Int J Disaster Risk Sci (2018) 9:472–485
https://doi.org/10.1007/s13753-018-0203-8

www.ijdrs.com
www.springer.com/13753

ARTICLE

The Difficult Path from Perception to Precautionary Action—Participatory Modeling as a Practical Tool to Overcome the Risk Perception Paradox in Flood Preparedness

Gisela Wachinger[1] · Patrick Keilholz[2] · Coral O'Brian[1]

Published online: 19 December 2018

Abstract The risk perception paradox illustrates the perception of natural hazards as not directly related to a willingness to act or engage in precautionary behavior. Yet the utilization of participatory processes can help to overcome this gap. In a practical example in the watershed of the Danube River and its contributing streams in Germany, we aimed to solve questions about the value of participatory modeling as a method to bridge the gap linked to flood polder planning and a relocation of a dike for protection against high floods (centennial floods and rarer). Local communities, citizen initiatives, and nongovernmental environmental organizations joined together for round table discussions initiated by the water management authorities. A participatory modeling process enabled these diverse stakeholders to engage with the experts who built the groundwater models for the planning process. As part of this study, two case studies are presented. In the first example, neutral mediators assisted the round table "Flood Polder Katzau (Danube)" in order to cultivate mutual trust and understanding between the authorities and the former opponents of the project. This process is still ongoing, challenged by long-term planning and the more immediate obstacle of current political changes. The second case study is located on the river Alz, a tributary of the river Inn, which flows into the Danube, where the relocation of a dike was planned. This article demonstrates how participatory modeling contributes to bridging the gap between a local resident's risk perception and real action in the case of flood preparedness.

Keywords Bavaria · Flood hazard · Flood perception · Flood risk · Germany · Participatory modeling · Precautionary action

DIALOGIK is a nonprofit institute for communication and cooperation research founded by Professor Dr. Ortwin Renn. Two major subjects of the institute are participation research and natural hazards. DHI is a global consulting and software company with more than 50 years' experience on water systems. DHI WASY GmbH is the German 100% subsidiary company of DHI.

✉ Gisela Wachinger
wachinger@dialogik-expert.de

1 DIALOGIK GmbH, 70176 Stuttgart, Germany

2 DHI WASY GmbH, 81671 Munich, Germany

1 Introduction

The theoretical background of flood risk perception is helpful in order to understand the two case studies in the article. The problem, which occurs in all planning processes that are meant to prepare communities for flood hazards, is that most people see a potential risk of flooding in the future but do not want to take action in the present. We therefore chose two case studies where German authorities ran a planning process for flood risk precaution with the involvement of local communities, citizens, and nongovernmental environmental organizations. The theoretical background is a study review on risk perception in Europe, which identified a paradox between risk perception and precautionary action.

1.1 Flood Preparedness and the Risk Perception Paradox

The risk perception paradox occupies a key role in conceptualizing the gap between risk perception and willingness to act in the face of flooding. As the paradox demonstrates, the assumption that perception of risk is positively correlated with likelihood of protective action is not necessarily a lived reality (Fig. 1). It then becomes crucial to address the factors that contribute to personal notions of perception and linked social behavior (Wachinger et al. 2013). In order to mitigate the potential damage brought on by extreme (statistical 100-yearly + 15% climate change addition) flood disasters in this region, the most influential determinant of flood risk perception has been identified as flood experience (direct and indirect). Intervening variables such as trust in authorities and experts shape risk perception (Wachinger et al. 2013). The factor "trust" is discussed broadly in the literature, as establishing trust is a bidirectional process that can flow between citizens and authorities both ways (for a literature review see Wachinger et al. 2013). In most cases, risk perception is positively correlated with willingness to act on a personal level. However, in certain cases, trust in authorities resulted in a higher risk perception and a lower willingness to take personal action. This occurred because people waited to act; trusting in responsible authorities to take action first. Therefore, their own personal willingness to act was reduced (Wachinger et al. 2013). In this article we would like to emphasize the gap from perception to precautionary action. There is a paradox in practical flood preparedness (indicated in Fig. 1 by a lightning bolt): even if willingness to act leads to preparedness, the last step to personal action is often not undertaken.

Given this foundation, the question of how to invoke real action for flood preparedness can be successfully addressed with the practice of risk governance and participation. Increased engagement between local residents and authorities contributes to greater social trust, more local motivation, and ultimately real action towards flood preparedness on the part of local residents. The role of trust comes into play in particular with natural hazard-induced disasters due to their uncertain and infrequent nature, and is therefore integral in influencing a layperson's decision to heed advice from authorities in moments of crisis (Wachinger et al. 2013). The more local residents have the possibility to take part in the decision-making process of flood preparations in their community, the greater their personal stake will become in the active development of decisions towards precautionary action. Trust between authorities and citizens in risk knowledge communication is a cornerstone towards building real action (Wachinger et al. 2013). Lay experience (of former floods, for example) and layperson local knowledge are valuable contributions to modeling flood processes.

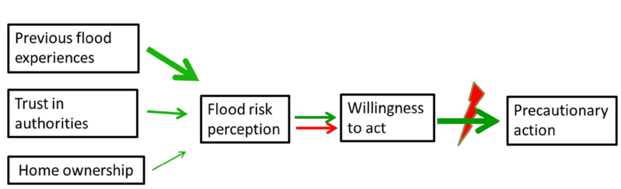

Fig. 1 Visualization of the gap between flood risk perception and flood precautionary action. *Source*: Adapted from Wachinger et al. (2013).

1.2 What is Successful Participation?

Defining participation is heavily context-based and settling on a one-size-fits-all definition is therefore problematic. It is helpful to start at the root when discussing successful participation: "At its most basic, participation involves action, a 'taking part' in 'something' (Radtke et al. 2018, p. 22). For the purpose of this article, the aim of participation is to involve those people in the decision-making process who do not have an official voice by employment or political position and yet, will be affected by the outcome of the decision. Participation is discussed here through three forms that are important to differentiate. We use the term "council" to refer to a formal, political gathering of elected authorities. "Forums" are an open invitation to all bodies who will be affected by the outcome of the decision and give voice to those who do not have one by election or employment. "Round tables" consist of approximately 25 participants and are an opportunity to bring together representatives of both formally recognized institutions (mayors, regional council officials), and informal groups (citizen initiatives, NGO members) to openly discuss the issues face-to-face. The engagement of diverse stakeholders through participatory processes is key to bridging the gap between risk perception and action. It is through the inclusion of local communities, citizen initiatives, environmental nongovernmental organizations (NGOs), and authorities (with the aid of neutral mediators) that such participation processes can begin to take place. Although it is a fluid and ever-evolving process, successful participation is comprised of the following important components (Wachinger et al. 2014, p. 218):

(1) open and transparent decision options;
(2) inclusion of all perspectives and decision makers;
(3) all participants equipped with relevant information;
(4) clearly communicated transparency and confidentiality;
(5) a clear process structure, with differentiation between process responsibility and subject responsibility; and
(6) a collaborative attitude among and between organizers and all participants.

Through the integration of these valuable elements of interaction, successful participation not only encourages a climate of learning, but also promotes increased trust and motivation for all stakeholders. In the special cases we describe in this article, we have tried to fulfill all the success factors in our concept.

1.3 What is the Aim of the Article?

The current use of participatory modeling in managing natural resources has sparked a diverse and nuanced collection of global efforts. Throughout the lived examples of participatory modeling is nestled the overarching purpose of engaging nonscientists in the scientific process. This article sheds light on a largely underexamined facet of determining precautionary environmental action: the gap between a local resident's perception of risk and that individual's willingness to take precautionary action to reduce the hazard risk.

