A Framework to Support the Initiation, Design and Evaluation of Participatory Modeling Processes in Water Resources Management

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Key Points

- The article presents a methodological framework for participatory modeling
- The framework supports context-sensitive process initiation, design, evaluation and analysis
- A case study application in Québec is provided
Abstract
Multiple barriers constrain the widespread application of participatory methods in water management, including the more technical focus of most water agencies, additional cost and time requirements for stakeholder involvement, as well as institutional structures that impede collaborative management. This paper proposes a stepwise methodological framework using the methods of systems thinking and system dynamics modeling that addresses the challenge of context-sensitive initiation, design and evaluation of participatory modeling processes. This paper describes the proposed Participatory Model Building (PMB) Framework and provides two case studies of its application in Cyprus and Québec, Canada. The case studies demonstrate the usefulness of the PMB framework in analyzing complex water issues and organizing effective participatory processes based upon a sound methodological framework.

Index Terms
1847 Modeling; 1880 Water management; 6319 Institutions; 6344 System operation and management

Key Words
Collaborative Water Management; Participatory Modeling; System Dynamics; Systems Thinking; Institutionalized Participation; Design of Participatory Processes
1 Introduction

Water legislation such as the U.S. Clean Water Act, the Québec Water Policy, and the European Water Framework Directive emphasize the need for integrated and participatory approaches for the sustainable management of water resource systems. Collaborative modeling has been found to be a useful methodology to combine stakeholder involvement and integrated analysis of water resources issues [cf., Serrat-Capdevila et al., 2011]. By building a model, stakeholders can express their points of view, learn about other perspectives, and examine factual knowledge and subjective perceptions [Pahl-Wostl, 2007]. The construction of simulation models allows for testing of underlying assumptions and thereby support learning about the system [Dörner, 1996; Sterman, 2000]. Participatory modeling is expected to facilitate the implementation of strategies and policies as stakeholders build a sense of ownership and commitment to the outcome of collaborative processes [Pahl-Wostl et al., 2007].

Participatory modeling can be utilized for several purposes comprising decision-support as well as communication and learning between scientists, policy-makers and further stakeholder groups [Brugnach and Pahl-Wostl, 2007] (for an overview on participatory modeling methods, see Renger et al., [2008]; Voinov and Bousquet, [2010]). These different purposes are also reflected in the design of participatory modeling processes. Stakeholders can be consulted at early and at late stages of the model building process to provide input on definitions and validity, without extensive participation in model construction. These “Front- and back-end participatory modeling” approaches are more often used for decision-support and communication of scientific findings [Hare, 2011]. “Co-construction participatory modeling“ approaches are also available, which involve stakeholders directly in the model building process and thereby are particularly suitable to induce social learning in collaborative management processes [Hare, 2011].

There are some limitations to current participatory modeling approaches that constrain their widespread and effective applicability in practice. First, the initiation of participatory modeling processes is often hampered due limited modeling and facilitation skills of potential initiators (e.g., water agencies) (cf., Hare [2011]). Other reasons for the resistance to apply participatory modeling methods in practice is the perception of stakeholder involvement as being a time-consuming and costly process while benefits of a participatory approach remain obscure (cf., Morrison [2003], Winz et al. [2009] and Hare [2011]). Second, approaches for the design of participatory modeling processes are needed to adapt the process design to the
specific context (consisting of physical, socio-economic and institutional characteristics) (cf., Hatzilacou et al. [2007]; Winz et al. [2009], and Metcalf et al. [2010]). In addition, participatory modeling processes are often constrained to short and mid-term ‘interventions’ in the scope of projects led by modeling experts (cf. Voinov and Bousquet [2010]), even though profound improvement of water issues often require long-term engagement [Pahl-Wostl et al., 2007]. Thus, approaches are needed that support even the design of long-term participatory modeling processes involving the visioning of supportive institutional structures. Such an institutionalization of participatory processes particularly includes capacity building in the water sector so that stakeholders are able to continue the process after the modeling experts are no longer involved in the process (see Hare [2011] and Serrat-Capdevilla et al. [2011]). Third, little attention is often paid towards rigorous evaluation of participatory modeling processes [Jones et al., 2008] even though continuous process evaluation is very important for assessing and improving the process’ effectiveness to reach the intended outcomes [Carr et al., 2012].

This paper presents a Participatory Model Building (PMB) Framework that addresses the aforementioned limitations by offering a stepwise approach for the initiation, design, and evaluation of participatory modeling processes. The methodological framework consists of five successive stages: (1) problem framing and stakeholder analysis, (2) process design, (3) individual modeling, (4) group model building, and (5) institutionalized participation. Systems thinking and system dynamics modeling is applied in a “co-construction modeling process” (Stages Three and Four) to examine diverging perceptions on water issues and multi-domain interactions. The Management and Transition Framework (MTF), which is a interdisciplinary methodological and conceptual framework for the analysis of water systems and management processes, is used for problem and stakeholder analysis (Stage One), process design and evaluation (Stage Two), and analysis and design of institutional structures that support long-term continuation of participatory modeling processes (Stage Five). The MTF bases upon the concepts of adaptive management (Holling 1978), social learning (Pahl-Wostl et al. 2007), and the Institutional Analysis and Development (IAD) Framework (Ostrom 2005) to analyze collective choice processes and institutional change. Starting with approaches that do not require mediation skills in the “exploratory phase” of the PMB Framework (Stages One-Three), the participatory process can be broadened step-by-step towards the design of effective long-term collaborative management in the “involvement phase” (Stages Four-Five). The exploratory phase can be implemented with limited financial and time resources (which is
often the case in practice), and, thus, supports the initiation of participatory model building processes.

This paper outlines the PMB Framework and its methodological foundations, and presents results of a case study in Québec, Canada, on water quality management.

2 The Participatory Model Building (PMB) Framework

Experiences with participatory processes in water resources planning and management presented in the scientific literature have tended to be focused on unique processes rather than offering general design principles [von Korff et al., 2010]. This is also true for the design of participatory model building processes since the participating stakeholders, the organization team, and the problems are unique to each situation (cf. Andersen and Richardson [1997]). Vennix [1996] and van den Belt [2004] offer general organizational principles for participatory modeling using systems thinking and systems dynamics, and these are included in the proposed methodological PMB Framework that is outlined below. Shared Vision Planning (SVP) is another collaborative planning approach developed by the U.S. Army Engineer Institute for Water Resources (IWR). SVP builds upon three pillars: traditional water resources planning, structured participation and an integrated computer model (Cardwell et al., 2008). The shared vision model is jointly constructed by technical analysts and stakeholder groups and is aimed at supporting negotiation by preparing the factual base of water issues. Shared vision modeling is a flexible approach that usually applies front/back-end modeling (through the establishment of stakeholder advisory groups), but can also include co-construction modeling in cases with high levels of potential controversy (cf., Creighton and Langsdale [2009]). Besides these general frameworks, there are many publications on singular participatory systems thinking and system dynamics modeling processes (cf., von Korff et al., 2010) that were organized in the form of a few workshops (e.g., Langsdale et al. [2006]) or 1-3 year projects (e.g., Tidwell et al. [2004]).

All the existing frameworks mentioned above require that the initiators of the participatory process (e.g., decision-makers, public agencies, interest groups) believe that the method is helpful and appropriate to their particular problem situation and that sufficient resources are provided. Furthermore, the frameworks mentioned above do not offer clear guidelines on how to monitor the participatory process and develop long-term collaborative management processes that are autonomously led by stakeholders at a later stage. The proposed stepwise Participatory Model Building (PMB) Framework offers a participatory modeling approach to
initiate bottom-up learning processes in unfavorable contexts (e.g., time and financial constraints as typically encountered in water management practice), while simultaneously providing a conceptualization of the path towards effective long-term collaborative management (see Figure 1).

Figure 1: The Participatory Model Building (PMB) Framework - a stepwise approach towards collaborative water management.

