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Why are decisions in flood disaster management so poorly supported by information from flood models?

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ABSTRACT

Flood simulation models can provide practitioners of Flood Disaster Management with sophisticated estimates of floods. Despite the advantages that flood simulation modeling may provide, experiences have proven that these models are of limited use. Until now, this problem has mainly been investigated by evaluations of which information is demanded by decision-makers versus what models can actually offer. However, the goal of this study is to investigate how model information is exchanged among participants in flood disaster organizations and how this exchange affects the use of modeling information. Our findings indicate that the extent to which a model is useful not only depends on the type and quality of its output, but also on how fast and flexible a model can be. In addition, methods of model use are required that support a fast exchange of model information between participants in the flood disaster organization.

1. Introduction

Flooding is a global phenomenon which causes widespread devastation, economic damages and loss of human lives. The occurrence of floods is the most frequent among all natural disasters. In 2010 alone, 178 million people were affected by floods. The total losses in exceptional years such as 1998 and 2010 exceeded $40 billion (Wahlström, 2012). Floods are not only a problem in developing countries. In western Europe, for example, floods occur each year several times. For example, in 2010, France, Germany and Belgium were hit by floods during which more than 30 people died. The estimated damage was more than 1.8 billion US$ (Source: EM-DAT, The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium)). Flood damages and loss of lives are mitigated through flood risk management. This includes the design of structural protection measures such as dikes and dams; the planning of a flood resilient environment; and flood disaster management (EU, 2005; Houghton et al., 1990; Lumbroso et al., 2011; Nicholls, 2004; Stive et al., 2011).

In this paper we analyze the use of *flood simulation models* in flood disaster management, which takes place from about 1 to 5 days in advance of a potential flood. Specifically in this period, the potential consequences of a flood can be importantly reduced, for example, by reinforcements of dikes or evacuation of people (Kolen, 2012). Flood simulation models can support practitioners in these decisions by estimating the consequences of floods, in terms of water depths, flow velocities or damages. They can also be used to test the effectiveness of various measures. These flood simulation models are computer programs based on physical equations, features of an area, such as elevation and roughness resistance, and external forces, such as storm events and dam breaches (Al-Sabhan et al., 2003; Bates and De Roo, 2000; De Moel and Aerts, 2011; Stelling, 2012).

Over the previous decade, the field of flood simulation modeling has rapidly grown, resulting in the development of many new and sophisticated models. The growth in model development has occurred for two main reasons: (1) advances in computer technology and modeling methods have opened new possibilities for modeling and simulating complex systems; and (2) unprecedented socio-economic and technical conditions have put new demands on decision-makers for complex and ready to use flood information (McCarthy et al., 2007). Nowadays, these models are very advanced in terms of the integration of physical processes, detail of outcomes and visualization techniques. For example, flood depth predictions can be provided at a spatial resolution of 0.25 m^2 and can be

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visualized in various formats, including realistic 3D-visualizations comparable with those used in flight simulators (Schuurmans et al., 2010).

Despite the advantages that flood simulation modeling may provide, experiences have proven that the information from these models is of limited use in flood disaster management. Morss et al. (2005) show that practitioners of flood disaster management, operating under regulatory, institutional, political, resource, and other constraints, prioritize other concerns over more sophisticated model information about flood risk, particularly when they cannot readily see the feasibility or value of incorporating new or more detailed information from models. This lack of consideration of sophisticated model information, under circumstances of high time pressure, large consequences, high complexity and uncertainty, can be understood as a 'simplification strategy'. This means that decision-makers, acting under these circumstances, tend to discard information that seems to increase the complexity they already have to deal with (Gray, 1989; Janis and Mann, 1977; Kahneman and Tversky, 1979; MacCrimmon and Taylor, 1976). This indicates that the modelers community develops models that provide information that is often not useful for practitioners of flood disaster management.

An underlying reason for this practice, indicated in literature, is the difference in the perception of flood risks between model developers and practitioners (Faulkner et al., 2007; Janssen et al., 2009; Timmerman et al., 2010; Wood et al., 2012). Modelers generally frame flood risk issues using scientific knowledge and expertise and assume that with more detailed model information analysis will improve and better decisions can be made. Practitioners, on the other hand, often lack the time and resources to perform such complex analyses. Moreover, they frame flood risk issues more on societal goals and values (Morss et al., 2005). They therefore need information that supports them in, for example, being decisive about which people have to be evacuated. As a result of these different perceptions of flood risks, a gap exists between what practitioners demand from models and what models provide. To overcome this gap, various solutions are proposed in the literature. They mainly focus on a better communication of model outputs and their accompanying uncertainties and more involvement of decision-makers in de modeling process (Brugnach et al., 2007; Demeritt et al., 2010; Faulkner et al., 2007; Frick and Hegg, 2011; Holmes, 2004; Kinzig et al., 2003; Linkov et al., 2009; McCarthy et al., 2007; Morss et al., 2005; Timmerman et al., 2010; Voinov and Bousquet, 2010).

