Evaluating the potential of Qualitative Reasoning to capture and communicate knowledge on sustainable catchment management

Andreas Zitek, Sabine Preis, Michaela Poppe, Susanne Muhar

Institute of Hydrobiology and Aquatic Ecosystem Management, University of Applied Life Sciences, Vienna;
Max-Emanuelstraße 17, 1180 Vienna
andreas.zitek@boku.ac.at, sabine.preis@boku.ac.at, michaela.poppe@boku.ac.at, susanne.muhar@boku.ac.at

Abstract

This paper presents the potential use of Qualitative Reasoning (QR) to capture and communicate knowledge on sustainable catchment management. Based on a case study, qualitative models dealing with issues of a sustainable development of riverine landscapes were developed and implemented using the Garp3 software following a general modeling framework. The evaluation of the models and the QR approach by students and experts revealed the high potential of QR models to capture and communicate complex knowledge in an understandable and interesting manner, mainly due to the ability of the presented approach to capture qualitative system dynamics and integrate 'hard' and 'soft' facts in a structured way. In the future a library of expert models might serve as an important source of information for both, education and management.

The issue of worldwide impaired river catchments

World wide river systems with their related catchments have been substantially altered due to the pressures of human populations with severe consequences for the ecological integrity and health of riverine landscapes (Dynesius and Nilsson 1994; Boon et al. 2000; Jungwirth et al. 2002). Furthermore the past lack of considering environmental variability and potential catastrophic events in an adequate manner, e.g. catastrophic flood events, increasingly causes avoidable damages to humans and human infrastructures globally (Singh 1996). Especially participatory approaches to natural resource use planning and management sustaining adequate communication and the integration of scientific knowledge with stakeholder needs are needed to achieve a sustainable development. Communication can be therefore seen as a central process to achieve integrated environmental management. To establish modeling approaches in the catchment management processes, the education of a new generation of students, managers, planners, scientists and politicians is needed being capable of dealing with this complex issue. Modeling approaches dealing with system dynamics (quantitatively and qualitatively) offered to interested students, scientists, managers, planners and politicians could significantly contribute to the peoples capability to deal with this complexity (Grant 1998). After Sterman (1994) effective methods for learning in and about complex dynamic systems must include:

(1) Tools to elicit participant knowledge, articulate and reframe perceptions, and create maps of the feedback structure of a problem from those perceptions.
(2) Simulation tools to assess the dynamics of those maps and test new policies.
(3) Methods to improve scientific reasoning skills, strengthen group process and overcome defensive routines for individuals and teams.

The use of QR in aquatic ecoscience and management

Besides traditional numerical approaches for mediated and integrated modeling (Van den Belt 2004), more recently 'Qualitative Reasoning' has become a new frontier for structuring and integrating qualitative knowledge (Bredeweg et al. 2007a,b) with increasing use in aquatic ecoscience and integrated management (Salles et al. 2006). For example QR models have been successfully used to capture the effects of anthropogenic activities on benthic macroinvertebrate communities in watersheds (Tullos and Neumann 2006), to describe general sustainability issues in river catchments (Salles et al. 2007) and to qualitatively representing the cause effects relationships related to the indicators of environmental sustainability of the millennium development goals (Salles 2005). Furthermore the application of QR modelling in social learning environments has been assessed (Bredeweg and Salles 2002) and it has been realized, that especially in complex systems integrating a variety of disciplines and viewpoints, the use of QR models and simulations as decision-support tools has significant potential (Lee 2000; Tullos and Neumann 2006). However, as the Garp3 software tool (http://www.garp3.org) for allowing a broader application of this modeling approach has become available only recently (Bredeweg et al. 2007a), the acceptance (Yearley

1999) and the future potential of the modeling approach and the models developed need to be assessed, as this has been done also for other approaches (Stavredes 2001; Van den Belt 2004) and more recently also for QR models on water quality (Araújo et al. 2008).

The river Kamp case study

Catastrophic floods and inundations in August 2002, a nearly 2000-annual event, set new conditions for life and economy in the Kamp-valley, Austria, facing flood control management, landscape architecture and land use planning with essential and future challenges. Consequently, the high water event finally represented a chance to develop the riverine landscape together with the local population as well as with the concerned scientific disciplines considering social, economic and ecological claims, especially with regard to the EU-WFD. On this basis an overall integrated concept towards the sustainable development of the River Kamp landscape has been developed at the University of Natural Resources and Applied Life Sciences, Vienna (Preis et al. 2006). Besides the consideration of the spatial scale (from catchment level up to planning onto municipalities) the interdisciplinary work of the different disciplines biology/nature conservation, landscape planning, water resources management, regional planning, agriculture and forestry and hydropower production was considered.

