Participatory and Collaborative Modelling; Key to Sustainable and Inclusive Development

Strengthening Stakeholder Ownership for Informed and Participatory Water Resources Management

Laura Basco Carrera

PARTICIPATORY & COLLABORATIVE MODELLING KEY TO SUSTAINABLE AND INCLUSIVE DEVELOPMENT

STRENGTHENING STAKEHOLDER OWNERSHIP FOR INFORMED AND PARTICIPATORY WATER RESOURCES MANAGEMENT

Laura Basco Carrera

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SUMMARY

Safe access to water is essential for sustainable development. Building resilience towards disaster risks and ensuring water availability by balancing the many competing uses and users of water, while maintaining healthy and diverse ecosystems, are critical elements to ultimately deliver water security. Following the Sustainable Development Agenda 2030, in this Ph.D. thesis Integrated Water Resources Management (IWRM) is conceived as the process that leads towards water security, and as a result, sustainable development. Lessons learnt from the past show, however, that the implementation of IWRM encounters major difficulties if most stakeholders still follow traditional planning mechanisms. Lack of knowledge about the water resources system, disagreements between water users and insufficient focus on operationalisation are frequent causes of limited acceptance and practical implementation of IWRM plans. Informed decision-making and engaging stakeholders in the planning and decision-making processes are therefore important elements that help to create the enabling conditions for sustainable water resources planning and management.

In this Ph.D. thesis, participatory and collaborative modelling is presented as a means towards sustainable development, as it supports informed decision-making and inclusive development. How to develop and use computer-based simulation models is analysed following a participatory or collaborative modelling approach for managing water resources, so their use can be enhanced, and the ownership of the development strengthened. The research approach comprises four main elements: (i) identifying the key components of participatory and collaborative modelling; (ii) making an inventory of existing approaches, methods and tools; and developing a conceptual framework for their design and evaluation; (iii) designing and applying four participatory and collaborative modelling approaches that make use of computer-based simulation models in specific cases; and (iv) testing and evaluating the technical and social contributions of the designed approaches.

Four key pillars of participatory and collaborative modelling in Water Resources Management (WRM) are identified: (i) water resources planning, (ii) informed decision-making by using computer-based models, (iii) stakeholder participation, and (iv)

negotiation. In essence, participatory and collaborative modelling help to bring those who develop analytical models to resolve complex water management problems together with stakeholders and decision-makers, to improve the decision-making process. Typically, both model developers and stakeholders are involved in water resources planning and management, but they tend to follow separate pathways. On the one hand, technical experts build analytical models to provide institutions with high-quality information to inform planning and decision-making. On the other hand, stakeholders engage in consultations about existing problems in the river basin and help to develop a set of possible interventions. These two paths often run parallel and tend only to cross at the beginning of the process when data is collected and at the end when model results are presented for discussion and decision-making. Stakeholders often have little option but to accept the results obtained by the experts. They tend to perceive models as 'black-boxes' about which they have little understanding and trust, and so they are often suspicious of the outcomes and decisions made. In contrast, participatory and collaborative modelling builds stronger connections between technical experts and stakeholders, as stakeholders and decision-makers are involved in the modelling process. Stakeholders learn more about the models, how they are developed and used, and their potential and limitations. In the process, modellers spend time away from their computer screens, working with stakeholders and using their local knowledge for the collection of data as well as the development and use of the models.

A distinction between participatory modelling and collaboration modelling is made that defines collaborative modelling as a subset and more intensive form of participatory modelling. Stakeholder participation and cooperation in collaborative modelling will be higher than in participatory modelling, leading to the increased importance of negotiation within the process (Chapter 2). These key components are used as a basis for the identification of the main factors that help in determining the most suitable approach, method and tools for different contexts and situations. The combination of these factors results in a generic framework for participatory and collaborative modelling approaches in WRM (Chapter 3). This framework is used for defining the generic characteristics and features of existing participatory and collaborative modelling approaches, such as Group Model Building, Companion Modelling and collaborative modelling using networked environments. The framework also supports generalising case-specific participatory and collaborative modelling approaches and corresponding tools. The primary use of the framework in this Ph.D. thesis is to design different approaches for particular contexts and situations and to categorise them into participatory or collaborative modelling approaches. Four methods are presented to engage stakeholders in the development and use of computer-based simulation models. These are: (i) collaborative modelling using system dynamics and simulation modelling (Chapter 4), (ii) Companion Modelling (Chapter 5), (iii) Fast Integrated Systems Modelling (Chapter 6), and (iv) crowdsourcing and Interactive Modelling (Chapter 7). The generic framework and the designed approaches are tested in nine study cases, from which this thesis focuses on five of them. The covered themes and countries include river basin planning in Indonesia, water quality management in Turkey and Indonesia, adaptive planning in Bangladesh, and flood risk management in Tanzania.

These methods support the decision-making process by making it evidence-based and inclusive. Stakeholders feel that they are part of the process as their knowledge, interests, and needs are actively considered and valued. Together, modellers and stakeholders share learning, build consensus, have a sense of ownership of the solutions developed and trust in the decision-making process. Moreover, the use of participatory and collaborative modelling makes the modelling process more efficient. The combination of both technical and local knowledge supports the construction of a more accurate model. Data collection does not become a bottle-neck in the modelling process, and model validation requires less duration.

In conclusion, the research presented in this Ph.D. thesis has resulted in two main outputs: (i) a generic framework that helps in designing and evaluating participatory and collaborative modelling approaches considering the local context; and (ii) providing design approaches (guidelines) on when and how to use four different methods of stakeholder involvement and use of computer-based models, depending on the socio-technical context defined via the developed generic framework. The methods were tested in the application areas of river basin planning, groundwater management, water quality management, adaptive planning and flood risk management.

"It always seems impossible until it's done" – Nelson Mandela

SAMENVATTING

Een verzekerde toegang tot schoon water is essentieel voor duurzame ontwikkeling. Het opbouwen van veerkracht om met extremen om te gaan en beschikbaarheid van water door het harmonizeren van de vele concurrerende gebruiksfuncties en gebruikers van water, met behoud van gezonde en diverse ecosystemen, zijn kritieke elementen om uiteindelijk waterzekerheid te bereiken. In lijn met Sustainable Development Agenda 2030, wordt Integrated Water Resources Management (IWRM) in deze Ph.D. thesis opgevat als het proces dat leidt tot waterzekerheid, en dientengevolge tot duurzame ontwikkeling. Lessen uit het verleden laten echter zien dat de implementatie van IWRM vaak grote problemen oplevert als de meeste belanghebbenden zich nog steeds baseren op traditionele planningsmechanismen. Gebrek aan kennis over het watersysteem, meningsverschillen tussen watergebruikers en onvoldoende aandacht voor het operationeel beheer zijn frequente oorzaken van beperkte acceptatie en feitelijke implementatie van de ontwikkelde IWRM-plannen. Kwantitatief onderbouwde besluitvorming en het betrekken van alle belanghebbenden bij de plannings- en besluitvormingsprocessen zijn daarom belangrijke elementen die helpen bij het creëren van de randvoorwaarden voor duurzame ontwikkeling en beheer van watersystemen.

In dit proefschrift wordt participatieve en collaboratieve modellering gepresenteerd als een middel voor duurzame ontwikkeling van watersystemen, omdat het kwantitatief onderbouwde besluitvorming en inclusieve ontwikkeling ondersteunt. Geanalyseerd wordt hoe computermodellen ontwikkeld en gebruikt kunnen worden op basis van participatieve of collaboratieve methoden. Doel is dat de ontwikkeling en gebruik van de resultaten kunnen worden verbeterd en de acceptatie van de ontwikkeling kan worden versterkt. De onderzoeks aanpak bestaat uit vier hoofdelementen: (i) het identificeren van de belangrijkste componenten van participatieve en collaboratieve modellering; (ii) het inventariseren van bestaande benaderingen, methoden en hulpmiddelen; en het ontwikkelen van een conceptueel kader voor het ontwerp van die benaderingen; (iii) het ontwerpen en toepassen van vier benaderingen voor participatieve en collaboratieve modellering; en (iv) het testen en evalueren van de technische en sociale bijdragen van de ontworpen benaderingen.

Dit proefschrift identificeert vier belangrijke pijlers van participatieve en collaboratieve modellering in Water Resources Management (WRM): (i) het maken van waterplannen, (ii) geïnformeerde besluitvorming door gebruik te maken van computermodellen, (iii) participatie van belanghebbenden; en (iv) onderhandeling . Participatieve en collaboratieve modellering helpen diegenen die analytische modellen ontwikkelen om complexe waterbeheerproblemen op te lossen, samen met belanghebbenden en besluitvormers, om zodoende het besluitvormingsproces te verbeteren. Typisch zijn zowel modelontwikkelaars als belanghebbenden betrokken bij de planning en het beheer van het watersysteem, maar ook zij hebben de neiging om afzonderlijke wegen te volgen. Aan de ene kant bouwen de technische experts analytische modellen om instellingen en belanghebbenden te voorzien van hoogwaardige informatie om het plannings en besluitvormings proces te ondersteunen. Anderzijds houden belanghebbenden zich bezig met het overleg over bestaande problemen in het stroomgebied en helpen ze een reeks mogelijke interventies te ontwikkelen. Deze twee paden lopen vaak parallel en hebben de neiging alleen samen te komen bij het begin van het proces wanneer gegevens worden verzameld en aan het einde wanneer modelresultaten worden gepresenteerd voor de discussie en besluitvorming. Stakeholders hebben vaak weinig andere keus dan de door de experts verkregen resultaten te accepteren. Ze hebben de neiging modellen te zien als 'black-boxes' waar ze weinig begrip voor en vertrouwen in hebben, en daarom zijn ze vaak achterdochtig over de resultaten en beslissingen die worden genomen. Daarentegen bouwt participatieve en collaboratieve modellering sterkere verbindingen op tussen de technische experts en de belanghebbenden doordat ze bij het modelleringsproces betrokken zijn. Belanghebbenden leren op deze manier over het watersysteem en de modellen, hoe de modellen worden ontwikkeld en gebruikt, en hun sterktes en zwaktes. Modelleurs worden van achter hun computerschermen gehaald om samen te werken met de belanghebbenden. Hierdoor gebruiken ze de lokale kennis van de belanghebbenden, onder andere voor het verzamelen van gegevens maar ook bij de ontwikkeling van schematisaties en het gebruik van de modellen.

Er wordt in het proefschrift onderscheid gemaakt tussen participerende en collaboratieve modellering waarbij collaboratieve modellering gedefinieerd wordt als een subset en een intensievere vorm van participerende modellering. De betrokkenheid van belanghebbenden en samenwerking bij collaboratieve modelleren zal groter zijn dan bij participatieve modellering, wat leidt tot een groter belang van de onderhandelingen binnen het proces (hoofdstuk 2). Deze sleutelcomponenten worden gebruikt als basis voor de identificatie van de belangrijkste factoren die helpen bij het bepalen van de meest geschikte aanpak, methode en hulpmiddelen voor verschillende contexten en situaties. De combinatie van deze factoren resulteert in een generiek raamwerk voor methoden voor participatieve en collaboratieve modellering in WRM (hoofdstuk 3). Dit raamwerk wordt gebruikt voor het definiëren van de generieke kenmerken van bestaande methoden voor participatieve en collaboratieve modellering, zoals Group Model Building, Companion Modeling en collaboratieve modeling met behulp van netwerkomgevingen. Het raamwerk ondersteunt ook het generaliseren van case-specifieke participatieve en collaboratieve modelleringsbenaderingen en bijbehorende tools. Het primaire gebruik van het raamwerk in dit Ph.D. proefschrift is om verschillende benaderingen voor specifieke contexten en situaties te ontwerpen en deze te categoriseren in participerende of collaboratieve modelleringsbenaderingen. Er zijn vier methoden ontwikkeld om belanghebbenden te betrekken bij de ontwikkeling en het gebruik van computergestuurde simulatiemodellen. Dit zijn: (i) collaboratieve modellering met behulp van systeemdynamica en simulatiemodellering (hoofdstuk 4), (ii) Companion-modellering (hoofdstuk 5), (iii) snelle geïntegreerde modelsystemen (hoofdstuk 6) en (iv) crowdsourcing en interactieve modellering (Hoofdstuk 7). Het generieke raamwerk en de ontworpen benaderingen worden getest in negen studiecases, waarvan dit proefschrift vijf in meer detail beschrijft. De behandelde thema's en landen omvatten stroomgebiedsplanning in Indonesië, waterkwaliteitsbeheer in Turkije en Indonesië, adaptieve planning in Bangladesh en overstromingsrisicobeheer in Tanzania.

Deze methoden ondersteunen het besluitvormingsproces door het te baseren op feitelijke plaatselijke informatie en alle betrokkenen in het proces mee te nemen. De betrokkenen voelen dat ze deel uitmaken van het proces, aangezien hun kennis, interesses en behoeften actief worden meegenomen en gewaardeerd. Modelleren en betrokkenen leren samen en bouwen consensus, waardoor ze het gevoel krijgen dat ze eigenaars van de ontwikkelde oplossingen en daarmee krijgen ze vertrouwen in het besluitvormingsproces. Bovendien maakt het gebruik van participerende en collaboratieve modellering het modelleringsproces efficiënter. De combinatie van zowel technische als lokale kennis ondersteunt de ontwikkeling van een nauwkeuriger model. Het verzamelen van gegevens wordt minder een bottleneck in het modelleringsproces en de validatie van modellen vereist minder inspanning.

Tot slot. Het onderzoek gepresenteerd in deze Ph.D. scriptie heeft geresulteerd in twee belangrijke resultaten. Ten eerste: een generiek raamwerk dat helpt bij het ontwerpen en evalueren van modellen voor participatieve en collaboratieve modellering, rekening houdend met de lokale context. Ten tweede het verschaffen van ontwerpbenaderingen (richtlijnen) over wanneer en hoe verschillende methoden van stakeholderbetrokkenheid en het gebruik van computermodellen kunnen worden gebruikt, afhankelijk van de socio-technische context. De methoden zijn getest in de toepassingsgebieden van stroomgebiedsplanning, grondwaterbeheer, waterkwaliteitsbeheer, adaptieve planning en overstromingsrisicobeheer.

"Het lijkt altijd onmogelijk totdat het gedaan is" – Nelson Mandela

CONTENTS

1
GENERAL INTRODUCTION

This chapter is partially based on:

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017. Collaborative modelling or participatory modelling? A framework for water resources management. Environmental Modelling & Software 91 95-110.

Basco-Carrera, L., Mendoza, G., 2017. Collaborative Modelling. Engaging stakeholders in solving complex problems of water management. Global Water Partnership. Perspectives Paper No. 10

Wehn, U., Collins, K., Anema, K., Basco-Carrera, L., Lerebours, A., 2017. Stakeholder engagement in water governance as social learning: Lessons from practice. Water International 1-26.

1.1. Sustainable and Inclusive Development towards Water Security

The Sustainable Development Goals (SDGs) were adopted by the United Nations and all Member States to end poverty, protect the planet, and ensure prosperity for all. Management of water resources has always been an important vehicle for development. Of all our natural resources, water underpins sustainable development as perhaps no other. Our food, energy, health, industry and biodiversity - all depend on it. Sustainable development can only be achieved if fresh water is conceived as a finite and vulnerable resource essential to sustain life, development and the environment (GWP, 2000). However, in many cases, urban development, industrialisation, the changing climate and population growth are limiting its availability and quality, as well as aggravating disaster risks. Two central challenges for sustainable development are building resilience towards disaster risks and balancing the many competing uses and users of water, to ensure the needs of all are met while maintaining healthy and diverse ecosystems and to ultimately deliver water security.

Multiple definitions of the concept of water security exist (Cook and Bakker, 2012; Grey and Sadoff, 2007; GWP, 2012; WEF Water Initiative, 2010). In this Ph.D. thesis the definition of UN-Water (2013) is used: *water security is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development for ensuring protection against water-borne pollution and water-related disasters; and for preserving ecosystems in a climate of peace and political stability*. Achieving the diverse elements of water security - the "*reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks*" (van Beek and Arriens 2014) - feature as a recurring theme in many of the seventeen SDGs.

Integrated Water Resources Management (IWRM) is proposed as the guiding development approach towards water security. The Sustainable Development Agenda 2030 includes a specific target in the Sustainable Development Goals (SDG 6, target 5) specifying to implement IWRM at all levels. The IWRM approach "*promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability* *of vital ecosystems"* (GWP, 2000). However, lessons learnt from the past show that implementing IWRM encounters difficulties if most stakeholders still follow traditional planning mechanisms. IWRM requires that enabling conditions are in place. The three pillars of IWRM: (i) an enabling environment, (b) an institutional framework and (iii) management instruments, are key conditioning factors for the needed transformation. In many cases, however, the proper enabling conditions are not in place. Lack of knowledge about the water resources system, disagreements between water users and little focus on operationalisation are frequently the causes of limited acceptance and implementability of IWRM (Biswas, 2004). The involvement of stakeholders is imperative to address these challenges, ensure that any proposed development encompass the variety of competing interests, perspectives and values; and ultimately to ensure sustainability into the future. Today it is globally acknowledged that inclusive development goes hand in hand with the sustainable development of water resources. The approval of the SDGs and corresponding targets by all Member States of the United Nations shows the willingness of all countries to implement such a change.

1.2. Why Collaborative Modelling for Water Security

1.2.1 Informed Decision-making

Water security requires sound integration, prioritisation and implementation of interventions over time. Informed decision-making is conceived as the way for formulating evidence-based solutions and taking low-risk investments. Today this is possible thanks to the latest developments in technology. Technology is becoming increasingly accessible around the world. More and more people are becoming familiar with the use of computers, and with mobile internet information can be accessed or transmitted from almost anywhere in the world. Computing power that was once only available to the best-resourced organisations and institutions can also now be easily leveraged by most organisations and stakeholders. New scientific and technological advances have allowed a better understanding of water resource systems. Computer-based mathematical models support planning and decision-making processes by providing quantitative information. Open and big data and global models via remote sensing have improved our understanding of water resources systems in data scarce areas. The use of mobile phones, GIS applications, networked environments, interactive touch screens also offer new and diverse possibilities to communicate and disseminate information. These developments have brought with them possibilities to inject more and more quantitative information into decision-making processes. But these developments also raise several important questions in relation to decision-making. What types of information do stakeholders use to inform and influence decisions? What information do decision-makers then prioritise when selecting a course of action? How should this information be communicated?

The development of Decision Support Systems (DSSs) has served as a major initiative targeted towards bridging the gap between the development and use of computer-based models with stakeholders and how the planning and decision-making processes are actually carried out (Alter, 1980; Georgakakos, 2007; Giupponi and Sgobbi, 2008; Jolk et al., 2010; Keen, 1987; Loucks and da Costa, 2013; Serrat-Capdevila et al., 2011; Sharda et al., 1988; Soncini-Sessa et al., 1991; Thiessen and Loucks, 1992; Walsh, 1993; Zindler et al., 2012). However, in many instances these initiatives have not been sufficient, with the DSSs not actually used by stakeholders and decision-makers. Extensive research has been carried out to identify the main challenges of the use of DSSs in WRM planning and decision-making. These are:

- The key points of a planning and decision-making process are the objectives and criteria. DSSs need to focus on the goals the decision-maker and stakeholders wish to achieve, which might differ depending on the decision-making process and might evolve over time (Bousset et al., 2005; Medema et al., 2008; Mintzberg, 1978);
- Most DSSs focus on the tool to be developed rather than on their participatory use by or with stakeholders and decision-makers. The main focus is often on the software structure, the user interface and the visualisation capacities. Less emphasis is placed on stakeholder-model interactions or the specific conditions that makes the use of models more effective (Refsgaard et al., 2005; Serrat-Capdevila et al., 2011);
- The use of DSSs in decision-making processes often demands that the modeller remains a central part of the process. Consequently, these models are commonly perceived by the stakeholders as 'black boxes'. They are often developed and implemented in the back-room, even in those instances when there is interactive work done during data collection and results are shown and discussed with

stakeholders (Bourget L. (Ed.), 2011; Loucks and Van Beek, 2017; Loucks et al., 2005).

It is evident that scientific and technical information can substantially improve informed decision-making; however, the identified challenges regarding DSSs show that their use still remains problematic and insufficiently effective. A key aspect of increasing their use is the involvement of decision-makers and stakeholders in the planning and modelling process. Participatory modelling and later collaborative modelling emerged as possible solutions to address some of these challenges.

1.2.2 Stakeholder Engagement

The sustainable development agenda 2030 (United Nations 2016), the IWRM principles (GWP, 2000), OECD water governance principles (Akhmouch and Clavreul, 2016), WFD guidelines (European Communities, 2003b) amongst other principles and guidelines, stress the engagement of stakeholders as a means towards sustainable development. In this Ph.D. thesis, a distinction is made between stakeholder engagement, participation and involvement.

A stakeholder is usually defined as someone having an interest in a particular situation, even if this interest is not recognised or acknowledged by others[1]. Nevertheless, awareness of the dynamics of engagement leads some authors (Collins et al., 2007; SLIM, 2004) to suggest that *stakeholding* may be a preferable concept because it conveys the notion that stakeholders actively construct, promote and defend their stake over time and can also defend their stake and exert influence by not engaging in participatory processes.

The OECD defines engagement as a broad umbrella term and stakeholder engagement as the opportunity for those with an interest, or 'stake', to take part in decision-making and implementation processes (OECD, 2015). Here, stakeholders are distinct from simply the wider 'public' and can also include governments, private sectors and regulators and non-governmental organisations. Stakeholder engagement is seen as a means of contributing to improved water governance where governance is defined as the policy and practices giving rise to particular forms of water managing in different contexts. It is defined as a critical principle for sustainable development and building a resilient society (Gunderson,

[1] In this Ph.D. thesis the "actor" and "stakeholder" are used interchangeably.

2003; Robbins and Emery) and both a means and an end, insofar as it can lead to increased stakeholder empowerment and make planning and decision-making processes more transparent and democratic (Hare et al., 2003). It is also claimed to enhance the capacity of individuals to improve their own lives, facilitating social change (Cleaver, 1999). Local knowledge and expertise can be a valuable tool for understanding domestic situations and contexts, planning objectives and policy measures, as well as improving and/or creating innovative and alternative strategies; as a result, the sustainability of the adopted policy strategy will generally be higher (Hurlbert and Gupta, 2015). Stakeholder engagement can also promote social learning, as stakeholders acquire (rather than just convey) knowledge and collective skills through better understanding of their situation as well as the perceptions, concerns and interests of other stakeholders (Collins and Ison, 2009; Evers et al., 2016; Hare, 2011; Hare et al., 2003; Voinov and Bousquet, 2010). Finally, stakeholder engagement can foster consensus among competing organisations by opening channels of communication, generating mutual understanding and negotiating alternative solutions (Loucks and Van Beek, 2017; Loucks et al., 2005; Sadoff and Grey, 2005; Zeitoun and Mirumachi, 2008). The OECD sets out various requirements for stakeholder engagement which in summary are: recognising the range of actors with a stake in a situation and understanding their possibly diverse responsibilities; paying particular attention to underrepresented groups; identifying the process of decision-making and stakeholder inputs; encouraging capacity development of stakeholders; assessing and evaluating engagement processes; promoting conducive institutions; and contextualising stakeholder engagement initiatives.

Participation as concept, method and practice has been discussed extensively in the literature since Arnstein's ladder (Arnstein, 1969). This offered a simple structure for identifying power-based degrees of citizen involvement in decision-making (Bruns, 2003; Collins and Ison, 2009; Fung, 2006; Hurlbert and Gupta, 2015; Ison et al., 2015; Mostert et al., 2007b; Reed, 2008; Voinov et al., 2016). There are distinctly different forms of participation with different outcomes and impacts (Fung, 2006; Reed, 2008) that depend on the contextual setting and the nature of the issue or problem at hand (Hurlbert and Gupta, 2015). This engagement is a wide-ranging, but active, dynamic process where stakeholders are 'allowed in' to participate in decision-making processes.

Finally, stakeholder involvement implies – explicitly or implicitly – trade-offs in terms of representativeness, inclusion, or (in)equality in interactive processes, i.e. between the "breadth" and "depth" of involvement (Voinov et al., 2016). Substantive aspects come into play (van Buuren et al., 2014), concerning the extent to which all stakeholder inputs and interest are taken into account. In WRM, policy-making and decision-making has tended to be expert-driven and expert-produced according to technocratic standards (DeSario and Langton, 1999; Fischer, 2000; Hisschemöller, 1993). This includes the belief that the desirability of the solution can be shown by standardised methods and technical procedures and that the use of available expert knowledge is sufficient for an efficient implementation of the solution. Consequently, the participation of stakeholders is often considered superfluous because they do not have the necessary (technical) knowledge and expertise required for situation appraisal or resolution (Edelenbos et al., 2008). Participatory and collaborative modelling is developed to address this challenge.

1.2.3 Participatory and Collaborative Modelling

Analytical models and tools support key decision-making for managing water stress, flood risk, building dams, managing groundwater, and bringing together the social, economic, and environmental issues and challenges of IWRM. However, models provide us with views of the world. There are, however, other views, like those of stakeholders who live and work in river basins. If decisions about water management are to be widely accepted and implemented, asking stakeholders to approve pre-selected solutions is not good enough. Participatory and collaborative modelling considers the creation of multi-stakeholder collaboration platforms and partnerships in combination with the use of models and tools for sustainable water resources planning and management (Collins et al., 2007; Pahl-Wostl, 2002; Solanes and Gonzalez-Villarreal, 1999). Participatory and collaborative modelling highlights the importance of stakeholder involvement in a modelling process (Hare et al., 2003; Voinov and Bousquet, 2010; Voinov and Gaddis, 2008; Voinov et al., 2016). It helps to bring stakeholders and technical experts together in a formal procedure much earlier in the planning process, and for developing models not just for analytical purposes but to build consensus, trust, and improve decision-making. In this research, a distinction is made between "participatory modelling" and "collaborative modelling". Collaborative modelling is a subset and more intensive form of participatory modelling, characterized by high levels of participation and cooperation.

The use of computer-based simulation models

Modelling and how to involve stakeholders in the modelling process are key elements of participatory and collaborative modelling. Some participatory and collaborative modelling approaches construct together with stakeholders the model from scratch. There are no formulas or assumptions predefined. The participation of stakeholders in these processes is very high, resulting in high transparency. Model validation and quality can however become an issue, especially in informed, formal decision-making processes. The models are constructed based on the perceptions, mental models [2] and beliefs from involved stakeholders. But what if involved stakeholders do not have a complete understanding of the system? Or some of their mental models are not consistent or rather questionable? Other quantitative tools used for participatory and collaborative modelling combine the use of local knowledge with technical or scientific knowledge. They are used in facilitation or pacification strategies to build consensus among stakeholders by providing clarity about the uncertainties of the system (Hanssen et al., 2009). Commonly, technicians and scientists take the role of neutral parties that provide non-strategic technical knowledge. Computer-based simulation models are examples of quantitative tools. They are used to interpret and understand the functioning of the physical system, via mathematical descriptions of the physical (natural) processes. The output is produced based on the input and by some mathematical or statistical formulas. Such proven mathematical models are crucially needed, especially if the problems analysed are complex. In the field of WRM, some examples include water balance and allocation models, hydrological models, water quality models, etc. In comparison, stakeholders have less freedom to make changes in the model. For instance, prior to starting the modelling process they need to be aware, understand and accept the formulas that describe the behaviour of the water cycle and natural resources. Based on these limitations, one can question: *Can participatory and*

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[2] Mental models are cognitive representations of external reality. The core idea behind the concept of mental models is that the interaction between an individual and the real world is mediated by a mental representation which is used to simplify our understanding of how the world functions, to filter information by focussing on relevant components and to test available behaviours (via mental simulation including counterfactual) before turning them into action (Jones et al., 2011b) (see Glossary)

collaborative modelling be used to efficiently develop computer-based simulation models based on pre-existing knowledge? This question and the aforementioned consideration lead to the formulation of this Ph.D. research.