Existing literature points to the value of participatory practices in managing natural resources with attention to the involvement of local people in the process. Local people are likely to be highly informed about where they live and provide information that scientists could miss (Kotir et al. 2017). Additionally, the complex and uncertain nature of environmental problems requires flexible and transparent decision-making, making a diverse set of values, knowledge, and life experience important to the decision-making process (Reed 2008). According to Reed (2008), the need to have clear objectives from the outset and include participation both as early as possible and throughout the entirety of the process is key to successful participatory modeling. The likelihood of successful solutions to environmental problems increases when stakeholder participation enables information to be shared by those holding different points of view and builds a common understanding of the system (Carmona 2013).

Throughout these case studies of flood preparedness at the Danube River and the Alz River (Fig. 2), we focus on the following factors of a successful participatory process: trust between local citizens and authorities, information transparency between diverse stakeholders, and inclusion of all perspectives and decision makers. In our two case studies, we address the question: Does the use of participatory modeling result in an increased willingness to take precautionary action from stakeholders?

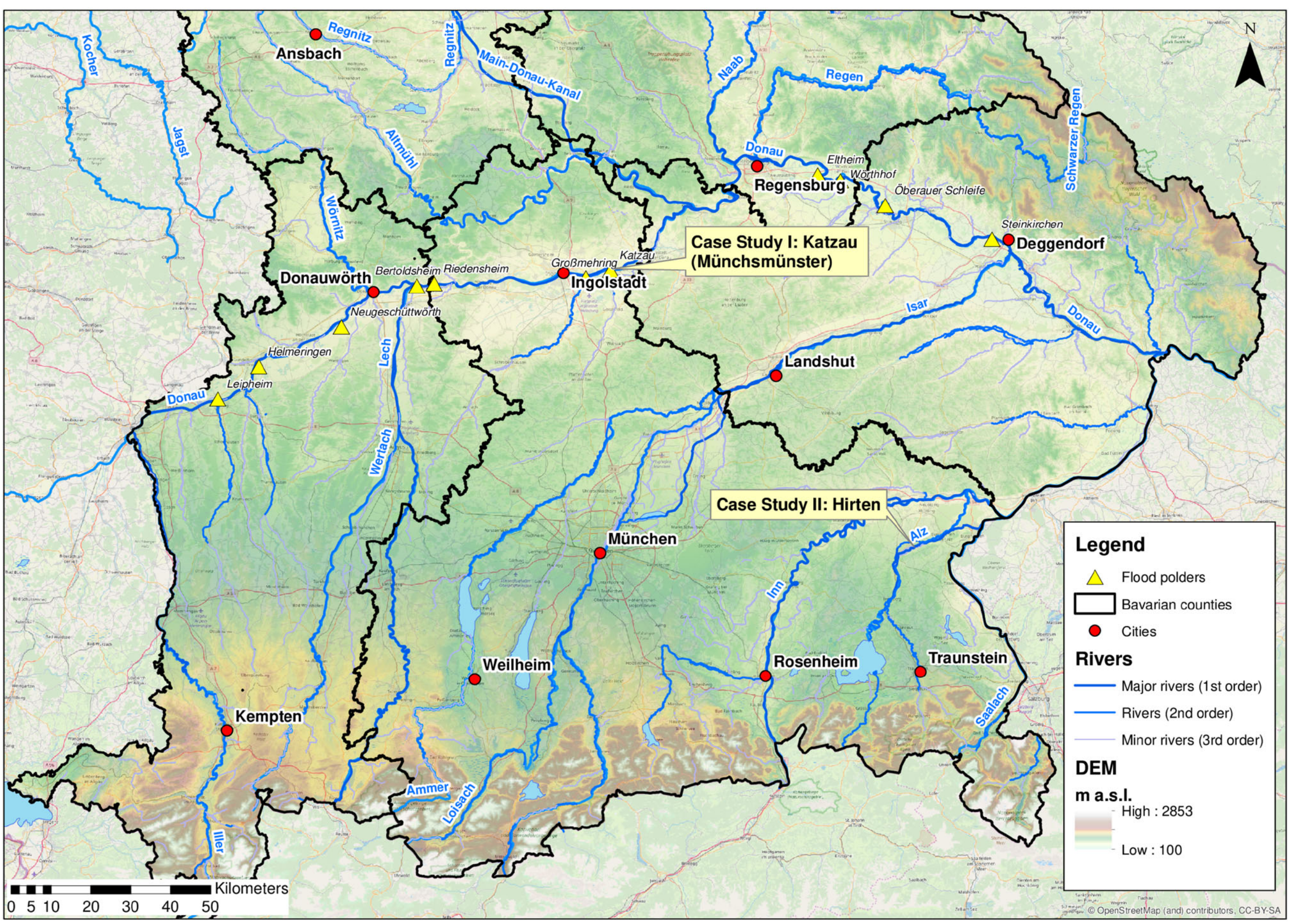

Fig. 2 Location of the case study project area and polders along the Danube River and the River Alz dike relocation case study at Hirten. All terrain representation is based on the Shuttle Radar Topography Mission and all elevations are provided in meters above sea level

2 Method of Participatory Modeling

Participatory modeling is a method that is well known in risk management, but is commonly known with reference to "mental models" (Henly-Shepard et al. 2015). The authors used participatory modeling as a tool to build trust in groundwater models.

When authorities place an order for a groundwater model, they have to follow a structured step-by-step process:

Step 1: Define the requirement specification;
Step 2: Place an invitation to tender/call for competitive bids;
Step 3: Select the modeling method and the providing company.

During the modeling process the model is built by engineering consultant experts who complete the process in the following steps:

Step 4: Define the frame for the model (spatial and temporal);
Step 5: Establish parameters;
Step 6: Implement the model;
Step 7: Calibrate the model;
Step 8: Validation 1 of the model by calculation of a different event;
Step 9: Validation 2 of the model by incorporation of local knowledge;
Step 10: Calculate planning scenarios; and
Step 11: Discuss the results obtained and assess their implications.

The last step in the process is undertaken by the authorities and local and regional boards:

Step 12: The board and authorities decide whether or not to implement the flood polder scheme.

In participatory modeling, the stakeholders present at the round table have the possibility to interact with the modeling process at some of these specific 12 steps. Our participatory modeling method is therefore characterized by the two components: (1) the scientific groundwater modeling component, which takes place within the legal framework of water management planning done by the authorities on one side (in Fig. 3 the right in blue); and (2)