Moreover, planning was conducted in participation with authorities, stakeholders and the local population to achieve sustainability. The integration of the population into the planning activities exceeded pure information policy with the possibility for the local population to actively participate in developing the future scenarios for their valley. The experiences and knowledge gained within the project provided the essential basis for the development of the models that were primarily developed as learning material for students and to inform managers on the system structure as a basis for decision making. Based on the data and experiences from the river Kamp case study, two models describing the basic issues for a sustainable development and management of the riverine landscape were developed. Besides a model representing the essential of entities and processes involved in the implementation and development of a sustainable management of the riverine landscape (‘model A’, Fig. 1), a second model describing the effect of hydropower production (water storage and release and water abstraction) on sensitive fish populations (‘model B’, Fig. 2). Following a general modeling framework (Bredeweg et al. 2007b) models were developed and implemented using the Garp3 software (Bredeweg et al. 2007a). After capturing the general system structure of the Kamp valley, setting the system boundaries for the modeling approach the causal models were set up in the modeling workbench of Garp3 in an interactive and collective modeling effort.

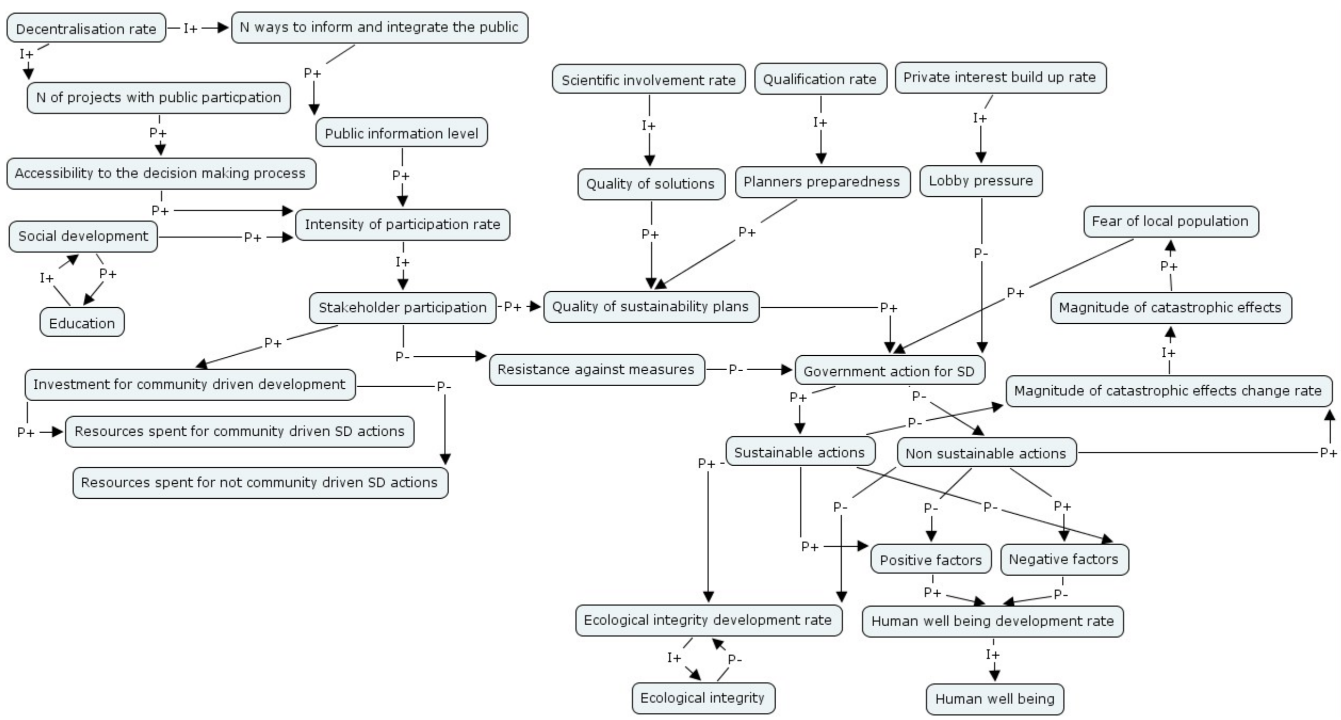

Figure 1:Causal model representing the process of the development and implementation of sustainable catchment management plans in the Kamp valley (‘model A’).

