Application of an Interactive Water Simulation Model in urban water management: a case study in Amsterdam

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ABSTRACT

Water simulation models are available to support decision-makers in urban water management. To use current water simulation models, special expertise is required. Therefore, model information is prepared prior to work sessions, in which decision-makers weigh different solutions. However, this model information quickly becomes outdated when new suggestions for solutions arise and are therefore limited in use. We suggest that new model techniques, i.e. fast and flexible computation algorithms and realistic visualizations, allow this problem to be solved by using simulation models *during* work sessions. A new Interactive Water Simulation Model was applied for two case study areas in Amsterdam and was used in two workshops. In these workshops, the Interactive Water Simulation Model was positively received. It included non-specialist participants in the process of suggesting and selecting possible solutions and made them part of the accompanying discussions and negotiations. It also provided the opportunity to evaluate and enhance possible solutions more often within the time horizon of a decision-making process. Several preconditions proved to be important for successfully applying the Interactive Water Simulation Model, such as the willingness of the stakeholders to participate and the preparation of different general main solutions that can be used for further iterations during a work session.

Key words | decision support systems, flood risk management, participative modeling, spatial planning, stakeholder participation

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INTRODUCTION

Water simulation models are computer programs that can simulate the physical processes that are involved in water management, such as rainfall-runoff, surface flow, drainage and sewer flow. These models allow decision-makers to diagnose extreme storm events and to identify and dimension alternative solutions. Model simulations are based on physical equations, features of an area, such as elevation and roughness resistance, and external forces, such as storm events (Bates & De Roo 2000; Al-Sabhan *et al.* 2003; De Moel & Aerts 2011; Stelling 2012).

To use water simulation models, special expertise is required. This includes expertise about how input model parameters have to be set, how model runs have to be executed and how model outputs have to be post-processed for tangible results. Organizations such as water boards or municipalities often have separate departments to operate models, staffed by model specialists. To actually use models for the decisions that need to be made, model outcomes are *communicated* from this separated modelers' domain to the decision-makers' domain (Morss *et al.* 2005). Traditionally, this is done by documents or maps in which the model outputs are translated to standardized performance indicators, such as the duration of inundation under a standardized storm event (e.g. 100 millimetres of rain in 1 hour). When these indicators exceed their norm, measures are prescribed from which decision-makers can choose, such as enlarged sewer pipes or a higher pump capacity (Rioned 2010).

Nowadays this standardized generation of model results and solutions does not fully meet the needs of the decision-makers' domain anymore. Instead of standardized solutions for improving sewer or drainage systems, a broader scope of possible solutions is being investigated, such as vegetation roofs that slow down the discharge of rainwater, squares that can function as water storage basins or elevated roads to maintain important

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transportation routes (Dawson 2007; MacKenzie 2010). These alternative solutions often benefit from specific opportunities that emerge in time, for instance when a road is restructured or when new houses are built (Lindley *et al.* 2007). It is therefore harder to prescribe this in standardized solutions, as is indeed possible in the case of solutions for sewer and drainage systems. Therefore, participants from departments and organizations that are active in spatial planning are involved in the decision-making process to explore opportunities to solve water problems as well (Walsh *et al.* 2011). To involve these parties, multi-stakeholder work sessions are often organized, for example to define problems, choose measures and divide responsibilities to take actions, or else less defined work sessions such as brainstorming sessions (Linkov *et al.* 2009).

As models can only be operated by model specialists in the 'modellers' domain', model information is prepared prior to these multi-stakeholder work sessions (Walsh *et al.* 2013). However, this model information quickly becomes outdated when problem definitions change or when new suggestions for solutions arise (Leskens *et al.* 2014). This leads to work sessions in which decision-makers have to deliberate about solutions whose technical effectiveness they do not know. It can even lead to decisions in which the technical effectiveness is ignored, since it is not directly available (Morss *et al.* 2005).

We suggest that available model technology, i.e. fast and flexible computation algorithms and realistic visualizations, allow this problem to be solved by using simulation models *during* work sessions so that decision-makers are directly involved in diagnosing water problems and in assessing suggested solutions. This is further clarified in Figure 1. It shows the decision-making process as a sequence of work sessions, typically lasting a few hours, to solve a certain issue (Lindblom 1959; Mintzberg *et al.* 1976). Each work session is prepared by models and preceded by actions, such as a redefinition of the issue, further research, the involvement of other actors, an elaboration of selected solutions or, finally, a satisfying solution (Hage 1980). Models used to be applied exclusively in the preparation phase. We propose the use of models in both the preparation phase and the work session itself.