1.3. Ph.D. Objective, Goals and Research Questions

The overall objective of this Ph.D. thesis is to support informed and participatory decision-making for achieving sustainable and inclusive development. Participatory and collaborative modelling is applied for enhancing the use and strengthening the ownership of the results of computer-based simulation models in participatory decision-making and planning processes in WRM. To achieve this research objective a generic framework is required to make it possible to identify the most suitable methods and tools to involve stakeholders in the modelling process and at the desired level in different stages of a decision-making and planning process. Next, the research focuses on the design of participatory and collaborative modelling approaches and methods that can boost the use of existing computer-based simulation models in informed and participatory decision-making processes to secure water for all. To derive this overall objective four research questions are formulated. These are:

> *RQ1: What are the key features of participatory and collaborative modelling approaches used for managing water resources?*

This first research question aims first to analyse the underlying reasons for the limited use of DSSs and participatory approaches in formal decision-making processes in WRM. The study also incorporates an exploration of the contexts and situations in which participatory and collaborative approaches and methods could be commonly applied. This information is used as a basis for identifying the main components prevalent in the majority of participatory and collaborative modelling applications and adapt them considering the requirements of informed and participatory planning and decision-making processes in WRM.

> *RQ2: What are the main methods and tools used in participatory and collaborative modelling? And how can these be evaluated to determine for which situations they are most suitable?*

The exploration of existing participatory and collaborative modelling approaches, methods and tools will lead to developing a generic framework that helps in identifying the most suitable participatory and collaborative modelling methods and tools for WRM. The study will also determine the factors that are often critical when selecting an existing participatory or collaborative modelling approach or designing a new or adapted method. By the end of this study, a comparative analysis between participatory modelling and collaborative modelling will be presented indicating for which situations each of them is most appropriate.

> *RQ3: How can participatory and collaborative modelling approaches be applied with existing and newly developed computer-based simulation models?*

This research question will lead to the design of different participatory and collaborative modelling methods that enhance the development and use of computer-based simulation models together with stakeholders. For this, it is argued that participatory and collaborative modelling approaches and tools can be adapted, maintaining their key features and elements, so they can have a broader applicability. The analysis includes a needs assessment on the use of modelling tools for informed decision-making, and communication and visualisation tools to ensure fruitful stakeholder involvement in the modelling process. Approaches will be designed and applied in river basin planning, water quality management, national water security, groundwater management and flood risk management.

> *RQ4: What is the added value of applying participatory and collaborative modelling to support water resources planning and management?*

This research question aims to provide an insight in the impacts of the approaches and methods designed and applied as part of research questions 2 and 3. The assessment will mainly focus on the successes and limitations regarding the modelling process, social and institutional dynamics, and planning and decision-making processes. These outputs will serve to provide recommendations for future research and applications. The study will analyse whether these methods have boosted sustainable and inclusive development through informed and participatory planning and decision-making in WRM.

1.4. Outline of the Ph.D. Thesis

This Ph.D. thesis is outlined in nine chapters. The remaining of the thesis is structured along the four research questions presented in Section 1.3. The chapters are prepared based on eleven publications (see Section "List of Publications"). These articles have already been published or are in the process of being published. A footnote at the beginning of each chapter indicates the article(s) based upon which the chapter has been prepared. Figure 1.1 illustrates the followed research framework.

Chapter 2 addresses the first research question. It describes the key components of participatory and collaborative modelling approaches and presents a recompilation of best practices.

Chapter 3 makes an inventory of the types of participatory and collaborative modelling approaches and the most representative tools and methods used. It addresses the first research goal by introducing the generic framework that permits determining the most suitable approaches and tools for involving stakeholders in the modelling process.

Chapter 4 describes a collaborative modelling approach designed to be applied for river basin planning, where an integrated analysis of the basin is indispensable. The approach combines the use of system dynamics with computer-based simulation models. It is applied in a study case in Indonesia.

Chapter 5 introduces an adapted Companion Modelling approach for enhancing multi-stakeholder cooperation. It follows the key features of companion modelling and combines the use of role-playing games with computer-based simulation models. The approach is applied in two water quality management cases, in Turkey and Indonesia.

Chapter 6 illustrates the design, development and application of Fast Integrated System Modelling (FISM) for managing uncertainties, integrating solutions and prioritizing projects. A case in Bangladesh is used to evaluate the effectiveness of the approach and the use of FISM models.

Chapter 7 presents the combination of crowdsourcing for participatory mapping with the use of Interactive Modelling. The approach is tested in a flood risk management case in Tanzania.

Chapter 8 provides an overview and summary of the key features of the four methods previously introduced. It also discusses the effectiveness of using participatory and collaborative modelling in combination with computer-based simulation models for WRM.

Chapter 9. The Ph.D. thesis concludes by answering the four research questions and providing some reflections for future research.

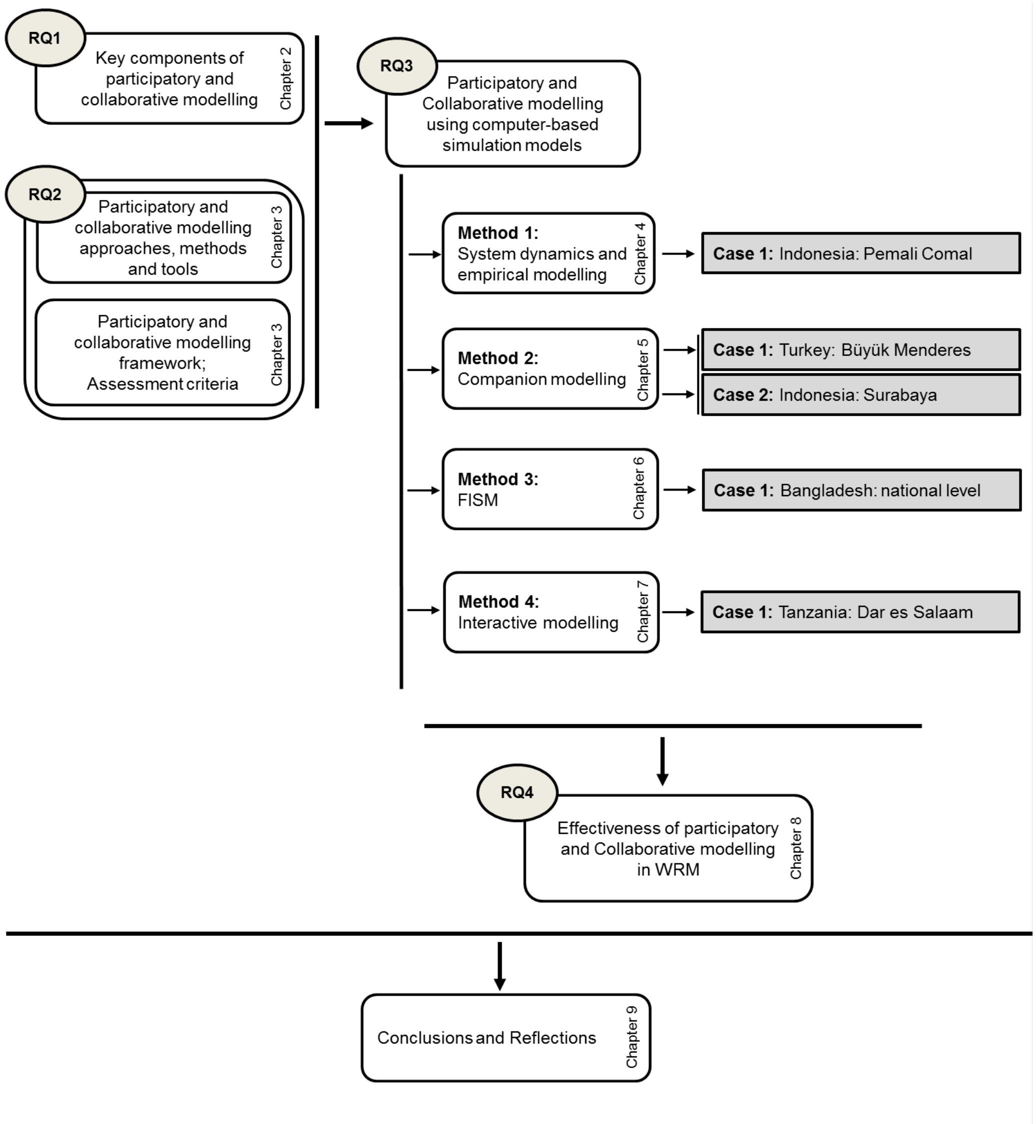

Figure 1.1 Ph.D. research framework

2

Participatory and Collaborative Modelling in Support of Decision-Making

This chapter addresses Research Question 1 by providing an elaborated answer to the question: *What are the key features of participatory and collaborative modelling approaches used for managing water resources?* The four key components are first introduced. These are then used to make the first distinction between participatory modelling and collaborative modelling considering the levels of participation and types of cooperation. The chapter finalises with a summary of the best practices when applying participatory and collaborative modelling in practical cases. These lessons learnt are critical for the design and application of the methods presented in Chapters 4-7.

This chapter is based on:

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017. Collaborative modelling or participatory modelling? A framework for water resources management. Environmental Modelling & Software 91 95-110.

2.1 Introduction

Over recent decades WRM has experienced a significant transformation. The top-down, mono-disciplinary and single sector managerial and planning approach was reformulated into IWRM (GWP, 2000). IWRM is a bottom-up, demand-oriented approach based on multi-disciplinary activities. It has paved the way for stakeholder participation in planning and decision-making processes (Rees, 1998). In particular, IWRM principles (known as Dublin Principles) have served as a turning point for public participation in WRM decision-making processes (GWP, 2000). Ever since their declaration in 1992, stakeholder participation has become increasingly institutionalised in legislation like the EU Water Framework Directive (Directive 2000/60/EC) and in global WRM frameworks and guidelines (GWP-ToolBox; Pegram et al., 2013; UNESCO, 2009).

A wide variety of participatory approaches and methods for participatory planning and decision-making in WRM have been developed in response to the prominence of public participation in IWRM. Focus groups (Dürrenberger et al., 1997; Gearin and Kahle, 2001), the Delphi method (Linstone H. and Turoff M. (Ed), 2002), citizen panels (Armour, 1995), World Café (Brown, 2002), and Participatory Rural Appraisal (PRA) (Chambers, 1994; Mukherjee, 1993) among other forms are being used to increase stakeholder participation in decision-making (Bousset et al., 2005). Much research has been oriented towards engaging stakeholders in planning and decision-making processes. Much less scientific research has been undertaken for exploring the use of conventional computer-based models within these participatory planning and decision-making processes. The development of DSSs emerged as a means to address this gap. However, in many cases DSSs were not used by stakeholders and decision-makers after their development. This was due to a variety of reasons, primarily associated with the different knowledge and expertise of the developers of such systems and the diverse stakeholders as intended users. Participatory modelling approaches then started to be conceived to strengthen stakeholder ownership of DSSs and modelling tools by increasing stakeholder involvement in the actual modelling process. Although stakeholder participation cannot be considered as the unique pre-requisite for guaranteeing long term use of computer-based models, it can be a critical factor. Consequently, today there are various participatory modelling approaches being used worldwide. Some refer to these approaches as participatory modelling, whilst others employ the term collaborative modelling. Although certain differences between the two terms may be identified, their inherent similarities can result in them being used interchangeably. This is in large part due to unclear distinction having been made between them in the literature. This makes it difficult for researchers, practitioners and policy-makers to identify which participatory or collaborative modelling approach is best suited to each type of decision-making and related processes (Bots and van Daalen, 2008; Hare et al., 2003; Serrat-Capdevila et al., 2011).

2.2 Rationale for Participatory and Collaborative Modelling

Participatory and collaborative modelling is a sub-process within a broader formal planning process. The planning process begins with identifying the problem, moves into formulating and assessing recommended measures, and ends with implementation. Participatory and collaborative modelling assigns a greater role to stakeholders who are able to participate in many aspects of model development including data collection, model definition, construction, validation, and verification. These stakeholders can also participate in applying models and analytical tools to assess the impacts of various measures and strategies. All these interventions provide opportunities to incorporate local knowledge and expertise into an analytical model. They help to identify and anticipate areas of concern and contention, and define acceptable planning objectives and policy interventions. Local expertise can improve and create innovative and alternative strategies, and provide information about the limitations of actions and their possible impacts. The interventions may even introduce alternatives that would not otherwise be explored or considered. Essentially, participatory and collaborative modelling gives a voice to stakeholders from those vulnerable communities that are meant to benefit from a process designed to promote sustainable development. This can both increase the acceptance of proposed strategies and enhance the sustainability of the adopted strategy. Stakeholder learning may also increase as community members interact not just with modellers but also with fellow stakeholders; all of this increases social capital among basin communities.

Technically, at the core level, both participatory modelling and collaborative modelling emphasise the importance of involving stakeholders in a modelling process (Voinov and Bousquet, 2010). Stakeholders should be exposed to the same information and problems encountered during the modelling process (Castelletti and Soncini-Sessa, 2007). Various scholars have built upon this basic definition; for instance, by distinguishing stakeholder involvement in various modelling stages (Hare, 2011), by specifying the stakeholder groups to be involved (Voinov and Gaddis, 2008), or by emphasizing the importance of communication activities and visualisation tools (Evers et al., 2012).

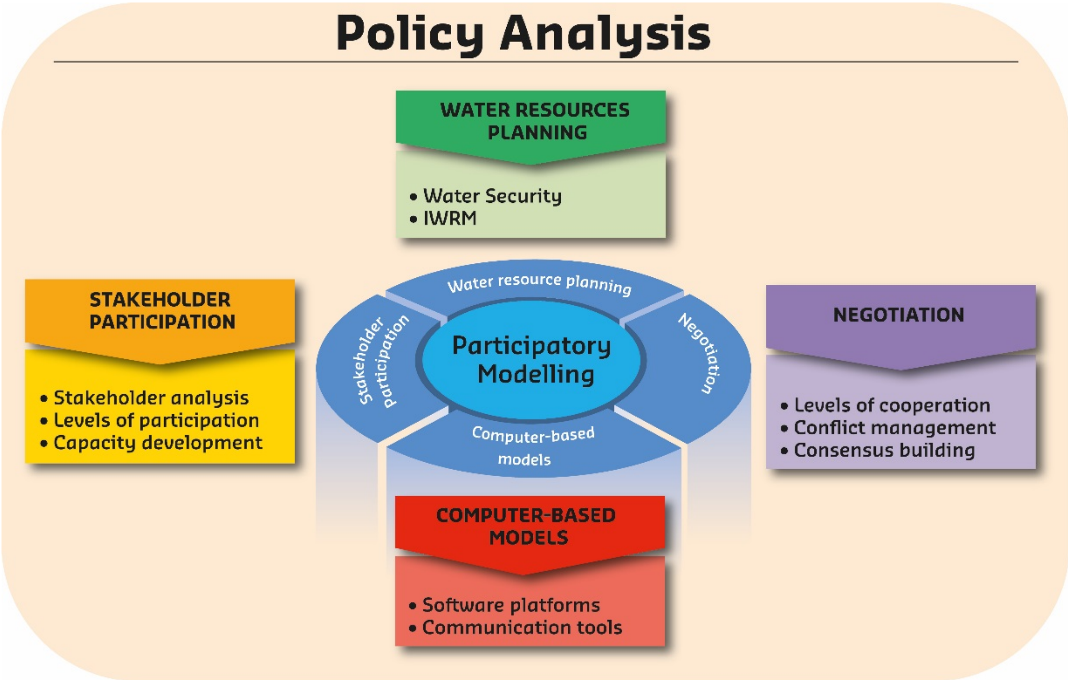

Figure 2.1 Key components of participatory modelling for policy analysis[3]

In this Ph.D. thesis, it is proposed that participatory and collaborative modelling for policy analysis in WRM rests upon the integration of four key pillars: (i) water resources planning, (ii) informed decision-making by means of computer-based models, (iii) stakeholder participation, and (iv) negotiation (Figure 2.1). Stakeholder cooperation in collaborative modelling will generally be greater than in other participatory modelling techniques, leading to the increased importance of negotiation within the process. These inter-linked pillars are considered the basis for effective and sustainable WRM.

2.2.1 Water Resources Planning

The planning and management of water resources has always been an important vehicle for development. A central challenge for sustainable development is how to balance the many competing uses and users of water, to ensure the needs of all are met, while

[3] Collaborative modelling is conceived as a form of participatory modelling, with the same pillars and components.

maintaining healthy and diverse ecosystems; in other words, to achieve water security. IWRM has been identified as the vehicle by which to achieve water security (Van Beek and Arriens, 2014). Taken together, they represent both the ultimate objective and the process by which it is attained. Hence, the water resources planning pillar encompasses these two components (Figure 2.1).

IWRM demands that solutions are found to complex problems that incorporate various environmental, economic and social dimensions (GWP, 2000). Commonly there is no single optimal solution to these complex, messy problems (Vennix, 1999). Participatory and collaborative modelling help characterise the relationship between the process of planning and decision-making and the resultant environmental, economic and social impacts of concern to stakeholders. Problem complexity is one of the factors that can determine whether to include participatory and/or collaborative modelling in a planning approach. The structure of policy problems in general (Simon, 1977) is determined by the degree of cooperation and conflict among stakeholders (Douglas and Wildavsky, 1983; Zeitoun and Mirumachi, 2008) and the level of knowledge uncertainty (Hommes, 2008; Van de Graaf and Hoppe, 1996). On this basis, three types of problems can be distinguished (Table 2.1):

(i) *structured problems,* for which a high level of scientific certainty exists and there is a high degree of consensus among stakeholders;

(ii) *semi-structured problems*, which can be the result of either (i) low degree of consensus (regarding values, norms and standards, beliefs and ambitions) in combination with some certainty about the scientific knowledge, or (ii) the knowledge of the system is limited in combination with consensus among stakeholders;

(iii) *unstructured problems,* for which a low degree of consensus exists and there is a lack of scientific certainty.

Table 2.1 Classification of policy problems (adjusted from Hommes, 2008; Van de Graaf and Hoppe, 1996)

		Uncertainty about scientific knowledge	
		Certain	Uncertain
Consensus	Agreement	Structured	Semi-structured
	Disagreement	Semi-structured	Unstructured

Many problems faced in water resources planning can be classified as being either semi-structured or unstructured. This is due to the complexity inherent to both natural and built water systems, as well as the fact that water is a shared resource for many different socio-economic and subsistence functions (leading to many diverse stakeholders). Water resources planning and its implementation occur at different scales and time horizons to the majority of functions they support. The IWRM planning cycle is the common mechanism with which to structure the planning process towards achieving water security. It includes a logical sequence of phases driven and supported by continuous management and promotion (Figure 2.2).

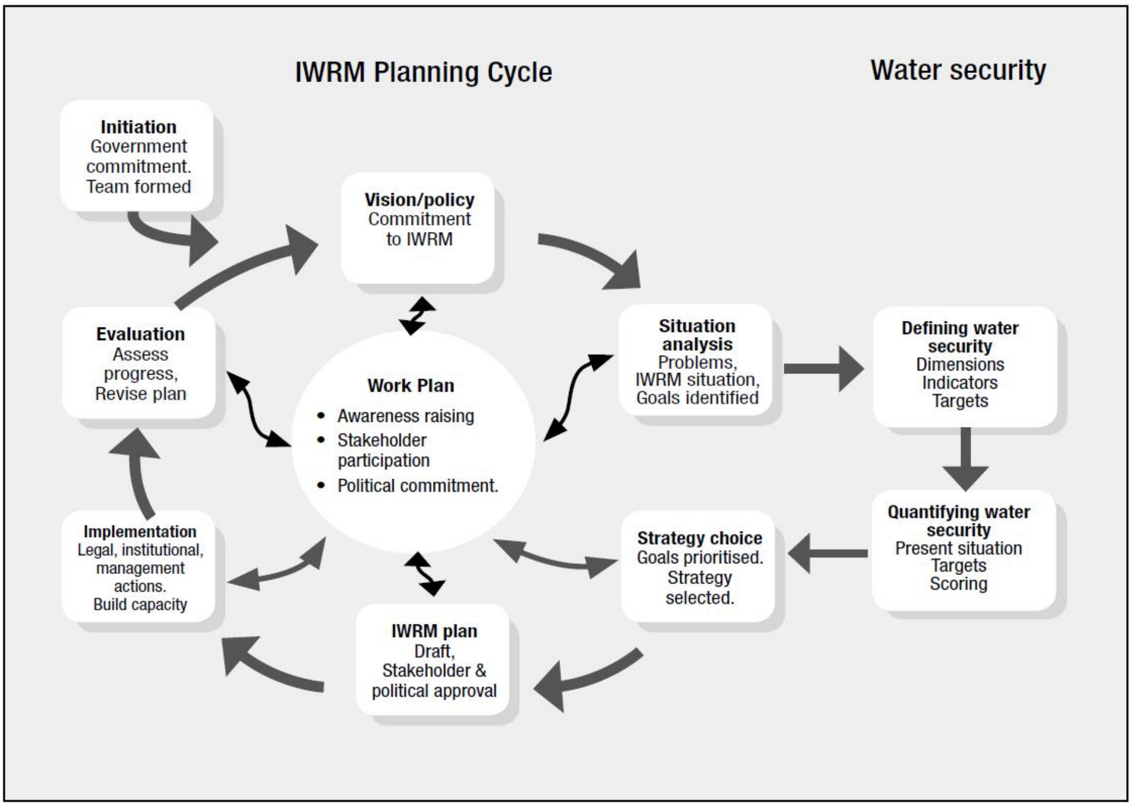

Figure 2.2 IWRM planning cycle to achieve water security (source: Van Beek and Arriens, 2014)

The approaches used in participatory and collaborative modelling must be flexible to facilitate stakeholder engagement during all the planning phases of the cycle and to allow the complexity associated with IWRM to be adequately addressed.

2.2.2 Computer-based Models for Informed Decision-Making

Modelling tools are central to collaborative modelling processes. Modellers and technical analysts develop, enhance, and validate these tools via a collaborative process for the purpose of informed decision-making. Models must be both understood and trusted by the stakeholders and decision-makers involved.

In recent decades, there has been a trend to develop computer-based models to improve understanding of water resource systems, to provide more integrated assessments and to better account for uncertainties (Haasnoot et al., 2014; Jakeman and Letcher, 2003; Loucks et al., 2005; Refsgaard et al., 2005). These models support evidence-based stakeholder dialogues and help focus and enhance the scientific basis of informed decision-making (Loucks and Van Beek, 2017; Loucks et al., 2005). DSSs are intended to communicate the necessary information and render modelling outputs understandable, transparent, acceptable and time appropriate for stakeholders (Bourget L. (Ed.), 2011; Jonoski and Evers, 2013). Different types of DSSs are depicted in Table 2.2. Depending on the type of problem to be addressed, as well as the stakeholders involved, DSSs can range from minimal if any computer-based model use (case 1 in Table 2.2) to DSSs that are fully automated (case 6 in Table 2.2). A clear example of automated decision-making is the automatic closing of the flood gates in Rotterdam harbour, where no human involvement is present (Loucks and Van Beek, 2017; Loucks et al., 2005). In many DSS, GIS and databases (DB) are used for data provision. Computer-based models can then support analysis of this data, generation of possible options as well as support decision-makers and stakeholders in evidence-based strategy making. Computer-based models can also be useful tools to assist stakeholders reach a common understanding and consensus regarding any conflicting interests, values, or norms. This is because they generally provide neutral information about the functioning of the system.

Table 2.2 Types of decision support systems (adjusted from: Loucks et al., 2017)

<table>
<tr><th></th><th>Data provided by</th><th>Data analyzed by</th><th>Options generated by</th><th>Decision selection by</th><th>Decision implemented by</th><th>Approach to decision making</th></tr>
<tr><td>1</td><td colspan="5">decision maker (stakeholders)</td><td>Completely unsupported</td></tr>
<tr><td>2</td><td>GIS/DB</td><td colspan="4">decision maker (stakeholders)</td><td>Information supported</td></tr>
<tr><td>3</td><td>GIS/DB</td><td>MODEL</td><td colspan="3">decision maker (stakeholders)</td><td>Systematic analysis</td></tr>
<tr><td>4</td><td>GIS/DB</td><td colspan="2">MODEL</td><td colspan="2">decision maker (stakeholders)</td><td>Sys. Analysis alternatives</td></tr>
<tr><td>5</td><td>GIS/DB</td><td colspan="3">MODEL</td><td>decision maker (st.)</td><td>System with over-ride</td></tr>
<tr><td>6</td><td>GIS/DB</td><td colspan="4">MODEL</td><td>Automated</td></tr>
</table>

Many different types of software platforms can be used in participatory and collaborative modelling approaches. For instance, one could develop conceptual diagrams using system dynamics software packages to help understand system relationships. Alternatively, one could develop narratives using fuzzy cognitive mapping approaches. Or, one could use OpenStreetMaps (OSM) together with local communities and technical analysts to provide feedback on the available or necessary data, models and possibilities. In many cases, several models may be coupled dynamically or using generalised functional relationships through a simple interface (e.g. as for the development of meta-models; Haasnoot et al., 2014).

Stakeholder involvement during one or more stages of the modelling process is critical in participatory and collaborative modelling approaches. Wherever possible, stakeholders should be directly involved in the construction of the models and tools, the formulation of scenarios and policy options to be modelled, as well as during assessments of the efficacy of these options against the key performance criteria (which they will have also defined). To enable such involvement, any developed models and tools should be constructed, where possible, using open source or freeware software that can facilitate their distribution to and use by the stakeholder population. Furthermore, sufficient attention should be placed on the visualisation and communication capabilities of these tools to facilitate the transmission of information to less-technically minded stakeholders. As such, participatory and collaborative modelling can encompass the development and use of various computer-based models and analytical tools, communication and visualisation tools, in addition to mental and cultural models (Jones et al., 2011; Paolisso, 2002).

2.2.3 Stakeholder Participation

It is generally accepted that stakeholder participation in WRM can serve as a tool for achieving sustainable WRM (Abbott and Jonoski, 2001; Edelenbos and Klijn, 2006). Stakeholder participation is both a means and an end, insofar as it can lead to increased stakeholder empowerment and make the planning and decision-making process more transparent and democratic (Hare et al., 2003). Participation is also a process that enhances the capacity of individuals to improve their own lives and that facilitates social change (Cleaver, 1999). Through building trust, ownership, and consensus the legitimacy and stakeholder support of the planning process and its outputs are increased. Local knowledge and expertise can be a valuable tool for understanding local situations and contexts, planning objectives and policy measures, as well as improving and/or creating innovative and alternative strategies. As a result, the sustainability of the adopted policy strategy will generally be higher.

Stakeholder participation can also promote collaborative learning. Two variants of collaborative learning are distinguished: social learning and shared learning. Social learning is the process where stakeholders acquire knowledge and collective skills through better understanding the system and its complexity; the perceptions, concerns and interests of other stakeholders; and on this basis the inter-connection between physical processes and social dynamics (Evers et al., 2012; Hare, 2011; Voinov and Bousquet, 2010). In shared learning, also referred to as co-learning, information flows occur in all directions. This means, information and knowledge flows from the organising team, including researchers and modellers, to stakeholders, and vice versa (Voinov and Bousquet, 2010). In collaborative learning individual knowledge is increased within the social context, further assisting the acquisition of collective skills (Hare, 2011; Mostert et al., 2007a; Pahl-Wostl et al., 2007; Voinov and Bousquet, 2010).

Stakeholder Engagement Process: from Stakeholder Analysis to Levels of Participation

The effectiveness of a participatory process is heavily influenced by the specific characteristics, interests, concerns and needs of the stakeholder groups involved. As

Voinov et al. (2016) stress, there is the need to consider not only the willingness of stakeholders to participate, but also how other powerful stakeholders might allow, facilitate or encourage the involvement of other stakeholders. Alternatively, they could prevent their participation. At the beginning of a participatory and/or collaborative modelling process it is always recommended to perform a stakeholder analysis. This is a useful tool to analyse stakeholder roles, responsibilities, interests, perceptions, concerns and dependencies (Grimble and Chan, 1995). The stakeholder community can then be later divided into various stakeholder groups to improve process efficiency if required. Common approaches include the Circles of Influence, the Nested approach or bull's eye approach used in the Water Framework Directive (Bourget L. (Ed.), 2011; European Communities, 2003a; Lamers et al., 2010; Werick, 1997). This then leads to the next challenge: the definition of stakeholder roles to systematise planning and decision-making processes.