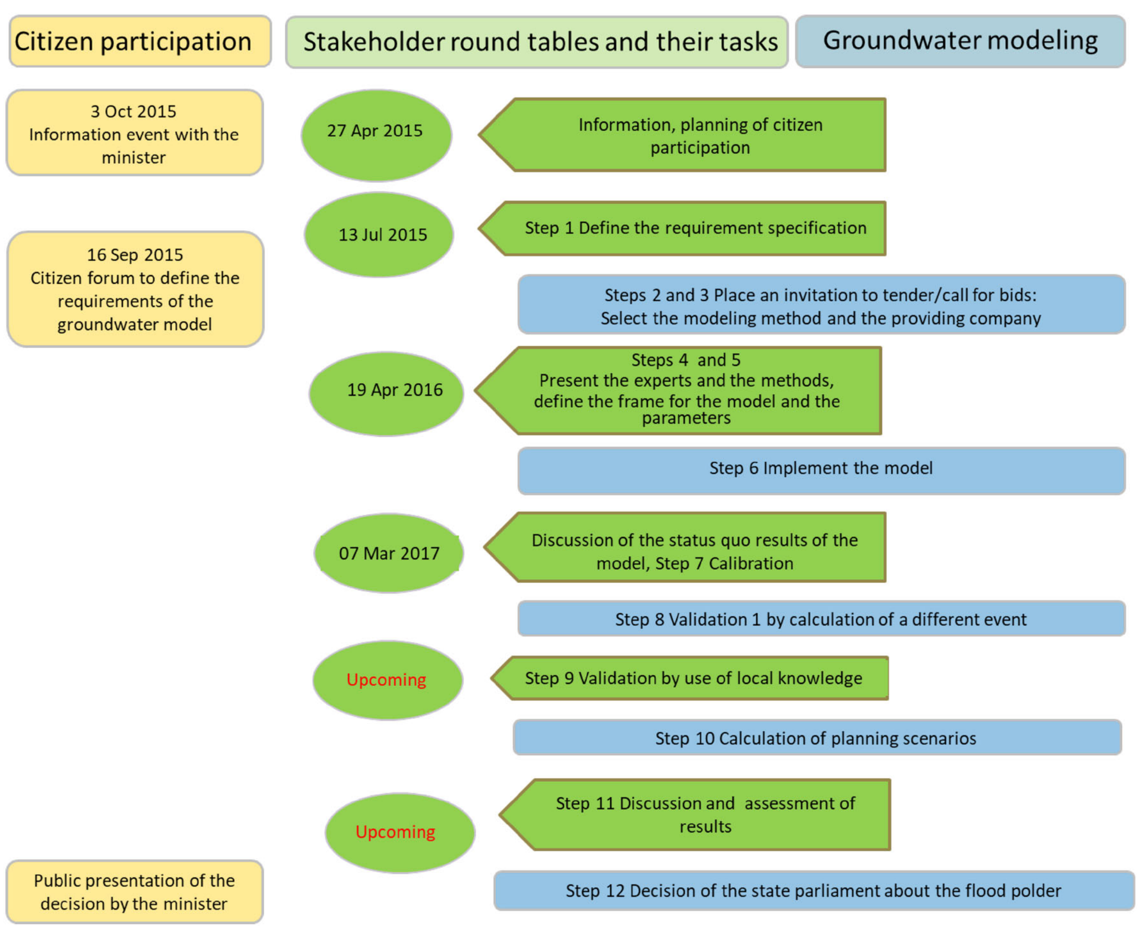

Fig. 3 The participatory modeling process in the Katzau polder case study near Ingolstadt in Bavaria, Germany

the citizen participation component, which is integrated in the 12 modeling steps (indicated in yellow and green on the left side in Fig. 3). Interaction between the two components is conceptualized and facilitated by neutral mediators, who have experience in social science concepts and conflict resolution methods.

The necessary steps of participatory modeling are defined by three goals:

Goal 1: Local knowledge of the participants is incorporated into the model to help make the results more valid;
Goal 2: The participants become familiar with the whole process of the modeling method and understand the scientific approach in order to contribute to more reliable results; and
Goal 3: Trust is built between the authorities, the modeling experts, and different stakeholders at the round table. This is helpful in implementation, which means in this case, the incorporation of the results into the flood preparation process that culminates in a decision as to whether or not a flood polder should be built.

In Fig. 3 the three components of our participatory modeling system (citizen participation, stakeholder round tables, and groundwater modeling) are shown for our first case study, the Katzau polder adjacent to the Danube River near Ingolstadt. The steps of the modeling process, which have been done in interaction with the stakeholders as round-table sessions, are indicated in green. It is important that the stakeholders had the opportunity to co-design the frame of the groundwater model, supply data for certain parameters, take part in the calibration and validation of the model, and have the possibility to discuss the results.

Nonetheless, there are steps that could only be undertaken by the experts such as providing the right method of groundwater modeling and the calculation itself. During parametrization, calibration, and validation the experts interacted with local participants of the round table. In this study the coupled software systems of the groundwater model FEFLOW (Diersch 2014), 1D hydrodynamic model MIKE 11 (DHI 2017a), integrated catchment model MIKE SHE (DHI 2017b), and 2D hydrodynamic model HYDRO_AS-2D (Nujic 2009) were used to analyze the complex hydrologic system. The final decision to implement the results of the study had to be undergone by the authorities and the appropriate local and regional boards. The round table cannot make the decision by itself. The role of the round table is to prepare decisions, give recommendations, and inform the authorities and the regional board.

The steps taken by the authorities and the modeling experts in between the round table sessions are indicated in blue boxes. To ensure transparency of information, the round table elected one of the participants (a local retired engineer) who took part as a representative of the round table in the meetings with the authorities and the modeling experts (blue boxes). In yellow boxes on the left side, the dates of the larger citizen meetings are marked, which were open to the public.

3 Case Study I: The Danube Flood Polder Planning with Participatory Modeling

The first case study contextualizes the method of participatory modeling in a controversial political discussion. The impact of the high dikes from the planned polder for the inhabitants of the villages near Katzau would be huge and the benefits in case of a potential flood not so obvious.

3.1 The 2013 Danube River Flood Case

In June 2013, the Danube River basin in Bavaria suffered from a severe flood (ICPDR 2014). In particular, the historic town of Regensburg was endangered. The state government of Bavaria decided, based on a study by Rutschmann et al. (2012), to go beyond the standard flood protections widely considered adequate to reduce the impact of a “centennial flood” (established by EU law), and originally planned to construct an additional 12 flood protection polders along the Danube River between Ulm and Deggendorf (Fig. 2). The final number of planned polders is still subject to variation from political decisions and/or expert opinions.

Polders are large, uninhabited areas close to the river and surrounded by dikes. Through a special technical facility, water is let in if an extreme flood occurs, remains in the polder for several days until the peak of the flood is over, and is then gradually released back into the river. The polders cover an area up to 100 hectares (1 square kilometer, or approximately 250 acres in the Imperial system) and it can store up to 7.2 million m^3 water. Retaining a river’s upstream watershed flow during peak flooding is a significant flood protection function and damage protection strategy for downstream cities. Furthermore, the polders in which flood water is temporarily stored are most effective if their functioning is controlled as part of one integrated strategy. Polders act as flood protection mainly on a regional scale. On a local scale, however, the protective function of one individual polder for the inhabitants who live close by is very small and is further offset by encroachment at the local scale.

Only 12 potential polder areas could be identified along the Danube River due to urbanization and natural protection within this area of Germany: a region rich with industry and tourism. Nonetheless, for the people living in these areas the polders pose infrequent yet colossal challenges, including high dikes and the potential loss of fields for farming due to contaminated soil after a flood. Local residents and environmental NGOs also raised concerns over the effects of the polders on natural habitats, natural protected areas, and fishery management. The minutes of the first round table session list the following concerns and ideas (Erzigkeit 2017):

(1) the groundwater will rise in the flooded polders and will damage the houses near the polders;
(2) the polluted river water and the river sediments in case of flooding will be a threat to farmland, home gardens, and fisheries;
(3) the important ecological wetland habitats along the river Danube will be destroyed; and
(4) it would be easier and ecologically more effective to plan larger retention areas and relocate the dykes.

The most problematic question was whether the cellars of the houses closest to the polder would become wet or even flooded in the case of a polder flooding. This is unfortunately a valid worry, as these houses were built in zones with high groundwater levels. One such concern, for example, stated: “Why have we to be taken responsible for the protection of people living in beautiful cities? Only because we are ‘poor’ and not in highly industrialized or university town areas, we have to suffer for ‘richer’ communities?” This line of argument was important for the mayors across these small communities. The conflict behind this example is an example of NIMBY (Not In My Back Yard), which is based on the assumption by local residents that implementation of a regional flood protection system that mainly helps the downstream cities inevitably has a serious negative influence on the local inhabitants.

To solve these conflicts, the environmental ministry of Bavaria (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz) in 2014 asked neutral professionals (the mediation alliance, represented by Ilse Erzigkeit, Petra Claus, and Gisela Wachinger) to craft a concept for citizen participation (Erzigkeit 2017).

3.2 Method of Participatory Modeling in the Danube Case

The method of participatory modeling was conceptualized for the Danube case and is indicated above (Fig. 3). Our participation concept consisted of a regular round table with all decision makers and stakeholders of each specific flood polder. In the region of Ingolstadt, we established three round tables for the three polders Bertoldsheim, Großmehring, and Katzau. At each polder region we had one large forum where all local residents were invited to discuss the opportunities and risks of the polder as well as the results of the round table discussions. Participants in the round tables consisted of members of the regional water authorities, the head of the regional board, mayors of the communities in the region, the heads of citizen initiatives, farmer associations, fishery clubs, and environmental NGOs. The authorities from other polder regions and delegates of the environmental ministry were invited to take part as observers.