The PMB framework is considered to be complementary to other modeling frameworks since it addresses major challenges that are typically encountered in participatory modeling processes. Thus, the PMB framework provides an approach to design participatory modeling processes which are adapted to a case-specific context. This includes the definition of expected results to allow for monitoring and evaluation of the process’ success and effectiveness. Stakeholders like water managers can test a hands-on participatory modeling method in the exploratory phase, and decide after these practical experiences whether a continuation of the process is useful for the specific problem situation. In addition, the conceptual modeling exercises in Stages Three and Four are helpful to develop a holistic picture of the water issue that supports the specification of more focused research needs. Another challenge is the short-term nature of many participatory modeling projects and lack of long-term continuation in planning processes. Institutionalized participation requires that water authorities (e.g., water boards, watershed organizations) are able to organize and implement participatory processes independently from external process facilitation experts in the long-term. Project based engagement of researchers is still needed to introduce modeling
methods (e.g. through workshops). However, the PMB Framework offers a methodology for the envisioning of pathways towards capacity building in water agencies and institutional change for the realization of collaborative water management which is also highly compatible with other modeling frameworks.

The five stages of the proposed PMB framework are succinctly described below.

2.1 Stage One: Problem and stakeholder analysis

The Management and Transition Framework (MTF) (Pahl-Wostl et al., 2010) is applied to develop a whole system perspective on water issues, and systematically sort data and information for problem and stakeholder analysis. The MTF provides an ontology and formalized representations of structural elements of a water system through a class diagram (Figure 2). Relational databases are used to support formalization and standardization of data collection and analysis protocols. A database includes classes, attributes of classes and relations (e.g. knowledge influences an action situation, actors participate in an action situation in a specific role). Guidance documents specify data collection procedures (Pahl-Wostl et al., 2009). Protocols have been design for targeted analyses such as tracing linkages (formed by institutions, knowledge or operational outcomes) along a sequence of action situations (Knieper et al., 2010).

Figure 2: Class diagram in UML, which is part of the Management and Transition Framework, for the analysis of structural elements of the water system (cf., Pahl-Wostl et al. [2010]).
The overarching boundaries are given by the ‘Water System’ which comprises all environmental and human components (Figure 2). The ‘Ecological System’ class comprises abiotic and biotic components of the water system. ‘Environmental Services’ capture the role of an ecological system to provide different kinds of services for human activities. ‘Environmental Hazards’ are the threats posed by an ecological system. The ‘Societal System’ is the social system in which an ‘action arena’ is embedded.

An ‘Action Arena’ is an issue specific political arena focused on a ‘societal function’ such as flood protection or water supply and characterised by ‘strategic management goals’, ‘actors’ and a number of ‘action situations’. An ‘Action Situation’ (AS) is a structured social interaction context that leads to specific outcomes. Results can be for example institutions or knowledge which affect social interactions in other actions situations or direct physical interventions in the system such as implementation of infrastructure or distribution of water to different uses. An AS is the regime element where ‘actors’ take certain ‘roles’ and perform certain ‘actions’. The level of an AS refers to different administrative units which could be based on the traditional boundaries of administrations (e.g. nation, province) or those defined by the hydrological principle (e.g. trans-boundary or national basin, sub-basin. As depicted in Figure 2, the MTF has a number of further classes (e.g. Institution, Actor, Knowledge, Role). Each class is characterised by certain attributes such as excludability or subtractability for the ecosystem service class (more explanations given in Pahl-Wostl et al., 2007b; Pahl-Wostl et al., 2010).

In the following, methods for problem and stakeholder analysis are presented to analyze MTF databases for the development of a preliminary problem definition and selection of stakeholders.

2.1.1 Problem analysis

Given the complexity of most problem situations in water resources management, several plausible and legitimate problem framings by stakeholders are possible which may lead to quite different conclusions on what is the problem and how it should be addressed (cf., Pahl-Wostl [2002], Dewulf et al. [2005]). The reframing process between stakeholder groups is facilitated in Stage Three (i.e., interviewees are asked whether they would like to refine the preliminary problem definition) and Stage Four of the PMB Framework (i.e., when stakeholders meet in person). However, the initiators of participatory processes need to come up with a preliminary problem definition as a basis for the selection of stakeholders that
should be invited to the participatory process. The preliminary problem definition should be broad enough to comprise various interpretations of stakeholders rather than being constrained to the specific interests like those of the initiators of the participatory process (e.g., resource managers or researchers, cf., Carr et al. [2012]). This is of particular importance since the starting position of the participatory process can significantly affect the evolution of the process. The definition of more focused problems and research questions becomes important in Stage Four (when stakeholders meet and discuss the problem as a group) in order to concentrate resources on the solutions of the most pressing issues. However, the preliminary framing process serves as a first review of the diverging frames of stakeholders involved in a particular water resources problem, and should result in a broad problem definition that comprises these individual problem framings. In light of this, the stages of problem definition (Stage One) and stakeholder analysis (Stage Two) are tightly connected and require iterative refinement.

First, one or more problem variables (e.g., water scarcity, water quality, flooding) must be defined that serve as indicators of the problem evolution over time. Second, the time horizon and geographical boundaries of the issue have to be agreed upon. The time horizon should include the processes in the past that caused the problem as well as those in the future that represent the delayed and indirect effects [Sterman, 2000]. All available data and information is included in the MTF class diagram (e.g., attributes of the water system and related technical infrastructure). The evolution of the water issue is defined through a sequence of action situations in the MTF class diagram. Actors should be included that were involved in the history of the water issue, and information on the actors’ role, mental models and situated knowledge (see Figure 2).

In this first stage, the main sources of information are the scientific literature dealing with the problem, as well as other documents that reflect the opinions and interests involved (e.g. newspapers articles, communication from interest groups). In addition, interviewing experts and other stakeholders can provide first impressions about hidden conflicts and perspectives.

### 2.1.2 Stakeholder analysis

Based upon data and information from the problem analysis, stakeholders are selected that are relevant for a solution of the water issue. Different methods, purposes, and application areas for stakeholder analysis exist (cf., Stanghellini [2010]). The following approach describes a structured selection process consisting of, firstly, a brainstorming process that
results in an extensive list of potential stakeholders which, secondly, are sorted into categories, and, thirdly, prioritized based on assigned attributes.

In the first step, a ‘Stakeholder Map’ is constructed via a brainstorming session with the aim of developing a list of all potential stakeholders based on the approach proposed by Elias et al., [2002]. Expert advice or existing contacts with local stakeholders can help guide the selection process.

In the second step, the identified stakeholders are sorted into categories according to their role in the water management process. The Common Implementation Strategy for the European Water Framework Directive [European Commission, 2003] presents such a sorting approach by defining four different types of actors with respect to resources issues: (a) decision makers; (b) users; (c) implementers/executives; and (d) experts/suppliers. Stakeholders are assigned to the respective groups, while gaps in the composition are examined to explore the omission of relevant parties.

In the third step, stakeholders are prioritized by using attributes in order to detect those stakeholder groups that are of critical importance for an effective stakeholder processes. The framework of Mitchell et al. [1997] serves as an example for such a priorization procedure. First, three central attributes are assigned to the stakeholders: presence of (1) power to influence the process, (2) legitimacy to influence, and (3) the perceived urgency for action. Stakeholders are sorted into classes depending on the assigned attributes. Groups that possess only one attribute are called “Latent Stakeholders” and are of minor importance for the participatory process according to Mitchell et al. [1997]. The relative importance of stakeholders with two attributes is higher and they are called “Expectant Stakeholders”. They should be invited to the participatory process or, at the very least, their interests should be considered. Finally, “Definitive Stakeholders” possess all attributes, namely power, legitimacy, and urgency. This group should definitely participate, as the name suggests. The dynamics related to the role of stakeholders are assessed by considering the changes of attributes over time. The approach by Mitchell et al. [1997] does not weigh attributes (e.g., low up to high power), and proposes the exclusion of stakeholders who only possess one attribute even though “Latent Stakeholders” could play an important role in water issues (e.g., powerful stakeholders). A power versus interest diagram is another prioritization approach that addresses these issues and thereby complements the framework by Mitchell et al. [1997]. In the power versus interest diagram, the interest dimension (x-axis) reflects the willingness of the stakeholder to become active in the issue at hand [Elias et al., 2002]. The power dimension (y-axis) refers to the stakeholder’s ability to affect the issue. The stakeholders are
grouped in the distinct fields as players (power + interest), subjects (interest + limited power), context setters (power + little interest), or crowd (little interest + limited power).