Even though the proposed solutions can be useful, these solutions are mainly based on evaluations of which information is demanded by decision-makers versus what output models can actually offer. However, these evaluations mostly ignore how decisions are made in the *practical* situation of flood disaster management. This practical situation can be characterized as a *process* in which actions are preceded by considerations of various participants, all adding insights and information to make sense of the actual situation and to undertake action (Hage, 1980; Nonaka, 1994; Weick, 1995). For example, model specialists are requested by policy analysts to provide information about the potential consequences of a dam breach, in order to advise decision-makers about which actions to undertake. These model specialists depend, among others, on the information about the actual situation, provided by people in the field, to interpret if existing model outputs are applicable or to make new model calculations. In this network of participants and under the dynamics of repeating information requests from policy makers, changing insight in the actual situation and information that is only partially available, model outputs are intended to be used. Therefore, besides the content of the information that models provide and the format in which this is communicated, also process factors, such as how the information is exchanged between modelers, people in the field, policy analysts and decision-makers, are expected to be important in investigating the limited use of models and proposing solutions to overcome this limited use.

Table 1
Reviewed evaluation reports.

Event	Period	Water board
Dike breach Wilnis	August 2003	Amstel Gooi and Vecht
Extensive precipitation period Delfland	July 2008	Delfland
High water river Lek	January 2011	Stichtse Rijnlanden
High water Eems channel	January 2012	Hunze en Aa's
Flood disaster exercise 'Noord-Holland Nat'	2008	Hollands Noorderkwartier
Flood disaster exercise 'Taskforce flood management'	2009	Hollands Noorderkwartier
Flood disaster exercise 'FloodEx'	2009	Hollands Noorderkwartier
Flood disaster exercise 'Laag Holland'	2011	Hollands Noorderkwartier
Flood disaster exercise 'Hofpoort'	2011	Stichtse Rijnlanden
Flood disaster exercise 'de Geer'	2012	Stichtse Rijnlanden

The goal of this study is to investigate how model information is exchanged among participants in flood disaster organizations and how this exchange affects the use of modeling information for decision-making. Based on our findings, we propose solutions that increase the acceptability of model information in flood disaster management and overcome the main barriers in its use. We assume that this process of information exchange, including its dynamics of repeating information requests from policy makers and changing insight in the actual situation, is constant across different cases of flood disaster management. We chose the Netherlands practice of flood disaster management for our research. This country has a long history of flood management and has access to the latest model technology. It is therefore suitable to investigate the problems decision-makers are facing in using models. After drawing conclusions for the Netherlands context, we discuss if our findings are applicable for flood disaster management in general. Consequently, we propose new directions for model development and process design.

Although this paper specifically focuses on the use of models in the context of flood disaster management, it is treating the wider topic of how environmental models can be practically applied in decision-making processes. Recently, this topic has received an increased attention in literature and is being investigated by different approaches. For example, Krueger et al. (2012) stress the role of expert opinion in the application of environmental models, Demir and Krajewski (2013) focus on the role of integrated information systems to communicate model outputs to decision-makers and Balica et al. (2013) and Zagonari and Rossi (2013) investigate how model results can be translated in performance indicators, usable in multi-criteria analysis. The findings in this paper contribute to this ongoing field of research and are therefore relevant for the modeling audience in general.

2. Methodology

2.1. General

To reach our goal, we carried out three research activities. First, to make a description of the state-of-the-art of flood disaster management and the application of model information, we reviewed ten evaluation reports of flood disasters and flood disaster exercises of the last decade. This review focused on the general experiences from practitioners about the use of models in the process of decision-making during flood disasters. Second, to understand how model information is exchanged during flood disasters, we applied a Social Network Analysis to map this information exchange, based on fifteen interviews of participants in the flood disaster organization of a Netherlands Water board. Third, to investigate how model information is perceived by individual participants, we organized a flood disaster exercise in which a state-of-the-art model was applied. The 100 people that participated in the flood disaster exercise were requested to fill in a questionnaire about their personal experiences with the model information. The set-up of these research activities is further elaborated below.

2.2. Document review

Ten evaluation reports of the decision-making process during flood disasters were collected among six different regional Water boards in The Netherlands, including four evaluation reports of real threatening floods and six evaluation reports of flood disaster exercises (see Table 1). These evaluation reports referred to situations of flood disaster management encountered in the period of 2003 till 2012. The review focused on finding out how technical information from flood models was used in the decision-making process and which were the constraints encountered during this use.