Finally the model with different scenarios was implemented in a compositional modeling approach based on semi-independent model fragments describing various aspects of objects and processes. Based on the full causal model, several smaller sub-models that could be linked via their different simulation outcomes were implemented. Besides a general description of both models, only the one scenario of 'model A' will be presented here in more detail, to show the basic principle of model building and simulation with the Garp3 software.

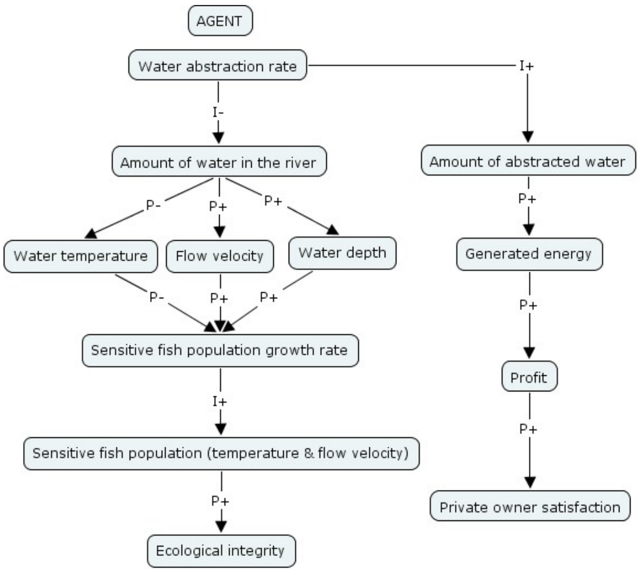

Figure 2: Causal model representing the effect of water abstraction on fish and stakeholder satisfaction ('model B').

Model A

The entities of 'model A' are divided into 5 groups 'Biological entity', 'Culture', 'Development plan', 'Environment' and 'Set of entities'. The main entities involved are 'Planners', 'Politicians' and 'Stakeholders' as biological entities (here we tried to capture the idea of the hierarchical structure of biological systems), the 'Community', which lives in the valley (can be seen as a set of entities – e.g. all people living there together with stakeholders), 'Education', 'Government' and 'Science' as expression of the culture of a country, the 'Development plan' as a basis for the implementation of sustainability issues and the 'River basin' (the 'Kamp valley') as the relevant environment. The entities are related by 'configurations' defining the basic system structure and describing mainly the direction and type of influences. Out of seven sub-models that were developed to simulate the full causal model presented in Fig. 1 (Zitek et al. 2006), only the sub-model 1 'Community fear influences government action for sustainable development (SD)' will be presented here. The 'sub-model 'Community fear affects government action for sustainable development (SD)' consists only of one model fragment that captures the basic processes, triggering the government to become active in the Kamp valley reducing 'Non-sustainable actions' and increasing 'Sustainable actions' (Fig. 3).

