Enhancement of urban pluvial flood risk management and resilience through collaborative modelling: a UK case study

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ABSTRACT
This paper presents the main findings and lessons learned from the development and implementation of a new methodology for collaborative modelling, social learning and social acceptance of flood risk management technologies. The proposed methodology entails three main phases: (1) stakeholder analysis and engagement; (2) improvement of urban pluvial flood modelling and forecasting tools; and (3) development and implementation of web-based tools for collaborative modelling in flood risk management and knowledge sharing. The developed methodology and tools were tested in the Cranbrook catchment (London Borough of Redbridge, UK), an area that has experienced severe pluvial (surface) flooding in the past. The developed methodologies proved to be useful for promoting interaction between stakeholders, developing collaborative modelling and achieving social acceptance of new technologies for flood risk management. Some limitations for stakeholder engagement were identified and are discussed in the present paper.

KEYWORDS
Collaborative modelling; flood risk management; pluvial flooding; stakeholder engagement.

INTRODUCTION
Flooding in urban areas is occurring with increasing frequency all over the world and is causing repeated and significant damage, thus calling for improved management of flood risk. In the past, interventionist and structural approaches, led almost exclusively by experts, were adopted. However, these approaches have proven to be insufficient for appropriately tackling flood risk (White *et al*., 2010). The experience gained from recent flood events and the deeper understanding of the uncertain impacts of climate change, increased urbanisation and increased population density have recently led to a change of paradigm. This new paradigm acknowledges that structural measures are insufficient to completely protect the population and critical infrastructure from flooding; instead, it is necessary to learn to "live with it", coping with the residual risk and improving the resilience of communities and cities to these events. Examples of this new approach are recent regulations and guidelines, such as "Making Space for Water" (Defra, 2005) and "Room for the River" (Programme Directorate Room for the River - Netherlands, 2007). Moreover, previous experiences have also demonstrated the importance of involving stakeholders from all levels in flood risk management, as it enhances

the acceptance of flood management measures and empowers the stakeholders to take an active role in protecting themselves from flooding, thus generating more benefits than interventionist approaches (Abott, 2001, 2007; Jonsson and Alkan-Olsson, 2005; Abott, 2007; Evers, 2008; White *et al.*, 2010). With the purpose of involving stakeholders and making flood risk management a dynamic and participatory process, several collaborative decision making systems have been recently developed and computer technologies are being increasingly used to enable and support these systems (e.g. Jonoski, 2002; Jonsson and Alkan-Olsson, 2005; Simonovic and Akter, 2006; Wien et al., 2010; White et al., 2010).

In this context, the European Union (EU) is currently supporting related research activities, such as the Crue Era-Net Programme, which aims to introduce structure within the area of European flood research by improving co-ordination between national programmes. The methodologies and results presented in this paper were developed within the DIANE-CM project (*Decentralised Integrated Analysis and Enhancement of Awareness through Collaborative Modelling and Management of Flood Risk*), funded through the Crue Era-Net Programme. The main objective of the DIANE-CM project is to enhance flood risk awareness and capacity through collaborative modelling and social learning, supported by improved flood modelling and mapping techniques and by the development of web-based decision support making tools. The proposed methodology and tools were implemented and tested in an urban catchment in the UK. The developed approach and the lessons learned from its implementation are summarised in this paper.

CASE STUDY: THE CRANBROOK CATCHMENT (UK)

The Cranbrook catchment is located within the London Borough of Redbridge, which is situated in the Northeast part of Greater London (See Figure 1). The Cranbrook catchment is predominantly urbanised and has a drainage area of approximately 865 hectares; the main water course is about 5.75 km long, of which 5.69 km are piped or culverted. This area has experienced several pluvial, fluvial and coincidental flooding in the past. The focus of this case study is on **surface or pluvial** flooding, which was the type of flooding responsible for about two thirds of the damages caused by the floods that took place in the UK in the summer of 2007 (Pitt, 2008).