In participatory and collaborative modelling it is important to find ways in which each stakeholder group can participate effectively. There exist many different roles that stakeholders may take in a planning and decision support process. Defining these roles according to the IWRM planning cycle and related modelling phases may be beneficial (Figure 2.2). Naturally, these choices will be based upon the goals of the specific water resources planning process. It may also be necessary to involve different stakeholders at different levels of participation. Arnstein (1969) provides useful insight into stakeholder participation by describing a ladder of participation related to power sharing. This varies from non-participation to citizen power processes such as partnership, delegated power and citizen control. Based on this, Bruns (2003) proposes an extended ladder of participation, ranging from low levels of participation such as informing, consulting and involving to higher levels such as establishing autonomy, advising and enabling. Similarly, Mostert (2003) identifies six main levels of stakeholder participation in water policy. These are information, consultation, discussion, co-designing, co-decision making and independent decision-making. These three ladders of participation have oriented the development of a simple typology of participation levels for planning and management of water resources. As illustrated in Figure 2.3, the revised ladder of participation includes one level of non-participation (i.e. ignorance), three levels of low participation (awareness, information and consultation) and three levels of high participation (discussion, co-design and co-decision making).

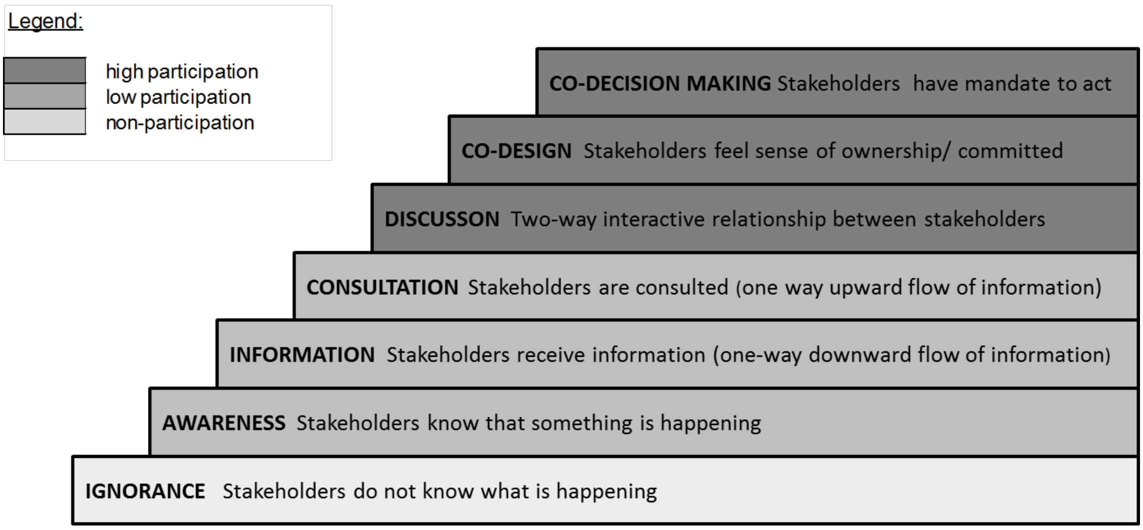

Figure 2.3 Ladder of participation for water resources planning and management (adapted from: Arnstein, 1969; Bruns, 2003; Mostert, 2003)

The organisation of stakeholder engagement according to varying levels of participation can extend involvement to those stakeholders affected by decisions, but who may not be able to actively collaborate in planning and decision making processes due to their characteristics, interests and/or capabilities. The use of participatory and decentralised tools such as social media can be an effective mechanism in this regard as they allow for the collection and provision of data that is both geographically and temporally traceable (Wendling et al., 2013).

In structuring stakeholder engagement in this way, a major challenge for stakeholder participation can be addressed: launching and maintaining the participatory decision-making process (Almoradie et al., 2015).

When combined with the use of modelling and analytical tools, effective stakeholder participation can foster consensus among competing organisations. It opens channels of communication via evidence-based stakeholder dialogues that generate mutual understanding and negotiated solutions (Hare, 2011; Loucks and Van Beek, 2017; Loucks et al., 2005). In doing so, it leads us to the final pillar of participatory modelling: negotiation.

2.2.4 Negotiation

A decision-making process concerning water resources typically involves complex problems that incorporate disputes among the stakeholders involved. Depending on the context and the structure of the problem, the willingness of the involved stakeholders to cooperate in joint decision-making might differ (i.e. competitive or cooperative interaction context). Stakeholder participation in WRM inevitably involves cooperation and conflict management that is achieved through negotiation. Participatory and collaborative modelling is used to support negotiations for policy and decision-making. Negotiation needs will determine the level of complexity required in analytical, visualisation, and communication tools. Different stakeholders may well need different tools and levels of information to both understand and interpret model results. Similarly, different negotiation processes may be required to cope with different interest groups. Particularly, collaborative modelling is well suited to interest-based negotiations. In these situations, after agreement is reached about facts and uncertainties, negotiations are held on any competing stakeholder interests.

Different types of cooperation can be used to assist stakeholders' transition from dispute to integration. Sadoff and Grey (2005) cooperation continuum, illustrated in Figure 2.4, is a useful tool for differentiating four principal types of cooperation: unilateral action, coordination, collaboration and joint action. Sadoff and Grey use this continuum to focus on transboundary cooperation in international rivers. In this Ph.D. thesis, their typology is adapted and applied to the concepts and contexts of participatory and collaborative modelling.

Unilateral action occurs when stakeholders work in an independent and non-transparent way. There is no cooperation as there is little or no communication or information sharing between the organising or modelling team and interested stakeholders.

Coordination is reached when there is regular communication and information exchange between the organising or modelling team and interested stakeholders. The exchange of information (e.g. collection of data) helps the organising or modelling team in the planning process. The coordination between sectors and governance levels helps to avoid conflicting ideas or initiatives, as the team can assess the possible benefits and impacts.

Collaboration is achieved when collective learning occurs and when the ideas and initiatives of stakeholders are adapted to achieve mutual benefits. This implies they are adapted to either secure mutual gains or to mitigate harm being caused to other stakeholders.

Joint action results when the organising and modelling team act as partners with other key organisations in the planning and decision-making process. This level of cooperation is generally formalised by legal agreements. Joint ownership, institutions and/or investments are some of the greatest cooperative efforts that can be achieved.

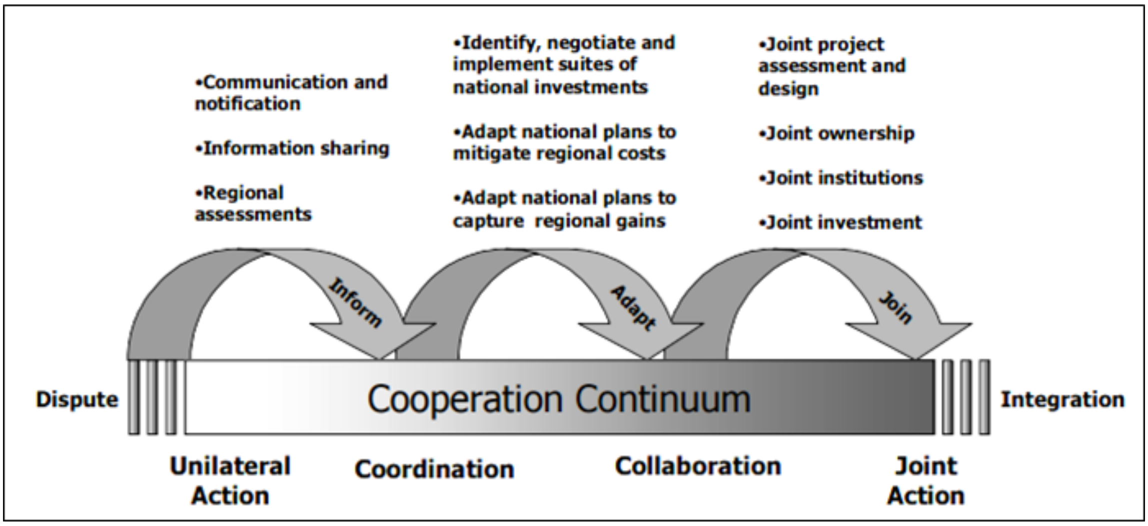

Figure 2.4 Types of cooperation – The Cooperative Continuum (source: Sadoff and Grey, 2005)

Negotiation processes within participatory and collaborative modelling can enhance capacity development for the stakeholders involved via individual and collaborative learning (Daniels and Walker, 1996; Evers et al., 2012; Hare, 2011; Voinov and Bousquet, 2010).

2.3 Participatory and Collaborative Modelling

2.3.1 Participation and Cooperation as Critical Dimensions for Stakeholder Involvement

The involvement of stakeholders in WRM planning processes is not a simple and straightforward process. Rather, it is a complex, interactive and iterative process to achieve certain specific objectives. Figure 2.5 organises the possible involvement of different stakeholder groups in a planning and decision-making process according to the four types of cooperation. Potential stakeholders have been labelled as either key stakeholders, other interested stakeholders and disinterested stakeholders. These are distinguished by different grey tones (see legend). Commonly, the organising team would be responsible for grouping stakeholders according to the local context and conditions via stakeholder analysis (Grimble and Chan, 1995).

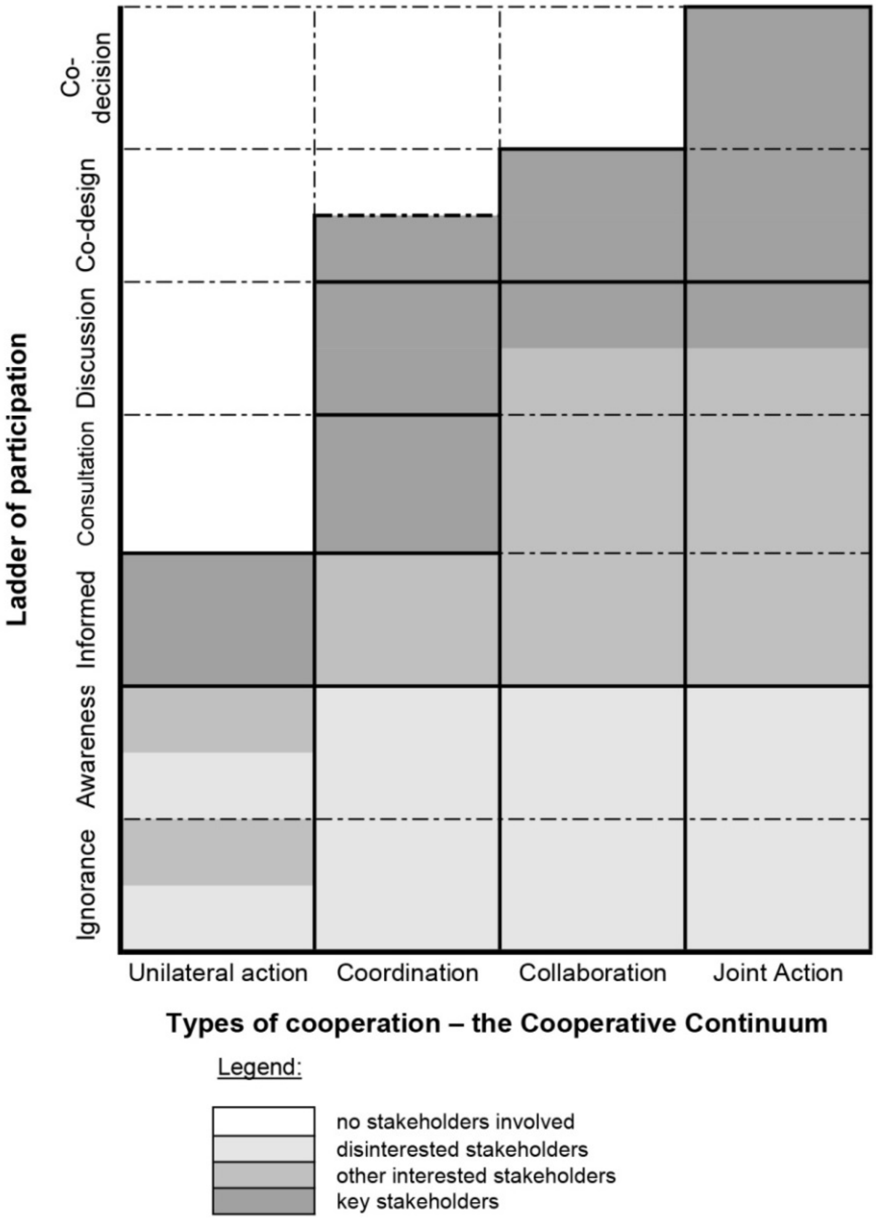

Figure 2.5 Categorisation of involvement of stakeholders based on levels of participation and types of cooperation

Four main cases of stakeholder involvement in participatory and collaborative modelling have been identified according to two critical dimensions: participation and cooperation. That is, the four cases are defined in relation to the seven levels of participation (Figure 2.3;

vertical axis) and the four types of cooperation (Figure 2.4; horizontal axis). It is important to highlight that each of the cases can relate to the timing of participation in the modelling process, and can change over the course of the participatory or collaborative modelling process.

Case 1: Unilateral action implies low levels of participation. Key stakeholders might be informed about the planning and/or decision-making process, however, they are not able to actively participate. Other stakeholders that may be interested in the process are either aware due to other information channels or else are completely unaware.

Case 2: Following the IWRM approach, decision-makers and the organising and modelling team agree to coordinate with key stakeholders in the planning process. These stakeholders might participate in stakeholder consultation meetings and discussions. In some instances, they can even be partly involved in the co-design of the modelling process and modelling tools. Other interested stakeholders can attend public meetings where they are informed about the planning process and the decisions taken. Social media can be used for engaging any disinterested stakeholders.

Case 3: Here, collaboration is considered crucial for the sustainability of WRM, and there is a willingness to actively involve key and other interested stakeholders in the planning process. The design of the planning and decision-making process is carried out jointly with key stakeholders, as is the construction of the computer-based model. They may also be involved in discussions depending on the timing of participation in the modelling process. Other interested stakeholders can participate in discussions (although their concerns and ideas may not end up determining outcomes), be consulted (e.g. attend public consultation meetings, provide information and data, etc.) or be informed. The use of social media is encouraged for the engagement of any disinterested stakeholders.

Case 4: This mainly differs from case 3 in terms of the high levels of participation of the key stakeholders. They are not only encouraged to co-design the modelling process and co-construct the computer-based model, but also jointly make decisions within the planning process. As in case 3, key stakeholders may also be involved in discussions depending on the timing of participation in the modelling process. There will be strong cooperation among stakeholders as well as high stakeholder capacity and a good governance setting. In more competitive contexts which may exhibit lower levels of trust and capacity, joint action that incorporates co-designing and co-decision-making can be an effective mechanism for providing transparency and comfort, and thereby, building trust.

2.3.2 Participatory Modelling versus Collaborative Modelling

In this Ph.D. thesis, a distinction is made that delineates collaborative modelling as a subset of participatory modelling. As depicted in Figure 2.6, collaborative modelling approaches are more suited to decision-making processes in highly cooperative contexts (collaboration and/or joint action) with high levels of participation for key stakeholders (i.e. co-design and co-decision making). In some cases when key stakeholders are involved in regular discussions, the approach may also be considered to be collaborative. By contrast, participatory modelling occurs across a wider spectrum and includes techniques that can involve lower levels of participation. It can include stakeholder involvement ranging from discussion to consultation to information sharing. Types of cooperation between the organising and modelling team, and stakeholders can range from coordination to joint action.

It is important to note that many participatory and collaborative modelling approaches consider one unique level of participation and type of cooperation for the relatively limited number of stakeholders involved. However, other approaches are used for large scale planning and decision-making, where large numbers of stakeholder groups preclude the common involvement of all stakeholders. Such approaches frequently divide the stakeholder community into various groups, in which the level of participation and type of cooperation for each of the groups might differ.

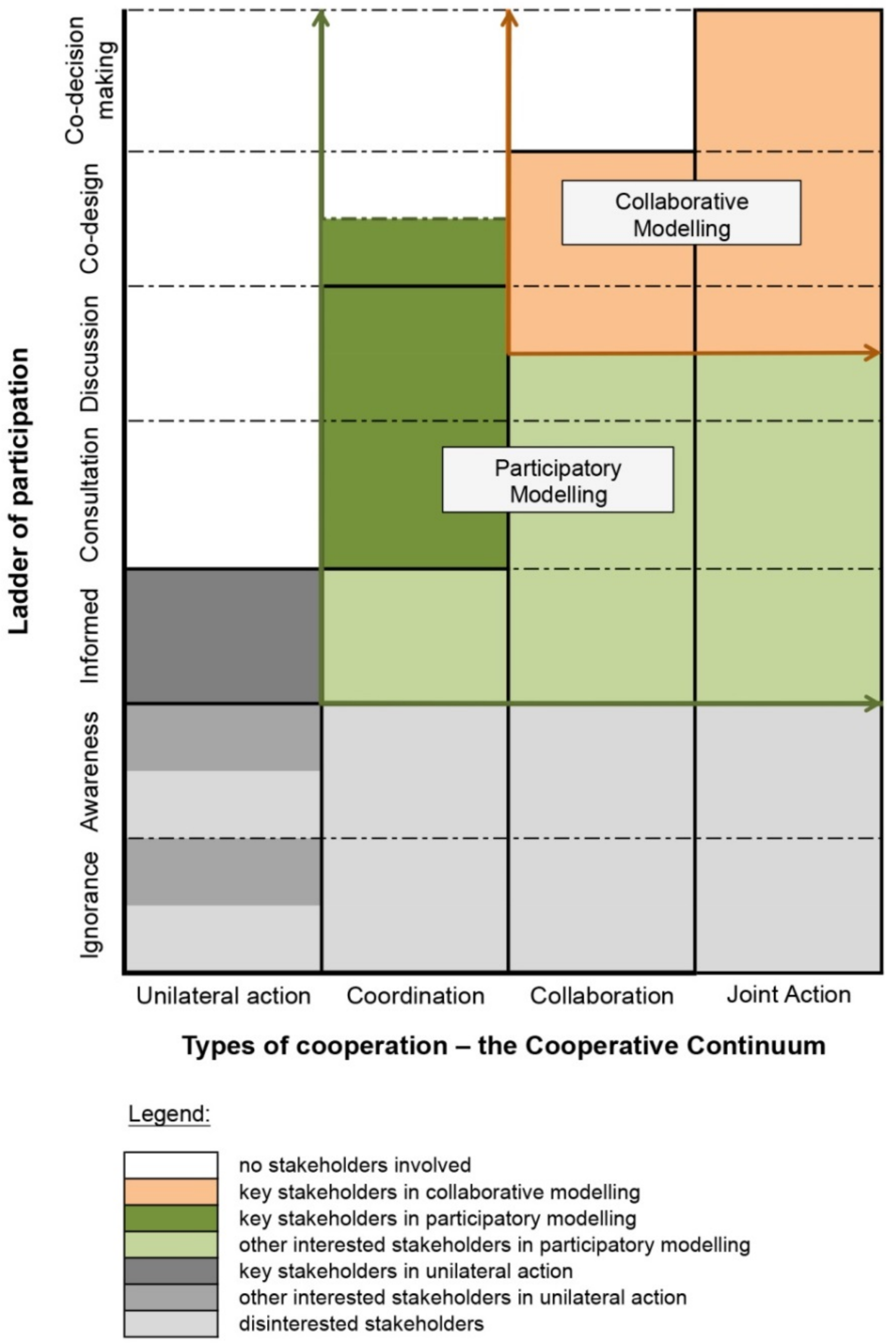

Figure 2.6 Classification of participatory and collaborative modelling based on the levels of participation and the types of cooperation

2.3.3 Best Practices

Participatory and collaborative modelling has already provided a wealth of experience for developing guidelines and best practice models for researchers, practitioners, policy-makers, and decision-makers. Useful experience comes from instances where decision-makers have struggled with a particular water resources planning process, and have identified participatory and collaborative modelling as a viable way of making progress.

Every participatory and collaborative modelling process will be unique and different because they are tailored to the nature of a problem, and the constitution (interests and capabilities) of stakeholders and decision-makers. In most cases, there is a 'champion' within an agency or decision-making institution who promotes the process. Facilitation is usually undertaken by a water resources agency or an independent consulting company. Typically, a neutral party is required to perform stakeholder analyses.

Three authors describe the best practices for participatory and collaborative modelling in WRM. Korfmacher (2001) identified transparency, continuity of stakeholder involvement, appropriate representative involvement, influence of stakeholders in modelling decisions, and a clear role of modelling in management as best practices of stakeholder participation in modelling processes. Later, Voinov and Gaddis (2008) outlined 12 lessons for successful participatory modelling. These include identifying a clear problem and leading stakeholders, early and frequent stakeholder engagement, creating representative working groups, establishing scientist neutrality to gain trust, managing conflict, selecting appropriate modelling tools, incorporating all forms of stakeholder knowledge, gaining acceptance for the modelling methodology, including uncertainty in stakeholder discussions, developing scenarios, jointly interpreting results with stakeholders, and treating the model as a process.

Building on the work of these three authors, Langsdale et al. (2013) formulated a set of best practices for collaborative modelling. These are to (i) gain support of decision-makers, (ii) identify who to invite to the process, (iii) select software that is easy to learn and can be made available to all, (iv) approach the project with humility, (v) design and execute a process where stakeholders are valued for their contributions, (vi) ensure that the model and modeller can accommodate rapid modifications and new alternatives and can simulate relatively quickly, (vii) frequently ask the team and all the participants throughout the process, "Who will use the model?" and "How will it be used", (viii) build a simple model early in the process, and then improve it over time with input from stakeholders and experts, (ix) engage stakeholder in iterative model development and technical analysis to foster shared learning and, (x) choose modellers with collaborative skills and diverse modelling abilities, as well as choose facilitators with the ability to understand and appreciate what modelling can provide.

2.4 Discussion and Conclusions

Effective and sustainable WRM demands systematic planning and decision-making processes that include stakeholder participation, are enabled by the use of computer-based models (informed decision-making), and promote cooperation and negotiation. Participatory and collaborative modelling are an emerging set of approaches that cover a variety of ways to combine these elements. This is particularly important when addressing complex problems. A useful first step in examining these problems is to look at the existing levels of consensus among stakeholders and the degree of scientific knowledge related to the problem being addressed. These factors are critical contextual determinants in identifying the participatory and/or collaborative modelling approach(es) suited to each problem type.

A distinction is made between participatory and collaborative modelling based upon two determining dimensions: levels of participation and types of cooperation. Collaborative Modelling occurs when key stakeholders co-design and/or take joint decisions within the modelling process, and when stakeholder cooperation manifests itself as collaboration and joint action. Participatory modelling, in contrast, covers a wider spectrum of participation levels (from awareness to being involved in discussions) and types of cooperation (from coordination to joint action). In some planning and decision-making processes, a combination of approaches may be appropriate. For instance, a collaborative modelling approach could be used for key stakeholders and a participatory approach (lower levels of participation) used for other interested stakeholders. This distinction between participatory and collaborative modelling will be applied in the remaining of the Ph.D. thesis.

3

GENERIC FRAMEWORK FOR SELECTING APPROACHES, METHODS AND TOOLS FOR PARTICIPATORY AND COLLABORATIVE MODELLING

This chapter answers the second research question: *What are the main methods and tools used in participatory and collaborative modelling? And how can these be evaluated to determine for which situations they are most suitable?* It first presents an inventory of existing participatory and collaborative modelling approaches being used in the fields of environmental modelling, natural resources management and WRM. It includes a description of eight approaches and 20 methods and tools. Second, by analysing these approaches and tools, a generic framework was developed. Six factors and 20 parameters are used for the analysis. Finally, this framework is used to further specify the similarities and differences between participatory modelling and collaborative modelling.

This chapter is based on:

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Voinov, A., Basco-Carrera, L., et al. 2018. Tools and methods in participatory modeling: selecting the right tool for the job. Environmental Modelling & Software (https://doi.org/10.1016/j.envsoft.2018.08.028)

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017b. Collaborative modelling or participatory modelling? A framework for water resources management. Environmental Modelling & Software (91) 95-110.

3.1 Introduction

Numerous approaches, tools and methods have been developed in the last few decades to work with stakeholders in the process of participatory and collaborative modelling. Voinov and Bousquet (2010) and Voinov et al. (2016) reviewed existing participatory approaches, tools and methods that have been used to enhance stakeholder participation in different components of the participatory modelling process. The research concludes that while many tools are developed for particular stages of the process, in reality a hybrid application of tools can be found. Indeed, a decision about methods is more influential for the whole process than the choice of a particular tool to be used, and should come before the choices on tools. The decision to use more quantitative tools rather than qualitative or conceptual ones can potentially and significantly change the outcome of the participatory modelling process.

Box 1: Approaches, Methods and Tools

An **approach** is a way a process is designed, structured and organised considering the context, situation, planning, decision-making and negotiation processes.

A **method** is a way of doing something. A particular method can be supported by one or several tools. Usually, a method can be implemented with several tools-a one-to-many relationship. Some tools serve several methods.

A **tool** is defined as a modelling technique used to carry out a particular function to achieve a certain goal. It is defined, documented, not overly modified through its use. It is clearly external to its users, albeit often created by them.

A careful selection of methods is essential for the modelling process and its implications. For many case studies, the choice of tools and even methods is driven mainly by the experiences of participating researchers, not necessarily by the particular goals and specifics of the problem at stake (Prell et al., 2007). This is a manifestation of the well-known 'hammer and nail' syndrome that says that once you learn to use a hammer, everything starts to look like a nail. A researcher with much expertise in system dynamics is very likely to try to apply this method to the next modelling project. Retraining is always time-consuming and resources scarce. However, there are several reasons why this approach is not optimal, especially in case of participatory and collaborative modelling.

First is the practical argument: the success of participatory modelling, regarding the development of high-quality models which can meet the client's and decision-maker's requirements efficiently and effectively, will improve by using methods that best fit the modelling purpose and project context. Available resources and the level of stakeholder's commitment are clear examples. This would be quite mundane for any modelling project, except that in participatory and collaborative modelling. The stakeholders are expected to be engaged in many, if not all steps of the modelling process, and participatory and collaborative modellers should be able always to explain how the chosen tools and methods are most appropriate for the specific conditions and purposes. This requires some flexibility in the process, whereby stakeholders and researchers move, collectively as a team, from the problem to an appropriate method, to tools and associated skills found within the project team. Such a process also requires a considerable amount of trust from funding agencies and clients to devote resources to processes that are vaguely defined and to rely on the project team to provide or add the expertise as the problem requires (Prell et al., 2007).

Second is the political argument, which implies that the choice of methods is more than a technical decision but a boundary judgment that the modeller makes about who/what to include in the modelling process (Midgley, 1995). This choice influences how much power the modeller is willing to give to participants over the modelling process, to ensure in exchange more process legitimacy (Nabavi et al., 2017), or to "level the playing field" in the case of asymmetries in the power or knowledge of different stakeholders (e.g. Barnaud, 2013). While the selection of the tools and methods is critical, it is also a difficult task. Among those numerous options, scientists, modellers and stakeholders are usually familiar with only a few of them. Often tools and methods are chosen because they are readily accessible, rather than being the right ones. Besides the lack of an awareness of potential tools and methods, the more critical issue is that there is no systematic approach and formal procedure to guide the choice of right tools and methods. Given that participatory modelling relies on participation, individuals must be invited to the process. When this occurs, others are necessarily excluded. Further, because modelling often requires some element of rules or strategy guiding the approach prior to the decision-making process, some decision-makers may have more significant power, which can be thought of as the ability to control or influence others' actions or choices. Because inequality in power can manifest itself in many ways (Kraus 2014), it is important for a truly participatory process to have all individuals informed not only about the decisions being made but also about the decision-making process.

The choice of tools and methods that drive the decision-making process can certainly impact the decisions made, yet scholarly discussion about how tools are chosen is sparse. A review of how tools are chosen, however, can also significantly empower certain participants at the expense of others. If a selected method is the one that you have a lot of experience with, would that give you a substantial advantage in understanding and controlling the process, compared to other stakeholders for whom the method is completely new and vague? Wouldn't your confidence and knowledge of the participatory process make you more likely to guide it?

In this chapter, the most relevant approaches, methods and tools used for modelling with stakeholders are first presented. Then, a list of considerations for selecting the most appropriate participatory modelling method for each context and local conditions is indicated. A new framework for evaluating participatory and collaborative modelling approaches in WRM has been developed and is presented to help in distinguishing the main characteristics of both approaches.