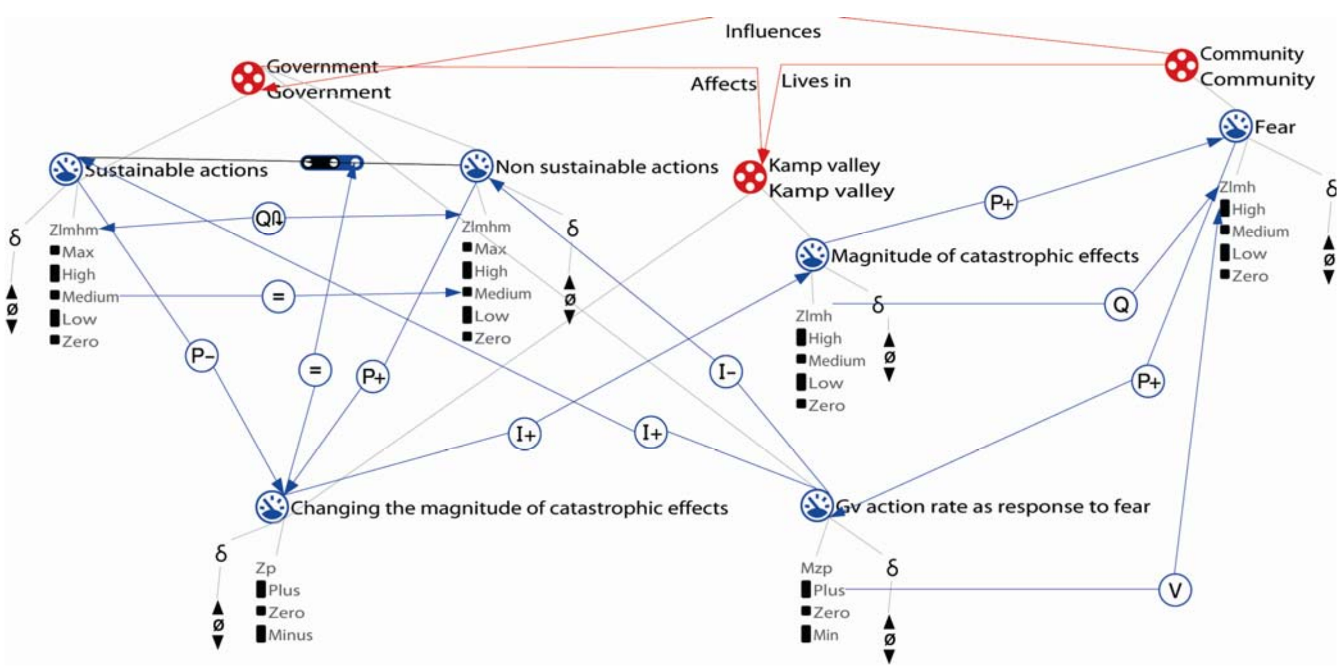

Figure 3: Model fragment 'Community fear affects government action for sustainable development (SD)' representing the whole sub-model 1 of 'model A'.

This sub-model shows how the ‘Magnitude of catastrophic effects’ is influenced by ‘Non-sustainable actions’ in the ‘Kamp valley’. When the ‘Magnitude of catastrophic effects’ is <High>, the ‘Fear’of the community from future catastrophic events is also <High>; this influences the government to force ‘Sustainable actions’ and a decrease ‘Non-sustainable actions’. Fig. 4 shows the behavior graph obtained in the simulation of sub-model 1 starting with low magnitude of catastrophic effects and low fear of the population, but a maximum of non-sustainable actions (see also the value history in Fig. 5). The model tries to capture the idea, that non-sustainable actions cause an increase of potential catastrophic effects, which then frightens the local population which lives in continuous fear from future catastrophic events creating pressure on the government; usually after a certain time people forget catastrophic events, which decreases the fear, and increasing the probability of new unsustainable actions to be implemented starting the reaction circle again. This leads to a circular behavior of the simulation.

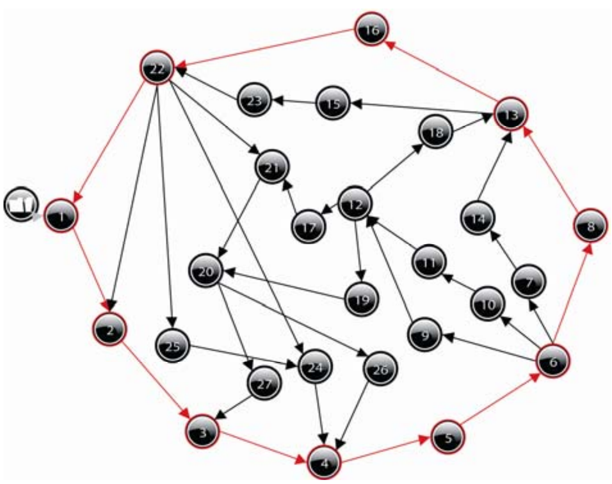

Figure 4: Behaviour graph obtained in a simulation of the sub-model 1 ‘Community fear affects government action for sustainable development (SD)’ of ‘model A’.

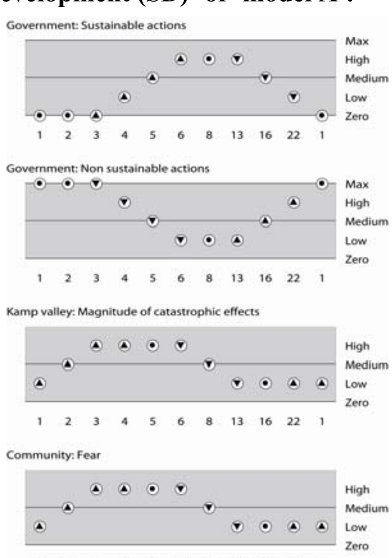

Figure 5: Value history diagram of relevant quantities in one selected behaviour path [1→22→1] of the simulation of the sub-model 1 of ‘model A’; rates are not shown.