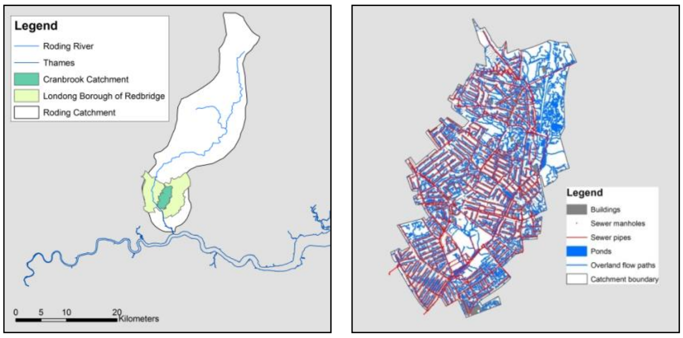

Figure 1. Cranbrook catchment. (a) location of Cranbrook catchment in relation to the Roding River catchment; (b) sewer and overland networks of the Cranbrook catchment

METHODS

The development and implementation of the collaborative modelling tools and methodologies is an iterative process in which stakeholder engagement and communication activities are constantly complemented by modelling and development of computer tools and vice versa. The steps carried out to complete this process are next described.

Stakeholder analysis

Stakeholder analysis is an approach used in different fields of study to understand a system, including its complexity and specific problems, by means of identifying the key factors and assessing their specific issues and interests in the system (Ramírez, 1999). The objective of the stakeholder analysis within the DIANE-CM project was to identify the relevant stakeholders, to understand the interrelations between them and to assess their flood risk awareness and the current situation regarding flood risk management in the study area. The results of this analysis constitute the basis for the design and implementation of the collaborative modelling methodologies and tools.

In order to carry out the stakeholder analysis, a framework consisting of a combination of different methods was developed. This framework is not case specific and could easily be applied to other case studies. The activities carried out for the analysis of the stakeholders included: identification of relevant stakeholders; "brainstorming" session to assess their flood risk awareness and current needs regarding flood risk management; interviewing of main stakeholders in order to determine their role in flood risk management and to identify how they interact with other relevant stakeholders; summarising the information collected from the interviews according to a parameter table developed for this purpose; categorisation of stakeholders according to their role in flood risk management and their relevance to the project; and elaboration of an organi- and sociogram that summarises the results of the stakeholder analysis (in particular the interrelations between stakeholders) and that allows for a better visualisation and understanding of the results.

Problem definition

Based on the results of the stakeholder analysis and on a review of the existing flood regulations, the current situation and needs regarding flood risk management in the study area were "diagnosed". This enabled defining the objectives of the collaborative modelling exercise, the flood scenarios to be analysed, and the flood risk management alternatives to be modelled and ranked in the collaborative modelling exercise.

Flood modelling, mapping and forecasting

As mentioned before, in the Cranbrook catchment (UK) the focus is on urban pluvial/surface flooding. Pluvial flooding is caused by intense local storms during which the capacity of the sewer network and of the surface drainage system is exceeded. This type of flooding takes place quickly and at small temporal and spatial scales; therefore, the flood models and the rainfall forecast used must be fast and must provide accurate information at these small scales. Considering these requirements, two types of physically-based, dual-drainage surface flood models of the study area were set up and calibrated in Infoworks CS: a 1D-2D model and a 1D-1D one. In the 1D-2D approach, the surface network is modelled as a 2D (two-dimensional) mesh of triangular elements generated based on the DTM (Digital Terrain Model) of the area. The 2D model of the surface network is coupled with the 1D (one-dimensional) model of the sewer network, thus obtaining a 1D-2D model. In the 1D-1D model approach, the Automatic Overland Flow Delineation (AOFD) tool is used to create a 1D model of the overland network, which is coupled with the 1D model of the sewer network. The output of the AOFD tool is a 1D model of the overland network which can be imported into Infoworks CS and is coupled with the sewer network model; for details of AOFD, the readers may refer to Maksimovic et al. (2009). The 1D-1D dual drainage model can reproduce the behaviour of the system, while keeping computational time reasonably short; this makes it suitable for real-time forecasting of pluvial flooding. However, the 1D-2D model, which is much more time-consuming, allows for a better visualisation of the results and was therefore used to generate flood risk maps to be included in the web-based tools implemented in this project. In addition to the pluvial flood models, improved rainfall downscaling techniques are being developed to generate statistically-feasible street-scale rainfall products and forecasts, which are further fed to the associated flood models (Wang *et al*., 2011). The final aim of the improved rainfall and pluvial flood models is to enable short-term, real-time, street-scale forecasting of these events, thus allowing issuing early warnings and timely triggering structural and non-structural measures in order to reduce the negative consequences of pluvial flooding.