Some may question the value of yet another 'framework' given that others have previously been developed. For example, several evaluation frameworks have been developed for assessing participatory processes (Abelson et al., 2003; Rowe and Frewer, 2004). Similarly, evaluation frameworks and protocols for participatory and collaborative modelling approaches have been variously developed to assess the value of these approaches and their outcomes. For instance, Smajgl and Ward (2015) present an evaluation protocol based on the Challenge and Reconstruct Learning (ChaRL) Framework to assess the learning process of decision-makers. Jones et al. (2011) developed the Protocol of Canberra to evaluate the influence of tools on the sharing of information among participants, their relations between each other and the outcomes of the participatory process. This was also based on an earlier participatory modelling evaluation initiative (HarmoniCOP) developed by Mostert et al. (2007b). Plus, other scholars have developed frameworks to compare case-specific participatory modelling processes, such as the Comparison of Participatory

Processes (COPP) framework (Hassenforder et al., 2015). The generic framework presented in this PhD research differs from all of these other existing frameworks as it distinguishes between the key characteristics and features of both "participatory modelling" and "collaborative modelling" approaches based on 20 relevant parameters for IWRM. This helps to categorise existing approaches and corresponding tools into one of the two generalised terms via a consideration of their generic characteristics and features (trade-offs).

3.2 Participatory and Collaborative Modelling Approaches

Specific types of participatory and collaborative modelling have emerged in the last few decades. Some are extensively used for WRM, while others are emerging approaches. The most frequently applied approaches in WRM are presented below. As Voinov and Bousquet (2010) highlight, these approaches share several similarities; however, several subtle differences also exist. These mainly refer to their applicable contexts, specific uses, information handling, stakeholder involvement, modelling/organising teams and/or means. These approaches are grouped in the following sub-section under a number of overarching main lines or umbrella terms identified from the literature.

I. Shared Vision Planning

Shared Vision Planning (SVP) was developed by the US Army Corps of Engineers Institute for Water Resources to integrate its planning principles with systems modelling and collaboration and provide a practical forum for making WRM decisions. The framework was devised and piloted on five river basins of the US East Coast due to the most severe flood ever recorded in the 1960s that led to conflict between states and cities. SVP integrates a 7 step planning process to a structured collaborative process called the 'circles of influence', which drives the technical analysis and the development of a decision support system (Cardwell et al., 2008; Langsdale et al., 2013; Mendoza et al., 2013).

II. Interactive Modelling

It implies the development of an analytical tool that provides extremely fast and accurate dynamic visualisation of a system. Stakeholders can interact and make direct changes to the tool as they use it as well as see the results of their changes almost instantly. Such direct interaction facilitates stakeholder understanding of complex physical processes (Berendrecht et al., 2007; Stock et al., 2008).

III. Fast Integrated Systems Modelling

Fast Integrated Systems Modelling (FISM) integrates and simplifies interactions and important feedbacks among complex systems into a fast, low-resolution model (for example in Excel) necessary for high-level reasoning and communication, exploratory analysis and long term decision support that takes into consideration the uncertainties. The collaborative development of the simple model promotes a shared understanding of the integrated systems, to better support evidence-based stakeholder dialogue (Davis and Bigelow, 2003; Haasnoot et al., 2014).

IV. Group Model Building and Mediated Modelling

Group Model Building and Mediated Modelling are types of participatory and collaborative modelling using systems analysis and dynamics. Causal Loop Diagrams, and/or Stocks and Flows are developed together with stakeholders and used to describe the cause-effect relationships and feedback loops between factors and systems. The approach enhances team learning, creates a shared social reality that results in a shared understanding of the problem and potential solutions (Antunes et al., 2006; Richardson and Andersen, 1995; Stave, 2010; Van den Belt, 2004; Vennix, 1996, 1999; Vennix et al., 1992; Videira et al., 2017; Videira et al., 2003).

V. Cooperative Modelling

Simplified Group Model Building processes that combine system dynamics with other simulation models are also used in Cooperative Modelling. In these cases, stakeholders co-construct a system dynamics model, which is then generally used as input for more complex simulation models. These are used later for analytical purposes together with stakeholders. In decision-making processes where stakeholders are located over large distances, the stakeholder engagement process can take place via web interfaces (Bourget L. (Ed.), 2011; Cockerill et al., 2007; Tidwell and Van Den Brink, 2008; Van den Brink, 2009).

VI. Bayesian Modelling

This approach is typically used in decision-making processes in which probabilities of occurrence want to be considered. This approach supports decision-making under uncertainty as it helps in defining the conditional probabilistic relations between variables in the network. The uncertainties associated with these probabilities are presented transparently and analysed together with stakeholders (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007).

VII. Companion Modelling and Participatory Simulation

In Companion Modelling, stakeholders are typically involved in the co-construction of agent-based models and use of role-playing games for Natural Resources Management, particularly at community level. In other cases, it is more convenient that stakeholders make use the agent-based model as an analytical tool rather than building it (i.e. Participatory Simulation). In both approaches there is the aim to enhance shared learning dialogues by settling existing disputes between stakeholders. The process can lead to collective action in the future (Briot et al., 2007; Castella et al., 2005; CIRAD, 2004; Étienne, 2011, 2013; Guyot et al., 2005; Lonsdale et al., 2004; Souchère et al., 2010).

VIII. Collaborative Modelling using Networked Environments

This approach combines participatory processes supported by a socio-technical framework. Simulation models are developed with a focus on individual stakeholder social learning to elevate flood risk awareness and planning activities. The process is supported by a web-based collaborative platform (Almoradie et al., 2015; Evers et al., 2012; Jonoski, 2002; Jonoski and Evers, 2013).

3.3 Participatory and Collaborative Modelling Methods and Tools

This section presents a quick scan of methods and tools commonly used in participatory and collaborative modelling processes. The methods and tools are divided into five categories: (i) data and information acquisition, (ii) process orchestration, (iii) qualitative modelling, (iv) semi-quantitative modelling, and (v) quantitative modelling.

3.3.1 Data and Information Acquisition

I. Surveys and Interviews

Surveys consist of a suite of questions; they can be undertaken in person or electronically. When face-to-face they are usually called interviews. Interviews can follow structured or semi-structured methods. Questionnaires are another method for data gathering. These can be paper-based or using 'Personal Digital Assistants' (PDAs) for collecting data electronically (Ficek, 2014; Lane et al., 2006; Onono et al., 2011).

The rapid spread of mobile phones, especially of low-end smartphones, all over the globe permits their use also for data collection. Location and multi-media data: photographs and audio interviews, apart from text data, for better visualisation, accuracy, and analysis of the data is some of the possible uses and functionalities. Several free and open-source solutions help users to customise these solutions to their requirements and collect, analyse and manage their data. These include: Open Data Kit (ODk)[4], KoBoToolbox[5] and Village GIS[6].

II. Crowdsourcing

Crowdsourcing is another data acquisition method which is becoming increasingly popular with increasing access to the internet across the world. It involves 'sourcing' data from a large number of people ('crowd'), including those unknown to the individual or organisation gathering it (Voinov et al., 2016). Some of its main advantages are: lower cost, speed, scalability, and diversity. However, a significant disadvantage is that the quality of data collected can be bad due to participation of less qualified people which is difficult to avoid. Data quality control is therefore of crucial importance when applying crowdsourcing. Volunteered geographic information (VGI) is a particular case of crowdsourcing where information provided by a volunteer is linked to a specific geographic region (Goodchild, 2007). A prominent example of VGI is OpenStreetMap (OSM)[7].

[4] https://opendatakit.org/
[5] http://www.kobotoolbox.org/
[6] https://www.iiits.ac.in/nagesh/
[7] https://www.openstreetmap.org/

3.3.2 Process Orchestration

Participatory modelling is a process. The organisation, management, monitoring and reporting of the process is therefore of key importance for its success.

III. Facilitation, Discussion Analyses

Facilitation is a primary component of any participatory and collaborative modelling process. Capability and knowledge mapping are tools to determine who in the process has specific capabilities of knowledge needed, to determine what knowledge gaps might be present. It also helps in mapping out the distribution and intensity of knowledge capabilities and distribution. Further, techniques such as brainstorming, diagramming, or using manipulatives can be used to help individuals express their ideas. Cards, stickers, or digital tools could be used to help facilitate and capture ideas (Fischer et al., 2002).

IV. Role-playing Games

The role-playing game is a useful tool to exchange knowledge and raise awareness among stakeholders in the desired context. The purpose is the creation of a virtual world, with simplified real world conditions, to collect information about the perceptions of stakeholders concerning a specific context and situation and for exploring possible alternatives. A role-playing game comprises four main elements: environmental settings, player components, rules of operation and input to the game (Eden and Ackermann, 2013). In the game, different members play the role of various stakeholders and develop proposals collectively. The use of role-playing games can support in addressing stakeholders' interests, effectively build a supportive coalition and ensure effective implementation.

V. Cultural Consensus

Cultural consensus fundamental theory assumes that correspondence between the answers of any two respondents is a function of the extent to which each is correlated with some truth (Romney, 1999). Cultural consensus estimates the culturally "correct" answers to a series of questions (group beliefs) and simultaneously estimates each respondent's knowledge or degree of sharing of the answers (Romney et al., 1986). In practice, the cultural consensus is a collection of analytical techniques and models that can be used to estimate cultural beliefs and the degree to which individuals know or report those beliefs" (Paolisso et al., 2015; Weller, 2007). Participant observations, interviews and survey questionnaires combined with text analysis using specialised software and descriptive statistics are commonly used methods.

3.3.3 Qualitative Modelling

VI. Cognitive / Concept Mapping

Concept maps are graphical representations of organised knowledge that visually illustrate the relationships between elements within a knowledge domain. A cognitive map is usually used to represent an individual's knowledge or beliefs about a particular issue or system of interest. A concept map contains the perspectives and inputs of several individuals who work together to negotiate and create a shared representation of the problem (Eden and Ackermann, 1998).By connecting concepts (nodes) with semantic or otherwise meaningful directed linkages, the relationships between concepts in a hierarchical structure are logically defined (Novak and Cañas, 2008).

VII. Rich Pictures

The rich picture is a diagramming tool that was developed as a part of the soft systems methodology (Checkland, 1999). It facilitates that participants can draw their ideas about a particular issue when they are not able to write or speak about (Bell and Morse, 2013). A rich picture makes use of flip-charts, texts, and symbols as communication tools. Whereas this freestyle nature allows for creativity, it makes difficult to share a rich picture outside the group without obvious explanation of the meaning embodied in the picture (Lewis, 1992).

VIII. Causal Loop Diagrams

Causal Loop Diagrams (CLD) is a commonly used tool in systems analysis modelling. It represents the key variables and relationships that are assumed to explain the dynamic behaviour. Arrows represent causal relationships. The polarity of the connection (i.e. positive, negative) indicates the direction of the relationship. The emphasis of drawing Causal Loop Diagrams is on eliciting and representing feedback loops and delays that explain the problem behaviour (Vennix, 1996). The use of Causal Loop Diagrams under the umbrella of participatory or collaborative modelling promotes knowledge co-production and facilitating group learning (Sedlacko et al., 2014).

3.3.4 Semi-quantitative Modelling

Where to draw the line between qualitative and quantitative modelling is still questioned. In this Ph.D. thesis semi-quantitative modelling is defined as quantitative methods that make use of formulas and equations to make certain calculations based on qualitative data obtained from "guessed", "eye-balled" or "approximated" information from the stakeholder.

IX. Fuzzy Cognitive Mapping

This simple and easy form of graphical stock-and-flow modelling allows groups to share and negotiate knowledge collaboratively and build semi-quantitative conceptual models. It facilitates the explicit representation of group assumptions about a system being modelled through parameterised cognitive mapping (Kosko, 1986). Specifically, Fuzzy Cognitive Mapping allows cognitive maps to be constructed by defining the most relevant variables that comprise a system, the dynamic relationships between these variables, and the degree of influence (either positive or negative) that one variable can have on another(Glykas, 2010).

X. Scenario Exploration

Scenario building (or exploration) is a method for exploring with decision-makers a set of "storylines" for the future, considering the associated uncertainty (Kwakkel, 2016). Generally, scenario building starts with stakeholders identifying what is important to them, what they would like in the future, and the crucial decisions they face in the present. Scenarios are an exploration of potential alternative visions. These can build from quantitative models or be based on lessons learned from other areas that previously faced similar situations.

XI. Social Network Analysis

This methodological approach helps in studying social relationships and interactions among agents (Prell, 2012). Generally, it is applied in structuring stakeholder's behaviour, values, knowledge and/or culture by understanding their social ties and patterns. In studying these structures and processes, analysts gain insight into how meaning is created and diffused across members of a network, thus informing policy-makers in developing interventions that affect societal members and various outcomes. In some study cases, social network analysis is also used to studying the relationships between critical infrastructure and their cascading effects (de Bruijn et al., 2016).

3.3.5 Quantitative Modelling

XII. GIS

The use of Geographical Information Systems (GIS) is a widely used computer-based mapping system that helps stakeholders to visualise and model systems spatially and temporally. It can provide quantitative inputs to a computer-based model. With such use of GIS by local stakeholders, a new area known as public participation GIS (PP-GIS) has emerged (Sieber, 2006). However, use of GIS typically requires a high level of technical skills and is likely to alienate those with limited such skills. Hence, there is a need to simplify GIS tools for use by ordinary stakeholders, and there are several attempts in this direction, especially with increasing popularity of mobile and web technologies such as the Map table (Kolagani and Ramu, 2017).

XIII. Computer-based Empirical & Simulation Modelling

These models are usually the first to be used to interpret and understand the quantitative data available. They are therefore often used in informed decision-making processes. The output is linked to the input by some mathematical or statistical formulas. Traditionally, these models are also called black-box models, because they operate as some closed devices that process information flows. These models are entirely driven by data and are risky to use outside the ranges covered by data (extrapolation). Physically-based modelling is the basis for most hydraulic, hydrological, water resources and flood related models. The models used in the four methods (see Chapters 4-7) such as RIBASIM and D-Flow FM are examples of physically-based modelling approaches.

XIV. Cost-benefit and other Economic Analyses

Economic analysis can come into play in participatory modelling in at least two different ways. First, a study may be conducted before designing the participatory or collaborative modelling process in view to estimate if the expected benefits of the process are higher than the resources invested or other costs of the process itself. Second, an economic analysis may be conducted as part of the participatory and collaborative modelling process itself in the latest stages of the planning cycle to help assess the benefits and costs of alternative decisions and investments (Loucks et al., 1981; Mishan and Quah, 2007).

XV. Multi Criterial (Decision) Analysis

As aforementioned, the participatory or collaborative modelling process goes hand in hand with the planning cycle. It can also be applied to assess the impact of designed strategies and prioritisation of investments. Criteria identified with the participation of stakeholders need to be combined into a model for evaluating alternatives and arriving at a decision. In FISM models (Chapter 6) this step is particularly relevant. Several multiple criteria decision analysis (MCDA) techniques exist for this purpose (Greco et al., 2005). Weighted summation technique by means of the Analytic Hierarchy Process method (Hajkowicz, 2008; Saaty, 2008) or scorecard analyses (Loucks and Van Beek, 2017; Loucks et al., 2005) are the simplest and most widely used.

XVI. Bayesian Models

Bayesian networks are statistical modelling technique where the model takes the form of a unidirectional network. Nodes represent variables in the problem, while links represent the causal relationships among these variables. Variables take discrete states with certain probabilities. The graphical representation makes them excellent methods for communicating about modelling assumptions and uncertainty and the complex interactions among different problems elements (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007; Chen and Pollino, 2012). They can use and integrate together a variety of input data as well as handle missing observations.

XVII. System Dynamics

System dynamics is a simulation-based method used to articulate and understand the causal interactions that describe the problem behaviour changes over time. The method makes use of stocks (where material, energy, or items are stored and accumulated) and flows (which are rates of exchange between stocks). A system dynamics model provides useful insights into the feedbacks, delays, and nonlinear interactions of system elements helping decision-makers to see the long-term, system-wide, and sometimes counterintuitive, outcomes of their decisions. Its application counts with several possible participatory modelling methodologies: Group Model Building (Vennix, 1996, 1999; Vennix et al., 1992), Mediated Modelling (Van den Belt, 2004), participatory system dynamics (Antunes et al., 2006), and system dynamics learning laboratories (Bosch et al., 2013).

XVIII. Cellular Automata

The cellular automata method is mainly developed for spatial modelling. Scape is represented as a grid of cells. Each cell is represented by a certain state that can change to one of the other states, depending on its current state and interactions with other, mainly neighbouring, cells. It is often used to model land use change (Veldkamp and Fresco, 1996; Verburg et al., 2006), water quality modelling (Chen, 2014; Chen and Mynett, 2006), and in spatial versions of the system dynamics models, when local system dynamics models are replicated over the grid of cells (Costanza and Voinov, 2003).

XIX. Agent-based modelling

Agent-Based Modelling is a simulation-based method used to articulate system behaviour and state changes over time. Instead of considering aggregates, global variables, representing whole entities (e.g. populations, amounts of water, energy, material, etc.), it aims at modelling how individual entities interact and what macro-patterns are emerging from their behaviours and interactions. It represents the entities of a system: their structure, their spatial location and their connection with the environment and other entities. Some of these entities, called agents, are able to take decisions and specify their behaviours.

XX. Integrated modelling

More recently there has been a growing interest in building models from existing models used as components that are coupled to represent new, more complex systems (Belete et al., 2017). Output from one model becomes input for another model. This can allow for the creation of quite complex and powerful simulation models by finding existing well-tested modules and plugging them together to represent the systems of interest. There is some promise that with properly documented models and with appropriate user-friendly interfaces this could be done on the fly, with stakeholder participation.

This inventory methods and tools helps understanding that a large toolset is available for supporting the participatory and collaborative modelling process. The selection of approaches and tools should be driven by the key factors that define the system rather on the experiences of the technicians (Prell et al., 2007). In the next section, a generic framework is presented that helps to identify key factors that define the system, and in the selection of the most suitable approach, method and tools.

3.4 Generic framework for Participatory and Collaborative Modelling in WRM

The preceding Chapter distinguished between participatory and collaborative modelling according to their two determining dimensions: levels of participation and cooperation (Figure 2.6). In this section, these two dimensions are expanded by taking into consideration other factors that can influence the selection of a particular participatory or collaborative modelling approach. Where relevant, distinction is drawn between participatory and collaborative modelling in relation to these factors. In spite of this, the reader should keep in mind that whether an approach can be considered to be participatory or collaborative will in the first instance be determined by its comparative levels of participation and cooperation. Any differences between the remaining factors serve as a guide to refine the design of the modelling approach by the stakeholders.

Purpose and structure

Decision-makers, stakeholders and practitioners must be able to identify when to use participatory or collaborative modelling approaches, or a combination of both. They need to be able to determine which tool or combination of tools, and which existing approach(es) is most suited to the given context, considering the trade-offs (Gray et al., 2015). This demands a systematic analysis of the conditions related to the problem being addressed as well as the enabling environment. The critical aspects that need to be considered can be summarised with the following question:

> *Who (which group of stakeholders) needs to be involved in which steps of the planning process (timing), to what extent (level of involvement) and how (participatory approach, communication techniques and visualisation tools)?*

All these aspects lead to the design of a participatory modelling or collaborative modelling approach. This analysis will help the design process of the participatory and/or collaborative modelling approach. The generic framework developed as part of this research to:

(i) define the generic characteristics and features (trade-offs) of existing participatory and collaborative modelling approaches and tools;
(ii) generalise case-specific participatory and collaborative modelling approaches, and corresponding tools; and finally,
(iii) categorise the previous approaches (i) and (ii) into participatory or collaborative modelling approaches.

The new generic framework for WRM is presented in Table 3.1. It combines the definitions and typologies described in the previous sections with other features identified in earlier work by other scholars. The generic framework comprises 20 parameters categorised in six main factors: context and application, specific use, information handling, stakeholder involvement structure, modelling and organising team and means. These are all important factors to consider during the selection of a particular participatory or collaborative modelling approach. Their selection was based upon their relevance to planning and decision-making processes for sustainable WRM. In this regard, Table 3.1 also concretises the peculiarities of participatory and collaborative modelling by stressing their differences in the design process according to selected parameters.

Table 3.1 Generic framework for participatory and collaborative modelling

Factors	Parameters		Participatory modelling	Collaborative Modelling
Context and application	Problem type	Problem structure Scale of action Time horizon	Semi-structured and unstructured	
	Domain		-	-
	Interaction context	Cooperative Competitive	Both	Preferably a cooperative context. More time required for a competitive context
Specific use	Participatory/Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	-	-
	Planning/Management cycle phase		-	-
Information handling	Model characterisation	Model system focus Model type	-	-
	Modelling tool / Software platform		Communication and visualisation of model and/or results is linked to knowledge and skills of stakeholders	Modelling tool/software platform (incl. visualisation) directly linked to knowledge and skills of key stakeholders
	Information type		-	-
	Information delivery medium	Virtual/web Face-to-face	-	-
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Participatory	Collaborative
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	Dependent upon modelling tool used	
	Model users	Direct/Indirect Technical skills	Dependent upon modelling tool used	Dependent upon modelling tool used. More frequent direct users
	Participation mode	Only modellers (no participation) Individuals and Groups	For cooperative contexts heterogeneous groups may be appropriate For competitive contexts homogeneous groups may be appropriate	

	Level of participation (Figure 2.3)	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	Maximal level of participation is discussion	Key stakeholders are involved in co-deciding and/or designing. Other interested stakeholders are involved in lower levels of participation.
	Timing of participation	Data collection Model definition Model construction Model validation and verification Model use Formulation of measures and design of strategies	Model construction is generally performed by the modelling team	All modelling phases, including model construction
	Type of cooperation (Figure 2.4)	Unilateral action Coordination Collaboration Joint action	Up to coordination	Collaboration and joint action
Modelling / organising team	Team		-	Frequently bigger team (e.g. addition of dedicated process manager)
	Skills	Modelling skills Facilitation skills Knowledge acquisition skills Process management skills	Organising/facilitation team requires minimal modelling skills	Organising/facilitation team requires some modelling skills. Modelling team requires some facilitation skills.
Means	Timing		-	Longer than in participatory modelling
	Financial resources		-	More resources required

Context and Application

Problem type

Problem structure. Problems can be distinguished based upon their degree of complexity. This relates to the degree of structure involved. Two factors are considered for the evaluation of problem structure: uncertainty and consensus. Problems can be classified as being either: structured, semi-structured (dominated by either uncertainty or disagreement), or unstructured (Table 2.1).

Scale of action. The scale of action for addressing a problem and the size of the potential stakeholder community can affect stakeholder participation in the various modelling stages. The problem scale (i.e. local, regional, national, transboundary) can determine the influence and interest of different stakeholders (Hare et al., 2003).

Time horizon. The planning time horizon can influence levels of stakeholder interest and involvement. The considered time horizons are: short (0-10 years), medium (15-30 years) and long (50-100 years).

Domain

Problem contexts can be categorised according to their dominant management domain (Hare et al., 2003). Certain participatory modelling approaches may be more suitable for particular WRM domains, for instance, Integrated River Basin Management, Integrated Coastal Zone Management, urban/rural water management, environment, groundwater management, spatial planning, land use management, etc.

Interaction Context

Two interaction contexts can be distinguished when considering the willingness of the involved stakeholders to cooperate in joint decision-making. This relates to problem structure (above) and therefore will impact the selection of the participatory modelling approach (selection of a participatory or collaborative modelling approach).

In *cooperative interaction contexts* two or more stakeholders agree to engage each other and work jointly towards a resolution of a particular decision-making problem. Also, information is commonly shared. In *competitive interaction contexts*, two or more stakeholders face a decision-making issue in which each stakeholder is less willing to give ground. Stakeholders typically generate preferred solutions independently without considering the concerns and ideas of others. Commonly, these contexts generate confrontation, discourage information sharing, and demand that agreed solutions are established through mediation and negotiation.

Specific use

Participatory Modelling Purpose

Different approaches better serve different purposes (Hare, 2011). Those purposes considered in the framework include:

Decision-making: where the outcome of the participatory modelling process is a management or planning decision. As stressed by Borowski and Hare (2007), not every recommendation from the participatory or collaborative modelling process needs to be adopted, but rather serve as an input to the decision-making process.

Capacity development through *collaborative learning*: where stakeholder education and learning is the principal purpose for the participatory or collaborative modelling approach. Learning is a social act; communication between individuals fosters both individual and collective learning (CL, 2009; Voinov and Gaddis, 2008). Stakeholders can share their concerns and perspectives, develop skills on joint problem solving and generate collective ideas and measures (Hare, 2011).

Mediation: where the intended outcome of the participatory modelling process is to help mitigate or resolve stakeholder disagreements and conflicts (i.e. in semi-structured or unstructured problems) (Van den Belt, 2004).

Model improvement: where the objective of the process is to improve the model in terms of quality, acceptance or integration (Hare, 2011).

Many participatory modelling approaches do not have a single purpose, but rather a combination of rationales (Voinov and Bousquet, 2010). In certain cases these can be complementary whilst in others they may act in opposition. Nevertheless, a dominant purpose should be identified to help better define the participatory or collaborative modelling approach.

Planning or Management Cycle Phase

When defining the participatory modelling or collaborative modelling approach, particularly when designing the stakeholder engagement process, it is important to consider each of the different phases of the planning cycle (Figure 2.2) and make clear that participation can never be all-inclusive. The involvement of stakeholders needs to be a balance between "breadth" and "depth" (Voinov et al., 2016). The level and structure of involving stakeholders as well as when to use the selected methods and tools needs to be defined based on the different stages of the modelling and planning processes (Loucks and Van Beek, 2017; Loucks et al., 2005).

Information Handling

Model Characterisation

Model system focus. The framework adopts Boots and van Daalen's (2008) five model system types. The three main components of a WRM system are the physical system, social system and actors. Models can, therefore, be classified according to their focus as either: *physical system models* (PSM), *single actor decision models* (SADM), *individual actor impact models* (IAIM), *social system models* (SSM) and socio-physical system models (SPSM).

Model type. The type of computer-based model can vary according to the modelling techniques used. Three modelling techniques are considered: (i) analytical models (including conceptual, (numerical) simulation models), (ii) data-driven models (e.g. statistical models), and (iii) optimisation models (Kelly et al., 2013; Loucks and Van Beek, 2017; Loucks et al., 2005).

Modelling Tool / Software Platform

Certain participatory and collaborative modelling approaches use specific modelling tool(s) or software platform(s), whilst others permit the use of a variety of tools. These can vary from Excel sheet models, agent based models, Bayesian network models, system dynamics models, spatial GIS-based models, hydraulic and hydrological models, to raster-based visualisation models that include both temporal and spatial dynamics (Gray et al., 2015; Kelly et al., 2013; Loucks and Van Beek, 2017; Loucks et al., 2005; Voinov and Bousquet, 2010; Voinov and Gaddis, 2008).

Information Type

The information that is being handled in the modelling process can relate most to either complex processes or system interactions. This can affect the model type and any visualisation of results. For complex processes, the main modelling focus is on the representation of a particular individual system and its sub-system processes at specific scales. For system interactions, models focus mainly on general interactions between various sub-systems elements, and not on any specific sub-system processes. This leads to the use of qualitative and/or quantitative information. The availability of one or another or the co-existence of both will also determine the modelling approach.

Information Delivery Medium

The medium in which the information is delivered can constrain the involvement of some stakeholder groups, particularly in remote areas. It can also affect the decision-making process. Two delivery media are included in the framework: face-to-face delivery and delivery via a virtual platform (Almoradie et al., 2015; Heller, 2010; Jonoski, 2002).

Stakeholder involvement structure

Participatory Method

Two dominant generic approaches for stakeholder involvement are considered: participatory or collaborative. These vary according to the prevailing levels of participation and types of cooperation in each approach (Figure 2.6).

Stakeholders Involved

A variety of stakeholders can be involved in participatory and collaborative modelling approaches. Certain modelling activities may demand specific skills and knowledge to develop and/or use the model or tool. In this framework, stakeholders are identified by *organisation*, *type of stake* in relation to the problem(s) addressed, their *backgrounds* and any *minimum skills and knowledge* requirements for participation in the approach (e.g. general local knowledge and technical skills/specific knowledge).

Model Users

A distinction is made for any stakeholders targeted as users of the model. *Direct users* are those who will directly manipulate and provide inputs to the models. *Indirect users* are those who will indirectly manipulate the model via an intermediary, for instance, an expert modeller. The *technical skills* and knowledge required to enable such model use are also defined (e.g. general, specific or no computer skills).

Participation Mode

Four participation modes of stakeholder involvement are considered in the framework: no participation (only modellers), individual (individual stakeholders are involved separately), and either homogeneous or heterogeneous groups (participation occurs collectively with multiple stakeholders). Homogeneous groups are groups where stakeholders with similar interests and perceptions participate together. Heterogeneous groups are those where participation occurs amongst stakeholder with divergent interests and perceptions of the problem (Andersen and Richardson, 1997; Bots and van Daalen, 2008). The participation modes may vary in time based on the specific planning step and modelling phase.