Naturally, this requires simulation models that can be easily adapted to assess suggested solutions during work sessions and are fast enough to provide multiple outcomes within the duration of a work session. It also requires a methodology to effectively apply such models in decision-making processes.

It cannot automatically be expected that technical outputs from interactive models will always be appreciated and used by decision-makers. Decision-makers may also have other motivations to value one solution above the other (March 1978; Simon 1987), such as former personal or political experiences with other participants in a work session (Langley *et al.* 1995). Moreover, the demands for sophisticated information from models depend on the degree of routine with which decisions have to be made, how regularly a decision is required, what the level of impact is that a decision will have and how quickly a

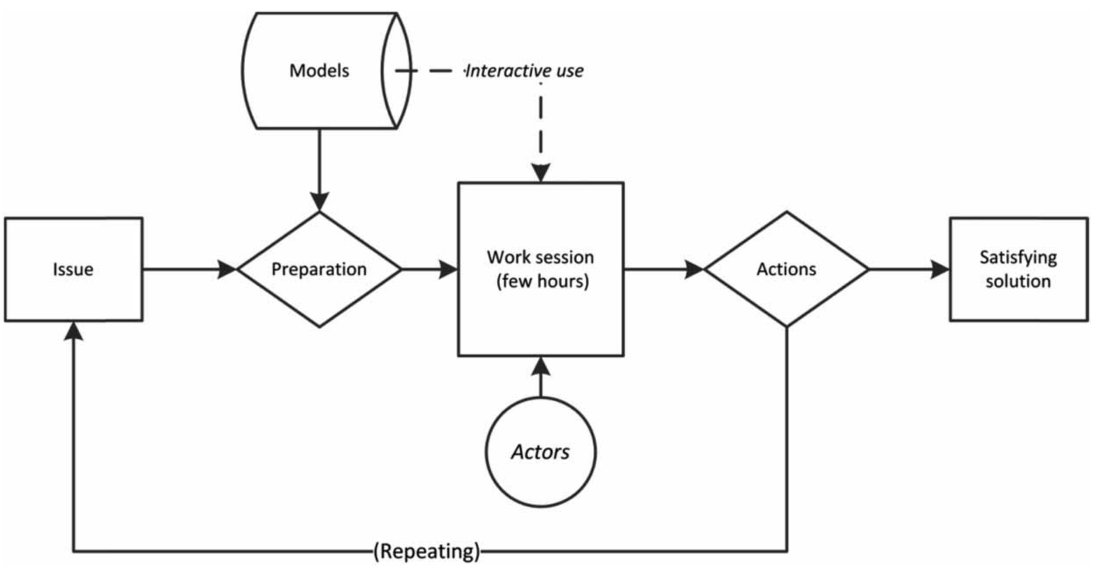

Figure 1 | Use of models for preparation or interactive use in the sequence of work sessions.

decision needs to be made (Butler *et al*. 1979). For example, in situations in which decision-makers are acting under circumstances of high time-pressure, large decision-impact and high complexity, they tend to discard sophisticated model results that seem to increase the complexity they already have to deal with (MacCrimmon & Taylor 1976; Janis & Mann 1977; Kahneman & Tversky 1979; Gray 1989; Morss *et al*. 2005).

The goal of this paper is to explore whether an interactive model can improve the decision-making process in urban water management and how it is accepted by decision-makers. To this end we applied an interactive model in two workshops and evaluated its use by group evaluations and questionnaires. This interactive model is named the 'Interactive Water Simulation Model' and was developed in the project 3Di Water Management in the period 2010–2013. It was technically developed by a team of model developers from the Delft University of Technology and Deltares, in close cooperation with two regional water boards (Hoogheemraadschap Holland Noorderkwartier and Hoogheemraadschap van Delfland) and Nelen & Schuurmans consultants.