Model B

Model B, ‘Hydropower production and sensitive fish species’, explores important problems related to hydropower use in the Kamp valley and its effect on fish (see the causal model in Fig. 3). Additionally the aspect of energy production, consumed energy, and energy sold is modeled together with stakeholder satisfaction to represent the causal principle behind the tendency of the owners of hydropower plants to maximize the amount of abstracted water. There are mainly two ways of influencing a river by hydropower use: (1) water abstraction and the creation of a residual or minimum flow stretch with the related effects to the physical environment (loss of water, loss of flow velocity, reduction of depth and increase of water temperature), and (2) the storage of water in a reservoir and a constant or peaking release of water from hypolimnetic parts of the reservoir leading to decreased temperatures below the reservoir. The decreased temperatures generally favor cold water species and repress the reproduction of warmwater species. If the water is on the one hand released at a constant rate this destroys mainly the natural flow regime of a river, if released in a peaking mode (‘hydropeaking’) it affects fish mainly due to the frequent changes of habitat conditions. Therefore model B focuses on the exploration of the two ways of hydropower use and its effects on fish and representations are developed that describe the effects of a reduced amount of water in the river (reduced flow velocity and increased temperature) on the fish fauna. Different effects the changed physical environment on different types of fish species (favoring fish with low requirements to flow velocity, the so called indifferent species, or suppressing species with high flow velocity needs, the so called rheophilous species; favoring fish due to temperature increase or suppressing them) are captured in model fragments and assumptions. This allows for a comprehensive representation of the effects of the different modes of hydropower production on different guilds of the river type specific fish community of the river Kamp. The entities are defined according the main perspectives we wanted to represent in ‘model B’: ‘Energy source’ (‘Hydropower plant’), ‘Fish’ (‘Flow velocity sensitive fish’, ‘Temperature sensitive fish’) representing the river type specific fish fauna, ‘Stakeholder (‘Private owner’) which run hydropower plants and try to maximize their economical benefit, ‘Water and water body’ (‘Reservoir’, ‘River’) as a basis for aquatic live and energy production.

Model evaluation

The evaluation of models is an important step in the model building process (Rykiel 1996). Validation proves if the scientific and conceptual contents of the model are acceptable for its intended use, verification proves that the model is correctly implemented by a demonstration of its use. Proving the acceptance of the QR approach and the software mainly evaluates the potential of the model and the modeling approach for broader use. The qualitative simulation models related to the sustainable development of the Kamp valley were generally intended to be used by stakeholders, decision makers and students to learn about the complex interactions between human use and natural resources in river catchments. To evaluate the models a two steps approach was chosen. A general evaluation was mainly focusing on the 'acceptance of the chosen approach and model' by students and scientists of different domains and an expert evaluation was more focusing on "validation and verification" of the models. The general evaluation was based on a power point presentation and a collective exploration of parts of the model using Garp3 on personal Laptops. Six students and five experts of different aquatic resource domains participated in the event, which lasted for about 2 hours. After the presentation and collective and interactive inspection of important scenarios and model fragments the participants were asked to fill in pre-prepared questionnaires. At the beginning of the evaluation process, the attendees were asked, whether they are an expert in a specific scientific field or a student. Next the participants were asked to rate a statement given with the following options: 'I fully disagree', 'I largely disagree', 'I somewhat disagree/agree', 'I largely agree', 'I fully agree'. They also were asked for additional statements. Furthermore separate expert evaluations were run with one domain expert per model as face to face discussions based on the printed causal maps and a conjoint exploration of important model fragments and simulations using Garp3 on one Laptop.

The following statements and questions were used for the general evaluation process:

1) QR models present complex knowledge in an understandable manner.
2) The QR approach allows for a clear representation of real world phenomena like a sustainable development of the riverine landscape "Kamp".
3) QR and Garp3 can be seen as a valuable learning tool for real world causal relationships related to a sustainable development of riverine landscapes.
4) The presented QR model might significantly contribute to the understanding of students and stakeholders which entities and processes drive a sustainable development of a riverine landscape and therefore enhances their capability of making decisions.
5) The causal map of the model reflects important information related to a sustainable development of the Kamp valley.
6) Which part of the model was most interesting for you?
7) Which part of the model most should be enhanced?
8) The model can be used for the targeted purpose of teaching students and other interested stakeholders on sustainability issues on a catchment level.
9) For which purpose do you think the presented QR approach is most suited?
    a. Stakeholder integration
    b. University lectures
    c. Decision making
    d. Others (to be added e.g. technical staff from the government, researchers, secondary school students).
10) Additional comments?

For the separate expert evaluations the following statements and questions were additionally used with the same questions being used re-verbalized for both expert evaluations:

11) The entities and configurations are relevant and sufficient to support a representation of the system structure.
12) The quantities used capture the most interesting properties of the entities.
13) The quantity spaces and values capture the most interesting qualitative states of the entities.
14) The (important) model fragments are conceptually correct and clear.
15) The presented scenarios describe a real situation that it is good enough to trigger an interesting/good simulation.
16) The general behavior (how it develops through the simulation) of the presented model is in accordance to what is already known (or accepted).