The different techniques described above provide multiple perspectives on the relative importance of stakeholders. In the final group composition, all stakeholder types should be represented (Step Two), as well as “Definitive Stakeholders”, players, subjects, and context setters (Step Three). In addition, changes in stakeholder attributes should be considered in order to detect potential participants who might become a part of the process in the future.

2.2 Stage 2: Process Design and Evaluation

The consideration of the context in the design of participatory processes is a critical success factor. Various institutional, socio-economic or environmental factors can have an influence on the success of the process. The MTF helps to analyze the embedment of the process in case-specific contexts through the conceptualization of the structure of the water system (see Figure 2) as well as management processes embedded. These management processes can be portrayed as a sequence of action situations (see Figure 3). As described in section 2.1, each action situation is characterized by, inter alia, the spatial unit as well as involved actors, management paradigms, and institutions. The outcomes of the action situation comprise institutions (e.g. new water act), knowledge (e.g. meaningful information and experience), and operational outcomes (e.g. behavioral changes or technological measures).

![Figure 3: Representation of policy and learning processes as a sequence of action situations that are embedded in an action arena and connected by institutions, knowledge and operational outcomes.](image)

While the conceptualization depicted in Figure 3 was used for historical analysis of water management processes in Stage One, the same scheme is applied to plan for the organization of a future participatory process in Stage Two. Thus, each step in the participatory process is
defined as an action situation (e.g., contacting potential stakeholders, organization of individual interviews). Influences and expected results of successive steps of the participatory process are defined. The analysis of the historical process (completed in Stage One) can be used to define potential influencing factors from past management efforts (e.g., a piece of legislation that influences the process) as well as potential ways how the participatory process can induce change in the water system (e.g., have a positive impact on the ecological system).

Stakeholders that take part in the organization of the participatory process should be involved in the definition of the process design and expected outcomes. This approach clarifies success indicators of the participatory process and supports a case-specific monitoring and evaluation of the process. The explicit definition of the different steps of the process (i.e., action situations), the process’ context (i.e., influencing factors) and expected outcomes (i.e., results of the process) ensures the recoverability of the process which is, according to Checkland and Holwell (1998), the central quality criterion of action research. High-quality action research has to define expected outcomes of participatory process and underlying theories and methods. This kind of analysis can be applied for ex-post analysis to evaluate the intermediary and management outcomes of the participatory processes, as well as for the planning and visioning of future involvements by defining expected outcomes of learning processes and pathways for the implementation of results (cf., Carr et al. [2012] for a review of methods for the evaluation of participation in water resources management).

Through this monitoring and evaluation procedure, the applicability and suitability of theories and methods can be tested, and conclusions can be drawn for similar problem situations.

The MTF also allows for the analysis of potential linkages of the participatory model building process to formal water policy making (see section 3.2 for the practical application of the MTF for the process in the Du Chêne Watershed in Québec). The application of the MTF thus supports evaluation and monitoring of participatory modeling process by providing a clear description of the underlying water system (Stage One) as well as the organization of the intervention strategy including expected outcomes (Stage Two).

2.3 Stage Three: Individual modeling

The building of individual causal loop models by each stakeholder or stakeholder group representative constitutes the third stage of the proposed PMB Framework. Systems thinking is a method for the qualitative analysis of systems through conceptual models (i.e., Causal Loop Diagrams) that visualize multi-causal relationships and feedback processes (cf., Senge
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[1990], Vennix [1996] and Sterman [2000]). System dynamics modeling builds upon the conceptual systems thinking models and allows for the participatory construction of quantitative simulation models (cf., Vennix [1994] and Sterman [2000]). The methods allow for the combined analysis of social and physical components of a system which make them particularly suitable for application in integrated water resources planning and management (cf., Serrat-Capdevila et al., 2011). Systems thinking and system dynamics methods have been applied for various water issues in water resources planning and management such as flooding (e.g., Ahmad and Simonovic [2006]), urban water supply (e.g., Bagheri and Hjorth [2007]), and watershed management (e.g., Elshorbagy et al., [2005]; Prodanovic and Simonovic [2010]). Participatory modeling using systems thinking and system dynamics is currently applied in different modeling frameworks including Mediated Modeling [van den Belt, 2004] and Shared Vision Planning [Lund and Palmer, 1997; Craigton and Langsdale, 2009] (see Winz et al. [2009] for a detailed overview of system dynamics applications in water resources management).

Conceptual modeling is sometimes an underestimated step in participatory modeling processes (cf., Gupta et al. [2011]). However, conceptual modeling is particularly appropriate approach to develop a common holistic understanding of how the system works, and thus supports communication and learning between modelers, decision makers and other stakeholders (cf., Liu et al., [2008]; Serrat-Capdevila et al. [2011]). Serrat-Capdevila et al. [2011] state that there are currently no formalized approaches for conceptual modeling available to be applied in the initial stages of a participatory process. They propose the application of participatory mapping in the course of a Participatory Rapid Assessment (PRA) process. In a PRA process, stakeholders draw maps, diagrams and timelines in a creative process to express their point of view in an integrated way [Chambers, 1994]. In contrast, the systems thinking method is applied in a more rigid way as stakeholders are guided through a predetermined set of consecutive steps to build their individual causal model (see section 2.3.1). Due to this more structured nature, the system thinking approach supports the comparison of individual models (as all participants follow the same methodology), and is thus included as part of the PMB framework.

Four steps are proposed as part of the individual modeling stage of the PMB framework: 1) Contact of stakeholders and building of Causal Loop Diagrams; 2) Merging of individual models into a holistic model; and 3) Preparation of a workbook. Conflicts and diverging points of views are elicited by comparing CLDs built by individual stakeholders. The introduction and application of the modeling method in individual interviews allows the
interviewer to address specific questions or needs of participants. By merging the individual models, water managers can develop a holistic picture of the water issues which is based on the different mental models of the stakeholders. Finally, the presentation of the merged model to the participants in the form of a workbook can induce a learning process as stakeholders learn about different perspectives and ideas. The workbook can also be combined with a questionnaire to ask for stakeholders' opinions about the merged model. Each of these steps is described in the following sections.

2.3.1 Building of Causal Loop Diagrams

The Causal Loop Diagram (CLD) is a powerful tool in the systems thinking approach that allows for the depiction and qualitative analysis of systems (cf., Senge [1990] and Sterman [2000]). In these diagrams, elements of the system are connected by arrows that together form causal chains (for an example see Figure 2). A positive link indicates the parallel behavior of variables: in the case of an increase in the causing variable, the variable that is affected also increases, while a decrease in the causing variable implies a decrease in the affected variable. A negative link indicates an inverse linkage between variables. A further central concept in system dynamics is the elaboration of feedback loops. Two different sorts of feedback loops exist that can be detected in CLDs: the self-correcting 'balancing loop' and the self-amplifying 'reinforcing loop' [Sterman, 2000].

The interviewee (i.e., each stakeholder from Stage Two) builds the CLD independently by choosing variables and drawing linkages. The interviewer provides only methodological support without influencing the content of the model. The individual modeling process begins with the discussion of the preliminary problem definition. The second step involves the identification of the causes of the defined problem as well as the polarity of causal links. In the third step, the consequences of the problem are studied, and finally, in the fourth step, the interviewee is encouraged to find feedback loops [Vennix, 1996]. Additional questions may facilitate the construction of a holistic model. For example, a question can be asked such as “What do you think are the policies that can help solve the problem?” with the aim to invite the participant to include their ideas for solutions in the model structure. Another question is related to the expectations of the participants regarding the policies they proposed: “Do you think these policies will be successful in solving the problem?” If the answer to this question is negative, a further question can elicit ideas on potential obstacles to these policies: “What do you think are the impediments to the success of these policies?”
In summary, the presented approach encourages the structured construction of a holistic system structure that includes a representation of the participants’ mental models of the status quo as well as their preferred strategies and challenges related to the problem being explored.