2.3. Social Network Analysis and accompanying interviews

Fifteen semi-structured interviews were conducted amongst professionals in the context of flood disaster management, selected from the Water board Hollands Noorderkwartier. This Water board covers a vast part of flood prone area in the north-western part of The Netherlands. In order to be able to retrieve insight in how models are embedded in the flood disaster management process, the interviews were used to draw a Social Network (Ebener et al., 2006; Liebowitz, 2005).

Social Network Analysis allows to structure roles, tasks and properties of information exchange in a flood disaster organization. First, participants were asked what their roles and accompanying tasks are in the organization (Choo, 2001; Gemert-Pijnen et al., 2010; Maguire, 2001; Meadow and Yuan, 1997). Second, the participants were asked with whom they usually communicate to fulfill their tasks and which information is important in this communication. To help in this process, information was coded into four different types: situational, technical, procedural and political information. Situational information covers the actual situation in the field, such as observed dam breaks and inundation areas. Technical information includes the physical aspects of floods, such as water depths, flow velocities and derived estimations of damages and losses of life (Gummesson, 2000). Procedural information covers information about organizational procedures, reports and planning (Leeuwis and Van den Ban, 2004; Wesselink et al., 2009). Political information is about the accumulated experience of decision-makers in various governmental organizations, willingness to cooperate, power relations, trust and responsibilities (Collins and Evans, 2002). For each information type, an indication was given of the lead time in which the information should be generated (see Figure 1).

The outcomes of the interviews were verified in a workshop with 10 of the interviewees (Leskens, 2011).

2.4. Flood disaster exercise

A flood disaster exercise was organized in which a state-of-the-art flood model was applied and evaluated. In this flood disaster exercise, a threatening flood was simulated in which the participants had to make decisions about, for example, evacuations and the closure of dam breaks to minimize economic consequences and losses of life. Around 100 professionals involved were selected from the Municipality of Delft, the emergency organization of the area of Haaglanden and the regional Water board Hoogheemraadschap of Delfland. These organizations cover a flood prone area in the south-western part of The Netherlands. The collaboration of these parties is shown in Fig. 2.

In this flood disaster exercise, a crisis was simulated by using a pre-designed script (Table 2) with several accidents, which were unknown beforehand by the 100 participants.

A sophisticated inundation model (Sobek1D2D, 2001) was made available to the team of model specialists. This model was able to simulate the overland flow and distribution of polluted water at a high spatial resolution of 1 m. The model results were communicated through digital maps in an internet interface and 3D visualizations on a projector screen to the policy makers (Table 3, Figs. 3 and 4).

At the end of the disaster exercise, the use of the model was evaluated by a questionnaire to all participants at the end of the exercise. In this questionnaire it was asked whether or not the participants used model information and, in the case they did, how this was valued. The results of the questionnaire were validated in a focus group with 8 representatives of the participants (Leskens and Pleumeekers, 2011).

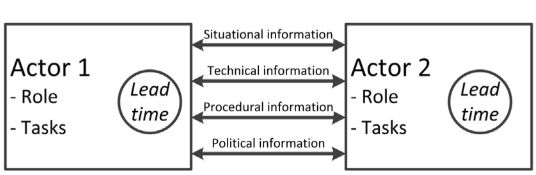

Fig. 1. Content of interviews: roles and tasks of actors different types of information and the lead time to generate this information.

3. Results

3.1. Results of the document review

The evaluation reports gave a general impression of the constraints in the use of technical information encountered during practical situations of flood disaster management. The information provided by flood simulation models is largely neglected and is still substituted by other preferred sources of information, such as elevation maps or rules of thumb, even when these sources do not capture the technical complexity of how floods evolve over time and depth under various conditions like model outputs do. Shortcomings of these preferred information sources are dealt with by assuming worst-case scenarios. For example, evacuation plans are based on the maximum area of inundation, which is the result of a comparison between maximum water levels and the elevation map. Flow patterns of water are not considered in this, whereas they highly influence the area that can be inundated and give valuable information about the course over time of the inundation. In short, decision-makers rather used basic information in combination with assumptions for worst-case scenarios than using advanced flood simulation models. In literature, this simplification strategy is well recognized under comparable situations of decision-making, characterized by time pressure, multi-actor collaboration and high complexity and uncertainty (Janis and Mann, 1977; MacCrimmon and Taylor, 1976). Unfortunately, this has sometimes led to wrong or unnecessary measures, for example the evacuation of areas that are not at risk of being inundated (Hoekstra, 2008).

We identified different reasons for this limited use of model results. Obviously, decision-makers required predictions that specifically connect to the actual situations and to the available means to undertake action. First, this overview of the actual situation was often not known by the modelers, whereas this insight was required to make model predictions that fit to the actual circumstances. Second, even when these actual circumstances were known, the used models were not fast enough to make model calculations during a flood disaster event. The decisions that were made were therefore usually based on the information that was directly available, such as an elevation map and basic rules of thumb as mentioned above. In cases that precalculated flood scenarios were available, an interpretation of this information had to be made in order to make it applicable in the actual circumstances. A recurring theme was that decision-makers were unsure if this information from flood models was reliable and whether they should make decisions based on that information.

