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Participatory modelling of vulnerability and adaptive capacity in flood risk management

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Abstract Being part of the EU-project NeWater on adaptive water resources management, the Ukrainian Tisa river basin is presented as an example for a participatory study dealing with flood risk, vulnerability and adaptive capacity. The Tisa valley is regularly and increasingly faced with hazardous floods at very limited local budgets and high poverty rates. In order to make flood risk management more resilient and better adapted to climate change, scientists and stakeholders applied a set of qualitative and quantitative modelling approaches to characterise prevailing flood risk management, to discover respective vulnerabilities and to identify barriers and options of adaptive capacity. The former were found in the defensive mentality paradigm and the inert and hierarchical structure of present institutions, the latter in, firstly, an enormous potential to link the knowledge of different stakeholders in the region, secondly, a better integration of the individual flood preparedness of households and thirdly, the active involvement of the Church as institution in local flood risk management.

Keywords Flood risk management · Vulnerability · Adaptive capacity · Tisa valley

1 Introduction

As part of the EU-project NeWater on adaptive water resources management under conditions of Global Change (Pahl-Wostl et al. 2007; www.NeWater.info), the Transcarpathian Tisa river valley was subject to a participatory study dealing with flood vulnerability, adaptive capacity and resilience (Haase and Bohn 2007; D. Haase et al., in prep.). The Transcarpathian part of the Tisa river basin is regularly and increasingly faced with hazardous floods but has very limited municipal budgets and high poverty rates. Some of these floods recently (1998, 2001, 2006) caused enormous damage: many people lost their

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homes, some their lives, and in other cases livelihoods and infrastructure was destroyed (TACIS 2007).

The origin of floods in Transcarpathia is twofold: firstly, there is the natural process due to heavy rainfall in the mountains and exacerbated by the snowmelt that occurs in the spring time. Secondly, settlement development in the floodplains and deforestation in the mountains after the political transition in 1991 caused an increase in water travel times and sediment loads after rainfall events and, simultaneously, increased the number of elements and values at risk in the valley (Jolonkai and Pataki 2005; TACIS 2007).

Flood protection systems in the region are mainly based on technical components such as canals, dikes, bank enforcement or reservoirs. Local monitoring systems work administratively on sectoral objectives, which are rather technical and related to the collection of data. Despite initial approaches to improve the warning system in the region, the monitoring system ignores the complex situation of "being flooded" that local municipal communities are facing (TACIS 2007; Haase and Bohn 2007). Water management institutions like the State Committee for Water Management (SCWM) and the regional water board thus fail to address local risks in flood management context, as they are not clearly linked to municipal decision-makers' needs and perceptions of risk. The perception of the local decision-makers of their own risk and that of "their villages" is significant as it will ultimately influence their behaviour. Only if risk perception existence and distribution among the stakeholders is known the adequate measures and options of FRM can be effectively applied (Pahl-Wostl 2007; Pahl-Wostl et al. 2007).

At present, the communities living in the Transcarpathian Tisa valley are extremely vulnerable. What is more, this situation is not expected to improve as the costs for further flood risk reduction would be hard to recover with the limited finances available and, if so, only address the structural (=technical, physical) flood protection measures and not the coping capacity of the communities. Recent papers on natural hazard management (e.g. Krysanova et al. 2008; Kundzewicz and Kaczmarek 2000) suggest to implement more participatory and non-structural (=non-technical, information-based, social network-using, adaptation-oriented) measure-oriented flood management and to identify new ways to reduce flood risk by enhancing the local capacity for coping with or adapting to the situation of extreme or increasing flooding (e.g. using existing knowledge, social networks and resources, improving individual flood education, etc.).

Using qualitative (conceptual) and quantitative modelling in a participatory way, it was our aim to identify diverse causes for flood vulnerability and reasons for failing risk management as a kind of prerequisite to assess barriers and options towards a more adaptive (in terms of sustainability and climate change) flood risk management. So doing, the objectives of this paper are firstly to characterise both flood risk management and flood vulnerability in the Tisa valley by way of collaboration and mutual learning between stakeholders and scientists and secondly to identify barriers and options of adaptive capacity.

If these options allow to (1) make flood risk management more robust against damages and other harmful effects of floods, (2) increase the coping capacity of the local people, (3) strengthen long-term flood adaptation strategies compared to short-term hazard management, we could call them in terms of flood risk management "more resilient" (following Sendzimir et al. 2008; Berkes 2007; Berkes et al. 2003; Steinführer et al. 2009; Kuhlicke and Kruse 2009).

2 The Transcarpathian Tisa valley

2.1 Physical environment and socioeconomic conditions

The Tisa River Basin is the largest river basin among the 15 sub-basins of the Danube River, which originates in the Black Forest in Germany and reaches the Black Sea at the border between Romania and Moldova. Five European countries and 14,400,000 people share the 157,200 km^2 area of the basin: Hungary, Romania, Serbia and Montenegro, Slovakia, and the Ukraine (Fig. 1).

In the Transcarpathian part of the Tisa valley in the Ukraine, hazardous flood events regularly cause enormous damage to poor regions that also have very limited financial