Development of a Collaborative Platform (CP) for shared understanding of flood risk

The main purpose of the DIANE-CM project is to make flood management decision-making more participatory by developing a shared understanding of flood risk and supporting the interaction between local stakeholders. For this purpose, an online collaborative platform (CP) was developed whereby information about flood risk in the Cranbrook catchment is provided and discussed amongst participants, and feedback can be provided. The CP guides the user through a series of steps aiming at developing a shared understanding of flood risk and at preparing him/her to take part in the subsequent Collaborative Modelling Exercise (CME). The steps through which the user is guided are the following:

1. *System definition:* Description of the study area, the types of flooding to which it is prone and summary of the current flood related legislation.
2. *Development of shared understanding of current flood risk and identification of flood risk management objectives*
3. *Definition and evaluation of external scenarios:* Different flood scenarios are analysed in order to understand the effects of different types of floods in the Cranbrook area. These scenarios are defined according to the existing flood legislation and to the areal characteristics. Based on the analysis of different scenarios, the most representative one is selected as “base case” to be used as reference when analysing the performance of different alternatives for flood risk management.
4. *Identification and evaluation of alternatives for flood risk management:* Different alternatives for dealing with flood risk in Cranbrook are proposed and open for discussion amongst participants.
5. *Ranking of alternatives through collaborative modelling:* Based on the information presented in the previous steps, the joint ranking of alternatives is carried out; the purpose is to identify the best alternatives for dealing with flood risk in the Cranbrook catchment.

Development of Collaborative Modelling Exercise (CME) for flood risk management and enhancement of flood risk awareness

In the final stage of this collaborative process, a participatory web-based decision making instrument was implemented as an additional feature of the main CP. The feedback provided by the stakeholders through the main CP (especially regarding the objectives and alternatives for flood risk management), constitutes the basis for the final design of this decision-making tool, whose purpose is to support a joint/collaborative selection of the most appropriate alternatives for managing surface flooding in the study area.

The joint ranking of flood risk management alternatives is developed through the following 3 stages, which are supported by the online tool developed for this purpose:

1. *Individual Profile:* At this stage each participant will develop an individual ranking of alternatives based on his/her preferences or interests. Participants must give a weight to

each objective and assess each flood risk management alternative in terms of each objective. The TOPSIS method –Technique for Order Preference by Similarity to Ideal Solution–, developed by Hwang and Yoon (1981) and later on adjusted for fuzzy logic applications by Chen and Hwang (1992), is employed to obtain the ranking of alternatives based on the assessment and weights given by the participants. This technique was implemented considering the prototype of a Network Distributed Decision Support System Aquavoice (NDDSS) proposed by Jonoski (2002). A new feature developed in this project was the estimation of a score between 0 and 5 for each alternative; this not only demonstrates the ranking of the alternatives, but also allows visualising how close together or far apart alternatives are from each other. Once each participant has finished his/her individual ranking, he/she would fill in a table indicating who (which institution) should be in charge of implementing each flood risk management alternative. In order to identify the participants and save their individual profile, a login is used and participants are required to login before submitting their ranking.