3.2. Results of interviews and Social Network Analysis

The Social Network Analysis provided in-depth insight in the flow of model information in the network of participants in a flood disaster organization. As for each individual participant the communication lines were mapped, a densely branched network was drawn. We summarized this network in Fig. 5, by aggregating individuals with the same connections and information exchange into groups. The connections between those people in one group

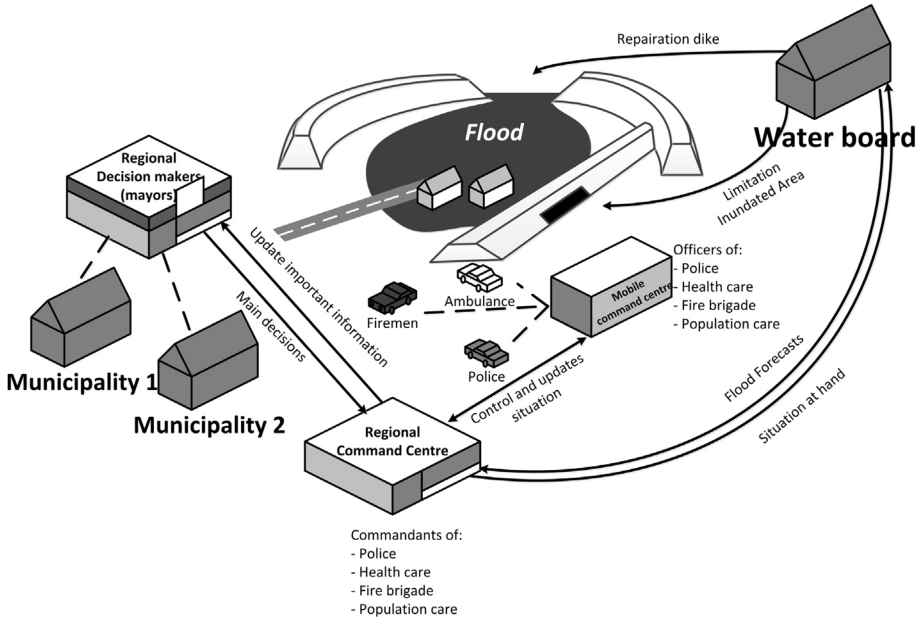

Fig. 2. General organization structure and information flow during a flood calamity in the Netherlands.

are not shown to have a better overview. The interviews showed that the interaction between participants within a group consisted mostly of face-to-face contact. The interaction between the different groups was arranged in formal meetings, in which representatives of the groups gathered and exchanged information. Also telephone and e-mail were used in the exchange of information between different groups. Given the discrimination between different types of information, the indication for the importance of this information and the lead time in which this information was generated, insight could be gained in the flow of information during a flood disaster. In Fig. 5 the type and lead time of the exchanged information is shown.

The following points can be concluded from the Social Network, specifically concerning the role of model information:

- The main consumers of model information are the policy makers, who need information to advise the decision-makers about the effectiveness of various measures and give the regional command centre forecasts about the arrival of a flood. Demanded information includes variables such as predicted future water levels and flow velocities in order to judge the seriousness of the situation and predicted arrival times of the flood in order to plan responses.
- Model information is generated by the operational team of model specialists. To provide model predictions that fit the actual situation in the field, these model specialists are dependent on situational reports of the policy makers, who in turn receive this from the operational team and the regional command centre.
- Both the situational reports and the demands for required scenarios are received by the model specialists with a delay. This delay is caused by the lead time in which situation information is passed to the model specialists in the meetings of the policy analysts, which generally takes place every half hour. For example, when information about the width of dam breach is observed in the field, which is a vital input for the models, this has to be passed from the regional command centre to the policy analysts and then from the policy analysts to the model specialists. As each team meets half hourly, this information will only reach the model specialists after approximately an hour. Given the calculation time of actual models, predictions fed with this new information, can be provided at the soonest after 2 h. Including the meetings that are required to hand over this information to the regional command centre, the total time between observation of the new dam breach width and the accompanying predictions is around 4 h.

Table 2
Time table of event exercise.

Time	Events related to water levels	Events related to water quality
5:00 AM–9:00 AM	Heavy rains and high water levels in main discharge canal ‘the Schie’	
9:00 AM	Inner city of Delft is threatened by high water levels (canals of inner city are directly connected to the Schie).	
9:30 AM	Sluices that close off the inner city of Delft from the Schie fail to work automatically	
9:30 AM–10:30 AM	Sluices have to be closed by hand	
11:00 AM	Accident with a truck containing a tank with poisonous matter that bumps against one of the main pumps in Delft. This pump has the function of pumping the excess rainwater from the canals of Delft into the Schie in case of a closure of the sluices.	Accident with truck: poisonous liquid flows into the inner city canals of Delft
11:00 AM–3:00 PM	Dilemma: open the sluices to dilute the poisonous matter and accept inundation, or: remain the sluices closed and accept the poisonous matter in the inner city.	