- **Merging of individual models and questionnaire preparation**

  Following the individual stakeholder modeling process, the resulting individual stakeholder CLDs are compared and merged into a comprehensive model that highlights the different perspectives regarding a particular problem. The diagrams from different stakeholders may consist of redundant, complementary, or oppositional elements. Oppositional system representations should be highlighted since these aspects may create potential conflicts between stakeholder groups (e.g., by an exclamation mark). Redundant aspects should be depicted in as much detail as possible. Hence, in the case of different levels of abstraction, the most detailed model structures should be added to the overall comprehensive model. If complementary system elements are available, the joining of these aspects will result in a more detailed model structure. Certainly, merging individual CLDs is a subjective task as interviewees may use different words for the same concept, may refer to different concepts with the same words, or use concepts that overlap but do not match exactly. Thus, some interpretation is needed to develop an encompassing model. To avoid misinterpretation, the modeler should listen to recordings of the model building process and contact the interviewee to clarify the original meaning.

  In the end, the merged model should be regarded as a preliminary group model that includes diverging stakeholder perspectives and therefore exemplifies a possible outcome from the later involvement stage. Stakeholders are able to criticize the merged model through a feedback from or a questionnaire. The designation of balancing and reinforcing feedback loops allows for the qualitative analysis of the system’s dynamics. Furthermore, the numerical labeling of loops helps to structure the intricate diagrams, and allows one to reference specific loops by referring to their number (see an example model in Figure 3). Narratives are provided that describe the underlying process of every feedback loop in detail. Thus, the participants are guided through a potentially complicated and comprehensive causal loop model. In case the many individual models render the merged model unwieldy, the model can be split into thematic models that highlight a certain aspect of the water resource issue. The practical application of these approaches is presented in section 3 for the case study in Québec.
The following section describes Stage Four of the proposed framework (group model building), which builds on the preceding exploratory stages.

2.4 Stage Four: Group model building

In the group model building stage of the PMB Framework, the stakeholder group meets in order to systematically discuss causes, consequences and potential solution strategies of prevalent issues with the help of the systems thinking and system dynamics methods. The group process can build upon the results found in Stages One to Three: stakeholders have gained experience in the application of conceptual modeling, and a preliminary comprehensive model provides a visualization of the scope of the issue and represents a potential outcome that could result from the group modeling process.

Initially, the group has to discuss the procedural rules as well as the purpose and content of the participatory group model building process, like mechanisms for conflict resolution, decision-making and implementation. The actual (conceptual) group modeling process can begin rapidly, as stakeholders have already become acquainted with the method through the construction of individual models in Stage Three. The merged model and the results of the questionnaires function as an entry point for discussion. The group has to decide whether to use or revise the merged model that was built in the previous stages, or whether to start from scratch (i.e., a new model is jointly developed by the group from the beginning) [Vennix, 1996].

The group model building process can start with the construction of qualitative causal diagrams by the stakeholder group. The building of a new qualitative model or the revision of the merged model proceeds in a similar fashion to the individual model building described earlier (see section 2.3.1). The group decides whether a quantification of the model would support the discussion process. Quantitative modeling should be used to verify the model structure, assess the effectiveness of policies, and initiate a dialogue on uncertainties.

System dynamics modeling allows for transparent and user-friendly quantification of models through icon-based software (e.g. Vensim or Stella) and the application of table functions for the definition of functional relationships. Established procedures exist to convert a qualitative systems thinking model (i.e., the CLDs built by stakeholders) into a quantitative system dynamics model, then test and evaluate the model structure and parameters, and finally assess policies and strategies through scenario analysis (see Vennix [1996], Sterman [2000] and van den Belt [2004]). Scenario analysis is a helpful approach to deal with high uncertainty involved in water planning and management (cf., Mahmoud et al. 2009). Stakeholders should
be involved in all steps of model development (including the definition of scenarios). However, model quantification is not a trivial task and requires substantial resources as well as modeling and facilitation skills.

*Liu et al.* [2008] rightly points out that it is “neither achievable nor desirable to aim for a single computational “super-model” that attempts to represent a consolidated view of all available knowledge”. Group-built system dynamics models are aimed more at showing an integrated picture of the water issue that is being explored. This usually requires the inclusion of social and physical processes at a high level of abstraction in order to retain comprehensiveness and transparency for stakeholders. Thus, physical processes (e.g., the hydrology of a watershed) need to be simplified even though detailed knowledge about these processes might be highly relevant for decision-making. Both kinds of models (i.e., integrated models with a high level of abstraction, and detailed scientific models) are, however, needed for an integrated analysis and management of water resources issues. Integrated modeling like conceptual group model building supports the detection of the most pressing issues, potential policies, and prevalent knowledge gaps. Once such a holistic perspective is achieved, more tangible and focused questions should be defined by stakeholders (including experts like physical scientists) in order to ensure that the process does not get lost in the complexity of the problem (cf., *Liu et al.*, 2008).

Different approaches have been developed for the combined use of more abstract, integrated simulation models and detailed expert models. *Liu et al.* [2008] propose a multi-resolution approach by informally coupling three modeling types (i.e., the models are not dynamically coupled but integrated in a generic framework). In the framework of *Liu et al.* [2008], comprehensive and high-level representations of the whole system (like participatory built models) are denoted as coarse resolution models. Fine resolution models are detailed physical models on vegetation, surface and groundwater hydrology that provide the scientific foundation. Medium resolution models integrate between coarse and fine modeling by simulating the interfaces between natural and socio-economic aspects, like resource allocation or land management topics. Another interesting approach is the formal coupling of expert models (e.g. water balance models) and group-built system dynamics models. Due to different modeling methods, model coupling requires the application of “component models” that make model outputs of the system dynamics model compatible as an input for the expert model, and vice versa (see Prodanovic and Simonovic [2010] for the dynamic coupling of an expert model such as the HEC-HMS model to a system dynamics model). Research on the development of effective and straightforward coupling approaches is still needed so that
participatory model building processes can concentrate on controversial issues (e.g. institutional or socio-economic aspects) while standardized expert models could support the discussion through more detailed aspects of water problems (e.g. hydrological aspects).

The modeling process usually proceeds in an iterative way. For instance, findings from scenario analysis can necessitate a revision of the group built CLD. In all model stages, the outcomes and proceedings of the model building need to be documented in a transparent manner in order to inform non-participating stakeholders (for example through research reports or action plans).

2.5 Stage Five: Institutionalized participation

While project-oriented and short-term group model building research has yielded remarkable outcomes (see Rouwette et al. [2002]), the implementation of long-term participatory processes beyond research projects is lacking (cf., Voinov and Bousquet [2010]), even though overcoming barriers towards collaborative management requires long-term engagement [Hatzilacou et al. 2007] to adapt the strategies, values and institutions to current challenges and achieve social learning [Pahl-Wostl et al., 2007]. The institutionalization of the participatory model building process comprises the development of the capacity to continue the participatory modeling process in the long-term (e.g., modeling skills), and the establishment of informal and formal rules to organize the process and specify its mandate (e.g., mechanisms for conflict resolution and implementation).

Social learning requires informal discourse in which water management problems (including the context, frames and mental models) are discussed, and the stakeholder group strives to develop the capacity to solve problems collectively. This must not imply consensus but at least the ability to deal with controversial perspectives constructively. These informal learning processes need to be linked to formal policy making in order to effectively initiate new routines or practices (cf., Sendzimir et al. [2010]. Such linkages might be a formal mandate for participatory processes, legal obligations that result from participatory processes, or representation of stakeholders in formal committees. Another opportunity might be clearly defined governmental involvement in the stakeholder processes. With respect to participatory model building, water agencies can function as a link between formal water management and informal learning processes. Water agencies (e.g., water boards or watershed organizations) are located at the interface between policy development and implementation where close collaboration with stakeholder groups are particularly important. To function as such a link,
water agencies require adequate funds, skills, and mandates to ensure long-term financing and organization of collaborative management processes.