The groundwater model was provided by DHI (Diersch 2014) Groundwater modeling is a deterministic approach to calculate groundwater heads and fluxes. The physical process is solved (3d-Darcy-Equation) via software models like FEFLOW or MIKE SHE. Models must be calibrated and validated by measured data. Groundwater models are part of the legal planning process for risk prevention measures of which flood polders are one example.

3.3 An Example of the Round Table Discussions

One round table is especially remarkable in demonstrating the process and the results of participatory modeling—the 3 March 2017 session. This meeting is described in detail because it shows the method of participatory modeling, the interaction between local lay experts and modeling experts in a facilitated deliberation, and the outcome of such a communication process. The aim of this session was the calibration of the model according to a real local flood event in recent history: the flood of June 2013 (Step 7 in the participatory modeling process).

3.3.1 Transparent and Understandable Information

First, the participants were informed about the status quo of the modeling process through a clear and accessible power point presentation. A strong objective was to improve public comprehension of the region’s groundwater systems. For non-experts, groundwater systems can be abstract because they cannot be seen. The modeling experts used visualizations coupled with hands-on soil and water experiments. With the use of visual aids, groundwater systems can be visualized, including the interaction between rainfall, flooding, infiltration, and dynamic groundwater head changes. A special feature was the virtual walkabout using virtual reality in the groundwater model. Anyone interested could walk into the hydrogeological system using this virtual reality tool (Fig. 4).

The physical aspects of a groundwater system can be complicated because the system is either a 3-phase system that consists of soil particles, water, and air (unsaturated) or a 2-phase system made up of soil particles and water (saturated). Saturated groundwater can be confined or unconfined, which has a large impact on the physical system. Only a small variation in the amount of water is necessary to generate high hydraulic head changes when

Fig. 4 Under the guidance of an expert, a participant walks via virtual reality through the groundwater model during exploratory phases of the 7 March 2017 round-table meeting

groundwater is confined by a loam cover (as is the case in part of the polder region). To explain this complex situation, our project's experts used a simple hands-on soil and water experiment. In the experiment, bowls with both the confined and unconfined water system were reconstructed. By putting the same amount of water in each bowl, the effect was visible. Therefore, the design and results of the groundwater model were understandable for the lay participants. The results of the model regarding the June 2013 flood event were generated, but not shown at this time of the presentation. This data were left open to give the participants room for an independent collection of local knowledge for calibrating the model.

3.3.2 Collection of Local Knowledge and Participatory Creation of a Flood Map

Next, the modeling experts showed a physical map of the flood polder area (Fig. 5). The participants were asked: "What is your experience from the flood in 2013? Please mark the points in the map where you remember a groundwater problem" (wet cellars in the houses or flooded fields). Local stakeholders (participants of the round table, but not the authorities, about 20 people) marked these points with post-it-notes, while the facilitators wrote down the stories and arguments that the participants shared with them. Through this process, a clearer picture of the "problem areas" was developed.

3.3.3 Comparison with the Flood Map Generated by the Model

At this stage of the article the groundwater model is still in the calibration process, particularly for the area in and around Münchsmünster. Calibration is a process and the experts need to understand the natural system. To incorporate this local dwellers' picture during the calibration of the model, the experts then showed a virtual map of the same area, where the potential "problem points" identified as a result of the modeling process had been shown by question marks (Fig. 6). In the modeling process, data from the flood in June 2013 was used to calibrate the model. At this stage the groundwater modeling experts were able to crosscheck and compare whether the preliminary results of the modeling (wet areas in the virtual map) could be validated by the local knowledge of the lay experts. The mayors of these communities were especially cognizant of the situation, because in the flood event of June 2013 all complaints and insurance issues had been brought directly to them. In the future, if the groundwater model is final calibrated, validated, and accepted by all participants, it can be used to calculate different planning scenarios. The capacity to virtually analyze and optimize different management strategies for polder projects and pumping stations prior to construction is a significant advantage.

3.4 Results of the Participatory Modeling in the Danube Case

The participants, in addition to the modeling experts, were surprised at how well the two different maps matched in displaying the wet areas. The results show that in the independent processes of generating the flood map of 2013—by preliminary results of groundwater modeling, see Fig. 5 and by local knowledge of the participants, see Fig. 6—similar maps were drawn. The wet "problem areas" showed a high similarity. These results are the technical output of the round-table process, but they also represent an outcome of participation that helped reach the following three results and matched the goals of participatory modeling in the Danube flood polder modeling case study:

Result 1: Local knowledge of the June 2013 flood event helped to calibrate the model with data from a real flood event;
Result 2: The round table created a two-way, data-sharing process that strengthened the model's results and enabled the participants to receive insights into the modeling process and to learn that the calibration with local knowledge data is important for the experts;
Result 3: Trust was built by the fact that modeling experts and lay experts (inhabitants with expertise in local knowledge) developed respect for each other that enabled interaction in all steps of the modeling process.

Based on our observations as scientists, the willingness of all parties to act increased during the four round-table sessions. All relevant stakeholders showed up in

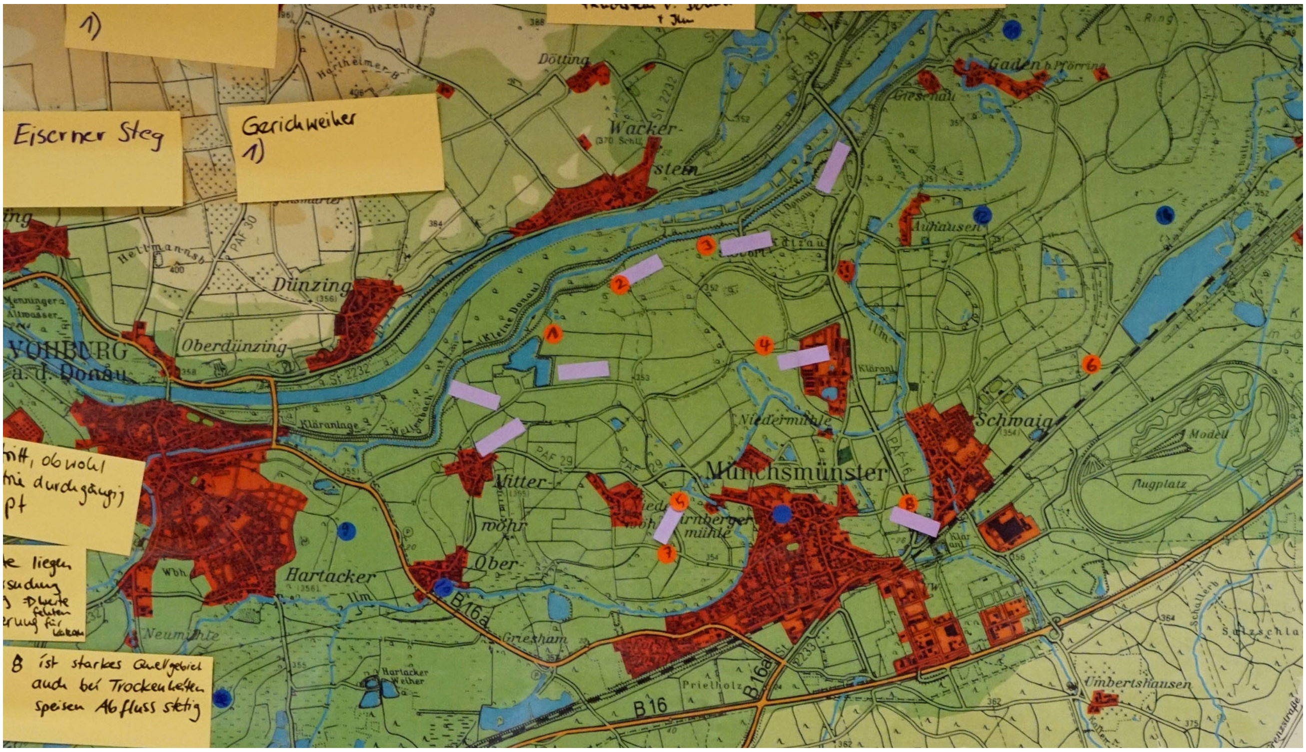

Fig. 5 Wet areas (red dots and pink stripes) in the Münchsmünster area during the Danube flood event in June 2013, as marked by the round table participants on 7 March 2017. Red areas are buildings (villages)