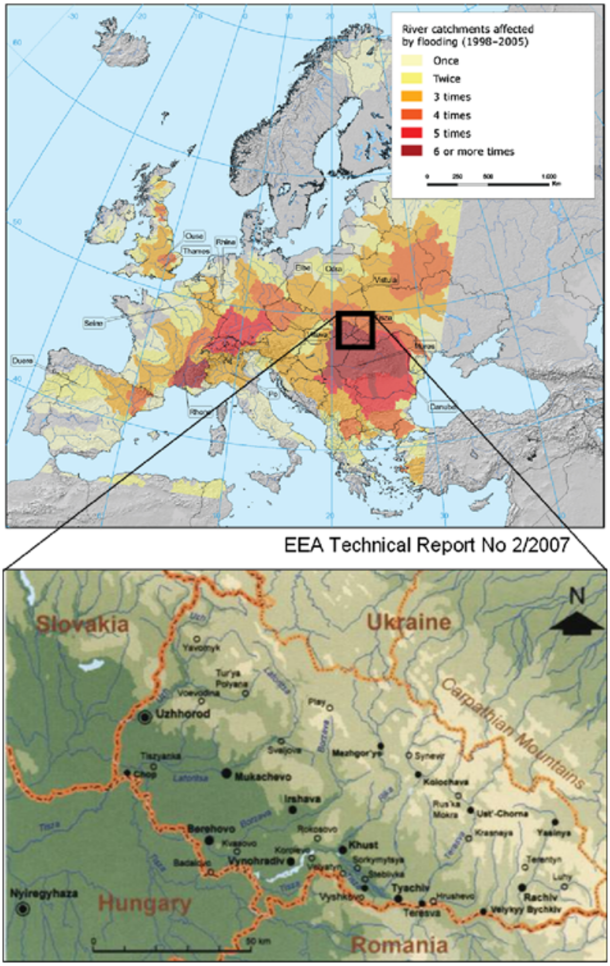

Fig. 1 Situation of the Tisa river basin in Europe (*black box*) and its Transcarpathian part (*lower map*): the *upper map* shows the frequency and occurrence of major floods in Europe from 1998 to 2002. The Tisa belongs to the most affected of basins across Europe. The *lower map* shows the transboundary situation of the Tisa river covering parts of the EU (Slovakia, Romania, Hungary) and the non-EU country of the Ukraine where, next to Romania, most of the hazardous floods of the Tisa river find their origin

budgets at local level to prevent or alleviate the impacts of flood damage or provide the aid for recovery. According to the European Environmental Agency (EEA 2007; Fig. 1) the Carpathian mountains and Transcarpathia belong to the most affected areas in Europe with regard to the occurrence and frequency of floods. Between 1998 and 2002 more than 6 heavy floods occurred here. This is in agreement with Jolonkai and Pataki (2005) who reported that due to frequent extreme weather conditions such as heavy rains and intensive snow-melting and amplified further by land use factors (e.g. deforestation), floods can occur three to eight times a year. The recent 1998, 2001 and 2006 floods were devastating, particularly in Transcarpathia. In 1998, the November flood caused 17 deaths, the destruction of a quarter of the road bridges and a total estimated damage of 81 million Euros. In 2001, more than 65 local communities were completely flooded, 10 people died and 76 telephone connections were lost (TACIS 2007). Therefore, flood risk management belongs to the major challenges in water management in the Tisa River Basin and particularly in the Transcarpathian region (Table 1).

The regional flood protection system is designed to provide protection for over 140 settlements in the mountains and the Tisa valley of the Oblast (=regional administrative unit comparable to the county level) and an area of >110,000 ha. It is very technical in nature, with canals, dikes, hydraulic structures, bank reinforcement structures, pumping stations and reservoirs covering most of the flood protection measures (Table 2; TACIS 2007; Krysanova et al. 2008). Recent activities by the regional branch of the State Committee for water management in Ushgorod who are mainly responsible for the operationalization of the flood risk management focus on the development of an improved and extended automatic warning system and a scoping for further water reservoirs in the mountains.

2.2 Institutional settings and the planning behind flood risk management

The overall flood management in Transcarpathia is in the hands of the regional administrative unit, the ‘Oblast’, which is linked to national ministries and organisations. The responsibility of managing the water resources is shared: whereas the oblast department of the Ministry of Environmental Protection is in charge of the water resources management and allocation as well as water quality and pollution control, the water-related hazard prevention, land reclamation, flood control and monitoring is in the hands of the State Committee for water management and its regional branch, the water board in Ushgorod (TACIS 2007).

Table 1 Key socioeconomic and environmental challenges and water management issues in the transboundary Tisa river basin collected in the mental modelling exercise—flood risk management has been put to the top (Haase and Bohn 2005)

Country	Key issues
Ukraine	Flood risk management; reforestation of the carpathians; reduction of contamination; job diversification; poverty reduction
Hungary	International cooperation; flood risk management; WFD; good agricultural practice
Romania	Flood risk and river basin management with ICPDR; water supply; water quality improvement; ecological reconstruction
Serbia	Flood risk management; water supply; water quality; biodiversity; navigation
Slovakia	Flood risk management; water supply; ecology (biodiversity); agricultural potential

Table 2 Current and future flood protection system in Transcarpathia as foreseen by the Regional Water Management Institutions

Component	Unit	Until 2001		2002–2005	
		Quantity	Costs (m EUR)	Quantity	Costs (m EUR)
Canals	km	1,296	0.65		
Dikes	km	707	5.42	957	7.66
Bridges	Number	–		91	86
Bank enforcement structure	km	260	12.3	110	6.25
Hydraulic structures	Number	1,109	1.9	155	0.22
Pumping stations[a]	Number	49	1.33	–	–
Polders	Number	–	0	22	31.2
Reservoirs[b]	Number	9	0.51	42	12
Subtotal		22.2		143.3	
Total		165.5			

[a] Total capacity 119 m^3/s

[b] Total volume 52,000 m^3

In case of a flood, the latter is supported by the oblast department from the Ministry of Emergency Situations in terms of civil defence and evacuation plans and in terms of stream flow and discharge data by the State Hydrological Survey (HydroMet). Most of the coordination and organisation work between the above mentioned bodies and the local municipalities is provided by the regional oblast administration and the sub-level, the so-called rayon administrations. Both information flow and decision-making structures appear to be very hierarchical (Fig. 2).

After the 1998 and 2001 floods, a new flood prevention plan was implemented with major national investments of >1,400 million Euros (details given in Table 2). First and foremost this covers construction and operational measures. Dispatcher centres are foreseen to share information with neighbouring countries like Hungary, Slovakia and Romania. The perceptions of risk and needs of both the local decision-makers and the local population fall short in top-down hierarchical systems (Wisner and Blaikie 2005) such as this of flood risk management in Transcarpathia. As a matter of course, the study area faces multiple stresses in terms of floods but in case of the institutional setting the ignorance of the local level was evaluated by national experts as decisive.

Since decision-making is a broad and complex field, in our study, we had to put exemplary focus on one particular group of stakeholders for the decision-making analysis (cf. Sect. 4.2).