The embedment of the participatory model building process in an institutional setting, and the analysis and detection of concrete pathways that overcome the prevailing barriers of collaborative management (such as limited funds or facilitation skills) require an analytical approach that allows for the analysis of the interdependence between structural context (i.e., boundary conditions of water management like water legislation or economic constrains) and process characteristics (i.e., the management process as such) [Halbe et al., 2013]. The Management and Transition Framework (MTF) has been developed for the integrated analysis of water resource management systems and complies to these methodological demands (i.e., allows for the analysis of institutional structures and water management processes) (Pahl-Wostl et al., 2010). The MTF can therefore applied as an analytical tool in the “institutionalized participation” stage of the proposed PMB Framework (Stage Five) to systematically analyze barriers and drivers of long-term participation. Of course, the application of the framework alone does not dissolve barriers for institutionalized participatory modeling like inadequate funds or limited capacities.

The analysis of institutionalization requirements will include financial instruments, dissemination of information and knowledge, as well as roles of actors in the learning process. For instance, a facilitator is required for the facilitation of the group discussion and the elicitation of the gained knowledge and insights. In addition, a process coach examines the social dimension and has skills for mediation and moderation of conflicts. Importance will also be attributed to emergent leadership which may be essential for moving for the implementation of measures which require inter-sectoral coordination (e.g. Gockerman, 2007). The prospective analysis of learning processes defines these and further roles, and, if required, suitable measures to develop skills and capacities required. Furthermore the societal and environmental context will be analysed in order to determine pathways towards social learning. For instance, legislative constraints may prevent some experimental approaches and forms of collaboration or the adoption of certain roles may be impeded by cultural norms.

The analysis will base on scientific analyses, and, additionally, they will be assessed in the course of the participatory process in the case studies. Up to now, the MTF has been used in a qualitative and quantitative way in order to detect requirements for adaptive and collaborative management in a range of different countries like Hungary [Sendzimir et al., 2010; Halbe et al., 2013], Uzbekistan [Schlüter et al., 2010], South Africa, Spain and Germany [Knueppe and Pahl-Wostl, 2012]. The results from the studies in the Tisza Basin in
Hungary (cf., Sendzimir et al. [2010]) and the Amudarya Basin in Uzbekistan (cf., Schlüter et al. [2010]) highlight the usefulness of informal learning processes facilitated by participatory modeling for the elaboration of sustainable solutions. Furthermore, the findings demonstrate the high influence that formal and informal institutions have on the implementation of innovative strategies and policies that are developed in collaborative management processes. These results underline the need for institutional analysis in order to analyze the institutional context of participatory processes as well as concrete strategies for implementation of solution strategies.

3 Application of the PMB Framework in Québec

In Québec, a participatory modeling process, following the steps of the PMB framework, was conducted in the Du Chêne watershed in cooperation with the local watershed organization (L’Organisme de bassins versants de la zone du Chêne: “OBV du Chêne”). The OBV Du Chêne is located in Southern Québec, Canada, about 40 km South of Québec city, and manages one of the 40 priority integrated watershed management zones. The OBV Du Chêne was formed in 2007 through a joint effort of the Union of Agricultural Producers and the MRC Lotbinuier. The Du Chêne is the major watershed in the Zone Du Chêne followed by a number of smaller adjacent watersheds that directly discharge in the Saint Lawrence River. The Du Chêne watershed is a medium sized watershed (800 km²) with intensive agricultural and forestry production which has resulted in pollution problems, soil erosion, and increasing water demands.

The participatory process started in 2010 with a meeting of McGill researchers and the OBV’s staff that considered a participatory modeling process as potentially useful to improve relations between stakeholders in the Du Chêne watershed, and to learn about the different perspectives on the causes, consequences, and solutions regarding the water quality problem.

3.1 Problem framing and stakeholder analysis

The problem and stakeholder analysis (Stages One-Two) was accomplished in close cooperation with the Du Chêne watershed organization. At the beginning of the participatory modeling process, a through literature review and interviews with the staff of the Du Chêne watershed organization were conducted. All information was sorted in a MTF database to systematically analyze water management issues in the Du Chêne. The OBV Du Chêne determined that the major issue in the watershed was the problem of declining water quality.
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(mainly due to eutrophication and chemical contamination). The sources of water pollution are thought to originate from the agriculture, forestry, and municipal sectors. However, the exact pathways and quantities are still unclear, and further research is required. The research project adopted this initial problem frame from the OBV Du Chêne, as it is broad enough to motivate several stakeholders to participate. In addition, this broad problem definition was expected to include different, more specific framings held by stakeholders.

The water quality issue of the Du Chêne watershed has emerged over a decade-long time horizon. The problem analysis starts in 1960 to involve long-term impacts from the agricultural, municipal and forestry sectors. Available information from the literature and interviews on emissions and key events (e.g., implementation of a new legislation) were included in the database. As a matter of fact, the level of detail of the problem analysis increases with time due to a higher availability of information and data (e.g., systematic monitoring of water quality data in the Du Chêne watershed started not until 2005). Important historical events for water quality management include the Programme d'assainissement des eaux du Québec (PAEQ) which was initiated in 1978 by the provincial government to foster water treatment in the municipal and industrial sectors as well as improved manure practices in agriculture (Gravel 2006). The Règlement sur les exploitations agricoles (REA) implemented in 2002 includes important regulations to address the issue of diffuse pollution from agriculture (including the development of fertilizer management plans, and limitation of agricultural expansion in degraded watersheds). Before the new Québec water policy was implemented in 2002, local municipalities and regional county municipalities (RCM) were responsible to enforce environmental law and manage rivers and adjacent areas. The Québec Water Policy introduced an integrated watershed-based management approach. Watershed agencies were formed at the local and regional levels to develop and implement a master plan for water which has to comply to priorities, guidelines, regulations and legislation at the national, provincial and municipal levels. The plan has to be submitted for evaluation and approval to the Minister of State for the Environment and Water. The watershed organizations are composed of representatives of stakeholder groups comprising citizens, elected officials of municipalities or RMCs and water-user representatives, such as agricultural or industry sectors. Provincial government representatives act as facilitators and provide scientific and technical support but do not have voting or decisional rights [Baril et al., 2005]. Watershed-based management is aimed to be synchronized at the provincial levels through a general reference framework established by the Ministère du Développement durable, de l’Environnement et des Parcs (MDDEP 2002). The Le Regroupement des organismes de
bassins versants du Québec (ROBVQ) represents local watershed agencies (i.e., OBVs) and thus is another central actor that fosters integration of local water management in Québec. Thus, the OBVs are still embedded in a multi-level water governance framework as master plans has to comply with provincial and national legislation, and needs to be approved by the provincial government. Due to the central importance of the OBVs, the Du Chêne watershed scale was chosen as an appropriate scale for the research project.

The Board of Directors the of the OBV Du Chêne aims at being a representation of all water-related stakeholders in the Zone Du Chêne. The analysis of the roles of stakeholders as experts, decision-makers, implementers, and users approved this claim. Through the analysis of stakeholder attributes and dynamics, it was determined that the following parties were “Definitive Stakeholders” and therefore crucial participants: directors of the OBV Du Chêne, representatives from the agriculture, municipality, forestry, tourism, environmental, and civil societal sectors. The analysis of stakeholder dynamics also highlighted the possibility of future participation by representatives of the industrial sectors, which has currently a minor importance in the watershed.

3.2: Process Design and Evaluation

Before each step in the participatory modeling process, a process analysis was conducted in collaboration with the OBV Du Chêne to specify the process’ design and expected outcomes. This included also an analysis of the linkage of the participatory modeling process to formal water management. The MTF analysis was applied to focus on these elements of the water system that are particularly important for adaptive and integrated water management: action situations (i.e., social interaction processes), institutions (i.e., formal or informal rules), knowledge (i.e., meaningful information and experience) and operational outcomes (i.e., direct physical interventions or changes in societal characteristics) (cp., chapter 2.5).