In this paper we focus on how the gap between the modelers' domain and the decision-makers' domain in environmental decision-making can be bridged by using a fast and easy adaptable model during work sessions. We hope our findings can contribute to the ongoing field of research concerning the practical application of environmental models in decision-making processes. This topic has recently become the subject of increasing attention in the 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 & Krajewski (2013) focus on the role of integrated information systems to communicate model outputs to decision-makers and Balica *et al*. (2013) and Zagonari & Rossi (2013) investigate how model results can be translated in performance indicators usable in multi-criteria analysis.

Aside from the introduction, this paper consists of five more sections. In the second section, the Interactive Water Simulation Model is presented. This is deliberately done in a separate section, since the development of this new model is not itself part of our research. However, the reader should have sufficient insight into the interactive characteristics of the model to be able to understand the findings of this research. Third, the methodology is presented, consisting of a case study in Amsterdam in which the Interactive Water Simulation Model was applied for a specific area, used in two workshops and evaluated by group evaluations and questionnaires. In the fourth section the results of these evaluations and questionnaires are presented. Finally, we discuss our findings and draw conclusions in the last two sections.

THE INTERACTIVE WATER SIMULATION MODEL

Development of the model

Before the technical development of the Interactive Water Simulation Model was carried out, user needs were investigated by means of interviews. These user needs are related to the *functions* that participants in a work session desire from an interactive model to support the decisions they make. For example, participants in a work session might desire that the model computes instantaneously the effectiveness of different proposed solutions in terms of reduced inundation depths and damages.

The interactive water model presented in this paper is based on user needs that were derived from interviews among policy analysts involved in the field of Urban Water Management, who often participate in stakeholder work sessions. The interviews were conducted in 2011 among 13 employees of the regional water board Hoogheemraadschap van Delfland and the municipality of Rijswijk, located in the southwest of the Netherlands. Each interview lasted 1 hour and was semi-structured. The interviews focused specifically on three questions: (1) What is your task or role in decision-making processes in urban water management? (2) What information do you require to carry out this task? (3) What functions do you need from a model that can be operated during a work session?

The 13 semi-structured interviews yielded the following functions as being considered important in using an interactive model: (1) technical reliability; (2) the possibility of assessing the effectiveness of multiple scenarios within the time horizon of a work session; and (3) understandable output for non-water specialists. A full report of the interviews can be requested from the author (Leskens & Pleumeekers 2012). Technical experts of the development program 3Di Water Management translated these functions to technical model properties by finding appropriate modeling techniques and implementing these in the model software (see Table 1). This is further elaborated in the following sections.

Table 1 | Technical model properties derived from user needs mentioned in the interviews

User needs	Technical model properties	Details
Technical reliability	Current input data	Current data of elevation, land use, sewer system and water system (ditches, canals, weirs, siphons, pumps, culverts)
	Accurate physical representation of processes	Rainfall-runoff, overland flow and sewer flow processes included
Ability to assess the effectiveness of multiple scenarios within the time horizon of a work session	Short computation times	2–5 min for a rainfall or dam break event of 48 h (standard area of 6 km^2)
	Ease in adapting input of the model to test suggested measures during work sessions	Adaptable elevation map, infiltration layer, interception layer and water system
Understandable output for non-water specialists	Resolution of output that connects to the spatial variability of inundations	Spatial resolution of 1 by 1 metre. Depths in centimetres
	Realistic visualization	Spatial visualization of inundation on topographic maps or images (two- or three-dimensional)

Technical properties of the model

The interactive water model we applied consisted of three core innovative aspects: (1) short computation times in combination with a high spatial resolution and an accurate physical representation of all relevant processes; (2) ease of model adaptability to test suggested measures; and (3) a realistic visualization of model outputs. These properties are further elaborated below. The description of other technical properties can be requested from the development team of 3Di Water Management (info@3di.nu).

Short computation times

The model combines a high spatial resolution (i.e. 0.5 metre by 0.5 metre) and the inclusion of all relevant processes (i.e. overland flow, groundwater flow, canal flow and sewer flow) with computation times in the order of minutes. This make the Interactive Water Simulation Model much faster than conventional models. These conventional models, such as Sobek (http://www.deltaressystems.com/hydro/product/108282/sobek-suite) or Mike11 (http://www.mikebydhi.com), have computation times in the order of hours, for the same level of detail. Further explanation about which process are included in the model and which computation algorithms are used to ensure the short computation times is given in the Appendix (available online at http://www.iwaponline.com/wst/070/240.pdf).