3 Defining vulnerability and adaptive capacity

3.1 Vulnerability

Several different concepts and definitions of vulnerability exist, originating from different scientific communities. Since its emergence in social and environmental research (Chambers 1989) a variety of overviews of the various concepts and understandings had been provided, e.g. by Villagrán de León (2006), Adger (2006), Fuchs (2009) or Samuels

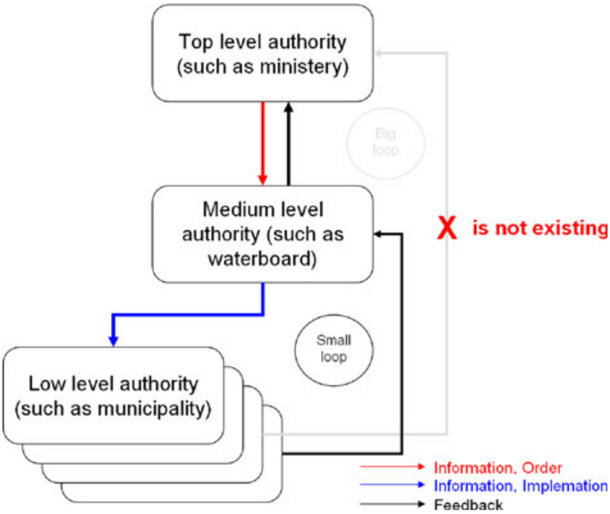

Fig. 2 Hierarchy of decision-making and feedback between the different levels involved in water resources and flood management in the Ukraine (authors' draft). The conceptual figure shows that decision-making is very top-down with a missing response from the local ("affected") level to the top (national; steering) level (big or long feedback loop). The response loop between the local and medium level contrariwise is given (small or short feedback loop). Thus, the national-level authorities, if they are not briefed by the medium level, do not possess knowledge about the local communities

et al. (2009), Gallopín (2006). In more general terms, vulnerability can be defined by the characteristics of a system that describe its potential to be harmed (Turner et al. 2003; Kienberger et al. 2009). It can be expressed in terms of functional relationships between expected damages regarding all elements at risk and the susceptibility and exposure characteristics of the affected group or sector, referring to the whole range of possible flood impacts (following Messner and Meyer 2006 as well as Downing et al. 2005). In this spirit, this paper defines vulnerability $V_{s,g}$ of a group or a sector as a function of the exposure E to the hazard and the consequences made up by the value of the elements at risk and the susceptibility of the elements at risk (Fig. 3). Steinführer et al. (2009) argue that defined in this way vulnerability is highly context-specific which also makes adaptation context-specific, accordingly, but not necessarily case-specific (which means only valid for Transcarpathia for example).

3.2 Adaptive capacity

For a given flood hazard AC is the potential for adaptations, which can reduce the vulnerability to this flood. This potential may increase with the ability (emerging from the capacity to modify the natural, built, human, social capital) to learn, experiment and be innovative so as to respond to shock and stress in ways that diminish them over the medium to long-term. Our methodological framework in the Tisa valley provides a wide variety of activities and factors that can comprehensively contribute to that potential as it will be detailed outlined in Sect. 4. But how do all of these extracted and elicited variables and causalities work—will it be individually or together—to build the potential of AC? Following Luers et al. (2003) we propose to define AC as a difference between vulnerability (as defined in Sect. 3.1) including or excluding adaptation processes:

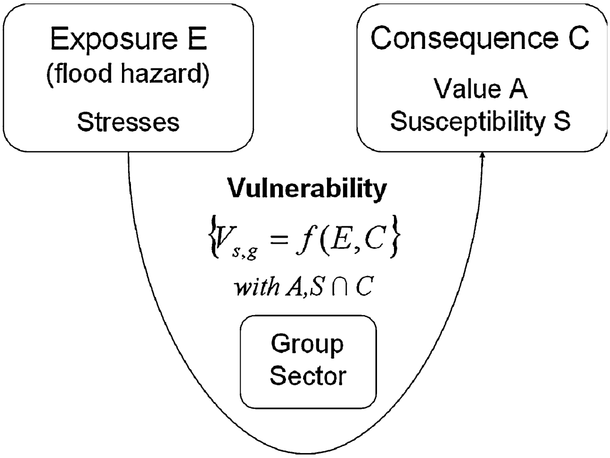

Fig. 3 Definition of vulnerability V based on the results of the participative mental and group model-building exercises and the quantitative system dynamics modelling where H is the flood hazard and its related various stresses, C the consequences in terms of values A and susceptibility S, s and g affected sectors and social groups

$AC = Vb - Va$ where Vb is the baseline vulnerability (excluding adaptation) and Va the vulnerability including adaptation. For a given flood hazard H, AC allows one to compute a vector of functions representing how a difference (between a case in- or excluding adaptation) in consequences C of this flood change over time t (which makes both vulnerability and adaptive capacity dynamic vectors): $AC_{H,t} = Vb_{H,t} - Va_{H,t} = Cb_t - Ca_t$. For more AC one can expect that this consequence difference should increase faster in time, reflecting a decrease in vulnerability (and high resilience?). For an extreme value of "no adaptive capacity" the difference will be zero (as resilience too) although vulnerability and adaptive capacity cannot always simply be expressed in quantitative and numeric terms (Fig. 4). However, due to implementation barriers the state of consequence difference may not necessarily reflect the full capacity of the system to adapt (Green 2004).

3.3 Resilience

Resilience is its capacity to absorb disturbances while maintaining its behavioural processes and structure. It can be defined as the capacity to buffer perturbations, to self-organise, and to learn and adapt (Seixas and Berkes 2003; Weik and Sutcliff 2007). Following this definition it includes the amount of change the system can undergo and still retain the same controls on function and structure, or still be in the same state within the same domain of attraction. Resilience defines the degree to which the system is capable of self-organisation and the ability to build and increase the capacity for learning and adaptation (Berkes et al. 2003). A way to uncover it in a system is to identify barriers and options towards resilience. Related to the key issue addressed in this paper—flood risk (management)—resilience depends on barriers and options to make flood risk management more robust against damages and other harmful effects of floods, to increase the short-term coping capacity of local communities and people, to strengthen long-term flood adaptation strategies (cf. again Sect. 1).