Figure 3 shows a conceptualization of the modeling process (elements highlighted in blue) and the formal water management process (white elements) in the Du Chêne watershed based on the MTF. More detailed information about expected results, underlying theories and participating actors were included in the MTF database. The Du Chêne Watershed Organization was established in 2007 on the basis of the Québec Water Policy. Until 2010, knowledge about water quality and other attributes of the watershed was gathered, and a technical committee was formed that consist of all major stakeholder groups (i.e., from the agriculture, economic, municipal and cultural sectors). From 2010 to 2014 the participatory analysis of the basin has been conducted in order to produce a portrait and a diagnostic report
of the basin. Based on these findings, the watershed organization will select specific problems and define objectives in 2014. This work will result in a master plan for the watershed specifying concrete actions and responsibilities.

Figure 3: Analysis of the linkages of the group model building process to the water management process in the Du Chêne watershed.

The participatory modeling process enters the official water management process at different points in time. The involvement of the researchers started in 2010 with a preparatory meeting in which a causal loop model was constructed with the staff of the watershed organization. Thereby, the members of the OBV du Chêne learned about the method and decided to initiate an individual modeling process that started in October 2010. The outcomes of this process were a collection of individual models and a merged model of all perspectives (as described in 3.3). The individual modeling process aimed at improved contacts and communication between the watershed organization and stakeholders to support the participatory analysis of the basin. Based on these positive experiences, the watershed organization decided to start a group model building process to achieve a common understanding of problems in the watershed (see section 3.4). In 2011, a group model was developed and the staff and stakeholders of the OBV gained new methodological knowledge. In 2013, the development of quantitative system dynamics model started based upon
individual and group models developed before. The analysis of scenarios that test different solution strategies for the water quality problem (e.g., alternative farming methods, planting of riparian vegetation) under varying context conditions (e.g., changing precipitation patterns due to climate change, population dynamics) will inform the choice for objectives and the preparation and revision of a master plan for the watershed. Also the application of physical models will be important to assess the effects of policies (e.g., on soil erosion) in detail. The model building process is mainly accomplished by McGill researchers; however, the staff of the OBV Du Chêne is closely involved in model development, data acquisition and model validation.

The application of the MTF is considered to be helpful by water managers of the OBV for process design and evaluation. The exposed linkages of the modeling process demonstrate how participatory processes feed into the formal decision making process (policy development process) (see Figure 3), and so fulfill the formal mandate of the OBV. This helps water managers to clearly communicate the purpose of the process to stakeholders and government agencies. In addition, the MTF analysis allows for the systematic specification of influences for each step of the participatory process (i.e., action situations) such as legal obligations (e.g., the Québec Water Policy) or obstructions by interest groups. This analysis of barriers to and drivers of the participatory process enables the design of an effective process that takes all those influences into account (the Québec case study did not face significant barriers since the Québec Water Policy supports experimentation with participatory methods by OBV’s). The specification of inputs to action situations (like applied methods or context factors) as well as expected outcomes (i.e., the results that are expected based on our current understanding of the system) supports the comprehensive evaluation of the process. The prior definition of applied methodologies and expected outputs is a prerequisite of well-organized participatory research (cf., Checkland and Holwell [1998]). If expectations are not met, process organizers have to rethink their understanding of the system and, based upon this, revise the organization of the participatory process (e.g., through the application of new methods). Thus, the application of the MTF constitutes an important step towards effective participatory process design and evaluation.

3.3: Individual Modeling

Individual models were built in nine stakeholder interviews. The choice for interviewees represented the composition of the Du Chêne Watershed Organization, namely the OBV’s
directors, and representatives of the community (3 representatives), municipality (3 representatives) and economic (2 representatives) sectors. These stakeholders brought a broad range of expertise into the participatory process, including training in environmental management, biology, ecology, and economics. CLDs were built by each interviewee while methodological support was jointly provided by two water managers of the Du Chêne Watershed Organization and one of the authors. The water managers were trained in the systems thinking method before the interviews. This was mainly accomplished through a two hour preparatory meeting in which the systems thinking method was presented and an individual model were built with the water managers. The interviews took about 1.5 hours each, and the entire individual interview process was accomplished in three days.

According to the guideline in section 2.3, the construction of the individual stakeholder CLDs began with the definition of the problem variable. All participants agreed that water quality is the major problem in the Du Chêne watershed. Most participants considered agricultural and forestry impacts as well as wastewater from urban and isolated areas as the main causes of the water quality issue. While agriculture and municipal sectors were seen as a contributing factor by all participants, the role of forestry was not seen uniformly by stakeholders (i.e., a number of models did not include impacts from forestry). The main impacts from agriculture are expected to stem from soil erosion and the use of pesticides and fertilizers that enter river through the agricultural drainage system. Some stakeholders proposed that more sustainable agricultural practices should be applied – however, it remained unclear which specific practices are suitable. For instance, organic agriculture was proposed by several participants, while others even expected negative effects on soil erosion from this approach due to higher tillage frequency. Dredging of rivers and drainage systems are also seen as a major impact by some stakeholders as velocity of river flow increases and natural filtration processes are disturbed. The municipal sector’s impact is related to a deficient wastewater infrastructure in urban areas and septic tanks of isolated residences. Emissions from the road network were also seen as a relevant source of emissions by some participants. Forestry contributes to the water quality issue through deforestation which causes higher water temperature and erosion. Natural emissions (e.g., from wetlands) were mentioned by some stakeholders as being an important factor which should be considered in water quality management. Participants considered consequences of the water quality issue on the environment (e.g., aquatic flora and fauna), tourism and recreation (e.g., bathing and fishing), and potable water supply (e.g., higher treatment costs). Various solutions to the problem have been proposed, such as tighter legislation and implementation of regulations (e.g., REA),
installment of riparian vegetation strips, reforestation, investment in wastewater infrastructure, and education campaigns. Responsibilities for the implementation of these measures are seen on a broad societal scale, including provincial ministries, municipal administration, OBVs, agriculture clubs, foresters and civic society.

Most of the questions that the participants posed revolved around the application of the method. Variables were written (by stakeholders) on sticky notes that were put on a large sheet of paper, and causal linkages were drawn by stakeholders by using a pencil (see example model in Figure 4). The outcomes of these individual model building sessions consisted of a number of multi-faceted CLDs. The participants were generally satisfied with their models and believed that they reflected their point of view in a comprehensive way. Figure 4 presents an original CLD model (upper part of Figure 4) developed by a stakeholder during a 1-hour stakeholder interview, and which was later digitized by the facilitators using the Vensim software (lower part of Figure 4).
Figure 4: Example of a causal loop diagram from a 1-hour interview (original model above; digitized, analyzed and translated model below). The red variable represents the problem variable. Variables marked in green are proposed measures for solution. A ‘+’ sign denotes a parallel behavior between linked variables, while a ‘−’ sign indicates an inverse behavior. Balancing (‘B’) and reinforcing (‘R’) feedback loops are marked by orange symbols (see section 2.3.1 for more details). The abbreviation CAAF stands for “Contrat d'Aménagement et d'Approvisionnement Forestier” (supply and management agreement for forests).
The model in Figure 4 show the perceived causes and consequences of the water quality problem in the Du Chêne watershed (red variable) as well as preferred solution strategies (variables marked in green). Feedback loops were analyzed in the digitized model. The model includes various processes that are expected to balance the water quality problem, e.g. new cultural practices, implementation of environmental regulations, or natural conservation. Reinforcing loops increase the water quality problem. In the model of Figure 3, only one reinforcing loop is included which refers to loads of organic environments, such as wetlands, that contribute to natural emissions of organic materials. The CLD depicts the stakeholder’s mental model on water quality issue including environmental (e.g. wetlands, forest cover), economic (e.g. financial resources), technical (e.g. sewage treatment, septic tanks), and social (e.g. education, sensitization) aspects.