Ease of the adaptability of the model to test suggested measures

A user interface was developed that allows the users to easily adapt the schematized study area in three aspects (see Figure 2). First, the elevation map can be incrementally increased and decreased on specific locations. Changes to the elevation map can, for instance, be applied to simulate water storage basins, gutters or elevated roads. Second, the land use can be changed in the user interface. This land use is related to the surface roughness, interception volume, infiltration rate, crop type and the porosity and permeability of the soil. By changing the land use from paved area into grassland, for instance, all the aforementioned physical parameters are changed in the model. This allows the user to simulate solutions such as permeable parking lots or green roofs. Third, the dimensions of the water system and sewer system can be changed in the interface, as in the widening or narrowing of canals or the addition of manholes for drainage purposes.

The user interacts with the user interface via a touch table. This is conducive to the workshop participants' direct involvement in the use of the interactive model. The operation of the model on the technical level was carried out by a model specialist.

The speed and ease with which all aspects of the model can be adapted by non-model experts are the core innovative aspects of this interface. In conventional model interfaces mentioned above, adaptations can only be made by model specialists. Making adaptations in these conventional

Figure 2 | Use of the Interactive Water Simulation Model for workshop Watergraafsmeer.

models, together with the accompanying computation time of an adapted model scenario, takes several hours and can therefore not be carried out during work sessions.

Realistic visualization of model outputs

The model output is visualized in a virtual three-dimensional environment. This environment is based on data from laser imaging detection and ranging (LIDAR), measured by aerial scanning with helicopters. This technology provides the opportunity to capture the surface of an area in dots, all having *x*-, *y*- and *z*-coordinates. The LIDAR data that are available in the study area consist of approximately 15 dots per square metre. This 'point cloud' is colored according to the aerial photographs which were also available in the study area. By applying big data processing technology (De Haan 2009) these data are presented in a virtual environment comparable to flight simulators. In this virtual environment, the model output of the Interactive Water Simulation Model is presented (see Figure 3). More details on this technology can be found in Kehl *et al.* (2013).

The core innovative aspect of this realistic visualization of model outputs, in comparison to the usual two-dimensional flood maps, is that users can assess the inundation depths in relation to real objects, such as houses, trees and cars. Therefore, no legend with color codes is necessary, which makes the assessment of model outcomes more accessible for users that are not used to working with maps.

METHODOLOGY

General

To reach our goal we carried out a case study in Amsterdam, consisting of two workshops in which the Interactive Water Simulation Model was applied. In the first workshop 20 people participated and in the second workshop 22 different people participated.

Figure 3 | Visualization of model outcomes in a 3D environment.

To assess whether the interactive model improved the decision-making process (i.e. the first part of the goal of our research) we chose three different criteria. These criteria are related to our perspective on decision-making processes as a sequence of work sessions in which various participants diagnose problems, redefine issues, elaborate suggested solutions and finally choose a satisfying solution. First, we focused on how the model helped the various participants to understand the existing problem; second, how the model influenced the process of generation of possible solutions; third, how the model helped in the selection of solutions. To assess the acceptance of the model (i.e. the second part of the goal of our research) we focused on the questions of whether participants considered the model as reliable (Brugnach *et al.* 2007) and whether they would apply an interactive model in future work sessions.

These criteria were further elaborated in a questionnaire that was send to the participants and were used in group evaluations after the workshops. The content of the workshop, the group evaluation and the questionnaire are further explained in the following subsections.

Set-up of workshops

Two work sessions with a similar set-up were organized to define a set of measures to make Amsterdam resilient to extreme rainfall events of 60–100 mm in 1 hour, which may be expected to occur more often as a result of climate changes (Hanel & Buishand 2010). The workshops focused on two districts in the region of Amsterdam: (1) Watergraafsmeer and (2) Purmerend. The workshop in the district Watergraafsmeer was carried out within a Dutch national research program called Knowledge for Climate, Climate Proof Cities 3.3. The workshop in Purmerend was carried out within the Urban Water Plan Purmerend 2015.