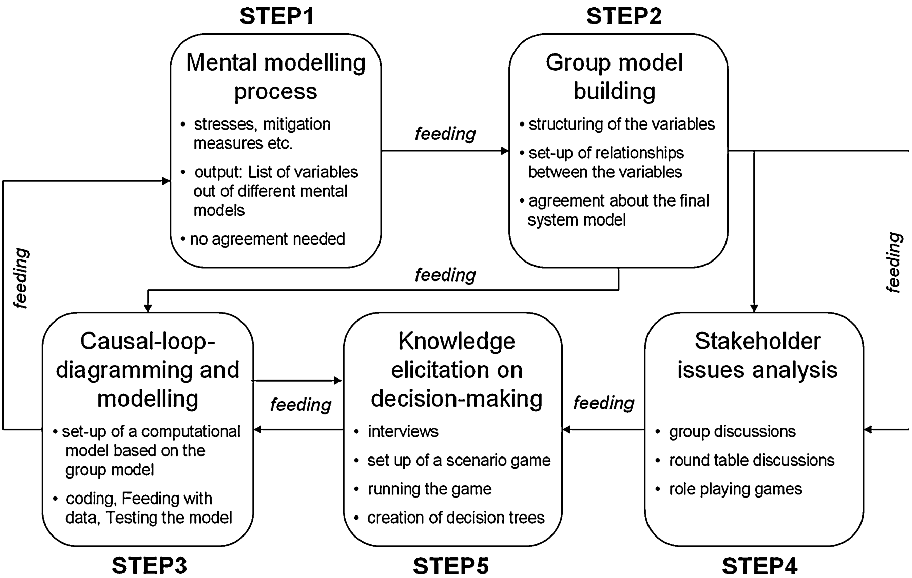

Fig. 4 The five-step methodological design used for analysing and understanding the Transcarpathian flood risk management

4 Analysing flood risk management: methodical steps and results

Based on the information given in Sect. 2, which was mainly gathered in the field or during interviews with local experts, it was the major task for a group of NeWater and national scientists and Ukrainian stakeholders to identify vulnerabilities and coping strategies in flood risk management to make it more adaptive to the local perceptions of risk and thus more responsive to local needs. NeWater scientists comprise hydrologists, landscape ecologists, sociologists, anthropologists and computational modellers. Regional and local stakeholders were represented by the Transcarpathian water board, national scientists (a.o. working in NGOs or at the HydroMet) and by municipal and village council heads. For the first group, the scientists, it was important to test the applicability of the concepts of vulnerability (Downing et al. 2005), adaptive capacity (Luers et al. 2003) and resilience (e.g. in Berkes et al. 2003). For the second group, the stakeholders, understanding the underlying mental models of the other stakeholders and recognising openings for intervention or transformation was of principal concern (Anderies et al. 2006).

Figure 4 displays the different steps of the research design applied: the results of step 1, a participatory mental modelling exercise, flow in step 2 into a process of group model building (constructing the shared model using a whiteboard, pen and cards). In step 3, both were taken up by a subsequent causal-loop-diagram (visualisation using the computer). The visualised causal-loop-model was finally converted into a numerical system dynamics model, which is able to quantify the collaboratively elaborated causal feedbacks and to show system responses (Costanza and Ruth 1998). The system dynamics model showed an obvious lack of system understanding in terms of stakeholder decision-making in flood risk management. Thus in step 4, after the stakeholder (issues) analysis a participatory game was conducted with one specific group of stakeholders. The game was intended to uncover the heuristics of their decision-making in case of either a flood situation or increasing uncertainty due to climate change (S. Kuptsova et al., submitted). These results were also integrated into the causal-loop-model.

4.1 System understanding

4.1.1 Mental modelling (step 1 of the research design)

Method. The first step of our research design was a mental modelling process (Sendzimir et al. 2010) in order to identify the most pressing problems in the Tisa River Basin in terms of water management and related uncertainties. This mental modelling process was carried out in the form of participatory brainstorming, which was organised in the Tisa region (a.o. in Ushgorod and Shayan). The mental modelling was organised in the form of 4–6 round table discussions in overall 3 small groups of 3–4 stakeholders and 1–2 scientists using either English or Ukrainian. The rational behind the relatively small groups was majorly driven by the continuity of the group because we used the iterative methodological design outlined in Fig. 4. Thus, it was important to keep the members at it. Since we started with an intensive stakeholder selection process at the very beginning of the project, the resulting group of stakeholders is representative and relevant for future implementation. For the realisation of the mental modelling exercise, we used cards, pens, a whiteboard and a pin wall to identify, fix and collect the ideas that emerged from each stakeholder (Fig. 5).

Results. Resulting from the mental modelling different variable lists, a ranking of them and a grouping into driving forces, pressures and impacts were compiled. Therefrom, the

Fig. 5 Participative mental modelling process on flood risk, vulnerability and flood risk management in the Tisa basin

major problem that most of the stakeholders placed at the top of about 10 water management problems was flood risk (management) and the role of non-structural measures. The idea about the latter was introduced by local and NeWater scientists and may have facilitated the generation of novel ideas among participants that came mainly from technical backgrounds and thus helped to broaden the perspective on potential flood management measures (Haase et al. 2008).

4.1.2 Group model building (step 2 of the research design)

Method. In a second step, based on the mental models, a series of group model-building (GMB) workshops was organised by the NeWater scientists involving Ukrainian scientists, water board members and local stakeholders. GMB (also known as cooperative modelling, collaborative modelling, participatory modelling or mediated modelling) is defined as "… [a collection]… of pieces of a facilitated group exercise and of techniques used to construct joint kind-of-model representations of the system that move a group forward in a systems thinking intervention" (according to Andersen and Richardson 1997 or Vennix 1999). The method implies that the knowledge available among the participants can jointly help to work out key elements of flood risk management and relationships between them more effectively (D. Haase et al., submitted). During the workshops, we again used round table plenary discussions and break out groups (to split a larger plenary into smaller groups to discuss specific issues; Fig. 6). Each workshop started with a constructed brainstorming at the beginning to serve as a comprehensive revision of the results achieved so far in the mental modelling process for continuously participating group members and as an introduction for the newcomers.

Results. Predominantly, break out groups discussed the issue of flood risk and turned the focus more and more towards flood preparedness in local communities, which were evaluated to be crucial to improve existing flood risk management (Haase and Bohn 2007). In the GMB sessions, the participants identified the basic components (variables, relationships) as well as initial structures (after variable grouping) from the mental models in step 1. After rejoining, the models were discussed and further developed into a conceptual causal-loop-group model that consists of different mental models from the participants in steps 1 and 2 but now agreed upon by all participants. The main features and intermediate results of the GMB process are summarised in Table 3. As the main focus of the paper is not on GMB, the single results will not be discussed in detail but influenced the following causal-loop-diagramming.