Table 3
Decision supporting model tools.

Property	Description
Processes modeled	Hydrodynamic overland flow, distribution of liquid pollution in water
Available results	Flood maps, flood simulations (movies), distribution maps of pollution
Detail (resolution)	Spatial: 1 m^2 Levels: 0.01 m
Communication of results	Digital maps and movies in web portal, 3D-visualization (see Figs. 3 and 4)
Initial conditions	Water level gradient in canal An initial concentration of the marker at a certain position

- Sequences of events in the flood prone area can evolve rapidly, but information about events is received only gradually by the regional command centre. Moreover, information can be contradictory as it is reported by different people. As a result, model information can fall far behind on the actual situation in the field and therefore become useless in a fast changing environment. In these cases, the model specialists tend to just use their common sense and give general advice instead of continuing to use the output of the detailed models.

3.3. Results of flood disaster exercise

In this questionnaire the decision-makers and policy analysts were asked if they used the model output as an input for their decisions and how they valued this. 24 of the 100 participants filled in the questionnaire. The main reason that the 74 other participants did not fill in the questionnaire was that they had no direct interaction with model information. This fact already confirms the limited use of model information during the flood disaster exercise. Also the outcomes of the questionnaire show the limited use of models in the decision-making process for both decision-makers and policy analysts at the Water board and the Municipality. They mainly disagree with the statements concerning the usefulness of model information as input for decisions (see Table 4). The main source of technical information for these decision-makers and policy analysts are the general estimates of the water experts. Only minor differences in the results of the questionnaire exist between decision-makers and policy analysts and members of the Water board and members of the Municipality of Delft.

The focus group, in which the results of the questionnaire were evaluated, yielded the following insights:

- While the specialists are the main source for model information for policy analysts and decision-makers, these experts are very restrained in providing this information. They lost trust in the model when it proved to be not flexible enough to predict the exact scenarios they were interested in. Given their responsibility in providing technical information to the policy makers and the big impact of the measures under consideration, they would not risk giving wrong interpretations to scenarios that are already calculated and therefore would rather switch to providing general information without using the model.
- Uncertainty of the technical information was mainly a consideration for specialists. They demanded ranges, numbers or percentages from the model results that quantified this uncertainty. As this information could mostly not be given in the desired extent, they were very cautious to hand over model results to the policy makers. Since other actors in the network considered information provided by the specialists as reliable, the specialist was cautious to supply information.
- The following answers were given to the question asked to model experts about what would constitute a useful decision-support flood model during a flood disaster:
  a. The flood model should support the expert by making new simulations, in the light of the current circumstances. The

Fig. 3. 3D-visualization: prediction of the inundation in the city of Delft.