The following program was followed in both workshops:

1. Introduction of the technical background for the Interactive Water Simulation Model.
2. Demonstration of the effects of a rainfall event of 100 mm in 1 hour in the Interactive Water Simulation Model.
3. Demonstration of various previously prepared scenarios in the model, based on the expert knowledge of urban water specialists of the municipality. As sewer systems are not designed for rain events of 100 mm in 1 hour, the focus was on measures above the surface, i.e. measures in the spatial planning of the city. This included permeable parking lots, squares with the ability to store rainwater and water storage on green roofs (MacKenzie 2010).
4. Application of the Interactive Water Simulation Models. The effectiveness of the prepared scenarios was presented directly in the model to the participants in groups of around ten people. Due to the short computation times and the flexibility to change the model, the participants in the workshops could test various other solutions such as elevated roads or widened gutters.

Group evaluation and questionnaire

The group evaluations were carried out after the application of the Interactive Water Simulation Model during the workshops. All participants were asked to express their opinions about if and how the application of the Interactive Water Simulation Model improved the decision-making process during the workshop, and how it can improve future decision-making processes. These opinions were recorded and minutes of the meetings were made, consisting of representative comments expressed by the participants.

After the workshop, the participants were asked to respond to a questionnaire. In this questionnaire the respondents were asked to give a score to different statements pertaining to their appreciation of the use of an interactive water model during work sessions. The participants were asked to give a score on a scale from 1 (totally disagree) to 5 (totally agree) on the following statements:

1. Work sessions are necessary links in a decision-making process.
2. Work sessions are important for understanding each other's perspectives on the problem.
3. In work sessions substantive decisions are made.
4. The interactive water model helped me to better understand the problem.
5. The interactive water model helped me to better understand the effectiveness of suggested measures.
6. The outcomes of the model were reliable.
7. The outcomes of the interactive water model were understandable.
8. I would apply the interactive water model in future work sessions.

RESULTS

Workshops

The workshops were attended by policy makers from the municipality, regional water board, province and fire department, all involved in spatial planning as it relates to Urban Water Management. Workshop 1 (Watergraafsmeer) was held on May 22, 2013. It was attended by 20 participants. Workshop 2 (Purmerend) was held on September 5, 2013 and was attended by 22 different participants.

Outcome group evaluations

In general, the Interactive Water Simulation Model was positively received during the work sessions. The participants agreed that the water model gave them understanding of the problems that heavy rainfall can cause in the study areas and of which solutions can solve these problems. The following quotations were representative of the general opinion during the group evaluations:

> *'The model gave me a new understanding of the consequences.'*

> *'This makes clear which options we have to choose from.'*

Besides a better understanding of problems and solutions among non-expert participants, the interactive water model also improved the engagement of the participants in the decision-making process. The participants appreciated their involvement in the diagnosis of the problems and the generation of possible solutions positively:

> *'It triggered me to get a better technical understanding of the problem.'*

'It gave me much inspiration for new work sessions.'

'This connects different people and disciplines.'

Most of the participants intended to use the interactive water model in future work sessions. This was illustrated by the following quotations:

'All policy makers involved in water management need to use this instrument.'

'The model should be used to test the effect of new spatial developments on urban water problems during heavy rainfall.'

The main concern, expressed during the group evaluations, was that the use of an interactive water model during work sessions can lead to a trial-and-error approach. The risk of such a trial-and-error approach is that solutions that are preferred beforehand can receive all the attention, whereas other possible solutions become underexposed. To limit this risk of a biased selection and elaboration of alternatives, the importance of a good process design of work sessions in which interactive models are applied was stressed by the participants:

'The use of the model was too much "trial and error". We need a more structural approach in the use of the model.'

'A process design to use the model is required. Otherwise the use remains trial and error.'

Another concern was how an underpinned weighing of alternatives can be organized under the rapid generation of possible solutions during a work session. The use of indicators, such as those applied in multi-criteria analysis, was suggested for this:

'The model should prioritize the effectiveness of measures based on indicators considered important by the participants, such as damages, costs of measures, cost allocation and responsibilities of the different stakeholders.'

This quotation also indicates the importance of linking the outcomes of the model with the different legal responsibilities and available funds of the organizations of the participants involved in work session. During the evaluations, the participants indicated that outside the work session these responsibilities and available funds can be decisive for the solution that is finally selected.