4.1.3 Causal-loop-diagrams and system dynamics modelling (step 3 of the research design)

Method. In the third step, a small group of scientists and some key expert stakeholders—that is mainly 2 members of the waterboard, a scientist from the national Hydromet Institute and another scientist from an NGO—developed a series of interlinked quantitative system dynamics (SD) models based on the group model (variables and relationships; cf. again Fig. 6). The modelling was carried out using the VenSim PLE software by *Ventana Systems, Inc*. Creating quantitative causal-loop-diagrams is typically part of a system dynamics based modelling effort. But according to Costanza and Ruth (1998), it serves ideally for approaching complex human–environmental systems such as flood risk management. Regardless of a partial lack of data, some very interesting and challenging models

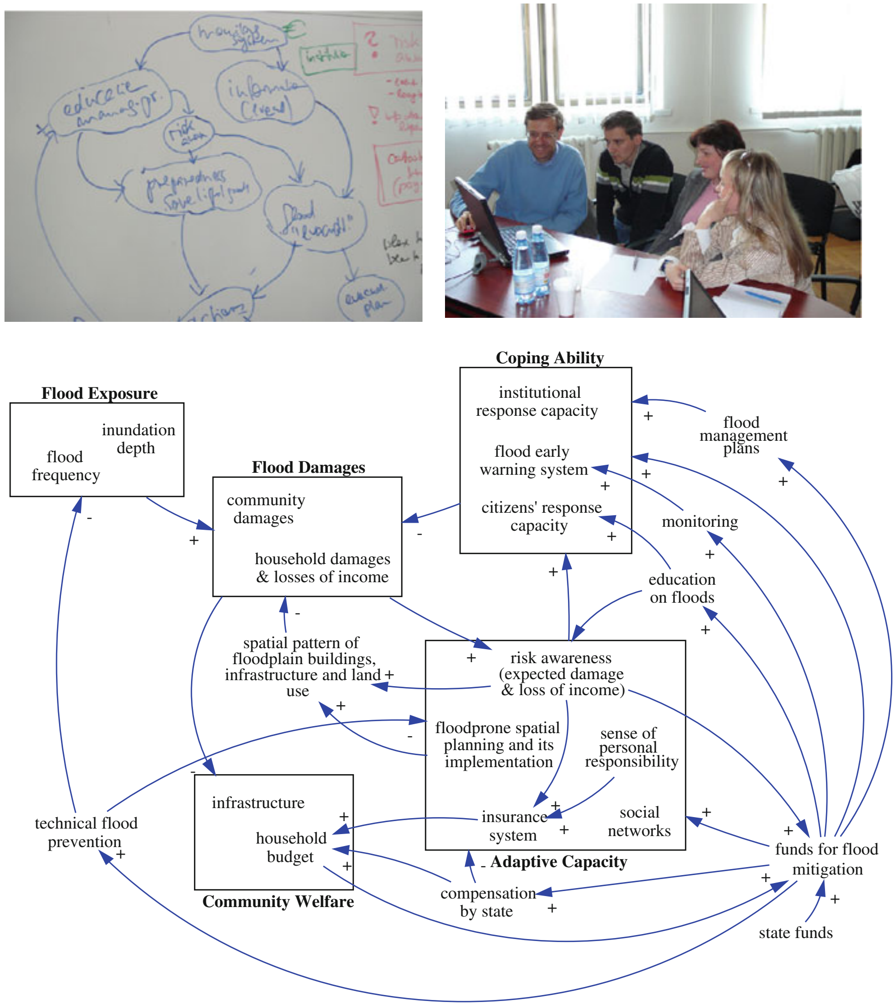

Fig. 6 Group models developed for the Transcarpathian Tisa basin: the causal-loop-diagram (1) of a concept of flood preparedness that links coping ability (short-term measure in the case of a hazard event) and adaptive capacity (long-term preparedness). The pluses (+) and minuses (−) indicate the polarity that the relationship is assumed to have (thanks to Piotr Magnszweski for contributing to the model structuring)

emerged, which—and this is very important—produced results that the stakeholders accepted and intensively discussed.

Results. The result of step 3 is a quantitative SD model that "translates" the aforementioned mental and group models on "how to improve flood risk management" into numbers and graphs. For example, potential flood damages and the recovery time under different conditions of flood preparedness was modelled (graphs are shown in Fig. 7). Hereby, variables were selected, which were previously assigned to the coping ability like e.g. the evacuation of vulnerable persons and the relocation of assets. Other variables were assigned to the adaptive capacity such as flood insurances and education on floods.

Table 3 Main features of the group model-building process in the Tisa valley

Process component	GMB process on flood risk management
Topics addressed	Improving flood risk management including Coping with extreme flood events Identifying adaptive capacities of local municipalities Introduction of non-structural flood mitigation and adaptation measures
Spatial scale	Upstream Ukrainian part of the Tisa river basin (Zacarpathian part) characterised by high water flow travel times and frequent flooding
Acceptance and uptake of method (low, medium, high)	Low to medium at beginning, then high
Prior involvement of participants in project	To a larger extent. Some of them are strongly involved in another NeWater activity (scenario games using KnETs)
Initiation of process (by whom)	NeWater European scientists and Ukrainian expert and scientific partners
Representativeness of stakeholders (all participants except the NeWater scientists and local scientists) (low, moderate, high)	Moderate—strong (local level not) Stakeholders from the local water management board participated. They all represent different roles in water management such as water quality, monitoring, flood prediction and public relations National level with a member from the Hydromet service present Policy level with department head from the Ministry of Environment NGO involvement (representing independent agents)
Design of process	Introduction by NeWater scientists
Mental modelling (MM)	2–3 breakout groups on definition of topics
Group model building (GMB)	MM: individual cognitive mapping by each participant within the breakout group; GMB: joint construction of GMB by all participants of all groups; each participant contributed major factors from her/his MM Summary/consolidation: emergence of mental models, loops, concept models, stock-flow approach
Duration of process	At each location cognitive mapping and GMB took place in separate sessions during a series of 2-day workshops
Goals/framing of the process	Identify factors that are crucial for improving current flood risk management practices and potential, particularly non-structural measures; roles of actors in the implementation process
Link to ongoing policy process	GMB in accordance with ongoing budget revision and re-allocation after flood in 2001; planning process of technical flood protection measures (reservoirs, dams); flood study in an international research project
Generation of novel ideas	List of non-structural flood mitigation and adaptation measures. Identification of new actors in flood management and flood preparedness (e.g. Church)
Focus of the resulting models	Flood risk management (from the beginning) but then biased in (short-term) mitigation and (long-term) adaptation
Comprehensiveness of the models	Comprehensive model but not complete