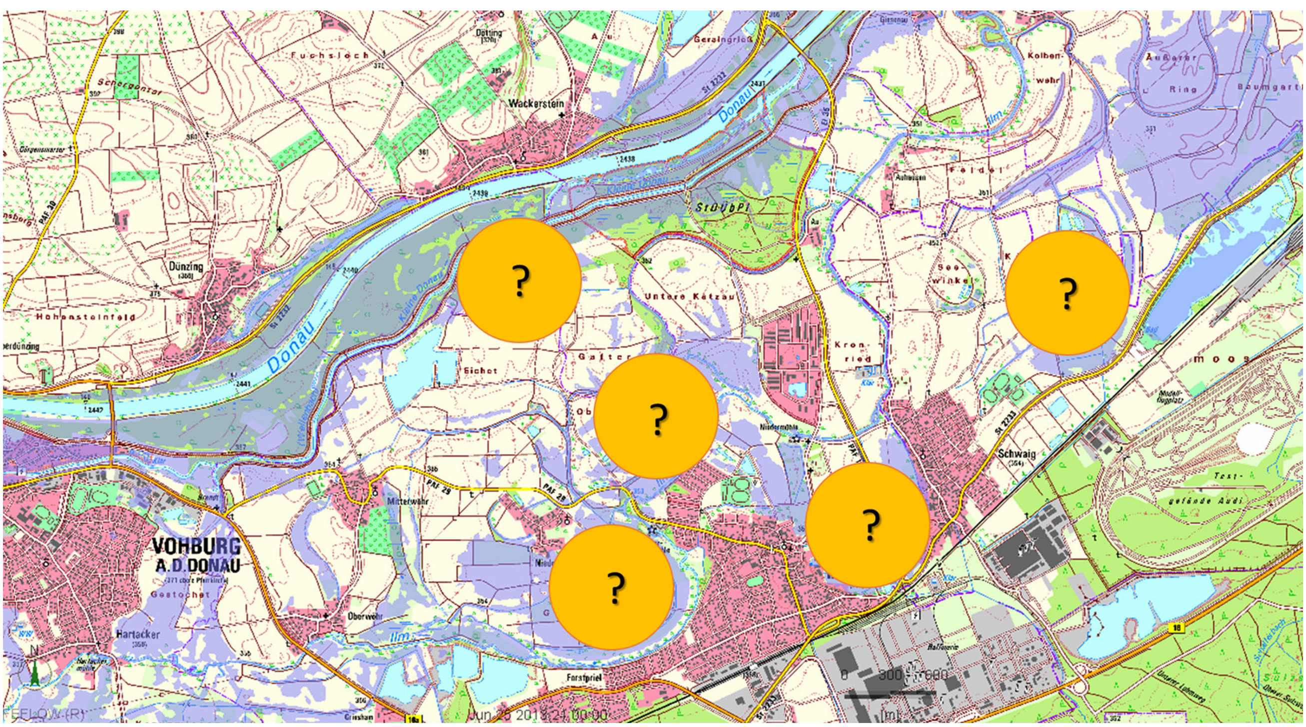

Fig. 6 Model calibration based on local knowledge and data generated through interaction between local residents and modeling experts at the DIALOGIK round table of 7 March 2017 in Münchsmünster, Bavaria. The question marks represent the areas where local knowledge was successfully used for calibration

every meeting, which is especially remarkable for heads of the regional boards and mayors because of their multiple commitments and tight schedules. Moreover, the NGO's and citizen initiatives, as well as the farmers' and fishermen's associations were present in every meeting even if they were opposed to the flood polder project. While writing this article the round table process was not finished. The agreement of these groups (who had been against the flood polder project at the beginning and might still be at the end) with the process will be an important indicator for the success factor "fairness of the process" at the end. We plan to measure the perception of fairness and trust in the process by questionnaires in the last meeting.

4 Case Study II: Dike Relocation at the Village of Hirten on the River Alz

The second case study contextualizes the method of participatory modeling accompanied by a questionnaire in a controversial discussion. The impact of the dike relocation for the inhabitants of the village Hirten would be positive for flood protection. However, the local groundwater levels can be influenced negatively.

4.1 The Alz River Flood Case

In June 2013, two intensive and lengthy rainfall events occurred. The result was extensive river flooding in the most parts of the Danube catchment that coincided with and followed these local rainfall events. The combination of heavy local rainfall (statistical 5 year return interval) and extreme flooding (70 year return interval) along the Alz River, a tributary of the Inn River before it flows into the Danube, generated a superposition effect (Keilholz et al. 2015). The village of Hirten, located approximately 70 km due east of Mūnchen (Munich) in the Alz River basin half way between the river's origin in the Chiemsee and its junction with the Inn, was protected by a small dike designed to withstand a flood magnitude encountered once every 10 years. In 2013, local residents built a temporary sandbag dam on top of the low dike, which is why only parts of Hirten where flooded by the river. However, the groundwater level greatly rose and many basements were flooded despite the sandbag-augmented dike.

To prevent dangerous future flooding, the authorities decided to increase flood protection for the village by constructing a higher dike that would insure a safety net against a once in 100-years flood. This protection was planned with an additional 15% margin to cope with expected climate change. To give the river more space during flooding for on-floodplain floodwater storage, it was proposed to build the new dike in a new line behind the existing low dike and closer to the village of Hirten (Fig. 7). Due to the new dike, the flooded area cannot extend until a 100-yearly event into the village. However, the flooded area can potentially affect the groundwater level.

Hirten residents suspect that a rise in groundwater level will take place in the village during future flood events. Due to the experience of the 2013 flood event, people wanted to have more flood protection as well as increased security from potentially raised groundwater levels. A groundwater study was necessary to analyze the potential impacts of the dike relocation.

4.2 Method of Participatory Modeling in the Alz Case

The same participatory modeling method was implemented in the Alz River dike case as in the Katzau polder project discussed above. Round tables and public consultations have been a central part of the participation process. Participants of the round tables consisted of members of the regional water authorities, the mayors of the communities in the region, and the heads of citizen initiatives. The public meeting feature provided an open forum in which Hirten-area residents could speak as well as listen to presentations from the regional water authorities and the consulting company hired to study the feasibility of polder contributions to flood protection. Similar to the Katzau polder case study, a questionnaire process was organized in the early stages of the project. The questionnaire contained a one-page information letter to inform the village inhabitants about the groundwater modeling activity and to gather the following detailed information:

- Names and addresses of respondents;
- Their land parcel number;
- Home basement floor level below ground level;
- Construction of the basement (materials, drainage); and
- Detailed information and pictures related to the flood events of June 2013.