Outcome questionnaires

Fifteen out of the 42 participants of the workshops responded to the questionnaire. The results per question are shown in Table 2. Although the number of responses was limited and therefore no significant conclusions can be drawn, the outcomes of the questionnaire confirm the outcomes of the group evaluations on the following points:

- A majority agreed that the Interactive Water Simulation Model helped them to better understand the problem during the workshops.
- Half of the respondents agreed or fully agreed that the Interactive Water Simulation Model helped them to better understand the effectiveness of suggested measures, whereas five respondents were neutral and a minority of two respondents disagreed.
- A majority of the respondents would apply the interactive water model in future work sessions.

Table 2 | Outcome questionnaire among participants of workshops 1 and 2

		Total responses	Fully agree	Agree	Neutral	Disagree	Fully disagree
1	Work sessions are necessary links in a decision-making process	15	3	3	6	3	0
2	Work sessions are important for understanding each other's perspectives on the problem	15	8	7	0	0	0
3	In work sessions substantive decisions are made	15	0	2	3	5	5
4	The interactive 2D model helped me to better understand the problem	15	5	7	2	1	0
5	The interactive 2D model helped me to better understand the effectiveness of suggested measures	15	2	5	5	3	0
6	The outcomes of the model were reliable	15	0	6	8	1	0
7	The outcomes of the interactive 2D model were understandable	15	9	6	0	0	0
8	I would apply the interactive 2D model in future work sessions	15	4	5	5	1	0

The first three questions, regarding the appreciation of work sessions in general, show that work sessions are considered as important for understanding each other's perspectives on the problem. Although, no substantive decisions are being made in current work sessions they strongly influence the selection of possible solutions and therefore the final outcomes of a decision-making process.

DISCUSSION

The workshops and accompanying questionnaires and evaluations showed that the Interactive Water Simulation Model was positively received and improved the decision-making process in at least three aspects. First, the realistic visualization of results helped the participants, who had various backgrounds and were not water specialists, to be able to understand the problem technically. This improved their engagement in the decision-making process. Second, the easily adaptable interface improved the involvement of the participants in the generation of possible solutions. This ensured that alternative solutions were generated from different perspectives on the problem. Third, given the short computation times of the model, multiple suggested solutions could be evaluated and enhanced within the time horizon of a work session. Either this can shorten the decision-making process as a whole or, under a fixed time horizon of a project, more iterations can be made on suggested solutions for finding the most attractive solution.

The workshops in which the participants used the Interactive Water Simulation Model consisted of a general exploration and selection of solutions. As this exploration had, in the short term, no direct financial or political consequences, the direct impact of the decisions was therefore low. One should therefore be careful in drawing conclusions from the outcomes of the evaluation of these workshops about the acceptance of interactive models in general. It is expected that an interactive model will be used differently when consequences in the short term are high, for example during disaster planning (Janis & Mann 1977; Morss *et al.* 2005).

Poor communication of the uncertainty in model outputs is often mentioned in the literature as one of the reasons why decision-makers do not trust model outputs (Brugnach *et al.* 2008; Timmerman *et al.* 2010; Voinov & Bousquet 2010). We expect that interactive modeling can contribute to a better understanding of uncertainties in model outputs among decision-makers as they can directly examine whether current data were used in the model set-up. They can also see how suggested solutions are translated into the model and therefore better understand the scope of the outcomes. Still, the reliability of the outcomes was mentioned in the evaluations as a point that requires further improvement. In common modeling practices, a validation with *real* measured data is applied for this. However, in environmental problems related to climate changes, the future is unpredictable and the nature of the relationship between processes is sometimes unknown. In these cases, different model concepts or variation in input data in *ensemble* calculations be considered (Bankes 1993; Demeritt *et al.* 2010; Kwakkel *et al.* 2010).

Technical developments used to develop the Interactive Water Simulation Model are also used in the development of *serious games*. Serious games are simulation models comparable with flight simulators, in which users can assume the roles of different participants so as to produce a better understanding of each other's perspectives on the problem as well as the accompanying solutions, or else for training purposes (Haasnoot *et al.* 2009; Voinov & Bousquet 2010). However, current serious games often contain prepared model scenarios for a limited number of solutions and do not support iterative processes that engage participants in optimizing suggested solutions (White *et al.* 2010). We believe that interactive models can therefore further improve serious games. The Interactive Water Simulation Model, as developed in our research, enables users to simulate most of the possible solutions and it supports iterative processes. An advantage of this approach is that the same model can also be used for other types of work sessions during the decision-making process. Participants are therefore always informed by the same model information over the course of the whole decision-making process.