Level of Participation

The level of stakeholder involvement can vary between approaches and for different activities within each approach. The ladder of participation is used for defining the levels of participation.

Timing of Participation (modelling phase)

Modelling phases in which stakeholder may be involved are distinguished as: data collection, model definition, model construction (e.g. initial model building or model refinement), model validation and verification, model use (e.g. providing model inputs, actual use of the model or acting in gaming simulations), and formulation of measures and design of alternative strategies. Depending on this timing and phase(s) of involvement the approaches can then be classified in four generalised participatory modelling forms: Front-and Back-End (FABE), Co-construction, Front-End (FE) or Back-End (BE) (Bots and van Daalen, 2008; Hare, 2011).

Type of Cooperation

Four types of cooperation are considered for this framework: *unilateral action*, *coordination*, *collaboration* and *joint action*. These are based on the cooperative continuum (Sadoff and Grey, 2005).

Modelling and organising team

Team. The organising team is responsible for the design and guidance of the participatory and collaborative modelling process. This includes model construction and use. A good organising team will typically include at least one modelling expert with comprehensive knowledge of the modelling tool used (Hare, 2011).

Skills. Additional information included refers to the skills required by the team to effectively guide the process (e.g. modelling skills, facilitation skills, knowledge acquisition skills and process management skills).

Means

Different participatory and collaborative modelling approaches demand different *time* and *financial commitments*.

3.5 Discussion

There is an increased attention to stakeholder involvement in modelling processes (Voinov et al., 2016). Therefore, a growing number of participatory planning and modelling approaches are now available in the field of WRM. Examples include Group Model Building, Shared Vision Planning, Interactive Modelling, Collaborative Modelling using Networked Environments, among others. Although these approaches have common similarities, there are trade-offs to consider (Gray et al., 2015). The terms "participatory modelling" and "collaborative modelling" are also used interchangeably. This leads to one of the main challenges faced by researchers, practitioners and policy-makers: to identify which participatory and collaborative modelling approach is best suited to each type of decision and related process. Besides presenting the various approaches, 20 different tools and methods that are frequently used in participatory and collaborative modelling processes were introduced. Finally, a generic framework is also developed to helps categorise existing approaches and their corresponding tools into "participatory modelling" or "collaborative modelling".

The use of the generic framework might seem a straightforward process; however, it frequently requires several iterations. The process begins with filling in known information about the given approach for each of the parameters. Information can be obtained through literature review or practical experience. For well-defined approaches, this first step will be quite straight-forward. In other cases where the approach is more case-specific, the generalisation will require a comparative analysis of a number of similar case-specific approaches. This may demand a more iterative process. This process will allow decision-makers, practitioners and researchers to define their generic characteristics and features. The last step is to categorise the given approach into "participatory modelling" or "collaborative modelling" or a combination of both by comparing the obtained results with the general characteristics and features of "participatory modelling" and "collaborative modelling" provided in Table 3.1. Main differences between both approaches remain in the types of cooperation and the levels of participation, being collaborative modelling a more inclusive approach. Therefore, collaborative modelling requires often higher means and a more structured stakeholder engagement process.

The design of the generic framework was firstly based on literature review. The majority of relevant parameters for WRM were then determined. Three different participatory and collaborative modelling cases were used to test its efficiency. A groundwater management case in the Netherlands was used for the initial testing, the MIPWA case (Basco et al., 2017). Validation and refinement followed, during which additional parameters were identified and included in the framework such as decision-making context, time horizon, planning or management cycle phase, and means, among others. The final version of the generic framework was then tested and validated in a groundwater and national flood study in the Netherlands (Warren, 2015).

3.6 Conclusions

Determining the suitability of a participatory or collaborative modelling approach for a particular planning and decision-making process is dependent on a set of critical factors relating to the local context and situation. A generic, detailed framework has been presented as a supporting tool. It can be used by policy-makers, practitioners, researchers, local stakeholders and decision-makers to support the evaluation of participatory and collaborative modelling approaches in WRM. The framework was adapted and further elaborated from other previously published evaluation frameworks. The proposed generic framework comprises 20 parameters that have been grouped into six main factors: context and application, specific use, information handling, stakeholder involvement structure, modelling and organising team, and means. In the following chapters the general applicability of the framework for water resources planning and management is tested through cases from different parts of the world.

4

Collaborative Modelling Using System Dynamics for an Integrated Analysis

The first collaborative modelling method developed as part of this Ph.D. thesis is presented in this chapter. It combines the use of a computer-based simulation model with systems analysis and system dynamics. The simulation model(s) helps in understanding the physical and social systems. The Group Model Building and Mediated Modelling approaches are used to orchestrate the stakeholder engagement process. The method is applied in a project in Indonesia: the preparation of the operational river basin master plan of the Pemali Comal River Basin Territory. A water balance and allocation model and different Causal Loop Diagrams are constructed jointly with stakeholders to boost the integrated view of the system, and better understanding the inter-relations between water-related issues over time. This helps creating a better collaborative learning environment among competing water users. With this chapter, the third research question is partly addressed: *How can participatory and collaborative modelling approaches be applied with existing and newly developed computer-based simulation models?*

This chapter is partly based on:

Basco-Carrera, L., van Beek, E., Jonoski, A., Benítez-Ávila, C., Guntoro, F.P., 2017. Collaborative Modelling for Informed Decision Making and Inclusive Water Development. Water Resources Management 31(9) 2611-2625.

Basco-Carrera, L., Benítez-Ávila, C., 2018. Group Model Building vs. Mediated Modelling for Water Resources Management (publication in progress)

4.1 Introduction

Water management is an important challenge that numerous countries must face in order to survive and improve their levels of economic development. Water is a key condition for sustaining rural livelihoods, growing food, producing energy, ensuring industrial and service sector growth, and guaranteeing the integrity of ecosystems and the goods and services they provide. However, the allocation of water resources can and likely will create disputes among water users. Moreover, population growth and its associated urban developments to accommodate it, leads to increasing water demand and water pollution, which are major causes of the growing pressures on our water resources systems (UN-Water, 2006). The Sustainable Development Agenda 2030 therefore includes a specific target in the Sustainable Development Goals (SDG 6, Target 6.5) specifying to implement IWRM at all levels.

Multiple definitions of the concept of water security exist, as highlighted in Chapter 1. In an attempt to quantify water security, the Asian Development Bank (ADB), in partnership with Asia-Pacific Water Forum (APWF), developed the Asian Water Development Outlook (AWDO) (ADB, 2016a). This framework provides a better understanding of the complexities and dimensions of water resources problems (i.e. household, urban, economic and environmental water security, and resilience towards water-related disasters). The framework supports policy and decision-making processes in terms of opportunities for investment, governance and capacity development. The framework is used as basis for the development of the new method presented in this chapter.

This chapter introduces a new collaborative modelling method that uses simulation modelling and system dynamics. The method facilitates integration of data and information with decision-making using modelling tools with stakeholder participation and negotiation for integrated studies such as the preparation of IWRM and Integrated River Basin Master Plans. The method is tested in a case in Indonesia. It is applied for the preparation of the operational integrated river basin master plan in Pemali Comal River Basin Territory in Indonesia. For this, the method was adapted considering the context and conditions of the Pemali Comal River Basin Territory.

4.2 Method

4.2.1 Systems Analysis and System Dynamics

A system is defined by Haraldsson (2005) as a network of multiple variables that are connected to each other through causal relationship and expresses some sort of behaviour that can only be characterized through observation as a whole. System thinking is based on the notion that all behaviour in a system is a consequence of its structure, and as such the failure, success and the development of a system is determined by its structure. It is therefore important to understand how causal relationships and feedbacks work in a problem. In this thesis we consider the framework defined by Haraldsson (2004), in which system thinking comprises two practical applications: systems analysis and system dynamics (Figure 4.1). Both concepts provide an approach to develop system models that can be used to get a better integrated understanding of the functioning of complex systems.

- Systems analysis refers to the qualitative/conceptual modelling component of system thinking. It aims to gain insight in the structure of a problem through the development of diagrams, i.e. Causal Loop Diagrams.
- System dynamics refers to the quantitative modelling component of system thinking. A mathematical representation of the problem is developed and a numerical analysis is performed to get more clarity on the uncertainty introduced when constructing the model.

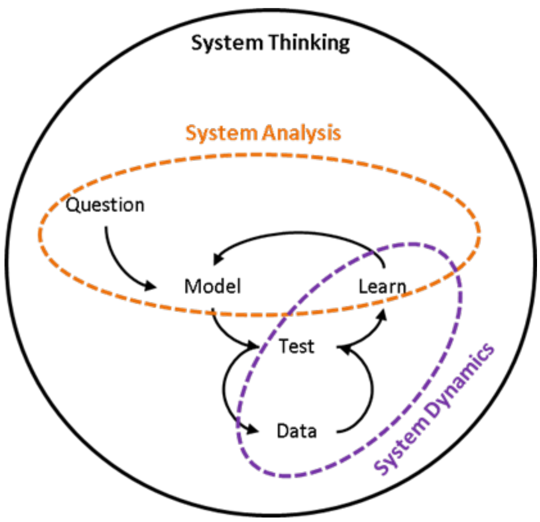


Figure 4.1 System thinking, systems analysis and system dynamics (source: Haraldsson, 2004)

Causal Loop Diagrams

Causal Loop Diagrams are diagrams that represent the key variables and relationships that are assumed to explain the dynamic behaviour of a system. Arrows represent causal relationships. The polarity of the connection (i.e. positive, negative) indicates the direction of the relationship. The emphasis of drawing Causal Loop Diagrams is on eliciting and representing feedback loops and delays that explain the problem behaviour (Vennix, 1996) (Section 3.3 for more information).

System Dynamics

System dynamics is a simulation-based method used to articulate and understand the causal interactions that describe the problem behaviour changes over time. The method makes use of stocks (where material, energy, or items are stored and accumulated) and flows (which are rates of exchange between stocks). A system dynamics model provides useful insights into the feedbacks, delays, and nonlinear interactions of system elements (Vennix, 1996) (Section 3.3 for more information).

Systems analysis and system dynamics is applied in several participatory and collaborative modelling approaches. Group Model Building (Vennix, 1996, 1999; Vennix et al., 1992) and Mediated Modelling (Van den Belt, 2004) are recommended approaches for the collaborative modelling method described in this chapter.

4.2.2 Group Model Building and Mediated Modelling

Group Model Building and Mediated Modelling approaches make use systems analysis and system dynamics tools. Both approaches are conceived as collaborative modelling approaches as participants are involved with high levels of participation i.e. co-designing the model and even in occasions co-deciding in the formulation and evaluation of measures and alternatives strategies. The approach also facilitates the collaboration among participants. They enhance team and group learning, and create a shared social reality that results in a shared understanding of the problem and potential solutions (Antunes et al., 2006; Richardson and Andersen, 1995; Stave, 2010; Van den Belt, 2004; Vennix, 1996, 1999; Vennix et al., 1992; Videira et al., 2017; Videira et al., 2003). The generic framework presented in Chapter 3 is used to evaluate the key features of Group Model Building and Mediated Modelling. Annex A presents the key features that distinguish both approaches.

The most characteristic features are highlighted in orange. A detailed assessment is available in Annex A.

The purpose of Group Model Building and Mediated Modelling is to use a group of professionals from the same team or groups of stakeholders to gain insight into so-called messy problems in an integrated manner. These complex problems are characterized with different views and which have relationships with other social or physical problems (Richardson and Andersen, 1995; Rouwette et al., 2008; Van den Belt, 2004; Vennix, 1996). These different views often result in high ambiguity in the early stages of the modelling process, which can result in high uncertainty about the resulting model. System dynamics is appropriate for situations where the problem is dynamically complex because of underlying feedback processes. This excludes all kind of "static" problems (i.e. questions which aim at identifying an existing situation at some point in time) (Vennix 1996).

Within Group Model Building and Mediated Modelling approaches a distinction is made between a group and a team[8]. Teams are in general more cohesive. Despite some disagreement in teams, as they have a common goal or mission which they want to accomplish, there is an open, informal atmosphere and mutual acceptance and understanding between team members (Vennix 1996). Participants in Group Model Building sessions are already part of a team. However, in certain occasions it can also be used for messy problems i.e. situations in which opinions in a management team differ considerably (Vennix 1996; 1999). Group Model Building is therefore more suitable for semi-structured problems. On the other hand, Mediated Modelling is more suitable in messy problems in which stakeholders participate as part of groups. There is little or no regular interaction between stakeholder groups, instead cooperation mainly occurs in ad hoc occasions (e.g. common projects or initiatives). The interaction context is frequently competitive with different positons and conflicting interests. Mediated Modelling is more suitable for un-structured problems.

[8] Although a distinction between "group" and "team" is made by some authors, in this PhD research both terms are used interchangeably. However, since in Group Model Building the concept of both terms is different, this is taken into account in the comparative analysis between Group Model Building and Mediated Modelling.

Group Model Building and Mediated Modelling aims to construct a qualitative and/or quantitative model by working together with teams and groups on strategic decisions (Andersen et al., 2007). The primary goal is not to build an optimal system model. The main objective is collaborative learning; participants gain insight on the functioning of the system in an integrated manner by getting to know the mental models, perceptions and knowledge from other professionals or stakeholders. The primary objective of Mediated Modelling is to enhance cooperation through mediation and collaborative learning. Ultimately, both approaches support the decision-making process, as they help providing a good insight on the system and its functioning over time in an integrated manner.

4.2.3 Phases and Steps

The participatory and collaborative modelling method is designed to be used in integrated planning processes such as the formulation process of IWRM master plans.

A process guide is designed to facilitate the convergence between the planning and simulation modelling process with the Group Model Building and Mediated Modelling processes. This was developed considering the major planning phases (Andersen and Richardson, 1997; Campbell, 2001; Luna - Reyes and Andersen, 2003; Richardson and Pugh III, 1981; Vennix, 1996; Vennix et al., 1992) and Group Model Building handbook (Hovmand et al., 2011). It is illustrated in Figure 4.2 and aims to serve as guidance rather than a standard procedure composed of a set of fixed steps. The seven major stages are presented in Table 4.2. However, there is not a fixed order in how the process proceeds, and it may be necessary to go back again and again, or to jump several steps forward if the milestones for each planning phase are already achieved.

Table 4.1 Comparative assessment between Group Model Building and Mediated Modelling

Factors	Parameters		Group Model Building (GMB)	Mediated Modelling (MM)
Context and application	Problem type	Problem structure Scale of action Time horizon	Commonly, semi-structured No specific scale and size Medium and long term problems	Commonly, unstructured No specific scale and size Medium and long term problems
	Domain		Business applications. In occasions, Natural Resources Management.	Natural Resources Management.
	Interaction context	Cooperative Competitive	Cooperative	Competitive
Specific use	Participatory/ Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Collaborative learning *Secondary purposes:* Decision-making via consensus building	*Primary purpose:* Mediation via collaborative learning *Secondary purposes:* Decision-making
	Planning/Management cycle phase		Early stages of the planning cycle	
Information handling	Model characterisation	Model system focus Model type	Socio and/or Physical System Model Analytical model	
	Modelling tool / Software platform		The model describes system interactions using Causal Loop Diagrams and/or stocks and flows	
	Information type		All information	
	Information delivery medium	Virtual/web Face-to-face	Frequently, face-to-face sessions. Online software platforms exist.	
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Commonly applied as collaborative modelling	Commonly applied as participatory modelling
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	Public sector clients or clients from consultant companies, with similar interests, goal and power to decide.	Different stakeholder groups involved with different interests, power and dependencies
	Model users	Direct/Indirect Technical skills	Direct users	
	Participation mode	Only modellers (no participation) Individuals Groups	Combination of modes	Due to the heterogeneous interests among participants, the formation of (homogeneous/ heterogeneous) groups is essential
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	Up to co-decision making	Up to co-design
	Timing of participation	Data collection Model definition Model construction Model validation Model use Measure formulation Strategy design	All modelling phases	
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Collaboration up to joint action	Up to coordination
Modelling / organising team	Team		Modellers, a facilitator, a gatekeeper, a process coach and a recorder	Modeller/reflector, mediator, recorder, a facilitator and a process coach
Means	Timing		2 or 3 sessions when including system analysing 1 or 2 sessions when only using system dynamics	Commonly, more time required. There is more flexibility on the number of sessions
	Financial resources		-	Frequently more resources than GMB

Table 4.2 Modelling stages of Group Model Building and Mediated Modelling processes

Planning phases	Steps
Problem identification and analysis	Define time horizon Identify reference models Define level of aggregation Define system boundaries
System conceptualization	Establish relevant variables Determine important variables/ stocks and flows Map relationships between variables Identify feedback loops Generate dynamic hypotheses
Model formulation	Develop mathematical equations Quantify model parameters
Model analysis and validation (evaluation)	Check model for logical values Validate (evaluate) model
Policy analysis and design	Conduct policy experiments Evaluate and rank policy experiments
Implementation	Model use

The modelling framework comprises the primary phases of the IWRM planning cycle (Figure 2.2) and associated simulation modelling process. It is adapted from the analytical framework used by Deltares for water resources studies (Loucks and Van Beek, 2017), which consists of an iterative step-by-step framework for informed planning and decision-making by making use of data and modelling tools. The modelling framework includes certain additional elements relevant for participatory and collaborative modelling. This is composed of seven main planning stages: Initial analysis, Stakeholder analysis, Approach, Technical analysis, Customisation, Preliminary analysis, and Detailed analysis (Figure 4.3). During each planning stage, a model and/or tool is developed or used jointly with stakeholders.

Based on the problem type (i.e. semi-structured or unstructured) and model type to be used (i.e. qualitative, quantitative or a combination of both) the process guide provides guidance on the stakeholder engagement structure and steps in the modelling process.

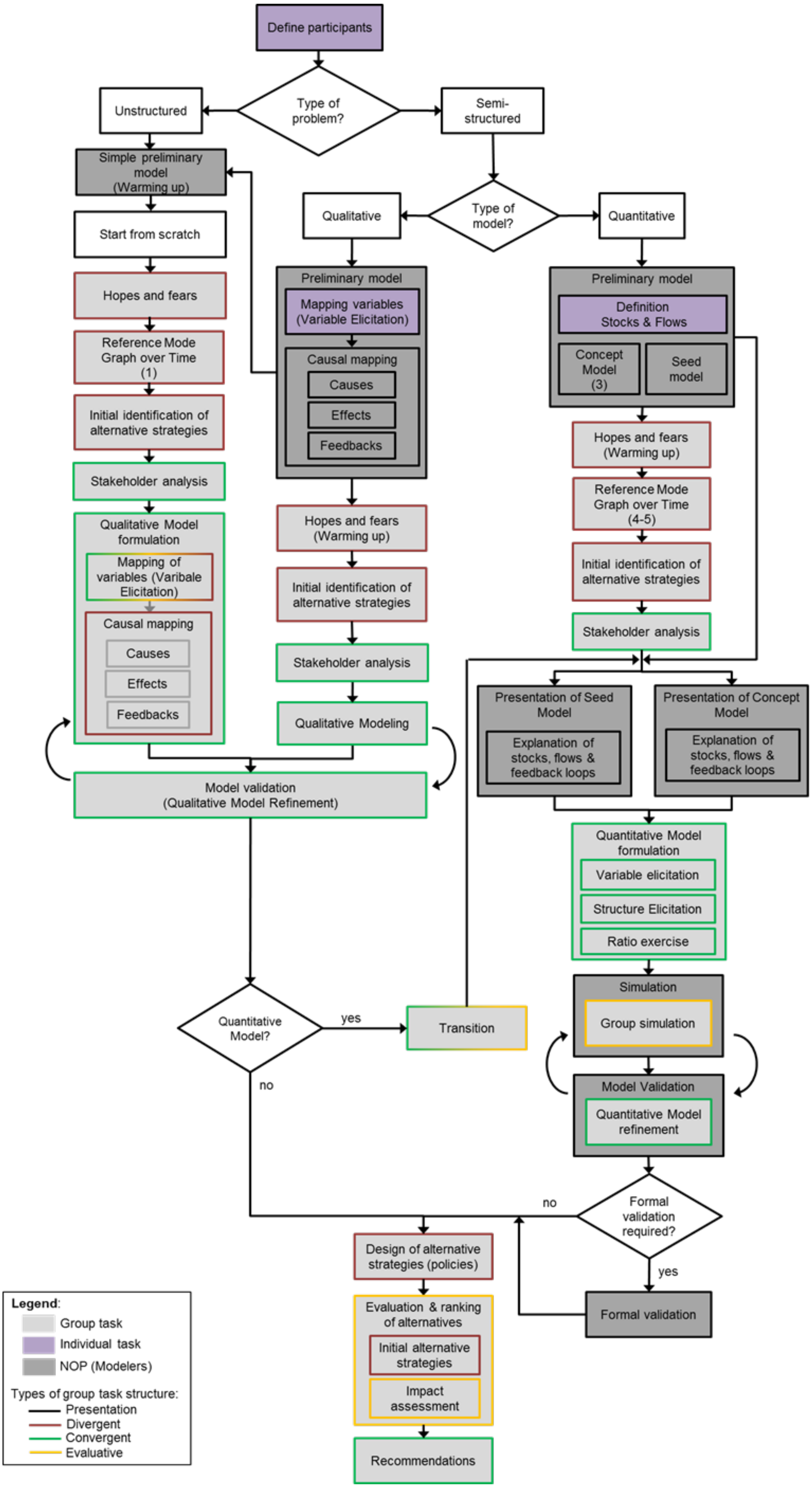


Figure 4.2 Group Model Building process guide (source: this thesis)

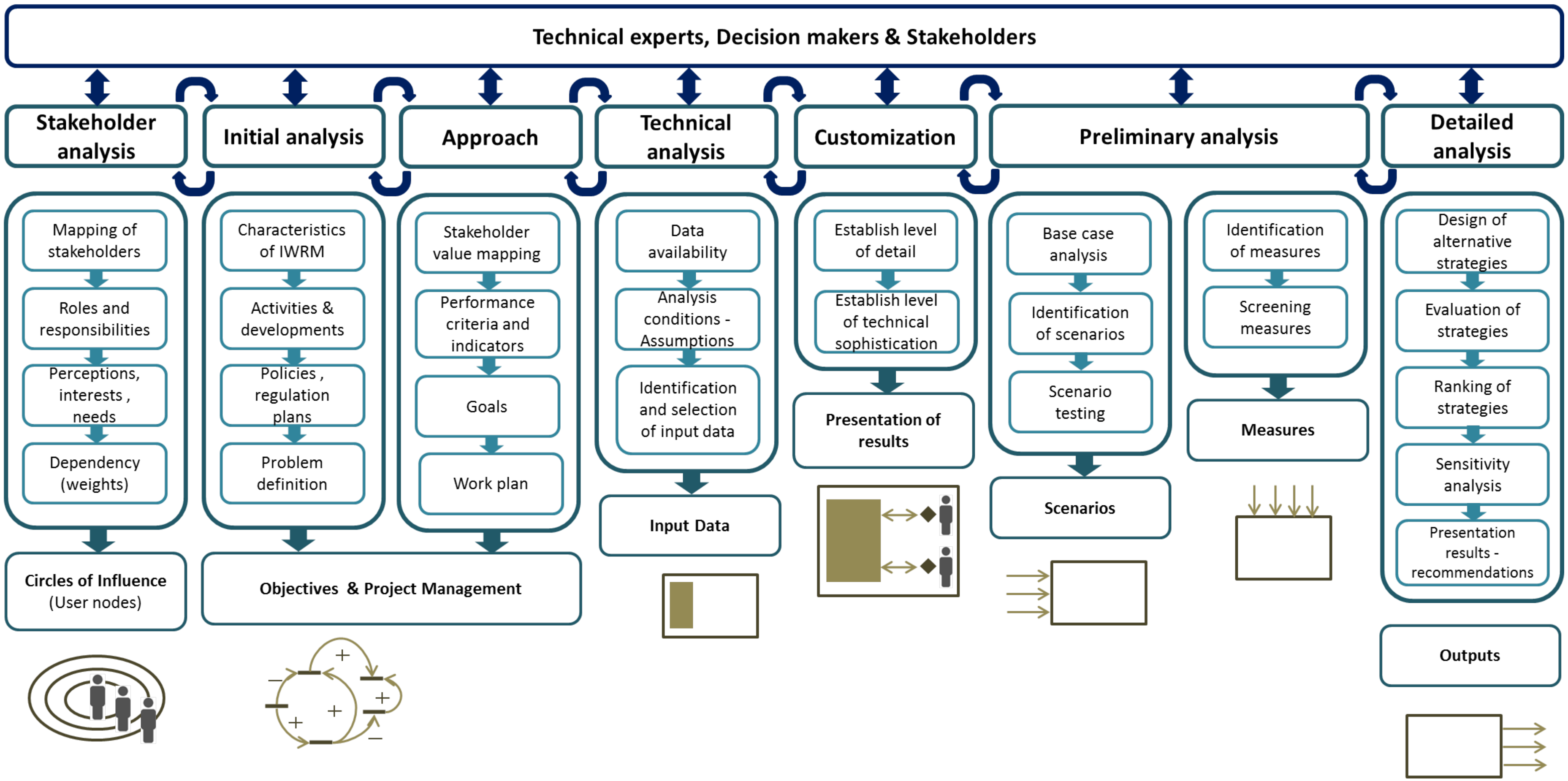


Figure 4.3 River basin modelling framework (source: this thesis)

In semi-structured problems, a preliminary model is the starting point for the participatory or collaborative modelling sessions. If the systems analysis and/or system dynamics process needs to be completed within one or two days then it is preferable to use concept models as starting point (Richardson and Andersen, 1995). Alternatively, if timing is not a constraint, the sessions can be started with a qualitative preliminary model. The expected results shall also determine the type of preliminary model used. In unstructured problems, it is preferable to organize two- or three-day sessions and starting from scratch. The use of a so-called tiny (= very simplified) preliminary model before starting from scratch can be useful in those cases where the goals of the sessions are not clear for the group members. The tiny preliminary model serves as warming up. Besides the problem type and timing, model purposes and the background of participants also determines the type of model used, either qualitative, quantitative or a combination of both. When starting from scratch or when using a qualitative preliminary model, qualitative system dynamics is used for problem identification and conceptualization. On the other hand, the use of tiny models implies using quantitative system dynamics as starting point. In both cases, however, the model aims to identify the feedback processes causing the system's problems and thus, looks for the dynamic structure underlying the system's behaviour (Vennix, 1996).

When starting from scratch the system dynamics model is built with the group at the spot. The model-building process starts during the first session and in this case preparatory interviews are not a prerequisite. However, interviews may be conducted in order to get acquainted with group members and to get a better understanding of the problem in question (Vennix 1996). Starting from scratch requires time availability and the organizing team requires extensive experience on system thinking, and Group Model Building and Mediated Modelling approaches.

When a preliminary model is employed, the modeller develops a system model, which is used as a starting point for the planning process (Vennix, 1996; Vennix et al., 1992). This model is presented to participants and they are then invited to criticize it extensively, redesign inadequate parts of the model and make modifications according to their observations (Vennix et al., 1992). This approach is particularly useful when timing is a limitation, as it eases group discussion based on the model presented (Vennix et al., 1988). However, it might reduce the sense of ownership over the model (Vennix et al. 1992;

Vennix 1996), leading to low commitment. Preliminary models can be constructed by means of individual interviews or literature review (Andersen and Richardson, 1997; Richardson et al., 1989; Vennix et al., 1992). Table 4.3 illustrates the types of preliminary models.