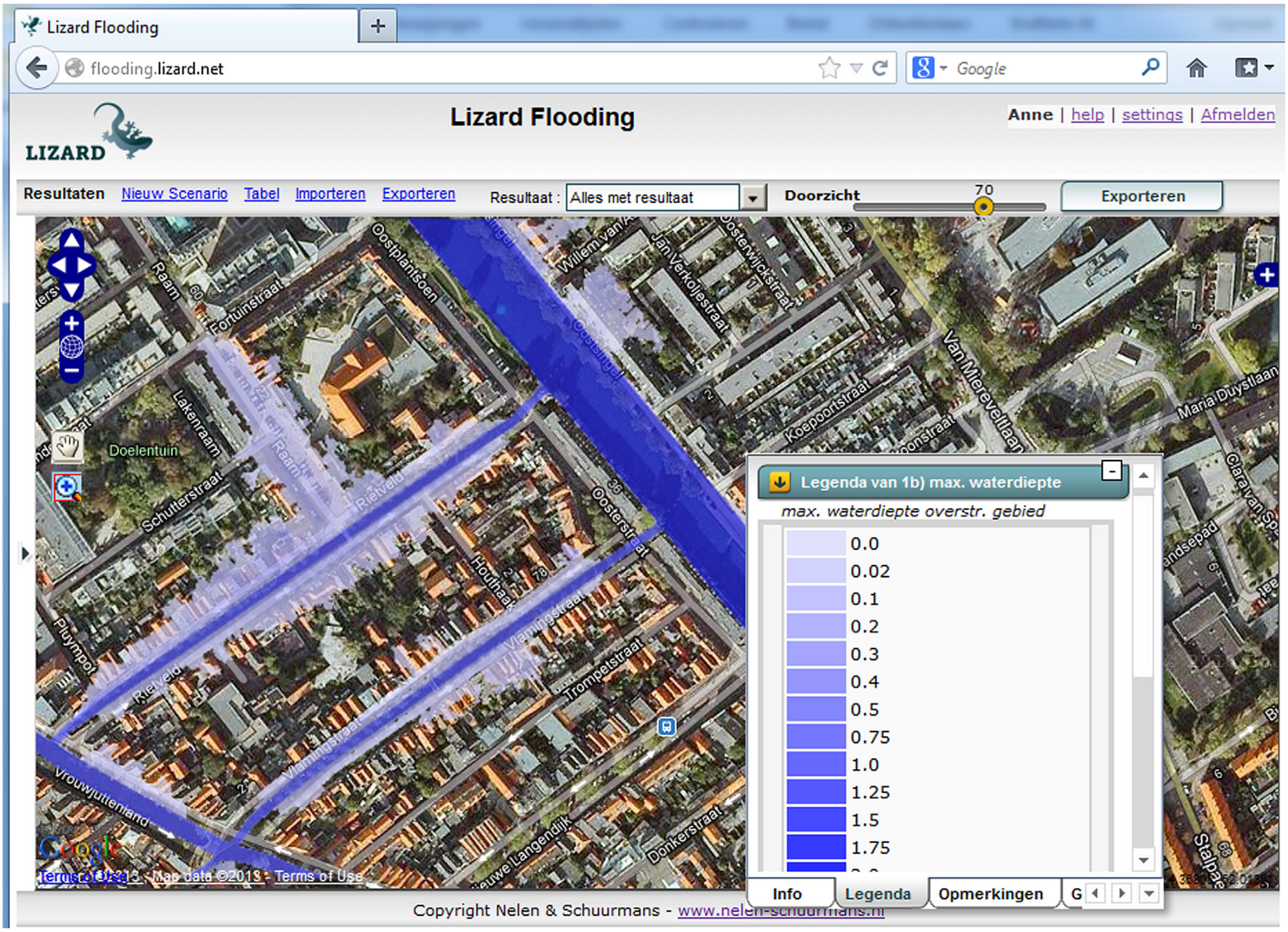

Fig. 4. Web portal with model results: prediction of the inundation in the city of Delft.

current model was considered to be too static as a consequence of fixed options in the model that did not allow recalculation of the scenarios that were under consideration.

b. Scenarios should be calculated quickly to be able to provide information to keep pace with events during a flood calamity. The current model had a calculation time of 2 h, but this should be in the order of minutes.
c. The users wish to practice regularly with the flood model.
d. The communication of model results in the current internet portal should be customized for various types of users. Two main groups were identified. First, water experts, to understand the actual situation and explore the effects of different measures and explain their advice to the decision-makers. Second, the decision-makers and stakeholders: to get an impression of the actual situation and effective measures.

Results from the document review, Social Network Analysis and the flood disaster exercise confirm that flood models are currently rarely used, although they are very sophisticated in terms of detail, physical processes and visualization means. This limited use was primarily caused by the delay in which this information is provided to decision-makers. According to our analysis, delays are caused by two main reasons. First, by technical reasons such as inflexibility to adapt a model to current situations and the computation times that are too long to match the frequency of the decisions that have to be made. Second, by delays that emerge in the exchange of information among participants in the flood disaster organization, which cause that decision-makers receive outdated information that is not useful. This delay in communication is related to the standardization of the flood disaster organization in terms of tasks, roles and communication lines. This standardization is very common in flood disaster management, as such a clear command structure, comparable with those in armies or fire departments, functioning well under circumstances of disasters and time pressure. However, this command structure also causes that model information is often outdated and therefore not used Moreover, once model information is sent into the network of actors, experts lose the possibility to give explanation to the applicability of this information, which can therefore be used wrong. This makes the model experts reserved to send model information to others in the network.

These technical and organizational limitations are inter-related. Namely, technical limitations of models make it necessary that model outputs are first interpreted by model specialists and, consequently, are translated by policy makers to useful information for decision-makers. In the same time, this exchange of information between specialists, policy analysts and decision-makers causes the delays that are an important reason for the limited use of the model outputs. These interdependencies between technical limitations, organization structure and use of models by decision-makers are shown in Fig. 6.