Results

General results

Both evaluations, the general evaluation and the expert evaluations yielded a very positive feedback with regard to the QR approach, the Garp3 software used to build models and the models themselves representing important issues related to the sustainable development of the riverine landscape Kamp. For example most people 'largely or fully agreed' that QR models represent complex knowledge in an understandable manner and that QR and Garp3 can be seen as a valuable learning tool for understanding real world causal relationships related to a sustainable development of riverine landscapes. Also most people 'largely or fully agreed' that the presented QR models might significantly contribute to the understanding of students and stakeholders which entities and processes drive a sustainable development of a riverine landscape and therefore enhances their capability of making decisions. So the produced software and models in QR language clearly allow students to interact with and learn about sustainable catchment management and to inform managers on the system structure as a basis for decision making. A high potential of an application of QR models in various fields, mainly in education but also in decision making and research was suggested by many participants. The potential of the Garp3 software and the QR approach to sustain collective, interactive social learning, also in a mediated modeling approach, was pointed out. Mainly the identification of dependencies and causal relationships was seen as a prerequisite for understanding a system and therefore also for learning and decision making. With regard to a broader use of QR models in society especially for decision making it was stated, that it might take some time and engagement to establish approaches like that in society. University education using and teaching such approaches was seen as an important basis for a further application.

Evaluation results of model A

Parts of 'model A', that were most interesting for the evaluators were:

• To see the causal interrelatedness of the involved entities of the Kamp management system.

• That private interest might negatively influence the sustainability process.

• Furthermore that the combined influence of planners, science and local population (stakeholders) defines the quality of sustainability plans and the whole sustainability process; this understanding opens up the possibility of different potential intervention options to reach the goal of a sustainable development.

• To see that both, ecological integrity and human well being are represented in the sustainability model.

• Identification of the catastrophic event as trigger for government action for sustainable development.

• The idea that money spent for measures can only be treated as money spent for a community driven development, if the community is involved in the process of developing and implementing measures (otherwise the money is suggested not to be spent for a community driven investment).

Parts of 'model A', that should be enhanced in the eyes of the evaluators were:

• Private interests should be better represented, as a basis to minimize them and achieve sustainable development

• The government action for sustainable development should be better described, as in reality this is of high complexity, being also driven by the general political structure, difficulties between different organization units with regard to their competences (personal behavior) and differences in financial resources; additionally very often policies with complementary aims exist, as policies often lack behind the social development. That means, a more detailed study and representation of the internal political structures determining the implementation process is needed.

• Generally it was noted, that it is of crucial importance to use a well agreed terminology and to well define the terms in use.

With regard to 'model A' it was noted that it could be of relevance, to think about which to degree each of the three known pillars for sustainable development (ecology, society, economy, Pope et al. 2004) is contributing to a sustainable development; in other words probably existing paradigms preferring one of the pillars might prevent a sustainable development (Lackey 1998).

Evaluation results of model B

Parts of the 'model B', that were most interesting for the evaluators were:

• That it is easy to change the content of a scenario by using and exchanging different assumptions allowing for a simplified modeling the effects of the same human pressure on different guilds of fish (positive and negative effects of flow velocity and water temperature on different guilds).

Parts of 'model B', that should be enhanced in the eyes of the evaluators were:

• A more realistic representation of the natural variability of the river discharge (probably by using the random function in the scenario editor) and the amount of abstracted water related to mean annual flow as this defines the frequency of water overflow events at weirs that are suspected to have a significant effect on fish.

• A more realistic representation of the influence of the length of the water abstraction stretch on the temperature development within the river (at the moment the river stretch is treated as a 'container' with the same abiotic factors everywhere).

• Integration of the effect of river morphology on fish and on water temperature.