Table 4.3 Types of preliminary models

Preliminary models	Goal	Model characteristics
Simple preliminary models	• Give an overview of system/ goals of the session(s) • Establish boundaries	• Very simple model. Not used as starting point • Shows an overview of system structure • No simulation
Concept models	• Start model discussion	• Uncompleted (incorrect) models. They can be used as starting point (starting discussion) or participants can start from scratch • The model behaviour needs to be modified
Seed models	• Detailed representation of the system	• Proper (correct) models. They are used as starting point. • Behaviour and/or values of parameters can be modified

A key moment in the process is the step namely "hopes and fears", as it defines the baseline for social learning (Hovmand et al., 2011). Another important step is the reference mode. In reference mode, participants get familiar with the dynamics of the system by producing sketches of key variables over time. By producing graphs over time, participants are engaged in (i) framing the problem, (ii) initiating mapping, (iii) eliciting variables and, (iv) defining inputs to decide the reference modes for the study. The initial identification of alternative strategies as part of the problem analysis planning stage helps (i) defining the problem(s), (ii) setting the model boundary conditions, (iii) setting realistic expectations for the direction and outcomes of the meetings and, (iv) guiding modellers to build a model that suits the stakeholders' needs (Hovmand et al. 2011; Vennix et al. 1992). The next step in the planning process is the stakeholder analysis. In this step, the organizing and modelling group, as well as, involved stakeholders get a better insight on the roles and responsibilities of other stakeholders, their interests and even power relations. This step also serves to corroborate whether all relevant stakeholders are engaged in the process. As part of model formulation, participants develop the Causal Loop Diagrams or system dynamics numerical model (using stocks and flows) by mapping variables and causal-effect relationships as well as feedback loops (Hovmand et al. 2011). The construction of the systems analysis and system dynamics models is complemented with the development of the computer-based simulation model. From that planning and modelling stage onwards, the construction, validation and refinement of both models will go hand in hand, up to the design, evaluation and ranking of alternative strategies. .

4.3 Application Example: Pemali Comal River Basin Master Plan

4.3.1 Study Area

Indonesia has a national water security index of 2 (out of a maximum of 5) according to ADB (2016a), as it scores low in the key dimensions of household and urban water security and in resilience to water-related disasters. Despite significantly increasing the percentage of its population with access to safe drinking water from 70% (1990) to 85% (2012), only 20% of households in rural areas presently have access to piped water. In urban settings, such access only increases to 36%. Similarly, approximately half of the total population (54%) have access to safe sanitation facilities. In terms of water quality, only 34% of the water is treated in waste water treatment plants in urban settings (ADB, 2015). On Java, water security is exacerbated by the high risk of floods and droughts (ADB, 2016c; Deltares, 2012).

Indonesia's policy and decision-making processes for achieving water security are based on an IWRM approach. This commenced in 1974 with the national river management water law (11/1974) and the establishment and formulation of River Basin Territories and master plans during the 1990s. However, these plans tended to follow a project-oriented development approach. In 2004, the legislation was renewed with Law No. 7/2004 on water resources and related governmental regulations (Peraturan Pemerintah), with the intention to shift to a more comprehensive and sustainable management approach. The integrated river basin master plan for Pemali Comal River Basin Territory was developed under this law. The new law aimed to protect, manage, rationalise usage, reduce waste and supervise the community utilisation of water resources to guarantee water supply, quality and conservation. In line with the IWRM approach, the water resources law also recognised data and information, and stakeholder participation as supportive components for sustainable planning and implementation of a WRM policy (ADB, 2016c; Sukardi et al., 2013).

Indonesia has been divided into River Basin Territories, which are areas with hydrological, and in some cases political boundaries, comprising one or more hydrological catchments (Peraturan Pemerintah RI 38/2011 Tentang Sungai) (ADB, 2016c). Pemali Juana covers two River Basin Territories: Pemali Comal and Jratunseluna. This study case focuses on Pemali Comal River Basin Territory. Pemali Comal is classified as cross-provincial River Basin and it is located in Central Java. It covers an area of about 4900 km^2 along the North Coast of Java and consists of 32 watersheds. The river discharge in Pemali Comal varies considerably from one river to the other. The lowest average annual discharge is found in the Waluh river (1m^3/s), and the highest in the Comal river (130 m^3/s). Average rainfall in the area is relatively high at 1700-5000 mm/year and there are considerable groundwater resources and springs in the region.

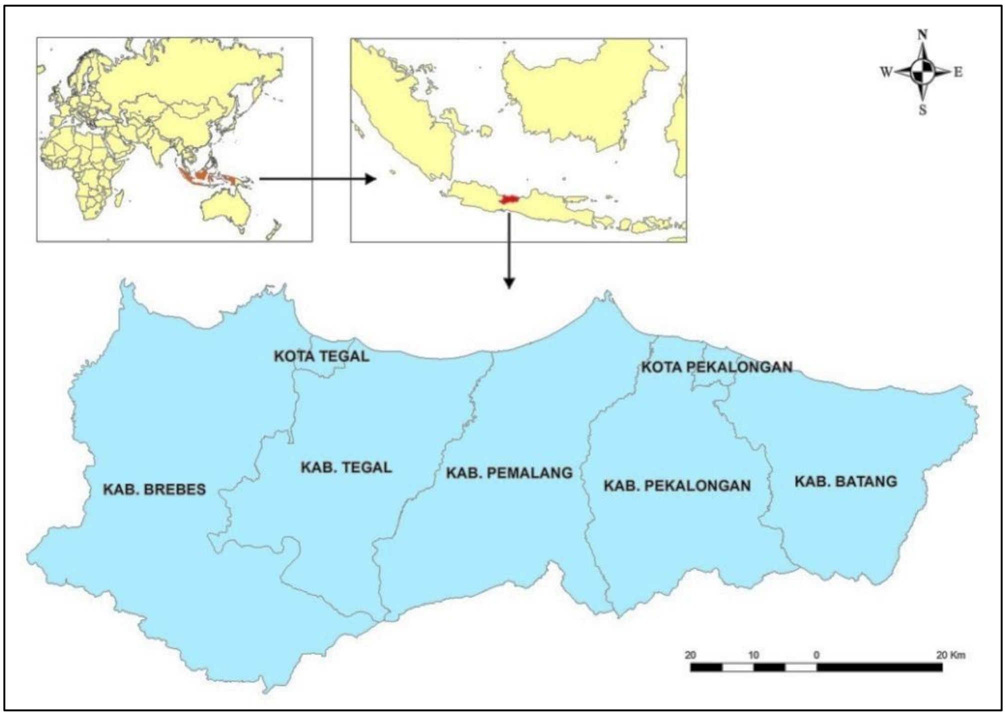


Figure 4.4 The Pemali Comal River Basin Territory

At administrative level, Pemali Comal is composed of 5 districts (Kabupaten) and 2 cities (Kota) (Figure 4.4). Its population is approximately 6.5 million (BAPPENAS, 2008), with Brebes and Pemalang being the most densely populated districts. Agriculture is the major economic activity in the region. Around 50% of the area is used for highly productive food crops. Coastal areas are the preferred location for the construction of fish ponds, and the textile (e.g. batik) and ship-building industries (ADB, 2016c).

4.3.2 Problem Context

Pemali Comal River Basin Territory has moderate vulnerability towards water security. Water stress is the main issue (ADB, 2016c; Deltares, 2012), regardless of its relatively high but very seasonal rainfall. Water pollution (mainly from the high disposal of pollutants into the river by households and industries) and sea water intrusion have also become considerable issues in the coastal area. Moreover, the over-abstraction of groundwater for drinking water supply has caused significant ground subsidence (8-10 cm/year at the coast). As such, regional water supply authorities have been forced to use springs located upstream for supplying water to coastal areas. This directly affects the water available for irrigation, causing water stress during dry seasons. Conflicts between public water supply companies and farmer associations have arisen as a consequence of this policy and its impacts. The poor condition of secondary infrastructure, erosion and sedimentation (mainly caused by the mining industry) are other important issues in Pemali Comal. Heavy erosion has resulted in a considerable reduction of reservoir storage capacity and reduced flood protection (Wahyudi et al., 2012).

Limited knowledge about the water resources system and capacities aggravate this situation. Thus, conservation and land use, awareness, education, institutional and administrative settings are among the other related issues facing decision-makers and stakeholders (Figure 4.5).

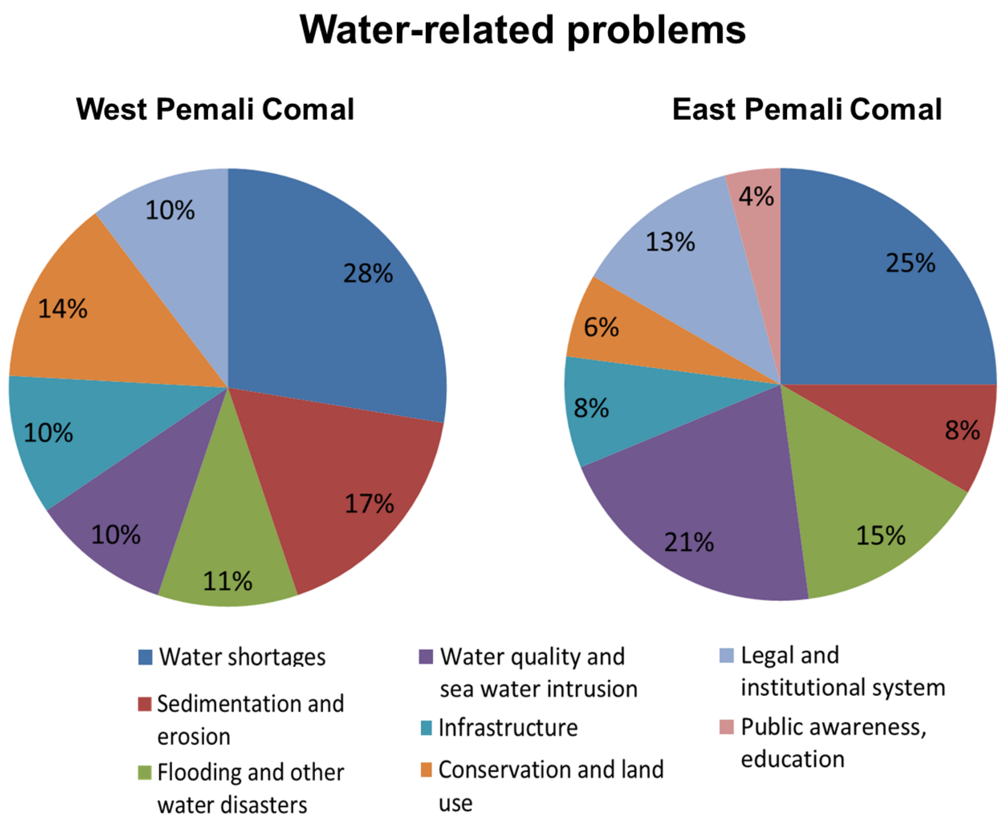


Figure 4.5 Stakeholder perceptions of water-related problems faced by decision-makers and stakeholders in Pemali Comal

4.3.3 Collaborative Modelling Approach

The collaborative modelling approach applied in Pemali Comal River Basin Territory was adapted from the generic method (Section 4.2) and developed according to the complexity of the policy problem encountered in Pemali Comal, as well as project means (2 years duration, 450000 Euros budget). Its high degree of knowledge uncertainty and levels of stakeholder disagreement meant that this case was considered to constitute an unstructured policy problem. The developed approach was thus conceived as an interactive and adaptive planning process in which stakeholder participation was complemented by the use of computer-based models and communication tools (Chapter 3). It included high levels of participation for key stakeholders (Figure 4.6) and reduced participation for other interested stakeholders. A specific goal of the collaborative modelling approach was to enhance cooperation between the stakeholders (Sadoff and Grey, 2005), as this is a critical factor for the implementability and sustainability of integrated river basin master plans. The planning and decision-making process was treated as an adaptive process in which decision-makers and involved stakeholders could determine the way to proceed depending upon the situation, goals and outputs obtained.

Information Handling

The Group Model Building process guide and the river basin modelling were used for the preparation of the master plan (Figures 4.2 and 4.3). A system dynamics model was constructed to identify and analyse the main water-related issues in Pemali Comal, following the Group Model Building approach (Vennix, 1999; Videira et al., 2017). The model aimed at creating a collective, integrated overview of the current and future problems in the territory. The water balance and water allocation analyses for Pemali Comal River Basin Territory were conducted using a RIver BAsin SIMulation (RIBASIM) model. Its design started during the technical analysis phase (Figure 4.3). The construction of the model finalised with the selection of scenario conditions and potential measures during the preliminary analysis phase. The identification of potential measures was carried out together with stakeholders using the system dynamics model. The process followed an adapted Mediated Modelling approach (Van den Belt, 2004). The RIBASIM model was then used for analysing the impacts of selected measures and their possible combinations, and supported the selection of the preferred strategy that was then included in the integrated river basin master plan (Figure 4.3; detailed analysis).

Participatory Engagement Structure

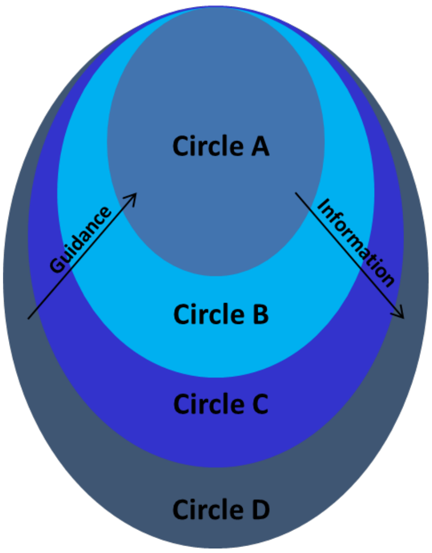
The participatory engagement structure followed an adapted Circles of Influence approach (Figure 4.6) (Bourget L. (Ed.), 2011; Cardwell et al., 2008) and was defined based on the results of a stakeholder analysis (Grimble and Chan, 1995). It included four circles: (i) Circle A: model development team, (ii) Circle B: model users and validation team, (iii) Circle C: consultation and information team, and (iv) Circle D: decision-makers. Stakeholder engagement comprised three levels of participation: co-construction, discussion and consultation (Arnstein, 1969; Bruns, 2003; Mostert, 2003). The design of the sessions, in terms of setup and stakeholder interaction, followed the process guide (Figure 4.2).

An organising and modelling team supported by a regional team was involved throughout the planning process. Members supported the stakeholder consultation process for the development of both models: the conceptual model using system dynamics and the RIBASIM model.

The entire planning process was coordinated by a process manager responsible for (i) managing the stakeholder processes, (ii) guiding the organising and modelling team, (iii) aiding in all negotiations, consensus building and decision-making processes, and (iv) acting as a focal point between decision-makers and the modelling team.

Data and Simulation Model

The analysis of the performance of the water resources system in Pemali Comal was undertaken using Deltares' RIBASIM modelling package (van der Krogt and Boccalon, 2013). This simulated the hydrological cycle under various hydrological conditions whilst giving consideration to existing water users in the basin. Simulations established water allocations according to their prioritisation, and thereby supported impact assessments of possible measures to each simulated scenario.



Circle	Involved stakeholders
A	1. Regional water resources management implementation centre 2. Public water supply authorities 3. Provincial office of water resources 4. Water users associations
B	1. Circle A 2. District water resources management authority 3. Provincial spatial planning authority 4. River basin water resources council
C	1. Non-governmental Organizations 2. Citizens organizations
D	1. Governor 2. Provincial water resources management authority 3. Provincial administrative water resources council

Figure 4.6 Circles of influence approach used in Pemali Comal River Basin Territory

Hydrological water inputs comprised rainfall data from 2003 to 2014. Data was obtained from the Tropical Rainfall Measuring Mission (TRMM). For the schematisation of Pemali Comal river basin, variable inflow nodes were used to represent the hydrological water inputs. Two major water users were considered in the analysis: public water supply and irrigation water demands. The model also included existing, planned and proposed storage facilities and other infrastructural measures (e.g. reservoirs, weirs, etc.) (Figure 4.7).

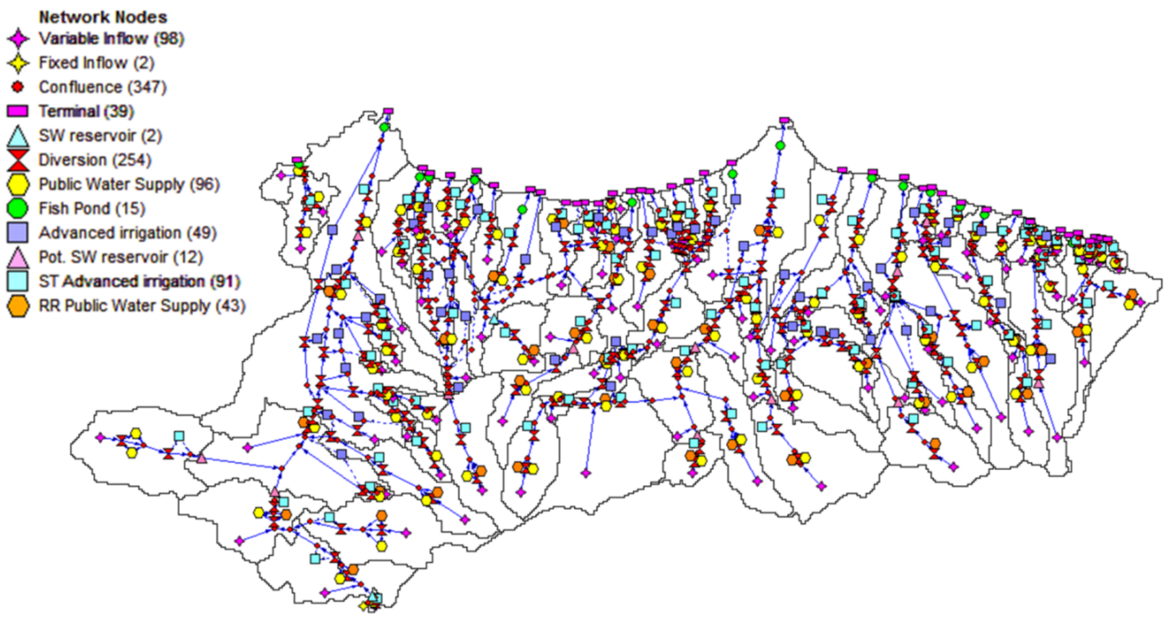


Figure 4.7 Layout of Pemali Comal schematisation

An adaptive planning approach was followed during modelling analyses to achieve flexibility in the allocation of water over time (Jeuken et al., 2015; R. Speed, 2013). Four scenario conditions (all in relation to spatial planning) were considered to analyse future system performance: population growth, economic development, climate change and institutional setting. Population was assumed to grow by 1.5% in urban areas and a reduction of 0.5% in rural areas. A moderate economic growth scenario (4.5%-6.5%) based on the GDP was agreed. Two scenarios conditions were considered for computing the effects of climate change in rainfall: ±3 mm/day (IPCC). Business as Usual and good governance were the two scenario conditions assumed for estimating the institutional setting in 2034. The good governance scenario assumed that decision-makers and stakeholders would support integrated river basin master plan and follow its policies, and work jointly in the achievement of SDGs.

4.3.4 Collaborative Modelling Process

The collaborative modelling process was designed according to the river basin modelling framework. For the planning process Pemali Comal River Basin Territory was divided into two areas. In one area the collaborative modelling approach was applied (referred in this study case as collaborative modelling area). In the other area, the traditional planning approach was followed (referred as conventional area). The collaborative modelling process comprised a public inception meeting, three collaborative modelling workshops and three public consultation events to discuss scope of the project, problem formulation, model design and construction, a set of rounds for model validation, water allocation and prioritisation, model use for testing of measures and assessing their impacts, and finally the finalisation of the plan. This process was combined with other participatory engagement methods: three consultation meetings and face-to-face interviews. In the conventional area, the stakeholder engagement process comprised a first meeting to present the project and three consultation meetings to present the results of the RIBASIM model, discuss possible measures and present the final integrated river basin master plan (Figure 4.8).

Inception Phase

The inception phase served to scope the project and collectively agree on specific goals and targets of the integrated river basin master plan. Collaborative modelling supported shared learning (Voinov and Bousquet, 2010), consequently stakeholders understood that these could evolve over time and needed to be adaptive (Bousset et al., 2005; Medema et al., 2008; Mintzberg, 1978). During this phase the stakeholder engagement structure and process, and the river basin modelling framework were also endorsed.

Problem Analysis, Model Construction and Validation

Information about system uncertainties and the dispute context was obtained through a set of individual consultation meetings. This information helped define the best path from the process guide (Figure 4.2). As the case of Pemali Comal basin was considered an unstructured policy problem, the adapted approach for WRM in Pemali Comal consisted of the construction of a qualitative, concept model using systems analysis (i.e. Causal Loop Diagram). It was composed of six main steps: problem identification, system conceptualization, model formulation, model analysis and validation, policy analysis and design, and finally implementation by combining it with RIBASIM. Two qualitative, concept models using system dynamics were constructed and validated jointly with stakeholders from Circle A to schematise systematic interactions and cause-effect relations between problems. The first model illustrated present water-related challenges. It showed cause-effect relationships regarding water withdrawal and water supply for agriculture and public water supply. The second model contained anticipated problems for the future horizon (2034). Outputs from the system dynamics model were used for constructing the schematisation of the Pemali Comal water balance model using RIBASIM. Following this, data collection and model verification was performed by the modelling team in collaboration with stakeholders from Circle A.

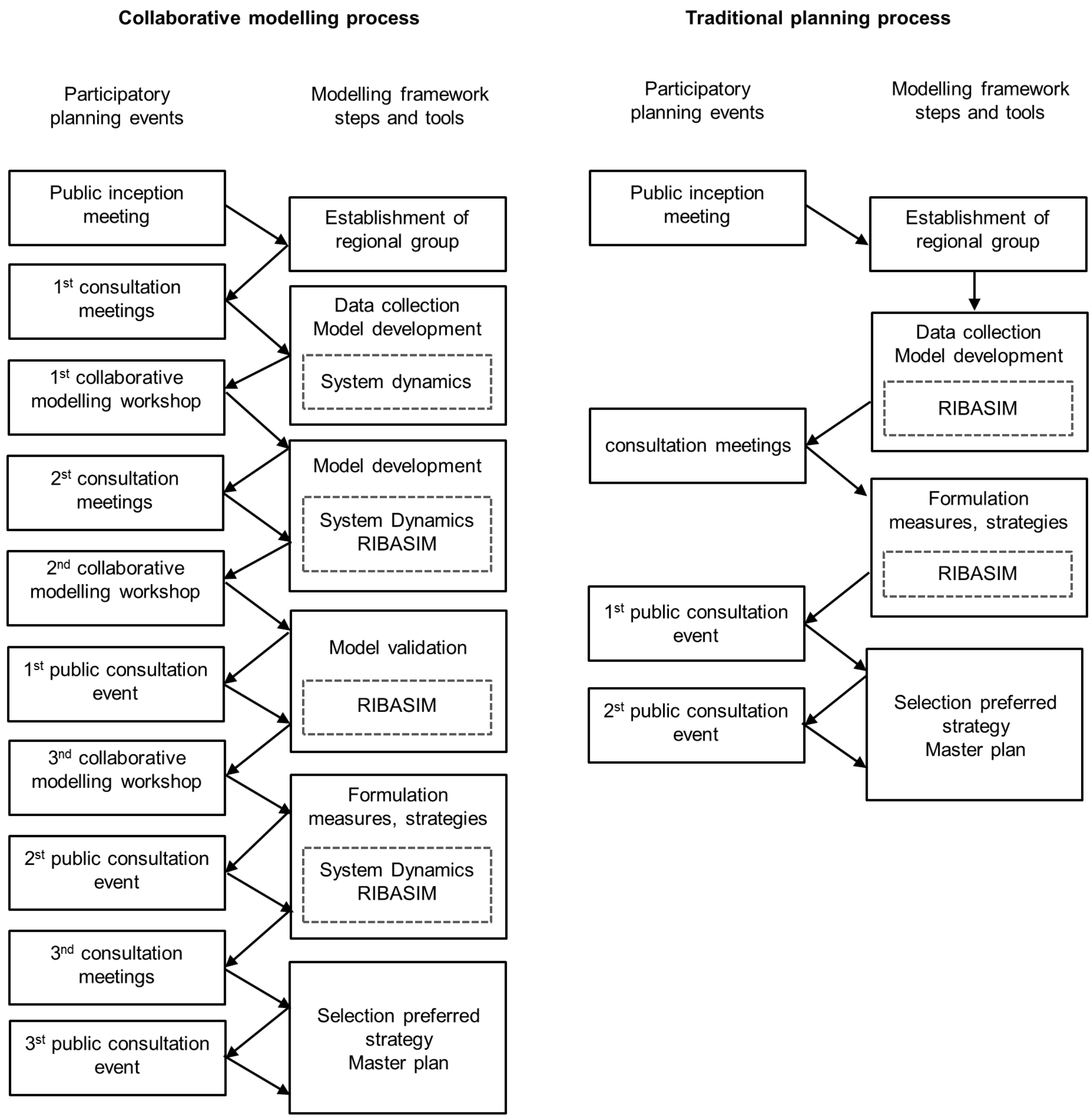


Figure 4.8 The collaborative and traditional modelling processes

Model Validation and Formulation of Measures

Due to persistent conflicts between water users in regards to the water withdrawals, uses, as well as cultural and hierarchical aspects (e.g. verbal dominance and freedom) (Akkermans and Vennix, 1997) of the Indonesian policy and institutional setup, Mediated Modelling was applied during the model use phase. This commenced with the selection of the four scenario conditions with Circle A stakeholders followed by an interactive process of converting water resources issues into solutions using system dynamics. The RIBASIM model was run to quantify the cause-effect relations defined during the problem analysis phase. The complete concept system dynamics models used for problem analysis were transformed into incomplete models to determine suitable solutions to each specific problem. A total of 40 different measures were identified. They comprised infrastructural and soft measures, legal and institutional arrangements. These were then combined and evaluated based on the various scenario conditions using the RIBASIM model. After the prioritisation of measures based on the outputs from the impact assessment, stakeholders and the modelling team selected the preferred strategy and incorporated it into the master plan. The master plan was then finalised and approved by the decision-makers.

4.4. Method Evaluation and Key Features

The evaluation of the method and its adequacy to the context and conditions of Pemali Comal River Basin Territory is analysed using the analytical framework (Chapter 3). The local context, specific purpose, information handling, stakeholder involvement, the modelling and organizing team and the means were the main factors considered for the evaluation. The results of the evaluations are presented in Table 4.4. The most characteristic features are highlighted in orange.

This method can be applied as a participatory modelling or collaborative modelling approach, depending on the levels of participation and the type of cooperation. However, it is most commonly applied as a collaborative modelling approach, with participants engaged in co-designing the model(s) and even co-deciding in the planning process. The approach allows high levels of collaboration, and even joint action, between involved professionals or stakeholders. The key features of the new method are as follows:

- *Context:* Suitable for semi-structured and unstructured problems characterized by limited knowledge on the system (in an integrated manner) and competing water users
- *Application:* Preparation of IWRM and integrated river basin master plans. System dynamics is most effective to be used in the early stages of the planning process. It can however, also be used in the formulation of measures.
- *Specific use:* The primary objective is collaborative learning. This method stresses to first help stakeholders to have a good understanding of the system and its functioning over time, in an integrated manner. Only when there is a shared understanding by all involved stakeholders, decision making can be supported. In

competing interaction contexts, the new approach helps mediating and reaching consensus among involved participants.

- *Modelling approach:* The method includes a river basin framework that helps combining the use of simulation model(s) and system dynamics (i.e Causal Loop Diagrams, stocks and flows or both), in the various stages of the planning process. It also includes a process guide to help the organizing team to apply Group Model Building and/or Mediated Modelling.
- *Process Orchestration:* The Group Model Building approach is recommended for cooperative interaction contexts, where participants are part of a team, and as such they share a common goal and vision, and there aren't significant disagreements among them. Mediated Modelling is recommended for competitive interaction contexts. Different groups of stakeholders are involved, but none or limited cooperation exists between them. There might be conflict of interests and complex power relations.
- *Stakeholder engagement:* The Group Model Building approach redistributes the power through negotiation between participants. The level of participation is similar for all participants. In more complex contexts, where Mediated Modelling is applied, a distinction in levels of participation between stakeholder groups might be needed. In these cases, the Circles of Influence or the Nested approaches are recommended for structuring the stakeholder engagement process.