Subsequent to the individual interviews, a merged model and a related workbook were prepared by one of the authors and sent to each of the participants. The merged model was presented successively by using thematic models, each highlighting a specific thematic aspect of the overall model: erosion and deforestation problems; water pollution and economic impacts; impacts of water quality on tourism and quality of life. In order to prevent the impression that these models are independent from each other, it was underlined that the nine models are intertwined and only presented in this way for clarity.

Due to the numerous and multi-faceted processes included in the CLDs, only selected outcomes are highlighted below. One of the nine thematic models focusing on erosion and deforestation is presented (see Figure 5), along with an analysis of the diagram and a demonstration of the dynamics.
Figure 5: Merged thematic model dealing with erosion and deforestation problems in the Du Chêne watershed.

The merged model (Figure 5) shows the different causes of erosion that were considered by stakeholders, such as deforestation, dredging of rivers, natural emissions, high velocity of rivers, fallow land, and tillage. Responsibility for soil erosion is mainly seen in the agriculture and forestry sectors. Several balancing loops are included in the model. First, the implementation of the REA (Loop 1) is expected to limit activities of the agriculture sector according to the nutrient capacity of the river. Riparian vegetation strips in agricultural and forest areas imply further balancing mechanisms (Loops 2.1 and 2.2) which are expected to decrease erosion. Another hands-on approach is the insertion of stones in the river bed to decrease velocity of river flow (Loop 3). This is expected to increase the potential of natural filtration processes. Further research was proposed to develop technology that has less impact on the soil (e.g., tractors that limit soil consolidation) and approaches for effective reforestation (Loop 4). Tighter policies for the protection of the environment were proposed to
foster reforestation (Loop 5). The thematic model only contains one reinforcing mechanism. The dredging loop (Loop 6) expressed that high erosion rates require continuous dredging of the river which increase the velocity of river flow, a lower natural filter capacity and finally further increase of erosion.

The individual modeling stage was considered to be very helpful by the water managers. The results comprise a collection of individual stakeholder built CLDs that demonstrate the different problem perspectives, ideas about causes and consequences, and solution strategies in a clear way. In addition, the water managers were able to strengthen their personal contacts with the stakeholders in a relaxed atmosphere (the interviews were mainly conducted in the private homes of the stakeholders) which resulted in an open and lively discussion. Both the interviewees and interviewers found the CLD process to be very useful at increasing shared understanding of the water quality problem, deepening personal relationships between stakeholders and the watershed organization, and learning about the methodology of systems thinking to analyze complex problems. The questionnaire provided a first overview of different aspects of the water quality issue in the Du Chêne watershed. Based on the positive experiences and the methodological knowledge that was acquired, the water managers decided to enter the “involvement phase” (Stages Four and Five) of the PMB framework through the organization of a group exercise.

3.4 Group Model Building

The group exercise was integrated into a regular meeting of the Watershed Organization. The meeting was attended by ten members of the organization with representatives of all sectors involved in the water quality issue. Two researchers supported the directors of the Watershed Organization to present the method (as some attendees did not participate in the individual modeling process), and structure the group exercise. Instead of discussing the general problem of “water quality”, the group decided to concentrate on the issue of soil erosion as this was perceived by them to be the major reason for the water quality problems in the Du Chêne.

The discussion of causes and consequences of soil erosion affirmed the diversity in stakeholders’ perceptions that had been revealed through the individual modeling process. The group exercise took about one hour and a half and helped to clarify differing definitions of terms and levels of abstraction with respect to causes, consequences and solution strategies. Each model variable was discussed by the group, and only added to the model if all
participants agreed upon its validity. This approach resulted in a structured and in-depth discussion. The model building process was considerably slower compared to the individual model building given all the discussions. However, this provided the stakeholders with a unique opportunity to discuss points of contention in a productive way, learn about the perspectives of others, and discover the interconnected system structure of soil erosion. As considerable time was needed to clarify stakeholders’ contributions to the discussion, the resulting model (see Figure 5) contains a lower number of variables and connections than the individual models that were built in a similar time frame (cf. Figure 3). The process of detailed explanation and rephrasing of statements is an important step towards social learning (cf., Pahl-Wostl [2007]).
Figure 5: Group model about soil erosion management in the Du Chêne Watershed in Québec (original model in the upper part, and digitized model in the lower part). The digitized model does not contain separate variables that were not connected to the model: “riparian vegetation strips”; “soil conservation practices”; “profit”.

The Watershed Organization was satisfied with the process, as the modeling exercise was the first time that stakeholders discussed the water issues in the Du Chêne watershed in an active manner. Before the group modeling exercise, stakeholders tended to be reserved and
did not participate in discussions. Despite the repeated attempts of staff members to stimulate an open discussion, stakeholder meetings had merely been one way ‘information’ meetings. The structured modeling process, however, helped to discuss the multiple dimensions of the issue comprising socio-economic, technical and environmental aspects. The modeling process was evaluated through a questionnaire that was handed out to all participants.

All respondents approved that the group model building method supported the discussion and the development of a deeper understanding of the water quality issue in the Du Chêne Watershed. The majority of participants suggested that the group modeling process continue in the future in order to explore the soil erosion problem and other issues related to water quality in more depth. In addition, some respondents explicitly asked that the PMB process be continued through to Stage Five (i.e., the institutionalized participation stage), including the quantification of the model and subsequent scenario analysis. Criticism was mainly related to the limited time allotted to the exercise and the differing involvement of participants (i.e., some participants chose to contribute more to the discussion than others). A continuation of the participatory modeling process could settle these demands by offering more time for discussion and additional opportunities for participants to express their points of view.

Following the group model building process, the development of a quantitative system dynamics model was planned based upon the qualitative models from the individual and group model building process. Due to the prioritization of the soil erosion problem, the model will initially focus on the simulation of erosion pathways and the effectiveness of measures, such as the improvement of riparian vegetation strips. The simulation model is expected to help the OBV in choosing their management actions to improve water quality in the Du Chêne watershed. The SWAT model was chosen to simulate hydrological processes while the system dynamics model focuses on socio-economic aspects of the water quality issue (e.g., costs of measures). The models are dynamically coupled by using Python scripting. A first prototype of the model is expected to be finalized in March 2014.

3.5 Institutionalized Participation

Up to now, the participatory modeling process was jointly facilitated by researchers and the directors from the OBV Du Chêne. Throughout the process, directors of the OBV Du Chêne were included as much as possible in the application of participatory methodologies to develop the capacity for independent continuation of the process. Legislative conditions for the institutionalization of the participatory modeling process are already supportive through the establishment of OBVs that are relatively free in their choice of approaches for
stakeholder participation. However, several requirements for a long-term continuation of the modeling process were revealed during the participatory process in the Zone Du Chêne. Figure 6 shows a simplified pathway to overcome detected barriers of long-term participatory modeling processes that are explained in more detail below.

Figure 6: Potential pathway towards institutionalized participatory model building in the Du Chêne watershed. The pathway includes required action situations and related inputs and outputs. Further information about the pathways (e.g., stakeholders participating in action situations) are included in the MTF database.

First, further training of modeling and moderation skills in OBVs would be required to be able to autonomously continue the process in future. While qualitative system analysis with the help of causal loop diagrams turned out to be a quite intuitive methodology, the further development of a quantitative system dynamics model requires profound modeling skills. A long-term cooperation between universities in the region and OBVs is a promising approach to guarantee methodological support and development of modeling skills of the OBV’s staff.

Second, such a long-term involvement of scientists in the process requires some financial resources. Up to now, the OBVs do not have sufficient funding for such a strategic partnership, but mainly depend upon resources from stakeholders (e.g., municipalities). This lack of funding and dependence upon the goodwill of stakeholders influences also the OBV’s
ability to implement measures and strategies laid down in their master plans (ROBQV 2013; CCD 2013).

Third, the initiation of further participatory modeling process in Québec is needed to gain experiences and demonstrate the potential of participatory model building to a wider audience (i.e., further OBVs, the ROBVQ and provincial ministries). As participatory modeling is more and more applied in research and teaching at Québécois universities, the number of students and senior scientist with such a methodological background is increasing which is a requirements for a broader application of participatory modeling approaches.