Additionally collected interesting statements

With regard to the presented models but also to the QR approach some further interesting statements were collected. For example it was stated, that some behaviors of simulations might not be true in real world systems (e.g. that they stay within an interval for a certain time steps before they change). This should be avoided, when not explicitly defined as model target, although there are still QR domain specific ingredients, semantics and behaviors (e.g. the quantity spaces as points and intervals), that might conflict with the intuitive way of stakeholders to express things. Simulation behaviors of presented final models should be restricted as much as needed to avoid outcomes that are not intended (although one also might significantly learn from unwanted outcomes of a simulation). Therefore it is suggested that the end user should (1) only be confronted with simulations & scenarios that exactly show the intended behavior and (2) as less as possible confronted with QR domain specific features not to irritate an intuitive modeling building practice by domain specific restrictions. There were also some suggestions specific to the software (Garp3) produced within the project. With regard to the software packages available for building QR models prior to the project, Garp3 can now be used very intuitively to build QR models representing a prerequisite for the target, to motivate stakeholders and students to use the software and put their conceptual knowledge in causal models. Some specific comments on future developments of Garp3 to make the modeling process easier were also collected. Finally it was stated that a linkage of the causal models to a GIS would open a new field of promising applications.

Summary & Discussion

Integrated catchment management is becoming a central issue for sustainable management of aquatic resources world wide. Although many approaches have been developed, successful implementation of integrated and sustainable management strategies heavily depend on individuals being capable to guide this process. Managers, planners, politicians and scientists are faced with new and complex tasks of the integration of different fields of science with social and political and economical stakeholders. Modeling has been recognized as an important tool that could be used within integrated catchment management processes for various tasks and as the ability of humans to process information and deal with complexity is relatively weak, generalizations are necessary for human (Flood and Carson 1993). Both at the individual and collective levels, coping with complexity requires the ability to strategically filter the vast quantity of available information, and to integrate the key information into some sort of implicit or explicit predictive model. (Beratan 2007). With the qualitative approach presented here, mainly the integration of results from different scientific fields, and soft knowledge from political and social sciences with stakeholder preferences was achieved. At the beginning the modeling process itself turned out to be a challenging task, especially the identification of the essential rates and entities to characterize a system when developing dynamic QR models. The following three questions might guide this definition process:
(1) Which entities should be included?
(2) Which quantities are related to this entity?
(3) Which are the main processes in the system of interest?
The evaluation of the QR approach, the software and the models within the present study gained promising results related to a broader application of QR models in an integrated catchment management. Especially the possibility to run dynamic simulations on conceptual knowledge offers a variety of applications in research and management. Although the presented models were found to be generally suited for the proposed use as learning material for students and to inform managers on the system structure as a basis for decision making, also improvements of the models for a more realistic reflection of the modelled systems were suggested. These suggestions could be easily implemented into the models, and themselves could be treated as results of the modelling process. To establish modeling approaches in the catchment management processes, the education of a new generation of students, managers, planners, scientists and politicians is needed being capable of dealing with this complex issue. The creation of a library of model fragments dealing with all aspects of sustainable catchment management might help to educate students and provide essential information to managers and politicians and scientists. A standard evaluation procedure should be developed to assure the quality of the models and simulations. Only certified models should be re-used, although also other models might represent interesting starting points for various modeling purposes. Qualitative reasoning due to its potential to integrate 'hard' and 'soft' facts, to build causal models and to run dynamic simulations has great potential to become an important contribution to integrated catchment management at multiple levels of the implementation process (Fig. 6).

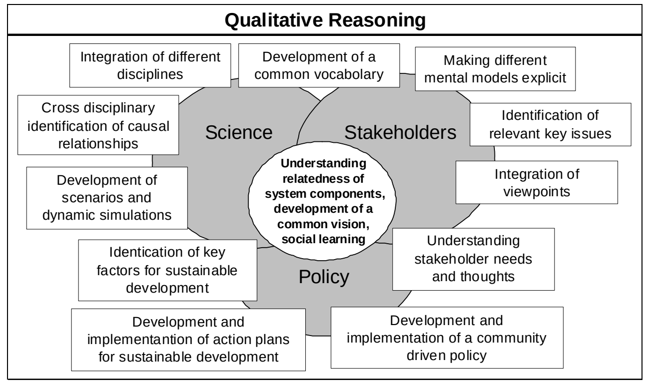

Figure 6: The potential of QR models to frame the process of integrated catchment management.

Acknowledgements. This research is co-funded by the European Commission within the Sixth (project number 004074, project acronym Naturnet-Redime, http://www.naturnet.org.) and Seventh Programme for Research and Development (project number 231526, project acronym DynaLearn, www.DynaLearn.eu). Furthermore the authors would like to thank Bert Bredeweg for helpful comments and suggestions to this manuscript.

References

Araújo, S. C. S., Salles P., and Saito, C. H. 2008. A case study on qualitative model evaluation using data about river water quality. *Ecological Informatics* **3,** 13-25.

Beratan, K. K. 2007. A cognition-based view of decision processes in complex social–ecological systems. *Ecology and Society* **12,** 27.