Table 3 continued

Process component	GMB process on flood risk management
Implementation/realisation of the models	Realisation as MM (visualisation of variables—stocks and flows—relationships and polarity) and quantitative model using empirical evidence/initial values from the Tisa valley
Degree of integration	Integrative in terms of geo-components, disciplines and hierarchies (of management)
Added value in view of stakeholders	Very useful joint brainstorming and identification of different "ways of thinking" of people that have known each other for a long time, more integrated perspective on the deficits and potential of flood risk management. Development of measures to address adaptive capacities
Added value for scientists	New insights into the system and flood risk management and actual management processes
	Creation of mutual understanding and trust in scientific models from the stakeholders' side

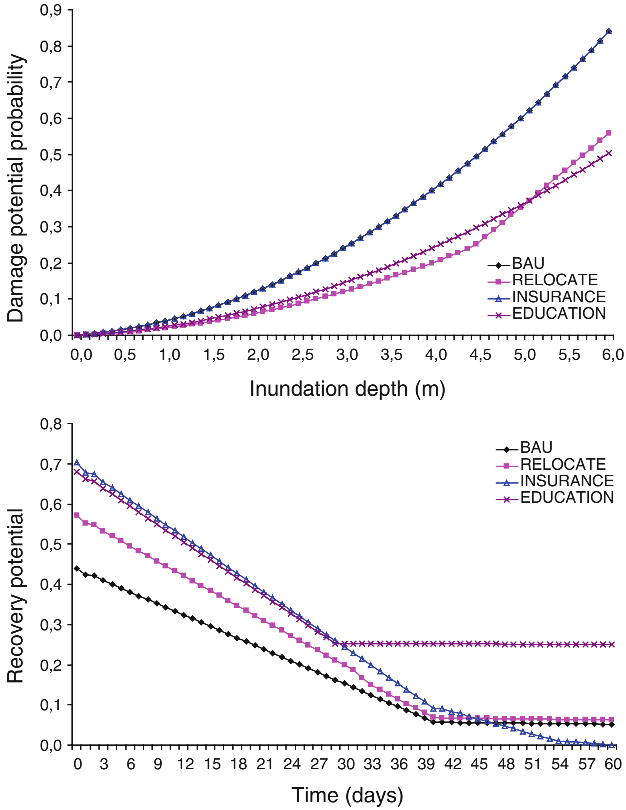

Fig. 7 Results of the quantitative system dynamics model for flood risk vulnerability and management options based on the mental and group models shown in Figs. 3 and 4. The model was realised using the VenSim PLE software. BAU represents the business-as-usual situation, RELOCATE means the relocation of vulnerable assets and the evacuation of vulnerable people, INSURANCE means the introduction of insurance packages and EDUCATION the implementation of flood education programmes in schools

Figure 7 displays the results modelled from these measures on the run of depth–damage curves and duration–damage curves, respectively.

It was very convincing for the stakeholders to learn that non-structural measures such as relocation activities or education programmes might physically reduce the damage during the event on the one hand. On the other hand, our model showed that particularly education on floods increases the overall recovery of the area, which could equate to something like the resilience of the community for a longer period since the overall damage potential and thus the vulnerability of a local community decrease. Although these model results are convincing, they do not tell us anything about the behavioural heuristics and the decision-making that might lead to the introduction of non-structural 'soft' flood measures as assumed in the model (S. Kuptsova et al., submitted). There are also other convincing results from non-structural measure programs that have been implemented such as those in the Netherlands (e.g. WATERLAND—Room for the River Programme for the Rhine); however, local stakeholders in the Ukraine need to implement them. Therefore, in steps 4 and 5, we attempt to approach decision-making issues, prerequisites and behaviour.

4.2 Stakeholder decision-making

4.2.1 Stakeholder issues analysis (step 4 of the research design)

Method. To identify key stakeholders, an assessment of their interests and the ways in which these interests affect management performance and viability, we used an enhanced stakeholder issue analysis (ODA 1995). In so far, a stakeholder issue analysis enables stakeholders and scientists to gain some insight into the goals, aims, views and interests of the other stakeholders to achieve the water resources management goals in a river basin (Poolman and van de Giesen 2006). Using the form of a facilitated round table discussion, NeWater and local Ukrainian scientists made an inventory of the stakeholders' interests, their goals, needs and capacity to oppose or support new ways in flood risk management.

Results. As a focal group, the local Village Council Heads (VCH—a traditional, but formal elected governance structure) in the main river and tributary valleys were identified. The VCH are crucial for implementing flood preparedness measures and deciding how to prepare their communities for a potential flood situation but even local experts only have fuzzy knowledge about them. The fifth step of our analysis framework focuses on the knowledge elicitation of existing and potential alternative decision-making processes by VCH in the Ukrainian Tisa valley.

4.2.2 Decision-making heuristics exploration using KnETs (step 5 of the research design)

Method. Eliciting existing local stakeholders' knowledge and learning about existing decision-making processes is key to uncovering vulnerabilities and adaptive capacity in flood risk management. The need to understand the multiple stresses outlined so far—increasing flood risk, uncertainty of precipitation trends, poverty and neglecting the local level in risk management decision-making—which interact to form complex vulnerabilities, such as those observed in the Tisa basin, has led to the design of participatory knowledge elicitation tools (KnETs).

KnETs tools represent a new and reproducible way to formalise local socioenvironmental knowledge while exploring future scenarios during interviews. KnETs can be understood as departing from classical empirical tools for qualitative social science research using a more structured, yet flexible and interactive interview method that results in a 'game' that is played iteratively to verify and validate decision-making knowledge. The KnETs process supports stakeholder-led research by providing a formal approach to knowledge elicitation, representation, verification and validation with iterative stakeholder engagement and feedback. The results of the game are a set of decision rules or decision trees for a given context that can also be used alone for learning and discussion purposes or as input data for the rule-based logic of agent-based or causality models (Bharwani et al. 2008; Wood and Ford 1993).

