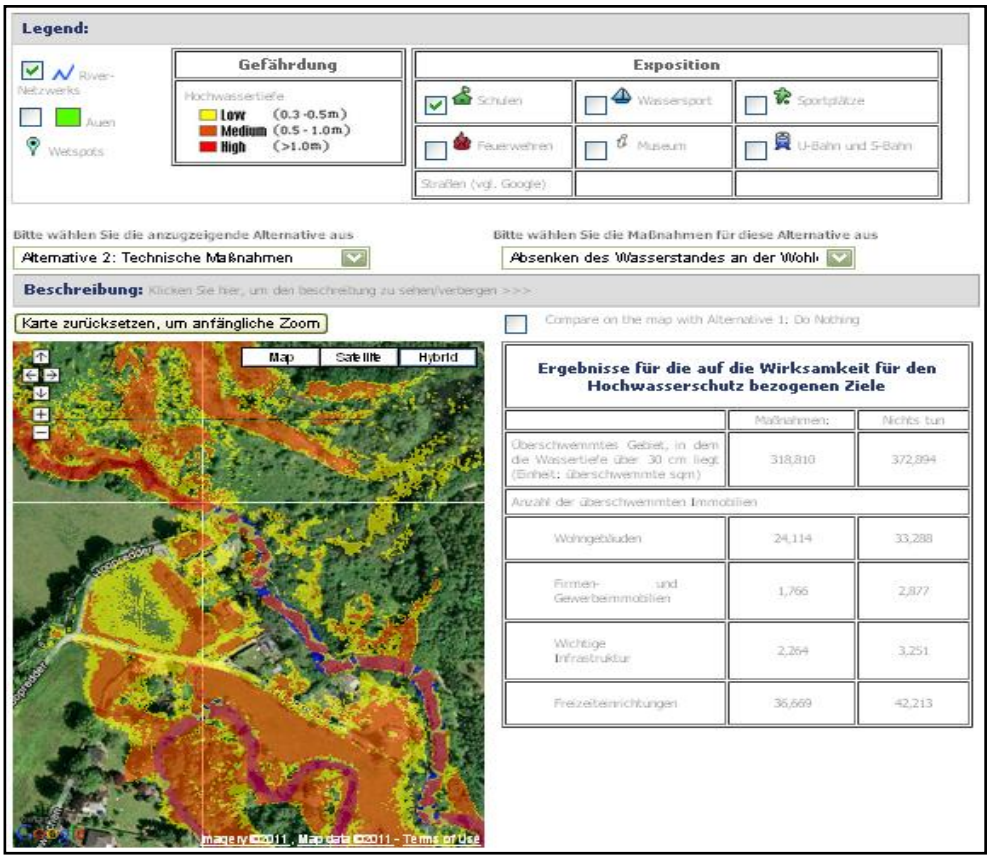


Figure 12. Example of flood maps created to support assessment of criteria 1 (i.e. Ability of the flood risk management alternative to reduce the magnitude of flooding)

Conclusions and Lessons Learned

- The main use of the flood hazard and risk estimates and communication tools (mainly flood hazard and risk maps) generated throughout the DIANE-CM project was to support the *Collaborative Modelling Exercise* (CME) for ranking of alternatives in flood risk management. This objective was achieved in both case studies and the developed tools (in spite of the limitation which will be next described), successfully supported the collaborative modelling activities.

- In general, the acquisition of the data required to set up and calibrate the flood models in both case studies was one of the hardest and most time consuming tasks (it took significantly longer than expected), due mainly to confidentiality and organisational issues. The setup and calibration of the models entailed big modelling/scientific challenges, but these were expected. Overall, the generation of proper flood risk maps was found to be hard, as it required detailed information about property types, values, population density in a detailed scale, amongst other, and it was not readily available in the case studies. In addition to the difficulties in obtaining data for flood risk estimation, **the concept of risk turned out to be more confusing for the users, who are more used to simply observing flood hazard** as represented by flood extent and depth (which most of them believe is flood risk). However, we found out that by providing additional information besides flood extent and depth (e.g. by showing the location of residential and commercial properties and of critical infrastructure in relation to the flood extent), it was possible to convey an idea of flood risk and the users understood it correctly. **This, together with the visualisation tools available in the Collaborative Platform, supported and enabled successful implementation of the CME**.