This information was important because in the beginning of the project it was clear that with the existing measured data a calibration of the model was not possible. Every model should be calibrated and validated by observed data. This is necessary because a model is a digital image of the natural system. Small inconsistencies and simplified parameters need to be fitted by calibration. For groundwater models, usually continuously observed groundwater heads are used. In this case, the measured data started after the calibration event in 2013. To close the missing data gap, citizen experience was important for the consulting company if it was to set up a reliable model of the groundwater system. Some modifications to the steps of

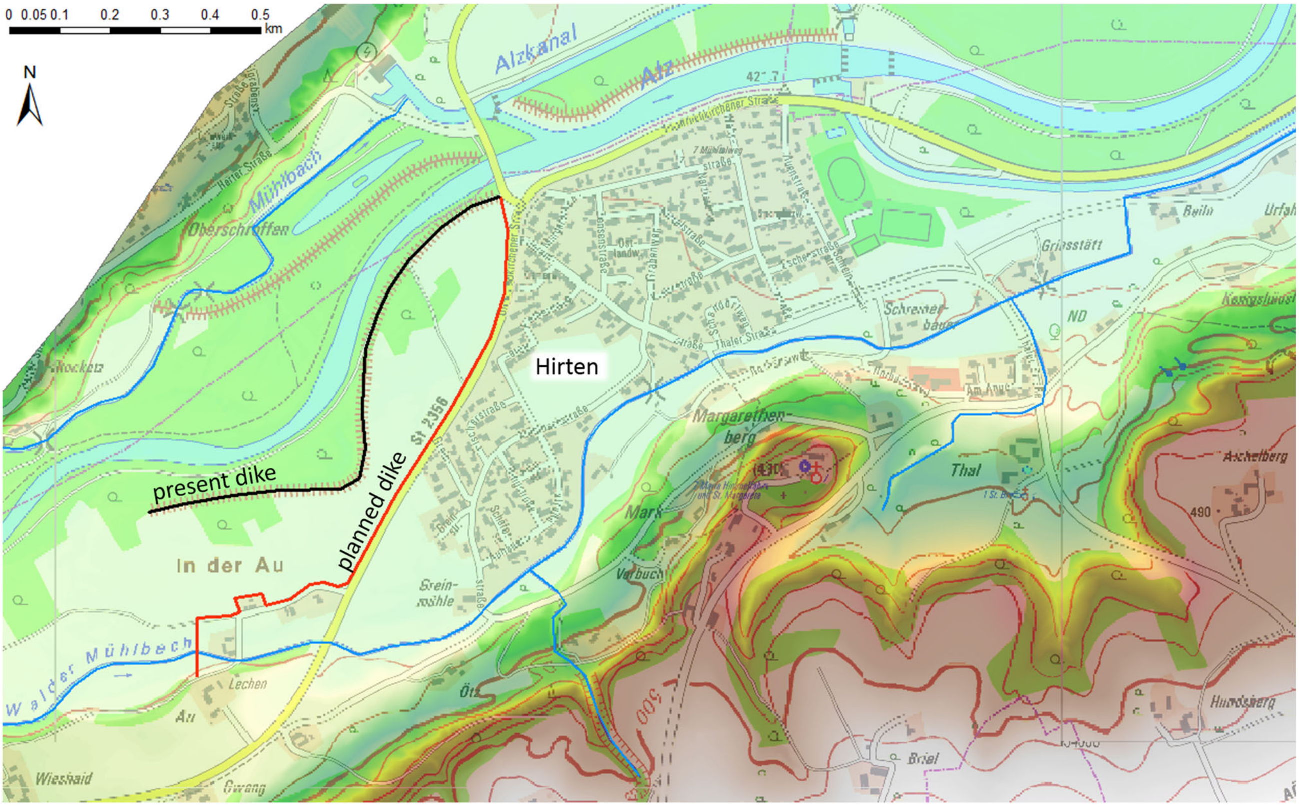

Fig. 7 Present and planned flood protection at Hirten village in southeastern Bavaria, Germany

the participatory modeling used in the Katzau polder case study had to be made to fit the special situation found at Hirten:

Step 1: Define the requirement specification;
Step 2: Place an invitation to tender/call for bids;
Step 3: Select the modeling method and the providing company;
Step 4: Organize a round table discussion to define the model;
Step 5: Send a questionnaire to the local residents;
Step 6: Interpret the questionnaire and reconstruction of the 2013 flood event by these data;
Step 7: Implement the model
Step 8: Conduct a steady state calibration to mean water levels with data from existing gauging stations;
Step 9: Carry out a transient validation for the 2013 flood event by using information from Step 3;
Step 10: Convene an open assembly and present results for validation by local knowledge;
Step 11: Implement a scenario analysis of different core wall depths in the old dike; and
Step 12: Reconvene a round table with the participants from Step 4 discussion and assessment of results.

From the Step 5 questionnaire process, it was already clear that the flooding in the eastern part of the village was due to flash flood events from small river branches coming from the connected hilly catchments in the south. During the modeling process this information was included in the study and analyzed.

4.3 An Example of Model Validation by Questionnaire Results

As a result of insufficient calibration data, it was necessary to get as much information about the June 2013 flood event as possible. More than 100 residents delivered information about their houses and the impact of flooding. A project email address was generated to which participants could send additional information, such as images and measurements, to the modeling company. This allowed a model validation by modeling the groundwater levels and surface water levels (Fig. 8).

For the modeling process, the coupled software models FEFLOW (groundwater model), MIKE SHE (integrated catchment model), and HYDRO_AS-2D (2D hydrodynamic model) were used. The surface water levels and the groundwater levels were compared with the questionnaire analysis to model the 2013 flood event (Fig. 9).

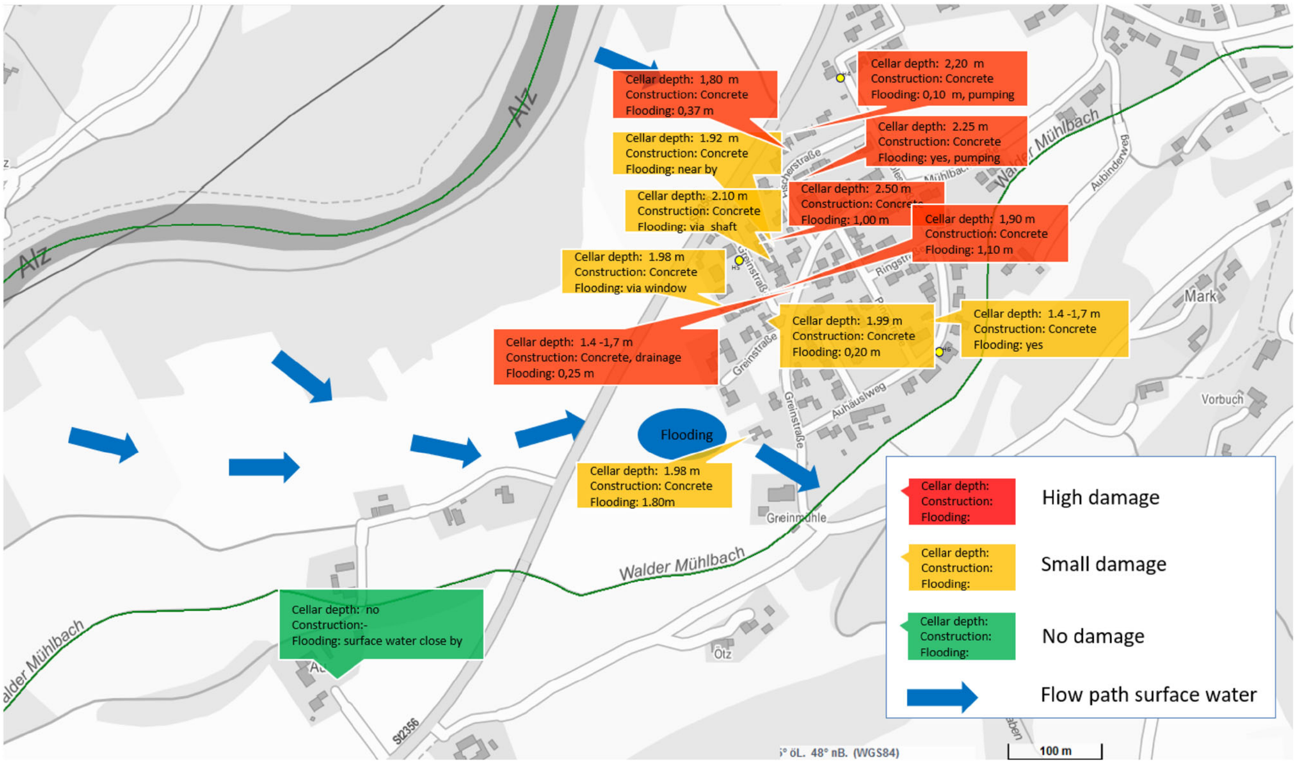

Fig. 8 Analysis of the Hirten questionnaire data (n = 100) of June 2013 flood impacts

4.4 Results of the Participatory Modeling in the Alz Case

With the coupled groundwater and surface water models and information from those inhabitants who experienced the June 2013 flood, the event could be reproduced successfully (Goal 1). It was also possible to show that damage in the eastern part (damage zone 6, Fig. 9) of Hirten did not occur by flood water from the Alz River. The strong rainfall (102 mm in 48 h; Station Forsting) event concentrated to a local flood event originating from the steep slopes immediately south of the village was mostly responsible for these damages.