CONCLUSIONS

The question addressed in this paper was whether interactive models can improve a decision-making process in urban water management and how they are accepted by decision-makers, with respect to non-interactive models that are only applied in the preparation of work sessions.

The interactive water model we applied consisted of three core innovative aspects: (1) a short computation time in combination with a high spatial resolution and an accurate physical representation of all relevant processes; (2) ease of model adaptability to test suggested measures; and (3) a realistic visualization of model outputs.

We assessed the improvement of the decision-making process in two workshops focusing on three criteria: first, how it helped the various participants to understand the existing problem; second, how it influenced the process of generation of suitable alternatives; third, how the model helped in the selection of alternatives. To assess the acceptance of the model we focused on the questions of whether participants considered the model as reliable and whether they would apply an interactive model in future work sessions.

Regarding the improvement of the decision-making process the following conclusions can be drawn, based on the workshops and accompanying questionnaires and evaluations:

- The realistic visualization of results helped the participants, who had various backgrounds and were not water specialists, to better understand the consequences of heavy rainfall in urban areas with respect to existing methods. This improved their engagement in the decision-making process.
- The easily adaptable interface helped in answering questions pertaining to the diagnosis of a problem, the interrelations and interdependences between different topics of the problem and the effectiveness of solutions. It therefore improved the involvement of the participants in the generation of possible solutions. This ensured that alternative solutions were generated from different perspectives on the problem.
- The short computation times of the model helped to focus dialogue and negotiations during work sessions on effective alternatives, as technically ineffective solutions were directly identified and discarded.
- The short computation times provided the opportunity to evaluate and enhance measures more often within work sessions. Either this can shorten the decision-making process as a whole or, under a project's fixed time horizon, more iterations can be made of suggested solutions to find the most attractive solution.

Regarding the acceptance of interactive models we are careful in drawing conclusions, as this is highly dependent on how a model is technically elaborated in terms of the user requirements and how its outcomes are validated. In our case, the willingness to apply the interactive water model in future decision-making processes was strong.

Independently of the outcomes of a model, participants can have other motivations to value one solution above the other, such as former personal or political experiences with other participants in a work session (March 1978; Simon 1987). It can therefore not be expected that the outcomes of interactive models that are applied during work sessions will always be accepted by the participants. However, during the workshops and their evaluations, we did not observe the participants refusing to accept model outcomes when these outcomes did not meet their expectations or preferences. For example, various participants withdrew from their initial preference for green storage roofs when the Interactive Water Simulation Model showed that the effectiveness of this measure was low. Still, this does not mean that participants in workshops in Urban Water Management will always renounce their preferences when a model shows the ineffectiveness of the proposed solutions. During the evaluations, the participants indicated that outside the work session the legal responsibilities of the different organizations and the available funds may be decisive (Levin & Cross 2004). Therefore, the application of interactive models during work sessions may be more useful when formal responsibilities and available funds are considered alongside the use of the model.

In the evaluations of the workshops, several participants remarked that the use of an interactive water model can lead to a trial-and-error approach, which can result in a non-coherent package of individual measures suggested by participants in the work sessions. This emphasizes the importance of applying an interactive water model within the context of a sophisticated process design. In our case, the preparation of different general main solutions that can be used for further iterations during work sessions was applied. We consider also a good follow-up to the work sessions by specialists, for example to investigate the technically feasibility and coherence of the proposed solutions.

In this paper we showed how new model technology (i.e. fast and flexible computation algorithms and realistic visualizations) that is applied in work sessions can bridge the gap between the modelers' domain and the decision-makers' domain in the field of urban water management. Comparable case studies are limited, since this model technology has only become very recently available. We encourage further research in other fields of water management, such as structural planning or flood disaster management, to see if the findings presented in this paper are also valid for these disciplines. Also other types of interactive modeling environments need further exploration, for example in meetings with civilians or in the setting of a serious game.

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