2. *Group Profile:* At this stage the individual ranking of alternatives done by each participant is made visible to all participants. In this way, participants are able to compare their individual judgment against that of other participants. Especial charts were developed in order to help the user understand his/her position as compared to other participant's position. Furthermore, at this stage a joint ranking of alternatives is generated, based on the individual ranking of all participants.
3. *Collaboration and Negotiation:* In this stage participants will be able to interact and discuss the outcomes of the ranking of alternatives using the communication tools available in the online platform (e.g. online forum, online messaging). The negotiation process enhances learning, transparency of information and results, confidence in the process and acceptance of negotiated measures.

Implementation of collaborative modelling tools and execution of Collaborative Modelling Exercise (CME)

The implementation of the collaborative modelling tools and the exercise was carried out through live workshops and also online, using the web-based tools developed for this purpose. Four workshops were held to discuss specific issues related to flood risk management amongst the stakeholders, to get feedback from them to further improve the associated tools, and to finally guide the execution of the CME. In order to resolve questions and provide support to the participants, tools such as online forums and feedback forms were set up in the web platforms. The exercise continued to evolve for 2 months, time during which the participants were able to interact and modify their individual profile using the tools designed for this purpose.

RESULTS

For the case study a list of over 20 relevant stakeholders was created and representatives of main stakeholders were interviewed during June, July and August 2010. A total of 11 structured interviews were conducted and the information was summarised in a parameter table. Based on the results of structured interviews, on the information collected from the first workshop (brainstorming session) and through the stakeholder analysis, the stakeholders were classified into four categories and their interactions were analysed (see organi- and sociogram summarising stakeholder analysis in Figure 2):

- *Local Champions:* Main institutions coordinating flood risk and event management in Redbridge; they either produce or centralise information and pass it on to other stakeholders.

- *Primary Stakeholders:* These stakeholders are highly relevant in flood risk management and flood emergency management; they usually get information and instructions from the Local Champions.
- *Secondary Stakeholders:* Either private/public/governmental institutions who are not as involved in flood emergency management as the Primary Stakeholders and Local Champions. However, they play a significant role in facilitating flood risk management.
- *Tertiary Stakeholders:* Community members, community organisations and other organisations in regular direct contact with the public. These stakeholders are likely to be affected by flooding, they would benefit from improved tools and measures for flood management, and they also could play a very important role as multipliers of flood prevention measures and flood risk awareness in their community.

Based on the information collected from the stakeholder analysis and from literature and legislation review, a tailor-made collaborative platform (CP) for shared understanding of flood risk was developed. Screenshots of the CP are shown in Figure 3. This platform can be accessed from the following link: http://hikm.ihe.nl/diane_cm/cranbrook/

A workshop to present the CP was organised and feedback was obtained from the participants regarding potential improvements to the CP and the parameters to be considered in the CME. Based on this, the final flood risk management objectives and potential alternatives to be considered in the CME were defined. The defined objectives are summarised in Table 1 and the selected alternatives are the following:

- Alternative 1 (base case): Do nothing
- Alternative 2: Rainwater harvesting
- Alternative 3: Improved and targeted maintenance regimes for the sewer system
- Alternative 4: Improved resistance for preventing water from entering properties
- Alternative 5: Improved rainfall and flood forecasting and warning

Table 1. Summary of flood risk management objectives to be considered in the CME

	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.	- Very Low damage - Low damage - Medium damage - High damage - Very High damage	- Very Low opportunity - Low opportunity - Medium opportunity - High opportunity - Very High opportunity	- Very Low feasibility - Low feasibility - Medium feasibility - High feasibility - Very High feasibility