Table 4.4 Evaluation of the collaborative modelling approach and its application in Indonesia

Factors	Parameters		Simulation Modelling & System Dynamics	Pemali Comal case Indonesia
Context and application	Problem type	Problem structure Scale of action Time horizon	Semi-structured & unstructured National and river basin levels Used for planning process, either short, medium or long term	Unstructured Regional (basin level) Medium (20 years)
	Domain		IWRM and integrated river basin plans	Integrated River Basin planning
	Interaction context	Cooperative Competitive	Commonly competitive. It can however be also used in cooperative environments.	Competitive
Specific use	Participatory/ Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Decision-making via Collaborative Learning In competitive contexts, emphasis on mediation.	*Main purpose:* Decision-making *Secondary purposes:* Mediation and collaborative learning
	Planning/Management cycle phase		From goal definition up to the master plan.	Situation analysis, strategy choice and IWRM plan.
Information handling	Model characterisation	Model system focus Model type	Socio-physical system models Analytical models	Socio-physical system models Analytical models
	Modelling tool / Software platform		Combination of systems analysis and system dynamics (using GMB and MM) and simulation models	Combination of system dynamics (using GMB and MM) and water-balance models
	Information type		Combination of system interactions and complex processes	Combination of system interactions and complex processes
	Information delivery medium	Virtual/web Face-to-face	Mainly, face-to-face Interactive tools can be used	Face-to-face
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Commonly, **collaborative modelling**	Collaborative
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	Different stakeholder groups engaged, with power asymmetries. Process orchestration methods can be Circles of Influence.	(Section 4.3.3) High local knowledge and experience. Limited knowledge on hydrology and water balance. Limited spatial knowledge
	Model users	Direct/Indirect Technical skills	Direct/Indirect depending on stakeholders' background and technical skills	Indirect Limited (only governmental WRM organizations)
	Participation mode	Only modellers (no participation) Individuals Groups	GMB will be followed in collaborative contexts. MM will be used for more competitive contexts.	Heterogeneous groups for model construction. Homogeneous groups for model use. Combination of GMB and MM
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	All. The level of participation can be the same for all participants or vary depending on the results of the stakeholder analysis.	Ranging from consultation to co-design (Sections 4.3.3 and 4.3.4)
	Timing of participation	Data collection Model definition Model construction Model validation Model use Measure formulation Strategy design	All	Up to formulation of measures
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Use of GMB when collaboration and joint action Use of MM, when unilateral action and coordination	Started in coordination (even in some occasions unilateral action) and developed into collaboration
Modelling / organising team	Team		Simulation and a system dynamics modellers. Gatekeeper and a facilitator recommended	National and regional modelling team, system dynamics modeller and a local gatekeeper.
Means	Timing		Usually 1-3 years	2 years
	Financial resources		-	450k EUR

4.5. Conclusions

This chapter has introduced a new method for applying collaborative modelling in IWMR and integrated river basin planning. The approach combines the use of simulation modelling and systems analysis and system dynamics. The systems thinking approach, and its two practical applications, i.e. systems analysis and system dynamics, have been briefly described. The two main approaches for applying both tools have been analysed used the generic framework presented in Chapter 3. The outputs of this analysis served as basis for designing the new method. This has been described and applied in Indonesia for the preparation of the Integrated River Basin Master Plan of Pemali Comal River Basin Territory. An evaluation of the method and its application in the study case shows its benefits for the preparation of integrated studies, such as IWRM and Integrated River Basin Master Plans, in comparison with traditional planning methodologies.

The application in Indonesia demonstrates the importance of the adaptive structure of the collaborative modelling approach. In this case, the heterogeneity of stakeholder groups in terms of hierarchical diversity, verbal dominance, freedom, organisational practices, background, culture and existing conflicts required the adaptation of the approach from Group Model Building for model construction to Mediated Modelling for model use. The approach also illustrates the benefits of using system dynamics in combination with RIBASIM. Both analytical models were useful for characterizing and analysing the socio-physical system and their inter-relations and supported the process of problem identification and measures formulation. The use of the water security framework helped structuring and guiding the formulation of potential measures, and led to the integrated planning approach required for sustainable IWRM. However, further analysis is necessary to transform the outputs from the IWRM planning process into specific inputs for evaluating water security in the region.

5

COMPANION MODELLING FOR ENHANCING MULTI-STAKEHOLDER COOPERATION

The second method applied as part of this Ph.D. thesis is presented in this chapter. A participatory modelling approach is developed to address complex water systems characterized by non-cooperative environments. The co-development and use of simulation models for understanding the complexity of the physical system is combined with the use of role-playing games and agent-based models via Companion Modelling to ensure the active involvement of stakeholders. Companion Modelling helps better understanding the social and institutional contexts for creating a common ground for negotiation and enhancing consensus. The use of simulation modelling enhances the cooperation by gaining a better insight in the physical system and possible joint actions. The approach is applied in two water quality management cases: a top-down planning process in Turkey and a bottom-up planning process in Indonesia. The generic framework illustrated in Chapter 3 is used for describing the key features of the approach and evaluate its application in both cases. This chapter also helps answering Research Question 3: *How can participatory and collaborative modelling approaches be applied with existing and newly developed computer-based simulation models?*.

This chapter is based on:

Basco-Carrera, L., Meijers, E., Sarısoy, H.D., Şanli, N.O., Coşkun, S., Oliemans, W., Van Beek, E., Karaaslan, Y., Jonoski, A., 2018. An adapted companion modelling approach for enhancing multi-stakeholder cooperation in complex river basins. International Journal of Sustainable Development & World Ecology, 1-18.

Basco-Carrera, L., Yangyue, Y., Rini, D.S., Mostert, E., Nooy, C., van Beek, E., 2018. Beyond the usual suspects: Local communities and the private sector engaged in modelling water quality (publication in progress).

5.1 Introduction

Fresh water is a finite and vulnerable resource. It is essential to sustain life, development and environment (GWP, 2000). However, just having access to water and sanitation is not sufficient for sustaining life and development for all. Good water quality is also an essential condition for development. The sustainable development agenda 2030 calls to "improve water quality by reducing pollution, eliminating dumping and minimising the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally, by 2030" (SDG 6 – Target 6.3). It also highlights the protection and restoration of ecosystems (SDG6, Target 6.6) (United Nations, 2016). These goals are essential for IWRM; however, sometimes they are considered as a lower priority and are set as longer term goals by governmental agencies and stakeholders due to its intrinsic complexity. At the household level, open defecation, toilet discharge and solid waste disposal into the river combined with bathing and laundry in the river are common practices in rural and peri-urban areas. The extensive and sometimes uncontrolled use of pesticides, herbicides and fertilisers in agricultural areas as well as deficient management of manure also have significant effects on water quality. Furthermore, industrialisation is perceived as a factor for development and economic growth. However, the assumption that industrialisation boosts sustainable development is sometimes questionable. The release of hazardous chemicals, toxics and other pollutants into the river is a common practice all over the world, despite the existing water quality policies and regulations. Polluted water is often used by other water users downstream for their livelihood activities and welfare, causing adverse impacts on human health and the environment. Regarding solutions, the construction of waste water treatment plants (WWTPs) is costly and does not solve the problem in the short term. Their operation and maintenance is a major issue faced by decision-makers and stakeholders. Lack of human and technical resources, availability of materials, financial mechanisms are some of the encountered constraints. However, the most challenging constraint is being able to understand and change people's mental models, perceptions and behaviour. Awareness raising and education can achieve this. Legal and financial instruments can also be used such as legislation enforcement, or a system of penalty sanctions and incentives – "a polluter pays" (Dukhovny, 2005). It is thus understandable that improving water quality is a complex and time-demanding target for sustainable development.

In this study, participatory modelling is proposed as an appropriate solution for addressing complex medium and large river basin systems. The basins addressed in this study are characterised by a poor water quality status, high urbanisation rates, data scarcity, complex institutional setups, power asymmetries between agencies and stakeholders, and reluctance to engage local stakeholders. The participatory modelling approach helps structuring the problem context by first enhancing consensus among stakeholders by generating collective reflection and resolving existing disputes among stakeholders related to the system. Its use is therefore recommended in the early stages of a planning process: vision and policy, and situation analysis (Figure 2.2).

In this chapter, an exploration of the key features of Companion Modelling, under the umbrella of participatory modelling is first made. The suitability of using an adapted approach to complex river basins is then evaluated. It combines the key features of companion (incl. simulation modelling) and takes into account the differences in the institutional setup, scale of action, stakeholders involved and modelling tools. The description and comparison of both approaches is presented in the following section. Two water quality planning cases are used to test the new method: a top-down planning case in Turkey and a bottom-up case in Indonesia. The chapter finalizes with an evaluation of the method and both applications, using the generic framework described in Chapter 3.

5.2 Method

5.2.1 Origins of Companion Modelling

Companion Modelling is a sub-type of participatory modelling that emerged in France in 1996 from the joint efforts of a group of researchers working in the fields of ecosystems and social systems. The approach is best suited for semi-structured problems (i.e. "stakeholder-oriented" problems), commonly in small watersheds, characterised by disputes (caused by differences in viewpoints and objectives) among stakeholders. With the co-design and use of "simple" role-playing games and agent-based models, Companion Modelling aims to structure and elicit the various knowledges on the key elements of a system, as well as possible solutions and objectives to be achieved. For this, the approach promotes simple and double loops of individual and collective learning. Repetitive back and forth steps between the conceptual model and the field situation characterise the Companion Modelling process.

Companion Modelling relies on sharing knowledge to advance relationships between individuals, and between individuals and the resources (socio-ecological systems) (CIRAD, 2004; Étienne, 2013). This process has the objective to generate collective reflection and help resolving existing disputes among stakeholders. Commodians (referring to individuals specialised in Companion Modelling processes (Barreteau et al., 2014)) and scientists/researchers are used as neutral parties to support the negotiation process. The modelling process is used to catalyse the interactions between the researchers and other stakeholders. Companion Modelling is therefore mainly used at the early stages of planning processes, where the main focus it to create a joint vision by alleviating tensions among stakeholders. Ultimately, the Companion Modelling process leads to collective action (CIRAD, 2004).

5.2.2 Why a new Approach

An adapted Companion Modelling approach is required to support the management of complex river basins characterised by:

- Poor water availability and quality status in the basin (limited scientific knowledge);
- Medium and large river basins;
- Strategic urban development areas;
- High urbanisation rates, and high inequality between rural and urban areas;
- Data scarcity environment, either due to lack of data or limited access to it;
- Complex institutional setup with multiple agencies having similar responsibilities;
- Considerable power asymmetries between different agencies and stakeholders;
- Lack of formalised negotiation procedures for river basin management and planning;
- Participation of local stakeholders is perceived as a risk;

Companion Modelling is identified as the most appropriate approach for the non-cooperative environments and domains, where it is commonly applied. Moreover, its primary purpose is to enhance cooperation between stakeholders by developing a common knowledge base. The adapted approach is therefore conceptualised as a participatory modelling approach that follows the principles and key moments of Companion Modelling.

However, its adaptation is required to fulfil the requirements of formal, informed (top-down and bottom-up) planning and management processes that require the use of simulation modelling for better understanding the complexity associated with medium and large river basins.

5.2.3 Exploring Companion Modelling key Characteristics

Extensive documentation provides guidance on the Companion Modelling approach and its application (Bousquet, 2005; CIRAD, 2015; Étienne, 2011, 2013). However, Barreteau et al. (2014) recognise the diversity in implementing a Companion Modelling process, and therefore extract the common points from these variants. These common points are: (i) there are four categories of main protagonists (i.e. lay, researcher, technician, institutional), (ii) a virtual world is created, (iii) the approach follows sequential steps, (iv) collective moments are included where interaction among participants occur, (v) an initial conceptual model is co-developed, (vi) it is an iterative process, and (vii) the process comprises loops and cycles. This Ph.D. thesis goes a step further in defining the generic characteristics and features of this process when applied in the field of WRM.

Ten different, recent cases, where it is claimed that Companion Modelling for WRM was applied, are used to evaluate the "common" Companion Modelling approach. The sample includes diversity regarding geographical context (various countries in different continents, rural/urban areas), stakeholders involved and environmental issues addressed. These 10 cases are: Barreteau et al. (2003), Barreteau et al. (2004), Gurung et al. (2006), Boisseau (2005), Ducrot et al. (2007), Faysse et al. (2007), Clavel et al. (2008), Farolfi et al. (2010), Ruankaew et al. (2010), and Worrapimphong et al. (2010).

The generic framework for participatory and collaborative modelling approaches, presented in Chapter 3, is used to present the key features of Companion Modelling under the umbrella of WRM. These factors and sub-parameters are presented in the remainder of this section, resulting in the overview Table 5.2.

5.2.4 Key Features of "common" and "adapted" Companion Modelling Approaches

Context and Application

Companion Modelling is commonly used for research studies related to Natural Resources Management (Barreteau and Bousquet, 1999; Barreteau et al., 1997; Étienne, 2013; Souchère et al., 2010). Its applications range from watershed and forest management, land use dynamics, irrigation, water dynamics and coastal management, amongst others. Particularly for WRM, Companion Modelling is often used for water allocation (Barreteau et al., 2003; Ducrot et al., 2007; Farolfi et al., 2010), irrigation (Barreteau et al., 2004; Faysse et al., 2007; Gurung et al., 2006), fishery management (Worrapimphong et al., 2010) and water quality management (Clavel et al., 2008; Ducrot et al., 2007). The approach is commonly applied at the local scale (i.e. villages and communities) or regional scale (i.e. small sub-catchments/watersheds). The Companion Modelling approach adapted to medium and large river basins often requires the integration (and sometimes prioritisation) of various domains, such as land use, irrigation and fishery management. As a result, it requires the use of simulation models of the physical systems.

Companion Modelling processes are commonly applied in contexts characterised by low degree of consensus among stakeholders regarding values, norms and standards, beliefs and ambitions (i.e. competitive interaction contexts). Disagreements can occur due to a lack of common ground regarding values, norms and standards (problem structure) or due to differences in stakes regarding water resources problems in the region. Water allocation priorities (Barreteau et al., 2014; Gurung et al., 2006), increased water stress caused by changes in water demand due to urbanisation (Ducrot et al., 2007; Faysse et al., 2007) or lack of good water governance (Farolfi et al., 2010; Fung, 2006) are common causes of disputes. The problem structure causes that even in more cooperative interaction contexts, disputes among stakeholders persist (Boisseau, 2005). This corroborates the findings from Zeitoun and Mirumachi (2008) that conflict and cooperation co-exist. The approach is particularly beneficial in neutral interactions characterised by low cooperation (Zeitoun and Mirumachi, 2008). Lack of scientific certainty about the systems can also occur (i.e unstructured or semi-structured problems (Hommes, 2008; Van de Graaf and Hoppe, 1996)). Non-strategic cultural or scientific support are thus the conflict management tools recommended for enhancing cooperation (Wolf et al., 2003). The adapted Companion Modelling approach tackles both challenges occurring in river basin management.

In Chapter 2, a distinction is made between "Collaborative Modelling" and "Participatory Modelling" by considering levels of participation and type of cooperation as conditioning factors. At the core level, both participatory and collaborative modelling emphasise the importance of involving stakeholders in the modelling process. However, collaborative modelling is considered to comprise a subset and more intensive form of participatory modelling (Figure 2.6). Participatory modelling is the starting context for the majority of Companion Modelling applications due to the low level of cooperation among stakeholders. Generally, however, the initial conditions change with the support of Companion Modelling. The type of cooperation, and as a result the level of participation, increase due to the development of a common understanding of the different systems and stakeholders by means of collaborative learning. A transformation can then occur from participatory modelling to collaborative modelling.

Specific Use

Companion Modelling is most suitable for supporting collective reflection and the integration of knowledge on different systems by settling existing disputes between stakeholders. The process can lead to collective action in the future (CIRAD, 2015; Étienne, 2013). The approach enhances stakeholders' knowledge of the physical system and local mechanisms (i.e. behaviours, interactions and human-induced drivers) (Castella et al., 2005). The iterative process, composed of various loops and cycles, creates a sustained interaction environment between scientists and stakeholders (Barreteau et al., 2014) that facilitates this knowledge development through collaborative learning (Voinov and Bousquet, 2010). A secondary output of a Companion Modelling process is a common, accepted representation of the social and physical systems. The model(s) helps in evaluating the impacts of social mechanisms (e.g. stakeholder interactions, dynamics, resources) on the dynamics of natural resources. Although it is a secondary output, the co-construction of models is a critical element for collaborative learning, as it facilitates the modification of perceptions or behaviours via shared and social learning (Collins and Ison, 2009; Evers et al., 2012; Hare et al., 2003).

The primary objective of this adapted Companion Modelling approach consists of facilitating dialogue, enhancing the common understanding of complex river basins among governmental agencies and local stakeholders, and by doing so, resolve disputes. This first objective will ultimately lead to collective informed decision-making for river basin planning and management.

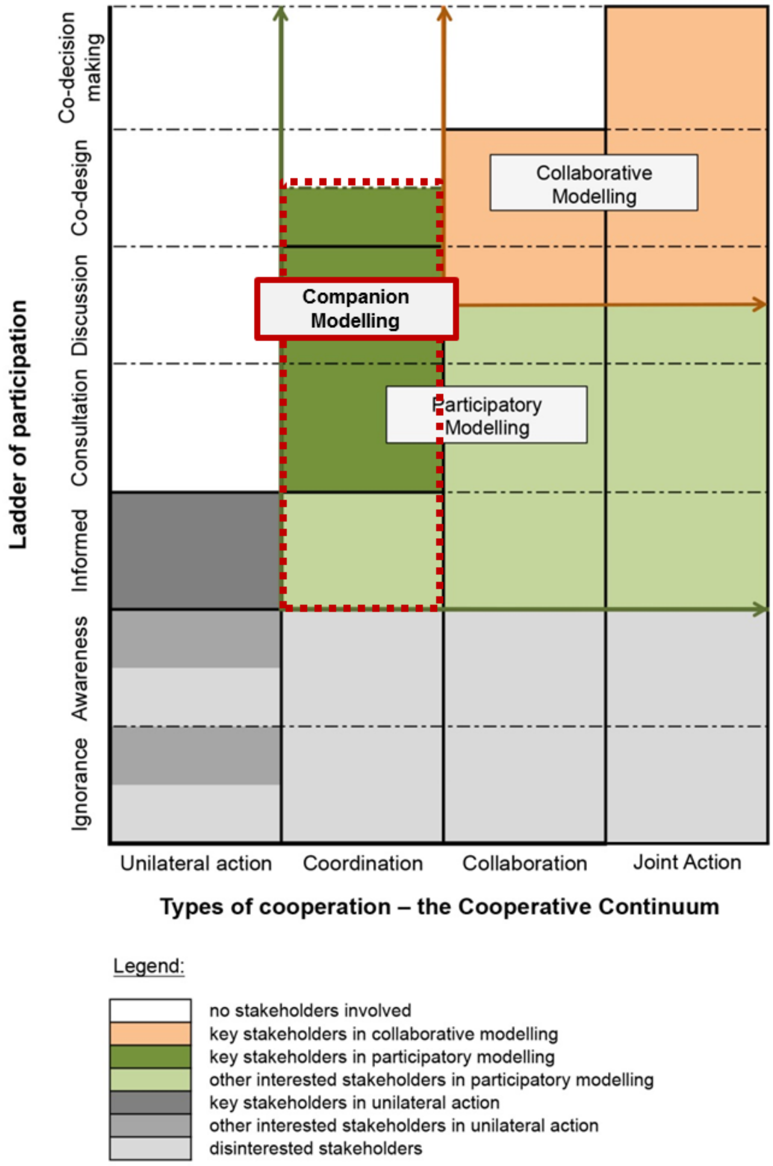


Figure 5.1 Classification of Companion Modelling considering the various levels of participation and the types of cooperation

Practically, Companion Modelling can be applied in any stage of planning/management cycle. Barreteau et al. (2014) exploration however shows that it is generally applied in the early stages of the integrated water resources planning and management cycle: (i) field work, (ii) modelling, (iii) simulation, (iv) field work (iterative process; CIRAD, 2004; Étienne, 2013). In particular, collective exploration and co-construction of the virtual world are the key moments. These findings are corroborated by our study. Nine out of ten analysed applications used Companion Modelling at the preliminary stages (situation analysis, problem identification and strategies design).

Information Handling

Companion Modelling is based on developing a representation of the social system, based on a network of human agents, and the physical system by co-constructing models with stakeholders (Bousquet et al., 1999). It is a multi-agent systems (MAS)-based approach (Ruankaew et al., 2010), as it represents the social, biological and physical systems as well as their interactions. Companion Modelling often combines the use of role-playing games (based on human agents) and an agent-based simulation model (based on computerised (virtual) agents). The use of one type or both depends on the different modelling phases (Barreteau et al., 2004; Boisseau, 2005; Bousquet, 2005; Castella et al., 2005; CIRAD, 2015; Janssen, 2002; Souchère et al., 2010; Worrapimphong et al., 2010). The information being handled relates to system interactions and relatively complex processes. According to Janssen (2002), multi-agent systems based approaches are particularly adapted to the representation of dynamic systems. However, the small scale in which Companion Modelling is commonly applied and the stakeholders involved (and their interactions) are factors that condition the use of conceptual and simulation models. The representation of the physical system are appropriate for collective action at small scale but frequently insufficient to be used in formal, informed decision-making processes related to planning and policy-making in larger scales.

The adapted approach presented in this chapter addresses this challenge. It is composed of three main elements: (i) a complex computer-based simulation model(s), (ii) a role playing game, and (iii) an agent-based model. The use of all elements or a combination of them can vary based on characteristics and conditions of each particular case. The main difference with the "common" Companion Modelling approach is the use of a complex model(s) of the physical system (e.g. computer-based simulation models, numerical models). Another important difference is its design. The construction of the virtual world for the role-playing game is based on the "real" problems in the basin and potential interventions. The simplified rules and structure of the role-playing game help stakeholders to better understand the functioning of the "real" system in an easy manner. Human agent interactions, dynamics and resources are analysed using the outcomes of the role playing game. Computer-based simulations are mainly used for providing more detailed information about the physical system. Merging both outputs helps in having a shared representation of the socio-physical systems and their interactions (Bousquet and Trébuil, 2005).

Stakeholder Involvement Structure

Companion Modelling follows the ARDI (*Actors, Resources, Dynamics, and Interactions*) method to identify the principal groups of stakeholders that need to be engaged, their management and institutional structures, the resources used, and the processes that drive the changes that affect these resources (Etienne et al., 2011). Main protagonists include four categories: lay, researchers, technicians and institutional (Barreteau et al., 2014). These usually include grassroots organisations and groups (e.g. local communities, citizens), economic bodies (industries and companies), regional governments, academics and research institutions, and NGOs. Minimal skills and knowledge is listed in the detailed assessment available in Annex A. Companion Modelling facilitates the active engagement of these stakeholders from the early stages of the modelling process. Results from our exploration show that in all cases stakeholders were consulted or directly involved in the construction and use of the agent-based model or role-playing game. This findings are in line with the exploration of Barreteau et al. (2014): the majority of case studies focused on the co-construction of the virtual world, its collective exploration and validation. The direct construction and manipulation of the agent-based model or role-playing game, makes participants as direct users. However, when more technically sophisticated modelling simulation tools are used, stakeholders (especially those from grassroots level) frequently become indirect users.

The common engagement structure in Companion Modelling process is that all stakeholders have a similar level of participation. Table 5.1 presents the most common levels of stakeholder participation in relation with the timing of participation. The flexibility of the approach however permits changes in levels of stakeholder involvement depending on the timing of participation. In river basins, where a bottom-up planning and management process is followed, using a similar level of participation is encouraged. The use of the Negotiated Approach, in combination with the participatory modelling approach, is recommended when involving disadvantaged groups (e.g. local communities) with low literacy and none or limited technical skills. The approach combines capacity development and negotiation techniques to empower these disadvantaged groups so they can comfortably participate in the water management planning and decision making processes. In large complex river basins, top-down approaches are more commonly used. Larger number of stakeholder groups need to be engaged to ensure collective action. The complexity of the institutional and political setup is high, with multiple agencies having similar responsibilities, power asymmetries, etc. This, in combination with constraints in resources, encourages the design of more structured engagement processes (e.g. circles of influence approach) that support the negotiation process despite the differences in the levels of participation of stakeholders.

Table 5.1 Timing of participation and level of stakeholder involvement

	Data Collection	Model (virtual world) Design	Model (virtual world) Construction	Model Verification & Validation	Model use	Measures Formulation & Strategy Design
Ignorance						
Awareness						
Information			■			
Consultation	■	■	■	■		
Discussion	■	■		■	■	■
Co-design		■				■
Co-decision-making						

Modelling and Organising Team

The neutrality of the established scientific and technical knowledge should not be compromised, as it serves as common ground for enhancing cooperation among stakeholders. The ethical framework (CIRAD, 2004) helps tacking any possible subjectivity issue by stating that the modelling and organising team composed of commodians, facilitators, technicians and scientists, are obliged to take all identified stakeholders' viewpoints into account equally, and to keep the process transparent. Commodians are participatory modelling experts familiar with Companion Modelling and are commonly responsible for the application of the approach. The organising team can be composed of other stakeholders. Academics and researchers in the field of natural resources management can also be part of the team (Boisseau, 2005; Clavel, L., et al., 2008; Faysse, N., et al, 2007). Stakeholders with political and economic knowledge of the system can also join the modelling and organising team (Barreteau et al., 2003). Required modelling, facilitation, knowledge acquisition and process management skills are listed in the detailed assessment in Annex A.

Means

The average duration of a Companion Modelling case ranges from 2-5 years. Commonly these projects are funded by research institutions, regional governments or international organisations.

Table 5.2 Categorisation of the "common" Companion Modelling approach

Factors	Parameters		Companion Modelling (ComMod)
Context and application	Problem type	Problem structure Scale of action Time horizon	Semi-structured and unstructured Local or regional scales (community level) Short term
	Domain		Natural resource management
	Interaction context	Cooperative Competitive	Competitive
Specific use	Participatory/Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Enhance cooperation via collective reflection, collaborative learning and dispute resolution. *Secondary purposes:* Support of the decision-making process with collective action.
	Planning/Management cycle phase		Early phases of the planning cycle.
Information handling	Model characterisation	Model system focus	Socio-physical system models
		Model type	Analytical models
	Modelling tool / Software platform		Agent-based model and role-playing game
	Information type		Mainly systems interactions
	Information delivery medium	Virtual/web Face-to-face	Face-to-face sessions. Virtual platforms can be used
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Participatory modelling
	Stakeholders involved	Organisation Background	ARDI method followed Local communities, economic bodies, regional authorities, universities and NGOs
	Model users	Direct/Indirect Technical skills	Direct users in the role-playing games
	Participation mode	Only modellers (no participation) Individuals Groups	Combination of all participation modes All stakeholder groups have similar levels of participation in the various modelling phases.
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	Level of participation varies from consultation up to co-design
	Timing of participation	Data collection; Model definition; Model construction; Model validation and verification; Model use; Formulation of interventions and design of strategies	All
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Unilateral action or coordination
Modelling / organising team	Team		Commodians, sometimes supported by scientists and local institutions.
Means	Timing		2-5 years (average)
	Financial resources		-

5.3 Application Example 1: Büyük Menderes Water Quality Study

5.3.1 Study Area

In the European Union, river basin plans need to follow the European Water Framework Directive (WFD) (Directive 2000/60/EC). The WFD is the major driver for achieving sustainable water management. Its ultimate goal is the protection and improvement of inland, transitional and coastal waters, as well as groundwater. Public participation is considered as a critical supporting element for the achievement of the WFD objectives, as defined in Directive Article 14 on Public information and consultation (Newig et al., 2005; Parker et al., 2003; Van Ast and Boot, 2003). A specific guideline has been developed for this purpose (Directive 2000/60/EC Guideline Document 8; European Communities (2003b)), providing insight on the stakeholder involvement process to leverage the success of the WFD by conceiving three forms of public participation: (i) information supply, (ii) consultation, and (iii) active involvement (Castelletti and Soncini-Sessa, 2006; De Stefano, 2010).

In Turkey, IWRM has received increased attention in the last few years. The establishment of the Directorate General on Water Management and river basin management committees are some of the institutional measures recently implemented. River basin projects with stakeholder engagement have also increased. However, a strongly centralised institutional setup and rivalry between agencies due to similar responsibilities and power asymmetries (i.e. competitive interaction context) are major institutional issues. Moreover, the lack of legislation on stakeholder engagement in water management combined with receiving criticism and rejection of their policies and planning mechanisms raises major concerns among decision-makers. They prefer to limit the involvement of local stakeholders to general public consultations.

The Büyük Menderes river basin is located in the south-western part of Turkey and has an area of 24873 km^2 (Figure 5.2). The population was 2.5 million in 2000 and it is expected to increase to 4.9 million by 2020. The river originates as a spring from limestone deposits and in conjunction with other tributaries it becomes the Büyük Menderes river at the basin lowlands. It then discharges into the Aegean Sea. The climate in the basin varies from continental climate in the upstream area to Mediterranean climate downstream. The average rainfall is 635 mm/year. Water quality is subject to the WFD guidelines. Its main objectives are to: (i) maintain 'high status' of waters where existing; (ii) prevent any deterioration in the existing status of waters; and, (iii) achieve 'good status' in all waters. According to the River Basin Management Plan for Büyük Menderes river basin (European Commission, 2010), the water quality of the majority of water bodies is moderate or poor. Data scarcity is a major problem, as it results in high uncertainty about the physical system and its functioning. It is however known that more than half of the water bodies are considered at risk. Industrial waste disposals are the main point source pressures. Agriculture and mining activities as well as urban runoff form the main sources of diffuse pollution (Koç, 2010). Finally, flow regulation (i.e. environmental flows) and physical barriers are the most notable hydro-morphological pressures. Interventions and strategies designed in this study should therefore be evidence-based solutions that help reaching the water quality and ecology objectives.