Finally, there are further potentials for improvement of water governance in Québec. For instance, an action plan for water is requested by the Sustainable Development Commissioner (from the Ministère du Développement durable, de l’Environnement et des Parcs) and the ROBVQ that involves all governmental agencies and supplements water master plans in the watershed (ROBQV 2013; CCD 2013). Another request by the Sustainable Development Commissioner and the ROBVQ relates to a management framework that specifies responsibilities between different entities of the water system, including OBVs, ministers, and municipalities (CCD 2013). Such a framework would support vertical (i.e., across management levels) and horizontal (i.e., across sectors such as water management and land planning) integration within the water governance system in Québec.

Further case-specific and provincial requirements for a long-term continuation of the participatory modeling process will be discussed and analyzed with the directors of the OBV Du Chêne after the development of the master plan for water (expected at the end of 2014). Literature analysis and further interviews with stakeholders will complement the MTF analysis which will define the water governance context in Québec in the present and in the future.

The detection of further opportunities for improvement of the Québec water governance system is expected from a comparative analysis between international water governance systems. This comparative analysis will build upon MTF databases from several international river basins.

3.6 Results: Insights for water management in Québec

In the Du Chêne case study, the method turned out to be accessible for all interviewees, and the process was considered to be helpful by the watershed organization. The individual modeling process revealed multiple diverging point of views between stakeholders. For instance, organic agriculture was considered by some stakeholders to be a solution for the
water quality problems in the watershed. However, another participant anticipated higher erosion and lower water quality as organic farming would require more tillage. In addition, the models contained different abstraction levels (for instance, some participants included hydrological aspects in a very detailed way, while others explained the hydrological system in a more abstract way by using only a few variables) and thematic foci comprising environmental, technical, economic, and social aspects. Stakeholders chose differing solution strategies for the water quality problems. For instance, farmers proposed more hands-on measures such as “placing stones in the riverbed” to reduce erosion while representatives from the municipalities included more policy approaches such as “application of the Environmental Quality Act”. In the end, the goals of achieving an overview of the perceptions and improve relationships to stakeholders were achieved. The subsequent group modeling process provided stakeholders with an environment to express their opinions, discuss differing opinions in a constructive manner, and supported a structured discussion of some of the main water issues in the Du Chêne watershed. This included the specification of the broad problem definition from the exploratory participation phase (i.e., “water quality”) towards “soil erosion”. Process design using the MTF helped to reflect on the group process and define its potential linkages to the formal decision-making process. Furthermore, the specification of inputs and outputs of action situations will allow for a detailed assessment at the end of the participatory process. The comparison of expected and realized outcomes enables a revision of prior assumptions which can lead to the iterative improvement of the process design in the future.

4 Discussion

The case study in Québec demonstrates the usefulness of the PMB Framework for the initiation of participatory processes in unfavorable contexts (i.e., low time and financial resources as well as limited methodological knowledge of staff members). While the time requirements for the researcher were considerable (about 3-4 months for problem and stakeholder analysis as well as individual modeling), the time requirements for other stakeholders like the Du Chêne watershed organization (about 3-4 weeks of involvement) and interviewees (about 1 - 1.5 hours each) was minimal. The intensive involvement of a researcher was needed to test, evaluate and refine the new PMB framework. In the future, we anticipate that Stages One to Three of the PMB framework can be accomplished with less involvement of researchers through the preparation of a website that contains guidance documents and further case study examples. The results of the exploratory phase in the case study area comprise a systemic analysis of stakeholders’ perspectives on the water quality
issue and the development of a holistic system representation. The Québec case revealed that further research is needed on economic and institutional aspects of the problem (e.g., effective policies to foster reforestation). Furthermore, the Québec case underlined the importance of physical models to analyze effects of water pollution and soil erosion. Besides these more problem-related outcomes, the modeling process significantly improved the relationship and discussion process of stakeholders. The inclusion of the watershed organization in the application of the participatory method will allow staff members to continue the participatory process in the future.

The PMB framework was iteratively developed bases upon experiences gathered in further modeling processes in Cyprus (topic: water scarcity management) and Pakistan (topic: soil salinity management). For instance, the Cyprus case study showed the importance of considering potential linkages to formal water management. While the exploratory stage of the framework was successfully applied in Cyprus, a long-term continuation of the process beyond the research project was not achieved. This experience induced the inclusion of the “project design and evaluation” step in the framework. Without the help of the exploratory participation approach presented in the PMB framework (i.e., Stages One-Three), it is likely that participatory modeling would not have been applied in the case study areas in Québec, Cyprus and Pakistan. Stakeholders were not aware of this method even though participatory water management was desired in the study areas. The PMB framework presents a promising approach to support widespread initiation and application of the participatory modeling method in water management practice. Watershed agencies can test the appropriateness of participatory modeling step-by-step. In the Québec case, various stakeholders requested the continuation of the process towards quantified modeling. Other frameworks like mediated modeling and shared vision modeling could be applied for this as part of the group model building stage. The inclusion of expert knowledge will remain important for specific quantitative modeling tasks (e.g. the modeling of soil erosion in the Du Chêne watershed). The conceptual modeling process, however, will set this expert knowledge in a larger context which might result in a wider dissemination and a more efficient implementation of modeling results.

The application of the MTF structured the planning and evaluation of the participatory process in Québec. It made clear from the beginning that the process was designed to build capacity in the watershed organization to continue the participatory process independently after the initial involvement of the researchers. This predetermination of the process design, applied methods and expected products is an important quality criterion for action research.
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(cf., Checkland, Holwell [1998]), and can be applied for participatory processes in general. In the same way, the MTF can be applied for the examination of more long-term processes towards the institutionalization of participatory modeling. For instance, Halbe et al. [2013] applied this methodology for the visioning of a transition process towards integrated flood management in the Hungarian reach of the Tisza Basin, which include a structural analysis of supportive water institutions.

The modeling processes in Cyprus and Québec will be continued in the future. In addition, a further case study has been started in Germany which will add to the experiences that have been gained so far. The application of the MTF for process evaluation will be further pursued in future research.

5 Conclusions

The proposed Participatory Model Building (PMB) Framework addresses the challenges of initiating, designing, and evaluating participatory model building processes in water resources management. To date, participatory modeling has resulted in promising outcomes in favorable contexts such as research projects, but widespread implementation is limited given the “unfavorable contexts” in practice that include low time and financial resources as well as facilitation skills. The proposed PMB framework offers a stepwise approach for water managers to move towards stakeholder involvement and integrated water resources planning and management. Starting with approaches that require low financial and time investments as well as low levels of mediation skills, water managers and agencies can obtain insights on the need and applicability of a participatory approach. In the event of positive experiences, the process can proceed to the involvement stage, where stakeholders meet and discuss causes and consequences of the water resource problem, as well as policies and strategies for its solution. The PMB framework highlights the importance of capacity building in the water sector to allow for independent implementation of participatory model building processes (which is an important requirement for institutionalized participation). Case specific requirements for continuous and effective collaborative management processes can be analyzed using the Management and Transition Framework, an analytical tool that allows for the integrated analysis and planning of water management processes.

The proposed PMB Framework was tested in three case studies in Cyprus, Québec and Pakistan. The results from the case study in Québec are presented in detail in this paper. The results of the Québec case study highlight the heterogeneity of perspectives of stakeholders,
which in turn underline the need for participatory and interdisciplinary approaches in water management. The case demonstrates the applicability and usefulness of the PMB approach for the initiation of participatory processes. Based upon the knowledge that has been generated in the study, watershed organizations in Québec are able to assess the need for the initiation of a long-term participation strategy and process that goes beyond the “exploratory participation phase” (Stages One to Three). In the Québec case study, water managers developed the capacity to apply the systems thinking method in individual interviews and group exercises. A group model process was organized that supported a structured and open discussion between stakeholders. The institutional analysis of the process clarified linkages between the group process and formal water management, and allowed for transparent and purposeful planning of the process.

Future work will include the evaluation and comparison of different participatory model building processes in order to detect general design principles for effective stakeholder involvement and learning.

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