Map visualization for a 100-year flood was calculated without (present situation) and with the planned dike. The model result (Fig. 10) shows that the relocation of the dike would have no negative effect on groundwater levels. It has become clear that the region has naturally high groundwater levels and that the new dike will have no negative influence on future levels.

An additional benefit of the participatory modeling approach was the integration of local residents into the research and planning process from the beginning of the project to such an extent that the participants became an important part of the model validation (Goal 2). The water systems could be analyzed and verified together, which gave the community a deeper trust in the groundwater models (Goal 3). Taken altogether, this made for a more successful implementation.

5 Discussion of the Two Cases

On the meta level the participatory modeling process helped to reach the three primary project goals (see above). In terms of building trust (Goal 3), it was especially important that the round table could engage early in the process from its first meeting, even before the modeling method and the experts had been chosen by the authorities. The participants of the round table were provided with the chance to talk to other contract-holders (which in many situations had not been possible in previous conflicts about the polder option) and to decide together about the collection of participants, the time frame, and the missing expertise to answer the main question: do we really need a flood polder in Katzau or a dike relocation in Hirten? What are the risks and what are the chances involved? Neutral facilitation made it possible for the round table to find a consensus on the participatory process before the answers to the main question were discussed. Some challenges

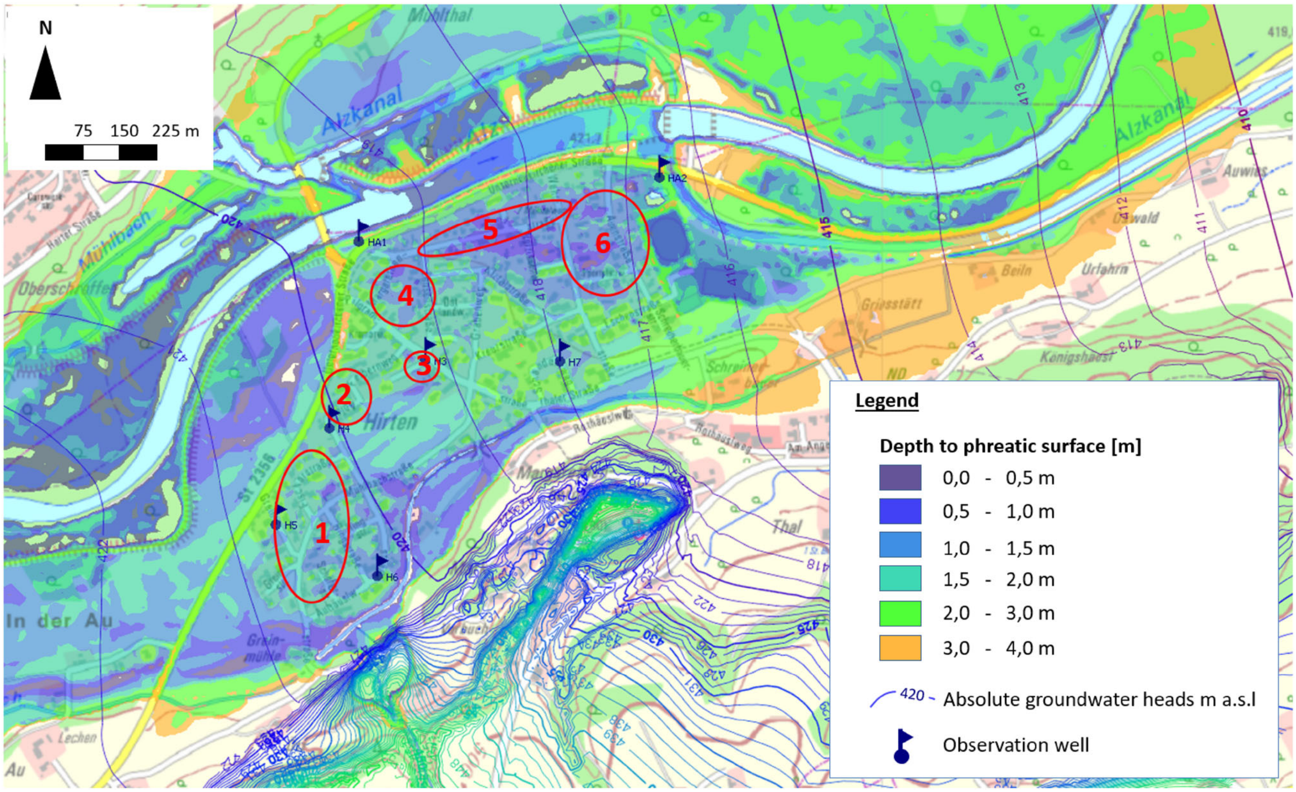

Fig. 9 Modeled groundwater levels for the 2013 event and without the planned dike overlapped with the cases of damage zones (red circles)

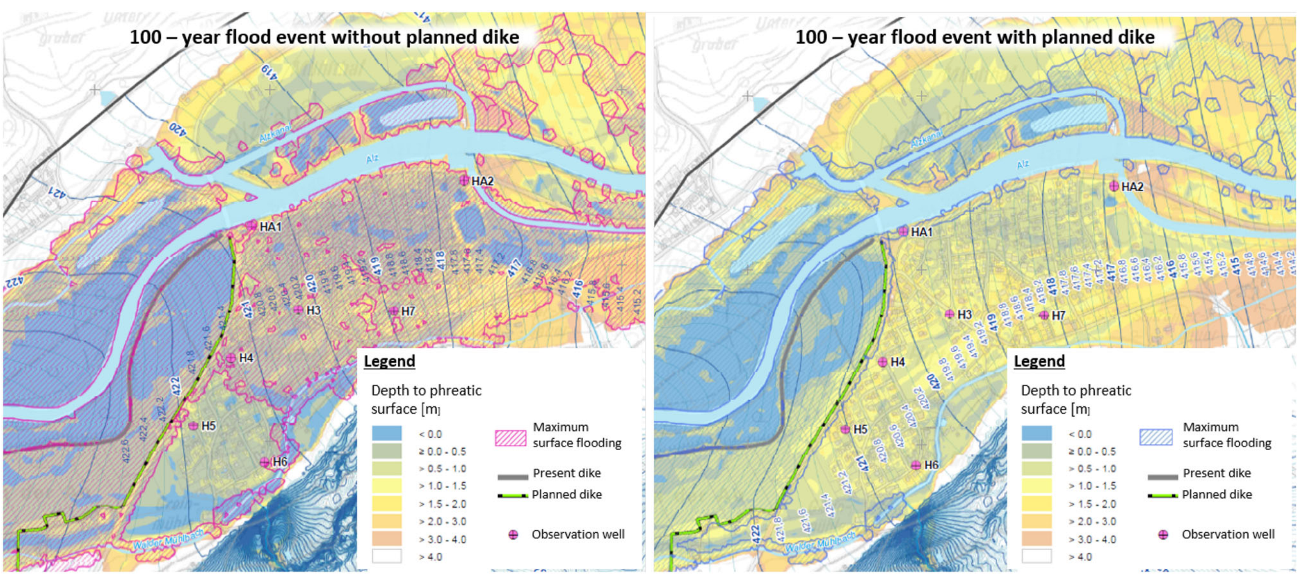

Fig. 10 Modeled groundwater levels for a 100-year event. Left: groundwater level and flooding without planned dike. Right: groundwater level and flooding with planed dike

remain, however, for the successful outcome of the process. A consensus on the question of whether the polder is needed and how it can be built without negative impacts on the community is outlined in this section.