- Regarding the modelling of flood risk management alternatives, not all the identified alternatives could be modelled. This was either due to limitations of the model or simply because the alternatives do not alter flood extent (e.g. early warnings for surface flooding). In the cases where the alternatives could not be modelled, qualitative descriptions and indicators were used and proved to work well.

References

Communities and Local Government. (2010). Planning Policy Statement 25: Development and Flood Risk. In Communities and Local Government website, http://www.communities.gov.uk/publications/planningandbuilding/pps25floodrisk, visited August 2011.

Defra (Department for Environment, Food and Rural Affairs). (2010). Surface Water Management Plan Technical Guidance. In Defra website, http://archive.defra.gov.uk/environment/flooding/documents/manage/surfacewater/swmp-guidance-annex.pdf, visited August 2011.

Djordjevic S., Prodanovic D., et al. (2004). SIPSON – Simulation of Interaction between Pipe flow and Surface Overland flow in Networks.Urban Drainage Modelling 04.

Gouldby B. and Samuels P. (2004). Language of Risk: Project Definitions. FLOODsite Project, T32-04-01. In FLOODsite website, http://www.floodsite.net/html/partner_area/project_docs/FLOODsite_Language_of_Risk_v4_0_P1.pdf, visited August 2011.

Legislation UK.(2009). UK Flood Risk Regulations 2009. In Legislation.gov.uk website: http://www.legislation.gov.uk/uksi/2009/3042/contents/made, visited August 2011.

LSBG (2009). Hochwasserschutz für die Hamburger Binnengewässer. Available under: http://lsbg.hamburg.de/contentblob/2181884/data/hochwasserschutz-hamburger-binnengewaesser.pdf (Last access: 15.08.2011).

Maksimović Č., Prodanović D., Boonya-aroonnet S., Leitão J.P., Djordjevic S. and Allitt R. (2009). Overland flow and pathway analysis for modelling of urban pluvial flooding. Journal of Hydraulic Research, 47 (4), 512-523.

MWH Soft.(2010). InfoWorks CS 11.0 help file. Wallingford, UK.

United Nations International Strategy for Disaster Reduction (UNISDR). (2009). Terminology on Disaster Risk Reduction. Geneva, Switzerland. In United Nations website, http://www.unisdr.org/we/inform/terminology, visited August 2011.

Appendix 1–Summary of inputs required for creation of flood hazard maps

As explained in Section 2, flood hazard maps indicate the geographical area that could be inundated for a given flood scenario. For each flood scenario the flood hazard maps shall show the likely extent of the flood, the water depth or level and, where appropriate, the likely direction and velocity of flow of possible floods. The flood extent and associated characteristics are indicated with different colours or textures, with a master map or other imagery as background. Flood hazard maps are the basis for preparation of flood risk maps, which must not only show the likely extent of flooding, but must also convey an idea of the potential consequences associated with a certain flood scenario.

Next, the main inputs required for creation of flood hazard and risk maps is described.