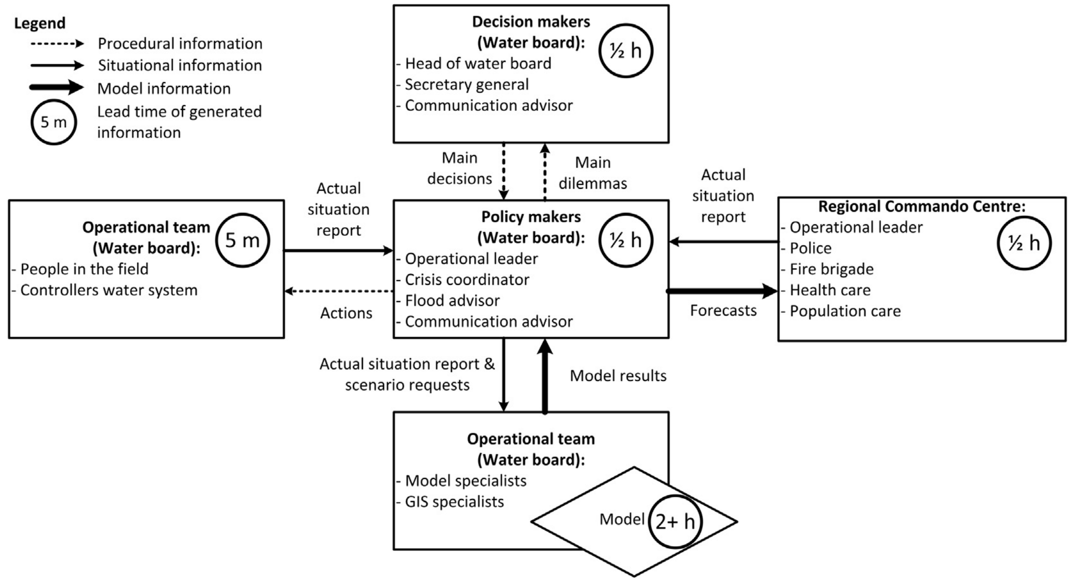

Fig. 5. Information flow during a flood calamity; in circles the typical lead time is shown per category of actors.

4. Discussion

The results of this research show that the discrepancy between what decision-makers demand from models and what models can actually provide is not only an issue of inadequate model output and levels of uncertainty but also an issue of slow and inflexible models and too many intermediaries between model output and decision-makers. These results were found in various case studies in the Netherlands practice of flood disaster management. We argue that the conditions, under which our findings are valid, can also be found in many cases outside the Netherlands. These conditions are that slow and inflexible models are applied in a complex network of participants, mutually depending on each other's information and having a strict division of tasks and responsibilities. This causes delays in providing model information as input for actions and hesitations with model experts to provide model information to others in the network, as they are considered fully accountable for its accuracy. Case studies of flood disaster management with comparable conditions can be found all over the world, for example in Sweden (Nobert et al., 2010), the US (Wood et al., 2012), Vietnam (Tran et al., 2009) and the UK (McCarthy et al., 2007).

Regarding the methods we used, Social Network Analysis has proven to be helpful to better understand the technical and organizational limitations of current flood disaster management. It provided valuable insights in which information the participants in the decision-making processes need in order to fulfill their tasks and it showed how information is passed on between different participants. One should be careful to draw generalized conclusions based on Social Network Analysis beyond flood disaster management. As the decision-making process during flood disasters is to a significant extent standardized in terms of tasks, roles and communication lines, generalized conclusions could be drawn for this specific field. Applying Social Network Analysis in other, less standardized decision-making contexts, such as decision-making about a flood resilient spatial planning, will yield mainly conclusions that count for that specific group of participants.

Although nowadays models are limited by long computation times and are too inflexible for the use during flood calamities, this does not mean that they are useless. For example, in the decision-making context in which structural protection measures are designed, such as dikes or dams, the variety of design options will be smaller and the available time to do model analysis much longer. Also the preparation to floods using flood hazard maps can still be done with present models, although this research shows that these maps often do not grasp the specific question of decision-makers facing flood disasters. These maps often reflect the technical view of the water expert who prepared them, whereas information demands that emerge during a flood calamity can hardly be taken into account.

The results of this research shed a new light on the methods proposed by scholars to overcome the discrepancy between what models provide and what decision-makers demand. The application of one of the methods proposed, direct involvement of

Table 4
Results of questionnaire flood disaster exercise.

	Total	*N*	Decision-makers water board	*N*	Decision-Delft	*N*	Policy analysts water board	*N*	Policy analysts Delft	*N*
Calculated water velocities useful as input for decisions	1.7	23	1.0	1	1.3	4	1.9	14	1.5	4
Calculated water depths useful as input for decisions	1.4	23	1.0	1	1.3	4	1.4	14	1.5	4
Calculated flood animations useful as input for decisions	2.0	24	1.0	1	1.3	4	2.3	14	1.8	5
Calculated water quality useful as input for decisions	2.2	24	1.0	1	1.3	4	2.7	14	1.8	5
Water specialists are a useful source for model information	2.8	24	4.0	1	2.0	4	3.0	14	2.8	5
Digital water portal useful as source for model information	1.9	22	1.0	1	1.3	4	2.1	12	2.2	5
3D visualization useful as source for model information	2.0	24	1.0	1	1.5	4	2.2	14	2.0	5

Scoring: 1 = fully disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = fully agree