KnETs allows the exploration of changing vulnerability by representing scenarios of the multiple stressors to which different groups—in our case the VCH that are faced with either a flood or varying rainfall trends—are exposed and have to make respective decisions and explores how these stressors influence different decision-making pathways over time (Downing et al. 2005; Ziervogel et al. 2006).

A KnETs game consists of 5 phases: (1) the interview to conceptualise the game, (2) playing the game, (3) machine learning, (4) deriving behavioural rules based on the results of the machine learning and (5) the verification and validation of the game (Bharwani 2006). In the Tisa basin, we run 40 games with different VCH: 5 of them were conducted to design the game, another 15 to run it, the next 5 to validate the game (conducted with VCH who were not involved in the two former steps) and to create decision rules (as shown in Fig. 8) and the last 5 to verify the game. In this last KnETs phase, the scientist uses the decision tree developed based on the rules created in phases 1–3 and tells the respective VCH what he/she would probably do in the case of a flood. If the VCH agrees, the tree is 'correct'. If not, the scientist is made aware that there is more (mostly intuitive or tacit) knowledge that the VCH uses to make his/her decisions (further details see Haase et al. 2008 at www.NeWater.info). The results of our KnETs game are shown in Fig. 8.

Results. The resulting decision tree indicates that long-term adaptation can only be planned when risk is low (medium or low precipitation periods) and when funding is available. However, when funding is not available in both low- and high-risk periods,

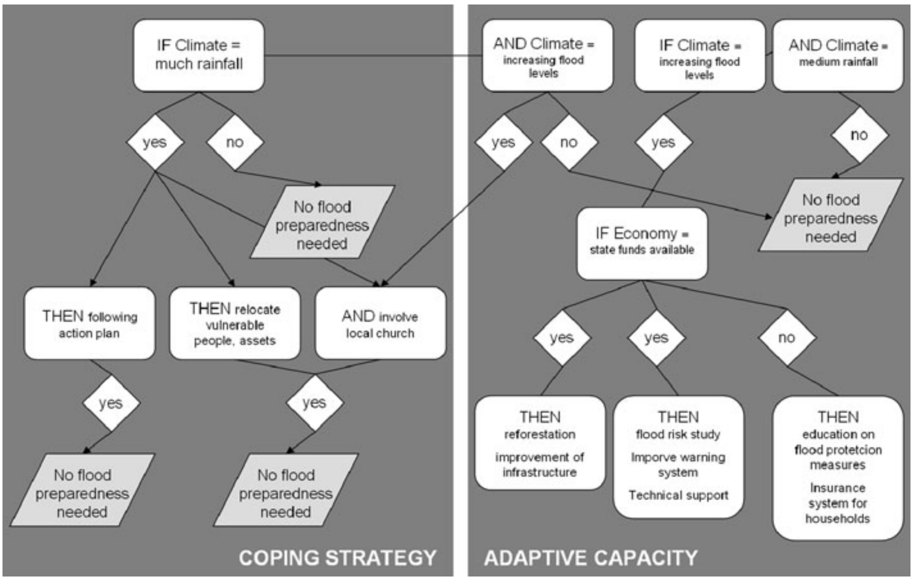

Fig. 8 Decision tree resulting from the KnETs scenario game on decision-making of the VCH

adaptation planning is not undertaken and responses are simply short-term coping strategies or highly dependent on individual household responsibility or on the (local) Church. This implies that above all else, governmental support is critical for long-term adaptation. That is, long-term planning is not neglected due to a lack of knowledge of adaptation strategies but rather due to firstly a lack of financial capacity (which also means flexibility to do something and achieving certain stability). And, secondly, VCHs feel uncomfortable and unwilling to accept the risks (that unknown and new non-structural flood protection measures might bring) to undertake these options. Social networks such as families, former cooperatives and collective structures and a related emphasis on social responsibility are used to compensate for the lack of external support.

New knowledge in terms of the potential and barriers for the implementation of non-structural flood risk prevention became accessible using KnETs as opposed to straightforward interviews because the research process can explore the role of local knowledge—knowledge that is voiced and knowledge that is actually used may be different. Furthermore, in the Tisa case, the knowledge that emerged in the list of strategies (stage 2—game design) after initial conversations with VCHs (stage 1—interviews) were in the form of new measures that were previously unknown to the scientist.

A more tangible use of the output from the KnETs games is that it may allow newly elected VCHs who are not experienced in flood protection measures to become quickly accustomed with the necessary information in this domain. This is very valuable particularly where an experienced VCH may not realise that certain knowledge needs to be communicated or where they may find it difficult to describe their knowledge.

5 Synthesising discussion

5.1 Vulnerability to floods

The research design presented in Fig. 5 helped to produce a range of interesting findings on flood risk management, vulnerability, barriers and option towards adaptive capacity in the Tisa valley. Apart from climate change, we found mostly human drivers increasing flood risk, damages and losses: the reduction of water storage capacity in the watersheds by river regulation, deforestation, urbanisation along with increasing sealed areas and related human activities in flood-prone areas (Haase and Bohn 2007). Further stressors include economic factors such as the lack of government funds and compensation. Combined with levels of personal capital, this results in different and diverging perceptions of flood 'risk' as outlined in the group model-building process. This influences the capacity and perceived available options for adaptation. As the flood-exposed groups are represented by local communities, the local village council heads were selected to search for such adaptation options using KnETs. The lack of local governance and top-down feedback (cf. Fig. 2) raises the importance of the role of the VCH considerably. Therefore, one could argue that if their uncertainty increases then the vulnerability of the entire system and particularly that of the exposed groups will also increase.