Lastly, the CME was set up and executed. So far, 10 participants have taken part in the exercise and it will remain active (online) for a total of 2 months. The current joint/group ranking of alternatives can be visualised in the CME platform (due to limited space, the reader may refer to: http://hikm.ihe.nl/diane_cm/internal/cranbrook/exercise/). Currently, the Alternative 5 is ranked first; however, the score of the other alternatives is not very distant from that of Alternative 5. Through the development of the exercise participants have interacted and have expressed that an ideal solution could be reached by combining alternatives. They have also expressed that they found interesting to learn about the preferences and ranking of the other participants and have learned about current flood risk in the study area and about alternatives for flood risk management. The stakeholder analysis and the exercise have also allowed realisation of disinformation about the role and responsibilities of the different authorities. Furthermore, it also has shown that the public in general wishes for structural measures to protect themselves and their property from flooding and that there is limited recognition for self-resilience measures. Although the implemented methodology helped in enhancing flood risk awareness in the Cranbrook area, some barriers for wider stakeholder engagement were identified; for example, lack of knowledge and motivation; language barriers (since a significant percentage of the population of the area are immigrants and do not speak English); high residential turnover rate; apathy to taking part in flood risk management and towards self-resilience measures. This realisation calls for long-term, tailor-made and stronger strategies for stakeholder engagement.

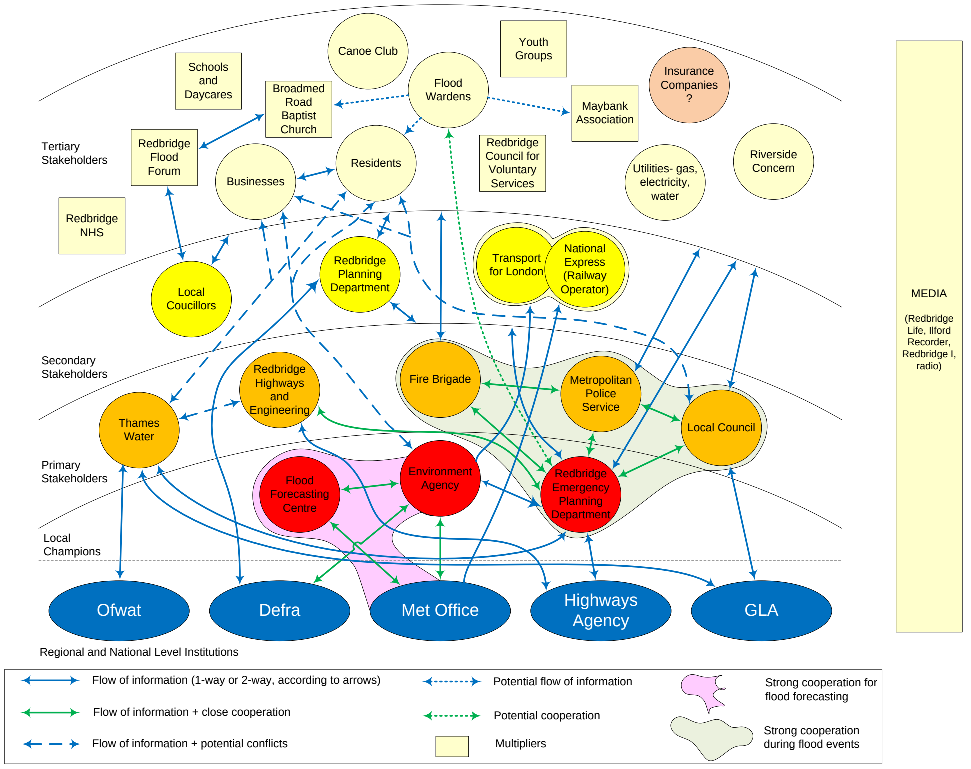

Figure 2. Stakeholder organi – sociogram, London Borough of Redbridge (UK)

Figure 3. Collaborative Platform (http://hikm.ihe.nl/diane_cm/cranbrook/)

CONCLUSIONS

The web-based tools and methodologies developed and implemented during the project proved to be useful for promoting interaction between stakeholders, developing shared knowledge, carrying out collaborative modelling and achieving social acceptance of new technologies for pluvial flood risk and event management. Engaging a wide variety of stakeholders in the decision-making process for flood risk management proved to make them more aware of the situation and increased their personal responsibility towards this issue; furthermore, it enabled assessing their flood risk awareness and their position regarding flood risk management. In spite of the good results achieved with the proposed approach, some barriers for stakeholder involvement remain and long-term, tailor-made and stronger strategies for stakeholder engagement must be implemented.

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