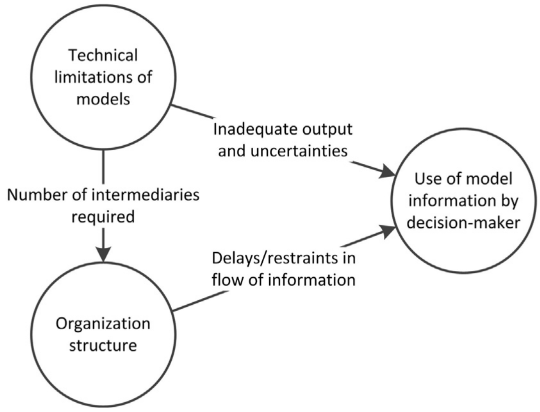

Fig. 6. Interdependencies between technical limitations, organization structure and use of models by decision-makers.

decision-makers in the computation of flood predictions (Voinov and Bousquet, 2010), will only work if technical limitations of models are overcome in terms of computation time and flexibility to adapt models to actual circumstances. Besides this, organizational delays in the exchange of situational information should be solved to use these actual circumstances as input for the model. The other method proposed, improved output of models, such as ensemble calculations (Demeritt et al., 2010; Frick and Hegg, 2011; Kwakkel et al., 2010; Walker et al., 2001), also sets high demands on technical requirements of the model. This method requires short computation times to provide ensemble results on time and flexibility to vary input parameters. This variation of input parameters should also be communicated properly and situational information should be exchanged fast. This will result in a range of outcomes which at least defines the scope of what may happen and what may not. This information can be valuable for decision-makers because actions can be undertaken in areas that, for example, will definitely be inundated, and further investigation can be undertaken for areas where inundation is uncertain.

5. Conclusions

In this paper we identify why important decisions in flood disaster management are so little supported by information from flood simulation models. The document review, Social Network Analysis and flood disaster exercise showed the importance that flood predictions have for policy analysts and decision-makers to plan measures and inform other parties, such as the emergency services. At present, data sources such as elevation maps and rules of thumb are used to provide these predictions. However, our results indicate that this information could be improved by models that provide rapid predictions of floods, based on actual information.

It was shown that these rapid predictions are hard to provide for model specialists due to both technical limitations of the current models and organizational limitations. Technical limitations imply that current models are too inflexible to adapt to the current situation or to predict the effect of responses and have too long calculation time to keep up the frequency in which decisions are made. Organizational limitations imply that the exchange of situational information and model information gets delayed by the several intermediaries it has to pass. Division of tasks and responsibilities in the flood disaster organization also cause hesitations with model experts to provide model information to others in the network, as they are considered fully accountable for its accuracy. Moreover, experts lose the possibility to give explanation to the applicability of their predictions, which makes them extra reserved to do so.

In conclusion, our research clearly provided new insights in the reasons for limited use of models for decisions in flood disaster management. Besides the discrepancy between what information is demanded by decision-makers and what models can actually offer in terms of output and accompanying uncertainties, also delays and constraints that emerge in the exchange of model information through the network of participants influence the use of models by decision-makers.

For model development this means that the first bottlenecks to solve are the technical limitation of models in terms of inflexibility and long computation times. For example, new numerical schemes for the computations of overland flow are available that allow for computation times that are more than 100 times shorter than conventional models (Casulli and Stelling, 2013; Stelling, 2012). This will not only provide more adequate model outputs, but will also decrease model uncertainties, as ensemble calculation become a serious option.

Our research shows that, even when in the future flexible and fast models become available, current communication lines in the flood disaster organization can still delay the communication of model results and can cause that they are easily outdated and not used. Currently, this is a consequence of the strict communication protocol during flood disasters, characterized by the exchange of model information during fixed periodic meetings with a frequency of a half to one hour. To benefit from future flexible and fast models, this frequency should be higher to provide policy makers and decision-makers for model information that fits in the actual circumstances. An option is to use those models directly during meetings in which decision-makers gather to diagnose flood risks and test the effectiveness of suggested measures. We suggest further research to explore how such an interactive use of models can be effectively applied in the decision-making process during flood disasters, in which, according to our results, decision-makers follow simplification strategies to deal with the large complexities and uncertainties (Kahneman and Tversky, 1979). Under such circumstances, vivid imagery from flood models can lead to an overestimation of the probability that a flood will actually materialize (Sunstein, 2002) and fast outcomes of models can easily be interpreted wrongly or differently by different decision-makers, which can lead to opposed measures (Weick and Sutcliffe, 2005). This demands a systematic and understandable framework to organize the various sources of technical information and requires expert judgment (Thacher, 2009). Also Multi-Criteria Decision Analysis (MCDA) can provide a systematic methodology to combine these inputs with cost/benefit information to rank decision alternatives (Huang et al., 2011). Different web-based communication systems are already available but need further implementation and improvement to be actually used for this information management.

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