5.1 Case Study I: Flood Polder Katzau at the Danube River

Although the participatory modeling process in case study I is not finished, some conclusions can be made:

(1) The focus on the question of "wet cellars" came from a statement of Ulrike Scharf, Minister of the Bavarian State Ministry of the Environment and Consumer Protection in the first public meeting that "the state would not build the polder, if there is a danger of wet cellars." If the model proves that there is no such danger, will the participants accept a pro-polder decision because of the modeling results?
(2) The groundwater modeling took far more time than expected due to its immense complexity. This is in part due to the wishes of the participants in the participation process, who asked for a model that included a wider geographical range around the flood polder area than was originally proposed.
(3) Political decisions might change. It was communicated to all stakeholders that construction of at least 10 of the 12 proposed polders was essential to reduction of the very real danger of significant damage from future extreme floods. Meanwhile, a discussion about planning a national park in the proposed polder area also would substantially impede technical flood mitigation measures.
(4) Floods are complex risks. These risks are often ambiguous, because the decision about how to prepare for these risks can be discussed from different perspectives and can change according to (personal) values (Renn 2008). In the Danube flood polder case study, this ambiguity is shaping the decision about how much space (fields, nature protected riverside woods, gardens, and so on) should be dedicated to a flood polder to save downstream villages and towns.

5.2 Case Study II: Dike Relocation in Hirten at the Alz River

The dike relocation project is in the implementation phase. The main results from the groundwater and participatory modeling are:

(1) Groundwater and surface water modeling show that the groundwater situation will not get worse. The more than 100-year flood protection improves protection from the impact of extreme events.
(2) The missing data gap remains a problem to solve. New drilling must be carried out to get more information about local geology. The questionnaire helped to overcome the missing measurements of groundwater and surface water levels during the 2013 flood event.
(3) Participants gave important information about surface and ground water systems like flooding by local rainfall events.
(4) Participatory modeling increased all participants' understanding of local natural systems and expanded acceptance for the dike relocation. About 5% of local residents found it hard to accept that the dike relocation would not solve the general problem of high groundwater levels in the region.

6 Conclusion

Our two case studies demonstrate that participatory modeling is a practical solution for polder and dike location. Keeping the challenges in mind, we believe that the participatory modeling process provides a method for solving severe environmental-flood protection conflicts. This process is not a guarantee of success, especially in the realm of accepting plans provided by the authorities. Nonetheless, participation can lead to trust if the opportunity for decision making is open from the onset, and participants have an influence on not just the process, but the decision itself. Participants will not explicitly make the decision per se (which has to be made by a representative board in a democracy), but the inclusion of meaningful input from local people in formulating a recommendation for authorities and representative boards offers a collaborative possibility for the solution of environmental conflicts. Participatory modeling can provide a framework in which the process of scientific modeling expertise is enriched by interaction with lay expertise and local knowledge in a step by step procedure of facilitated round-table sessions. Overcoming the risk perception paradox cannot occur without the fair participation of all stakeholders.

Acknowledgements The authors would like to thank the Bavarian water management office Ingolstadt for publishing the preliminary results belonging to the flood polder Katzau project and the Bavarian water management office Traunstein for publishing the final results belonging to the dike relocation Hirten project. We also extend our thanks to our colleagues on the facilitation team: Petra Claus and Ilse Erzigkeit, as well as all participants at the round tables—it is because of them this publication was made possible.

References

Carmona, G., C. Varela-Ortega, and J. Bromley. 2013. Participatory modelling to support decision making in water management under uncertainty: Two comparative case studies in the

Guadiana river basin, Spain. *Journal of Environmental Management* 128: 400–412.

DHI (Danish Hydraulic Institute). 2017a. MIKE 11. A modelling system for rivers and channels. Reference manual. http://manuals.mikepoweredbydhi.help/2017/Water_Resources/MIKE11_UserManual.pdf. Accessed 3 Dec 2018.

DHI (Danish Hydraulic Institute). 2017b. MIKE SHE. Volume 2: Reference manual. http://manuals.mikepoweredbydhi.help/2017/Water_Resources/MIKE_SHE_Printed_V2.pdf. Accessed 3 Dec 2018.

Diersch, H.-J.G. 2014. FEFLOW finite element modeling of flow, mass and heat transport in porous and fractured media. Berlin: Springer.

Erzigkeit, I. 2017. High-water dialogue on the Bavarian flood polder program (*Hochwasserdialog zum bayerischen Flutpolderprogramm*) (Contribution to the focus issue "Quality criteria for citizen participation processes"/*Beitrag zum Schwerpunktthema "Qualitätskriterien für Bürgerbeteiligungsprozesse"*). *Der Mediator* 2017(1): 9–12. Fernuniversität in Hagen (in German).

Henly-Shepard, S., S.A. Gray, and L.J. Cox. 2015. The use of participatory modeling to promote social learning and facilitate community disaster planning. *Environmental Science and Policy* 45: 109–122.

ICPDR (International Commission for the Protection of the Danube River). 2014. *Floods in June 2013 in the Danube River basin: Brief oversight of key events and lessons learned*. Vienna: ICPDR. https://www.icpdr.org/main/sites/default/files/nodes/documents/icpdr_floods-report-web_0.pdf. Accessed 12 Nov 2018

Keilholz, P., M. Disse, and P.K. Bhola. 2015. Integrated consideration of the problem of high groundwater in the community of Tacherting (Bavaria) (*Integrierte Betrachtung der Grundhochwasser-Problematik in der Gemeinde Tacherting (Bayern)*). *Korrespondenz Wasserwirtschaft* 2015(11): 688–693 (in German).

Kotir, J.H., G. Brown, N. Marshall, and R. Johnstone. 2017. Systemic feedback modelling for sustainable water resources management and agricultural development: An application of participatory modelling approach in the Volta River Basin. *Environmental Modelling & Software* 88: 106–118.

Nujic, M. 2009. *Hydro_AS-2D—Ein zweidimensionales Strömungsmodell für die wasserwirtschaftliche Praxis*, Hydro_AS-2D User Manual. https://www.hydrotec.de/software/support/downloads/hydro_as2d/. Accessed 3 Dec 2018.

Radtke, J., L. Holstenkamp, J. Barnes, and O. Renn. 2018. Concepts, formats, and methods of participation: Theory and practice. In *Energy transition and participation manual (Handbuch Energiewende und Partizipation)*, ed. L. Holstenkamp, and J. Radtke. Wiesbaden: Springer.

Reed, M.S. 2008. Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141(10): 2417–2431.

Renn, O. 2008. *Risk governance. Coping with uncertainty in a complex world*. London: Earthscan.

Rutschmann, P., M. Asenkerschbaumer, and D. Skublics. 2012. Delay and assessment of high flood waves along the Bavarian Danube (*Verzögerung und Abschätzung von Hochwasserwellen entlang der bayerischen Donau*). Final report 2012, Chair and Research Institute for Hydraulic Engineering and Water Economy, Technical University of Munich (*Abschlussbericht 2012, Lehrstuhl und Versuchsanstalt für Wasserbau und Wasserwirtschaft, Technische Universität München*) (in German).

Wachinger, G., C. Begg, O. Renn, and C. Kuhlicke. 2013. The risk perception paradox—Implications for governance and communication of natural hazards. *Risk Analysis* 33(6): 1049–1065.

Wachinger, G., O. Renn, S.-K. Wist, S.-M. Steinhilber, and U. Triemer. 2014. Using participation to create resilience: How to involve citizens in designing a hospital system? *Environment Systems and Decisions* 34(2): 208–223.