Boon, P. J., Davies, B. R., and Petts, G. E., Eds. 2000. *Global Perspectives on River Conservation: Science, Policy and Practice.* Chichester: John Wiley.

Bredeweg, B., Bouwer, A., Jellema, J., Bertels, D., Linnebank, F., and Liem, J. 2007a. Garp3: a new workbench for qualitative reasoning and modelling. In: *Proceedings of the 4th international conference on Knowledge capture*, Whistler, BC, Canada, ACM, New York, NY, USA.

Bredeweg, B., and Salles, P. 2002. A case study of collaborative modelling: building qualitative models in ecology. In: B. BREDEWEG (Ed.) Proceedings of the International workshop on Model-based Systems and Qualitative Reasoning for Intelligent Tutoring Systems, San Sebastian, Spain.

Bredeweg, B., Salles, P., Bouwer, A., Liem, J., Nuttle, T., Cioaca, E., Nakova, E., Noble, R., Rios Caldas, A.-L., Uzunov, Y., Varadinova, E., and Zitek, A. 2007b. Towards a Structured Approach to Building Qualitative Reasoning Models and Simulations. *Ecological Informatics* **3,** 1-12.

Dynesius, M., and Nilsson, C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* **266,** 753-762.

Grant, W. E. 1998. Ecology and natural resource management: reflections from a systems perspective. *Ecological Modelling* **108,** 67–76.

Jungwirth, M., Muhar, S., and Schmutz, S. 2002. Re-establishing and assessing ecological integrity in riverine landscapes. *Freshwater Biology* **47,** 867-887.

Lackey, R. T. 1998. Seven pillars of ecosystem management. *Landscape and Urban Planning* **40,** 21-30.

Lee, M. H. 2000. Model-Based Reasoning: A Principled Approach for Software Engineering. *Software - Concepts and Tools* **19,** 179-189.

Pope, J., Annandale, D., and Morrison-Saunders, A. 2004. Conceptualising sustainability assessment. *Environmental Impact Assessment Review* **24,** 595-616.

Preis, S., Muhar, S., Habersack, H., Hauer, C., Hofbauer, S., and Jungwirth, M. 2006. Sustainable development of the river landscape Kamp: Presentation of a management process with regard to the requirements of the EU water framework directive (EU-WRRL) *(in German)*. *Österreichische Wasser- und Abfallwirtschaft* **11-12,** 159-167.

Rykiel, E. J. 1996. Testing ecological models: the meaning of validation. *Ecological Modelling* **90,** 229–244.

Salles, P. 2005. Qualitative Representations of Indicators of Environmental Sustainability of the Millennium Development Goals. In: M. HOFBAUR, B. RINNER and F. WOTAWA (Eds.). Proceedings of the Nineteenth International Workshop on Qualitative Reasoning (QR05), Graz, Austria.

Salles, P., Bredeweg, B., and Araujo, S. 2006. Qualitative models about stream ecosystem recovery: exploratory studies. *Ecological modelling* **194,** 80-89.

Salles, P., Bredeweg, B., Caldas, A. L. R., and Nuttle, T. 2007. Modelling sustainability in the Riacho Fundo water basin (Brasília, Brazil). In: C. PRICE (Ed. Proceedings of the 21st International Workshop on Qualitative Reasoning (QR'07), Aberystwyth, Wales, U.K.

Singh, V. P. 1996. *Hydrology of Disasters*. Water Science and Technology Library. Kluwer Academic Publishers.

Stavredes, T. 2000. A system dynamics evaluation model and methodology for instructional technology support. *Computers in Human Behavior* **17,** 409-419.

Sterman, J. 1994. Learning in and about complex systems. *System Dynamics Review* **10,** 291-330.

Tullos, D., and Neumann, M. 2006. A qualitative model for analyzing the effects of anthropogenic activities in the watershed on benthic macroinvertebrate communities. *Ecological Modelling* **196,** 209-220.

Van den Belt, M. 2004. *Mediated modeling: a system dynamics approach to environmental consenus building*. Washington-Covelo-London: Island Press, 339 pp.

Yearley, S. 1999. Computer models and the public`s understanding of science: a case study analysis. *Social Studies of Science* **29,** 845-866.

Zitek, A., Muhar, S., Preis, S., Schmutz, S., Bredeweg, B., and Salles, P. 2006. QR models and documentation for learning about sustainable development, focusing on basic ecological and socio-economic features for an integrative and sustainable development of the riverine landscape of the Kamp valley. Deliverable D6.6.2, STREP project FP6 no. 004074, Naturnet-Redime.