Flood hazard maps are created by post processing data from the hydraulic models with which flood scenarios are simulated. The main inputs and tools required to create good quality **hazard maps** are the following:

- Background map of the area: DTMs/DEMs, satellite images, or other representations of the area could be used as a background for the hazard maps.
- Water level and/or flow velocity data for given flood scenarios; this is obtained from hydraulic models. Depending on the type of system that is being analysed, different software packages can be used for hydraulic modelling. In the case of rivers, software packages such as MIKE 11, HEC-RAS, SOBEK, SWMM and InfoWorks RS can be used. Examples of software packages which can be used for urban pluvial flood modelling are: InfoWorks CS, MOUSE, SOBEK, SWMM. **The reliability and quality of flood hazard maps greatly depends on the quality of the hydraulic models** (whose quality depends on the input data used to set them up and on the calibration process).
- A GIS software package (e.g. MapInfo, ArcGIS, QuantumGIS) to post-process and map the water level and / or flow velocity. *Spatial Analyst Tool*, *HEC-GeoRAS* and *FLOODAREA* are some ArcGIS extensions which can be used for preparation of hazard maps.

In addition to the flood extent and the associated flow depth or velocity shown in **flood hazard maps**, **flood risk maps** must also show the potential consequences of a given flood event. To estimate the potential consequences of a flood event and map them appropriately, the following inputs can be used (in addition to the inputs required for **flood hazard maps**):

- Number and distribution of people living in the area
- Land use distribution in the area
- Location and characteristics of the different types of properties in the area (e.g. commercial, residential, industrial, health centres, schools, cultural centres, etc.)
- Economic activities likely to be affected in the event of flooding in the area

Same as in the case of **flood hazard maps**, a GIS software package can be used to post-process the information from the hydraulic models, as well as the additional inputs mentioned above in order to estimate and map **flood risk**.

Appendix 2 – Summary of flood hazard and risk maps generated in the DIANE-CM project

The main use of the flood hazard and risk maps generated throughout the DIANE-CM project was to support the *Collaborative Modelling Exercise* for ranking of alternatives in flood risk management. A brief description of the maps generated in each case study is next provided.

- **Flood hazard and risk maps generated for the Cranbrook catchment (UK)**

In the UK case study, a 1D-2D urban pluvial flood model of the Cranbrook catchment was set up in InfoWorks CS and its results were used to generate flood hazard maps in ArcGIS. In the hydraulic model the surface network was modelled in 2D, using a detailed DTM as main input, and the sewer network was modelled in 1D (the model was obtained from Thames Water, the water utility of the area). The surface and sewer network models were coupled together in order to realistically model pluvial flooding. With the resulting hydraulic model different flood events were simulated (using design storms) and the effect of different flood risk management alternatives was also simulated. The flood depths estimated for each flood scenario were exported as shapefiles and were afterwards post-processed in ArcGIS in order to create the corresponding flood hazard maps (on which different flood depths were assigned different colours). In addition, layers containing information about location of buildings, roads and critical infrastructure were added to the maps, in order to convey an idea of flood risk (i.e. an idea of the potential consequences of a given flood scenario).

The resulting **hazard + risk maps** were included in the Collaborative Platform and Google maps were used as background (therefore, the functionalities of Google maps can be used when visualising the generated maps; e.g. zooming, satellite view, map view, etc.). In addition, several tools were provided so that the user can choose the information that he/she wants to display in the map (e.g. flood extent, flood risk management alternative, location of properties and critical infrastructure, etc.).

- **Flood hazard and risk maps generated for the river Alster catchment (GE)**

In the German case study, simulation results from the 1D hydraulic model of the river Alster were presented in the form of flood hazard maps. Afterwards, the information of the hazard maps was combined with land use maps in order to determine areas at high risk of flooding (wet spots). Two hydraulic models were set up for the the German case study: a 1D MIKE 11 model upstream of Fuhlsbüttler sluice and a HEC-RAS model downstream of Fuhlsbüttler sluice. The results of the HEC-RAS model were imported into ArcGIS and processed using the HEC-GeoRAS extension tool to produced hazard maps. The MIKE 11 model was used to simulate some alternatives to solve flooding problems at the wet spots. The results of this model were processed in FLOODAREA to create the hazard maps.

Same as in the UK case study, layers containing information about location of critical infrastructure were added to the maps in order to convey an idea of flood risk. The resulting **hazard + risk maps** were included in the Collaborative Platform and Google maps were used as background.