5.2 Barriers towards adaptive capacity

According to our second research objectives—identifying barriers and options towards adaptive capacity—we could identify a range of barriers: the entire flood management system focusses on protection from the river and technical protection measures. The institutional inertia from Soviet times is still alive and can be characterised as strong hierarchical in combination with a lobbying of the local and regional “players”. The structure of local NGOs or local mayors contrariwise is dispersed. This means that the current institutional and personal structures do now permit an implementation of a more preparedness-based and individual flood risk management. But also local stakeholders and farmers hold intertia by firstly their passive attitudes, secondly their missing trust in cross-regional actions and thirdly the general opinion that flood defence is a state or national task. This latter argument is supported by the huge financial investments in the technical flood defence system after the 1998 and 2001 floods. By contrast, people do not believe in local human capital, local skills and local knowledge. Some communities have expressed the feeling that their adaptation decisions are constrained by a lack of alternatives (financial but also administratively supported) or by traditional or cultural beliefs (people have no option to resettle away from flood-prone areas due to restricted household budgets and a basic education. The experts of the water board in Ushgorod are often from other regions and have a high level of education but do not “belong” to the region and thus only have a limited capacity to influence local communities and people). A further barrier towards being more adaptive is clearly the lack of knowledge on non-structural flood protection measures. There is also a lack of experience and knowledge of alternative bottom-up governance structures due to decades of dictatorships and repressive regimes in the past: the Habsburgian Empire, the Russian Empire, the Soviet Union—there is a lack of “achievable” examples to “copy” or something like an “equilibrium state” or at least a “defensive mentality” to return to as a best practice in flood risk management (Sendzimir et al. 2008, found the same for the Hungarian Tisza part).

5.3 Options of adaptive capacity

But are there also options of adaptive capacity in the current flood risk management system which could make it more resilient? There are. We found that both short- and long-term mitigation and adaptation measures such as land use and spatial planning, flood forecasting and warning systems, community emergency planning and community and household preparedness are possible with varying amounts of investment. However, community and household preparedness strategies that can provide protection in the absence of additional assistance from the government are also possible given a working communication and moreover an interest from the side of the VCH to collaborate with the water board. The range of these options include firstly switching to ‘soft’ risk adaptation paths: providing new insurance mechanisms or packages that are affordable for Ukrainian farmers, improving and maintaining existing social networks that partially survived socialist times, providing and supporting education on floods at school such as existing NGO activities for ICZM in the Ukraine (http://www.biodiversity.ru/coastlearn/pp-eng/introducingpp.html), developing a floodplain management plan as required by both the EU Water Framework and Flood Directives, improving early warning systems and technical support by better weather and cross-section data for hydraulic inundation modelling, involving the Church as an institution people trust, improving information networks by the use of e.g. private cell phone chains, evacuation plans for vulnerable groups and, more related to the origin of floods, reforestation based on state-owned mountain land.

The application of the KnETs game methodology revealed the salient criteria and thresholds of decision-making by municipal representatives concerning ‘soft’ mitigation decision pathways in flood risk management. The resulting decision rules shed light on what knowledge is used for decision-making and how different criteria are prioritised in these choices. Interventions, whether these are related to water management or vulnerability reduction generally, must take sociocultural context and perceptions into account to understand what drives adaptive and non-adaptive options and triggers changes in this behaviour. This can be described as the capacity of local stakeholders to adapt. The existing gaps in these decision-making structures could be potential niches, where development interventions may be most valuable. In this case, government funding specifically targeted towards long-term adaptation planning, such as an early warning system and technological support for it, specific flood education programmes and improved insurance mechanisms would resonate most strongly with the needs expressed by those whose responsibility is to prepare local communities for flood events.

At present, most of the local communities in the Tisa valley are still highly dependent on individual households, social networks and the Church for support. Therefore, local government support reinforcing these institutions would also provide greater stability and security for communities in times of ‘high’ risk. What is most striking is that adaptation planning is not neglected due to a lack of knowledge about adaptation strategies but rather due to a lack of institutional and financial capacity to utilise these options to their maximum benefit.

How this capacity could be improved? Regional institutions like the waterboard could better link their monitoring and technical knowledge to the local “knowledge of the site” provided by VCH but also church representatives and teachers for example, also transboundary with Romanian and Slovakian communities. They could regularly meet and exchange information and thus create a new institution. A participation of national NGOs and scientific projects like NeWater in our case, in addition, could bring new knowledge about flood adaptation into a region that still faces a defensive mentality based on fear of water. Aforementioned new regional–local institutions could be approached by scientists to cooperate and thus to ensure the diffusion of scientific results to both levels, regional and local.

Climate change may be an additional driver to induce action in terms of state funds and financial support for long-term adaptation. This could also strengthen the recently started communication and cooperation between the local (community) and regional (water board) scale. Here, NeWater could directly contribute by initialising communication between those levels.

6 Conclusions

Using a combined approach of mental modelling, group model building, causal-loop-diagramming and KnETs evidence of the Tisa case study showed that there are different and interlinked vulnerabilities and respective niches of adaptive capacity at different scales. It became even clearer where possible local communities attempt to adapt to a (potential hazard) situation where they have the knowledge, technology or resources to do so. However, responses to sub-system-level vulnerability, multiple stresses and dynamic vulnerability result in emergence of some level of adaptive capacity that may still not adequately provide the systems’ resilience. The climatic, social and economic thresholds at which a potential resilience is undermined should be explored further in order to state the usefulness of the concept and, in more practical terms, before interventions that may alter current development pathways are implemented. Adaptive measures may enable different actors to be more resilient to future stresses, supporting a pathway to stability and sustainability; they may as well result in increased or even new forms of vulnerability such as population ageing and exodus for example which seems to be a new danger in the Ukrainian Tisa valley.

A useful future step would be to follow up with such an iterative modelling chain to illuminate what happens over time and if flood risk management is modified in terms of reducing the barriers and supporting the options that were communicated in the participatory modelling process. Deeper insights into the resilience of the system would emerge if to the knowledge of structures and decision-making new knowledge of influence dynamics (defined by Sendzimir et al. 2008) could be added. This is by far the most critical step since good or best practice examples of implementation of such options of AC are still rare.

However, the paper showed that in response to an extreme flood hazard, regional or national bodies could more successfully encourage (local) governments to change their behaviour using context-specific stakeholder consultation, mind mapping and integrated communication combined with support for adaptation at the municipal/local level. So far, the research design of the Tisa case study helped to provide empirical evidence for theoretical constructions such as vulnerability, barriers and options towards adaptive capacity which all contribute—as defined in the introduction section of the paper—to the resilience of the flood risk management system.

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