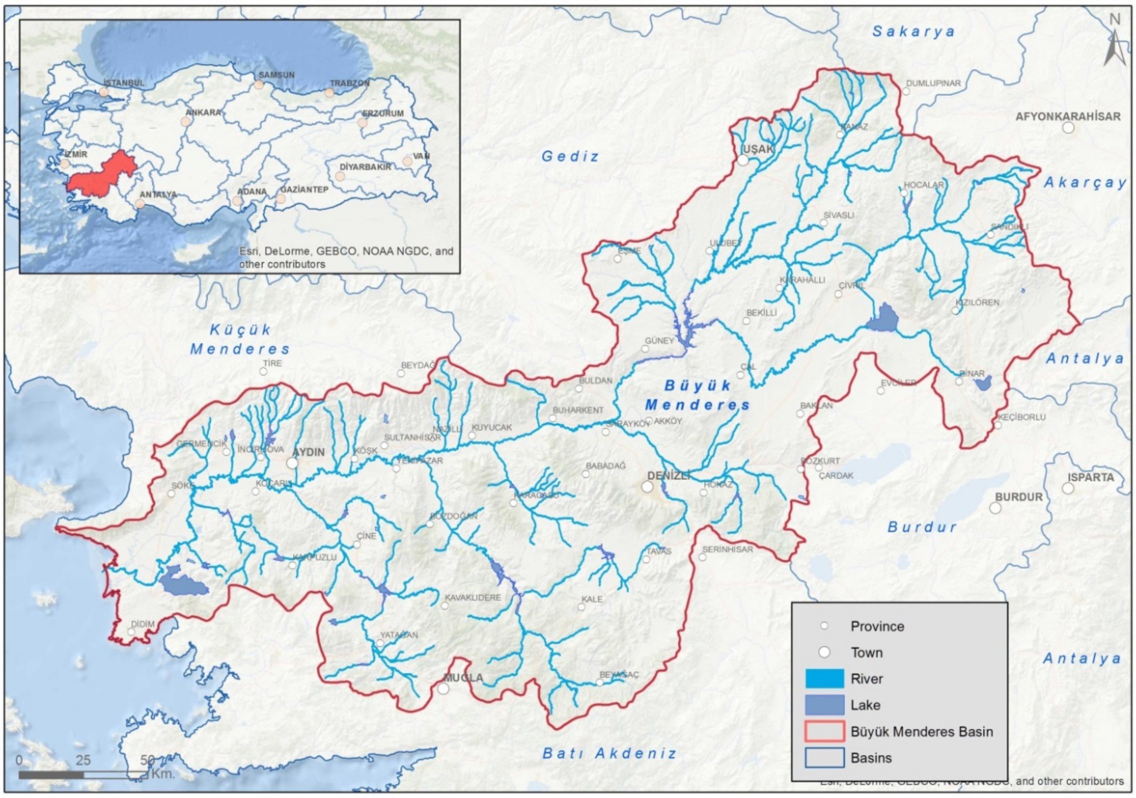


Figure 5.2 The Büyük Menderes river basin in Turkey *(source basemap: ESRI, 2009)*

5.3.2 Adapted Companion Modelling Approach

The main objective of applying an adapted Companion Modelling approach was to facilitate dialogue and settling existing disputes by enhancing a common understanding of the complex river basin among governmental agencies and local stakeholders. For this, the approach combined the use of two simulation models and a role-playing game. The approach helped:

- Raising awareness and developing a common understanding of how to manage the river basin in a sustainable and inclusive manner via stakeholder workshops and capacity development sessions;
- Joint identification of main issues related to river basin management in the basin, and formulation of potential interventions and strategies;
- Co-designing a user-friendly but complex computer-based simulation model to analyse the water availability and water quality in the basin;
- Testing possible cost-effective interventions and strategies under different scenario conditions;
- Structuring the stakeholder engagement process, mediate between parties and support the negotiation of commonly agreed interventions.

Project Organisation and Means

The modelling team included two local modelling teams focusing on hydrology and ecology (Figure 5.3) and an international modelling team composed of technical experts from Deltares research institute and Witteveen+Bos consultancy company. The organising and facilitation team was composed of a commodian (from Deltares), two experts in the Water Framework Directive and river basin management (from Deltares and a Dutch water board) and a local team composed of members of the Directorate General on Water Management Modelling Section and the Nature Conservation Centre NGO. The involvement of NGOs as part of the organising team helped the modelling team to have continuous support in understanding of the local environment, as the majority of NGO staff has considerable local and technical knowledge on natural resources management. Moreover, they commonly understand and support the interests of local communities. This helped ensuring that all identified stakeholders' viewpoints were taken into account equally. Finally, local NGOs helped in reducing cultural barriers between the modelling team, commodians and the local stakeholders (e.g. communication –language-, session protocols). It was critical for them to keep their neutral position throughout the process by following the ethical framework (CIRAD, 2004).

The project was 16 months in duration. It started in September 2014 and finalised in December 2015. The total budget for the project was 400,000 EUR. It was funded by Partners for Water Programme in the Netherlands, the Ministry of Forestry and Water Affairs in Turkey and Deltares.

Stakeholder Engagement Structure

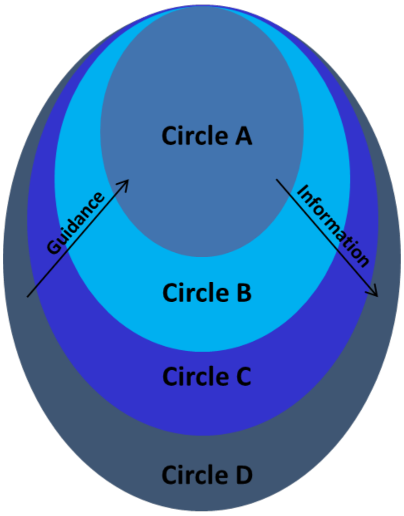
A stakeholder engagement structure was designed to ensure fruitful participation in the modelling process. The ARDI method was followed to identify the groups of stakeholders that needed to be involved in the study and analyse their interactions, key resources, dynamics as well as their capacity to modify the processes (Etienne et al., 2011). Information obtained from individual interviews and focus group discussions served as input for the design of the engagement process. Other key points of interest for the design included the participatory planning and institutional setup in Turkey, as well as the data, modelling tools and financial mechanisms used for implementation.

The 146 stakeholder representatives were engaged considering the circles of influence approach, developed by US Army Corps of Engineers (Cardwell et al., 2008). Four levels of influence were used in the Büyük Menderes case: (i) Circle A: model construction team, (ii) Circle B: model users and validation team, (iii) Circle C: other interested stakeholders, and (iii) Circle D: decision-makers (Figure 5.3).The level of involvement of each circle was decided considering the contextual type of cooperation in the project (Hurlbert and Gupta, 2015).

The participatory modelling process was designed based on the stakeholder engagement structure (Figure 5.3). It included a kick-off, mid-term and closure meetings combined with regular consultation meetings with decision-makers and local stakeholders. A capacity building session on WRM and participatory modelling was organised. Moreover, four participatory modelling sessions were conducted: three for model construction and one for model use. The process followed simple and double loops of individual and collective learning (Étienne, 2013).

Modelling Approach

The participatory modelling approach for the Büyük Menderes basin incorporated two simulation modelling suites and a role playing game.



Circle	Involved stakeholders
A	1. Ministries (i.e. Ministry of Forest and Water Affairs, Directorate General for State Hydraulic Works (DSI), Ministry of Food, Agriculture and Livestock) 2. National universities and research institutes 3. Non-governmental organization Nature Conservation Centre 4. Consulting companies
B	1. Ministries (i.e. Ministry of Forest and Water Affairs, DSI, Ministry of Environment and urbanization and Ministry of Food, Agriculture and Livestock) 2. Irrigation unions 3. National universities and research institutes 4. Chamber of commerce 5. Organized industrial areas 6. Non-governmental organizations 7. Consulting companies
C	1. Non-governmental Organizations 2. Fish cooperatives 3. Operators of waste water treatment plants 4. European Union commission in Turkey
D	1. Deputy under-secretary 2. Directorate General (DG) Water Management 3. Governors of Uşak, Denizli, Afyon and Aydin 4. Municipalities

Figure 5.3 Circles of influence structure for Büyük Menderes river basin

Computer-based Simulation Models

The Büyük Menderes study comprised two modelling suites, i.e. RIBASIM and WFD Explorer, using three functional modules: (i) hydrology and water distribution using RIBASIM, (ii) water quality using DELWAQ, and (iii) ecology using Product Unit Neural Network (PUNN) (Figure 5.4).

The River Basin Simulation model package, RIBASIM, is a decision support tool for multi-sector planning to allocate scarce resources at the river basin level (van der Krogt and Boccalon, 2013). The model represents the hydrological situation of the Büyük Menderes on catchment scale, including reservoir operation, river runoff, urban water fluxes and water use by crops. It also enables the screening of possible measures related to infrastructure, operational and demand management and testing of alternative future strategies. The RIBASIM model for the Büyük Menderes study was used for modelling the hydrological relations in which water allocation was simulated. It was constructed with historical data from 2003 to 2011 with a monthly time step. Hydrological data was based on observed discharges. For those non-measured basins, the hydrological data was extrapolated by using the runoff depth of similar neighbouring catchments. A total of six main cities and organised industrial areas were considered for the study of Domestic, Municipal and Industrial water demands. Likewise, 34 irrigation schemes were represented. Existing storage facilities such as weirs and reservoirs were also included in the model, as well as the corresponding environmental flows.

The WFD Explorer is an analysis tool to support the implementation of the Water Framework Directive. It is a modular toolbox that incorporates hydrology, water quality, emissions and ecology (Wortelboer, 2015). This modelling structure permits the calculation of the effect of restoration and mitigation measures on the chemical and ecological quality of surface waters (Mouton et al., 2009). Decision-makers and stakeholders can then assess how effective the potential measures are in reaching the WFD objectives. The WFD Explorer 2.0 was used for water quality assessment in Büyük Menderes basin. A DELWAQ model was used for water quality modelling (i.e. D-Water quality and D-Ecology of the Delft3D suite) and a PUNN model for ecology. The DELWAQ model covered basic tracers, dissolved oxygen, nutrients, organic matter, inorganic suspended matter, heavy metals, bacteria and organic micro-pollutants (Deltares, 2016a). Ecological knowledge captured in rules was simulated using the PUNN method. This method is based on the linkage between ecological steering factors and the Ecological Quality Ratio (EQR) (de Niet et al., 2014). The WFD Explorer schematisation included 67 sub-catchment areas and 266 explicitly modelled surface water nodes. Water fluxes driving the transport of nutrients and COD in the water quality model were derived from RIBASIM. Water fluxes were available for the period October 2003 till September 2011. Based on these results, three-monthly averaged water balances were compiled. The model was calibrated for three water quality parameters; tot-N, tot-P and COD on 12 monitoring stations. The most recent complete year (2010) was used for calibration of the model. The calibration procedure consisted of a four-step routine. The routine started with performing minor adjustments to the RIBASIM model, including the addition of minimal environmental flows. Hydrological patterns were added to the release of nutrients from the diffuse sources. This second step was followed by adding a first order decay process to the model. The process caused the removal or decrease of COD, Tot-N, Tot-P due to hydraulic residence time.

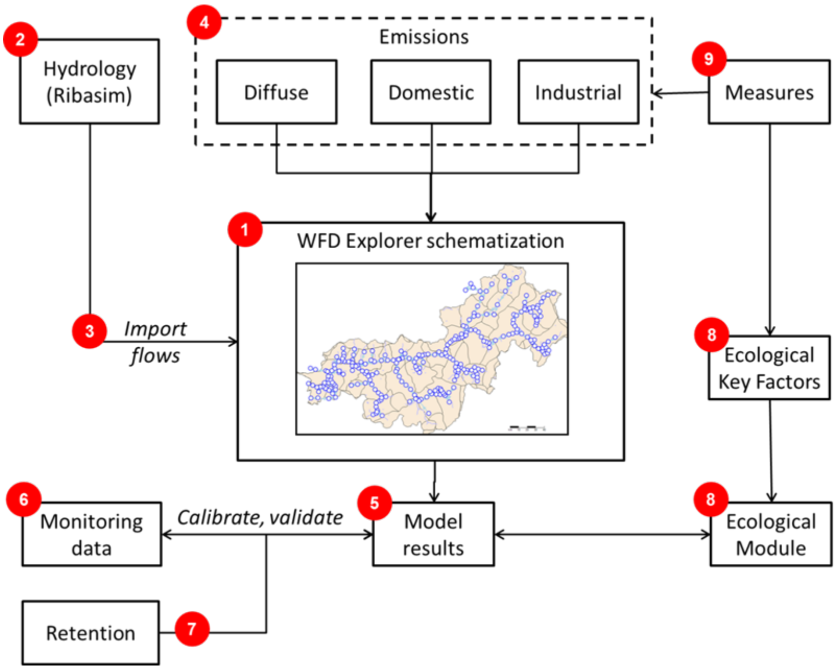


Figure 5.4 Modelling approach for Büyük Menderes river basin *(source: Deltares, 2016b).* The order of the tasks is indicated by the numbering within the red circles.

Role-playing Game

A role playing game was co-designed and used for the formulation potential interventions and design of potential strategies. The main objectives of the game were to: (i) understand stakeholders' perceptions, behaviours, interactions and dynamics, (ii) facilitate the exchange of points of view, knowledge and experiences, and initiate collective learning, and (iii) build trust and ownership of the simulation models and designed strategies (Eden and Ackermann, 2013).

The reality conditions (i.e. context and application) defined the game setting. This comprised four main elements: environmental setting, players, rules of operations and input to the game. The environmental information on water availability and quality was extracted from RIBASIM and WFD Explorer, respectively. It included the "real" problems in Büyük Menderes river basin and the potential interventions. 3 maps, 24 measure cards, a computer, a projector, stickers and markers were used as communication and visualisation tools. The maps illustrated the RIBASIM schematisation and the water quality status of Büyük Menderes river basin. The design of the measure cards followed Bots et al. (2011) information-transparency rules. Key elements of the cards included: name of the intervention, brief description, estimation of cost (i.e. high, moderate, low) and impact reduction (as percentage) of COD, Suspended Solids, Tot-N, Tot-P, toxics and ecology. These were categorised into structural measures for addressing point or diffuse sources, ecological measures, institutional arrangements and soft measures such as capacity building. Each category was represented by a different card colour.

The physical and social systems were connected by players (stakeholders) and their roles. The "real" roles and dynamics of the different groups of stakeholders were maintained, as the game aimed to represent the "real" systems as much as possible. Figure 5.5 shows the diagram of interactions. Interactions between stakeholders (white boxes) and resources (grey boxes), or among stakeholders, are represented with arrows. Arrows are associated with actions. The real roles and dynamics were also reflected in the rules of the game. These reflected the institutional setup and legitimate procedures for water resources planning and implementation in Turkey. Focus groups were formed, which also determined the participation mode. During the first focus group, participants were divided into three homogeneous groups. During the second focus group, participants were grouped in two heterogeneous groups. In the group they could decide to actively intervene by being involved in proposing potential interventions and their location using the measure cards or have a passive attitude. Each group could only select two measure cards as part of the preferred strategy. The final negotiation of the preferred strategy was performed by a representative of each group. Support by an academic or technician could be asked if additional technical and scientific knowledge was needed during the decision-making process.

5.3.3 Evaluation Process

An evaluation of the model results relevant to participatory research of using Companion Modelling was performed. Three mechanisms were used for gathering data in the study: (i) project documents, (ii) semi-structured interviews, and (iii) focus groups. Two focus groups were used to challenge data previously collected via face-to-face interviews on WRM policies, planning and implementation. It was also used to evaluate group dynamics (e.g. group norms, language, interactions and narratives) (Gill et al., 2008). The three main questions asked were: (i) what are the key water management issues your organisation is facing as well as the successes and future needs in terms of IWRM implementation and stakeholder engagement? (ii) how can modelling tools, such as RIBASIM and the Water

Framework Explorer, support you addressing these issues and needs?, and (iii) how can the combination of modelling tools and local knowledge support the management of water related issues in the Büyük Menderes River Basin?. Some post-interviews with decision-makers and investment banks were conducted after the focus groups to clarify some of the data. The data collected served for designing the participatory modelling approach and adapt it to the local conditions.

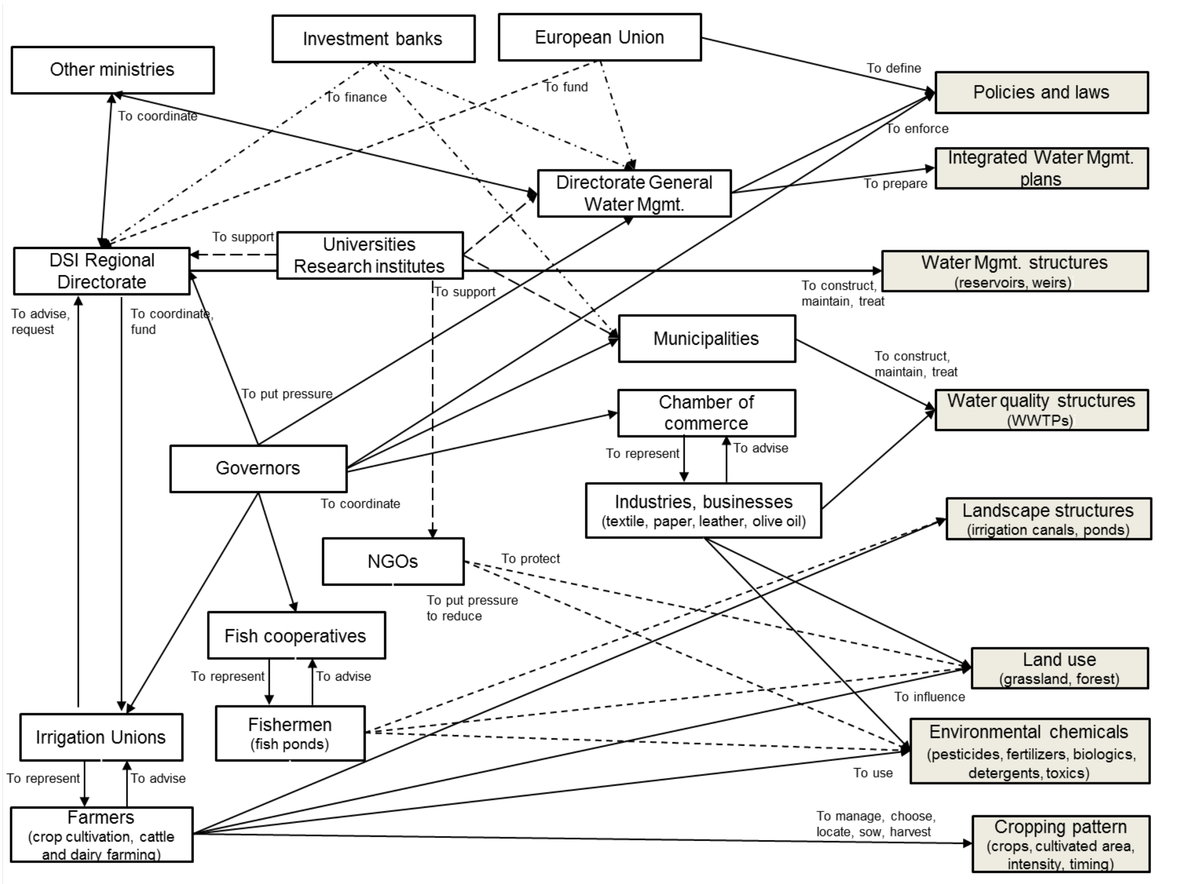


Figure 5.5 Diagram of interactions of Büyük Menderes river basin

5.3.4 Results and Discussion of the Evaluation Process

Creating an Enabling Environment

The interactive setup of the stakeholder sessions surprised the majority of stakeholders, as they were expecting the commonly used formal meetings. Decision-makers had serious concerns regarding the active involvement of local stakeholders in the modelling and planning processes, due to the frequent criticism and rejection received on their policies. They initially disapproved having NGOs as part of the organising team. Moreover, the use of role-playing games in formal planning and management processes was not well perceived. The approach got finally accepted after a 2-month negotiation process between decision-makers and the organising team. It was agreed that a pacification strategy (Hanssen et al., 2009) would be followed: uncertainties about the socio-physical system would be first reduced, and the shared understanding about the system would be then used to reach consensus among stakeholders. In practice, the co-construction process with Circle A stakeholders prior to the role-playing game sessions was critical for ensuring that the model was trusted by the national authorities and therefore more interactive sessions with local stakeholders could be held.

Accepted Representation of the Real System

The competitive environment in Turkey, in which certain governmental authorities and stakeholders have similar responsibilities, creates tensions and leads to unilateral action. Disputes also occur due to disagreements regarding values, norms and standards or perceptions of the water resources system in Büyük Menderes river basin. The establishment of a common ground accepted by all involved stakeholders was a critical first step in the negotiation process. The adapted Companion Modelling approach was used to enhance multi-stakeholder cooperation between national and regional stakeholders, and between sectors and disciplines by means of non-strategic scientific support. Having independent technicians and scientists in the organising team and the co-development of "complex" simulation models with stakeholders helped in raising their acceptance in the scientific support received. However, having an agreed representation of the real socio-physical system was essential for creating a common ground. The models and their outputs needed to be considered by all stakeholders as being neutral. The role-playing game needed to be accepted as a tool that can be used in formal decision-making processes. A comparison between the results of the simulation models (i.e. RIBASIM and WFD Explorer) and the mental models of the national and regional stakeholders was thus required. The model outputs showed that the water quality status, considering COD, suspended solids, Tot-N and Tot-P, is particularly "bad" downstream and in urban and industrial areas (e.g. Denizli) (Figure 5.6). This assessment was in line with the expectations of national stakeholders. These results can be understood by the fact that the majority of them had been involved in the construction of the quantitative model. More variation could be observed between the mental models of the regional stakeholders and the results the WFD Explorer model regarding the principal physical issues in the basin. All expressed water stress and poor water quality as the principal physical issues. However, the specific issues, including their geo-spatial location, pressures and environmental impacts were barely known. Two small group facilitators from Nature Conservation Centre recognised the benefits of using maps to display the outputs of the WFD Explorer during the discussions. National and regional stakeholders collaborated to understand the pressures in each region and the impacts in terms of water availability and quality. For instance, industrial effluents combined with the not adequate consideration of environmental flow requirements were identified as major pollution pressures in Denizli and downstream areas (e.g. Kuyucak, Buharken). The bad practices of farmers regarding management of manure, use of fertilizers and pesticides also exacerbates water pollution downstream Denizli and Aydin.

After the creation of a general consensus regarding the water quality status in the Büyük Menderes river basin, stakeholders collaborated in the validation of the WFD explorer model and the formulation of possible future improvements. This step was particularly important to commence a collaborative attitude among stakeholders. Possible future improvements identified include: (i) collection of more continuous data sets at the same location and by better validating data for improving the quality of discharge monitoring, (ii) addition of data on irrigation areas, hydropower generation and demand, and domestic water demand and supply, (iii) collection of "updated" reservoir operation rules, as well as, (iv) collect data on monthly inflow, outflow and levels of all reservoirs. The evaluation of the negotiation process shows that all 59 stakeholders (i.e. Circle B) felt confident that their knowledge was taken into account for the construction and validation of the models. They indicated that the open and transparent process helped in building trust towards the data, models used and in creating an agreed representation of the real system. Particularly regional stakeholders recognised that the adapted Companion Modelling approach helped them to get a better insight in the functioning of the river basin.

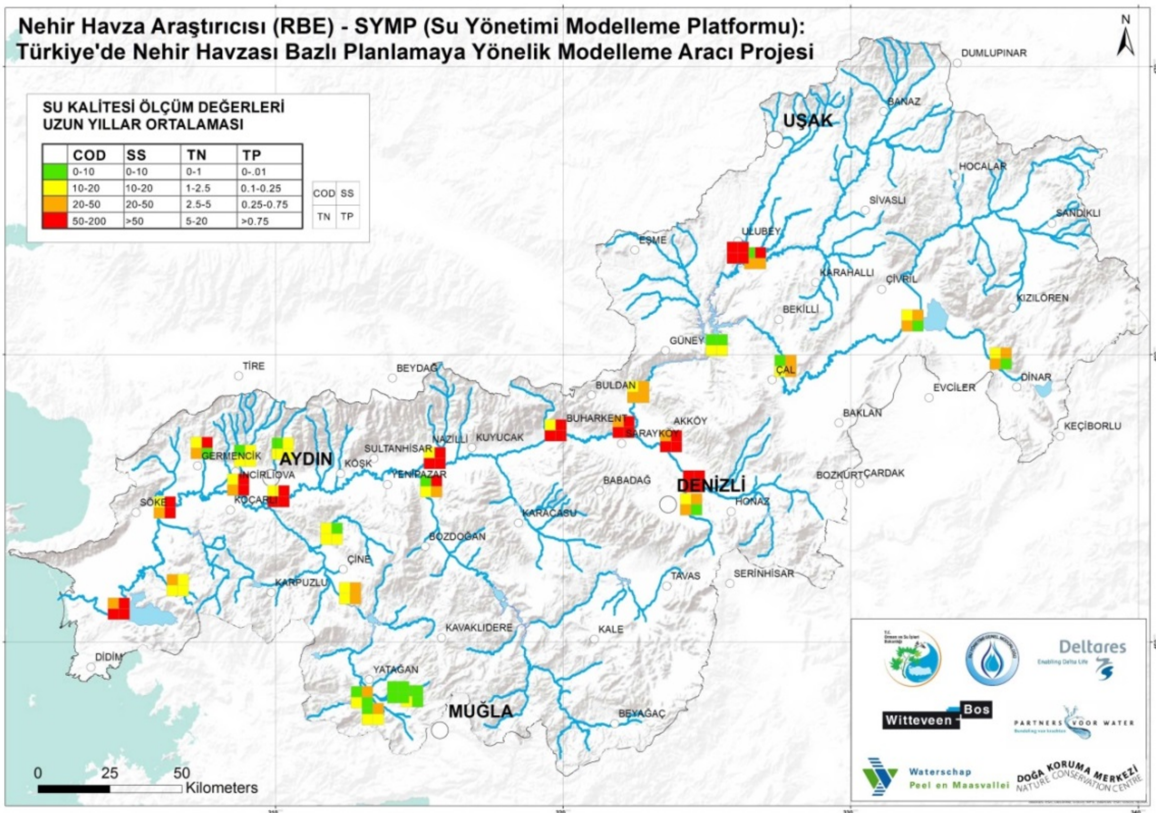


Figure 5.6 *Water quality status for Büyük Menderes river basin obtained from WFD Explorer*

Shared Understanding of the Social and Institutional Dimension

Understanding the social and institutional dimension was essential for the creation of the enabling conditions and a common ground for cooperation, and as a result the role-playing game. This was done during the capacity development session where stakeholders were asked to jointly explore the successes, limitations and needs of the social and institutional aspects of IWRM in Turkey. Key was the division of participants in heterogeneous small groups, as it facilitated their knowledge exchange and interaction. The organising team recognised that such cooperation could not have been achieved without having ensured first a shared understanding of the physical system (i.e. pacification strategy).

Stakeholders from Circles A and B identified limiting factors that have a direct effect on the physical issues. The lack of qualified personnel that knows how to use modelling and socio-economic impact assessment tools in the national and regional levels is a key challenge. The Directorate General on Water Management and other ministries recognised that the national funds allocated to IWRM and the access to international financial mechanisms has increased in the last decade. However, the lack of evidence-based solutions and investment plans slows the implementation process. Bad water governance characterised by insufficient cooperation among institutions and stakeholders also hampers the decision-making process. Finally, stakeholders from Circles A and B recognised the important role that local stakeholders have in the implementation and O&M of measures to ensure their sustainability. However, the lack of support, national stakeholder engagement protocols and limited technical knowledge in the basin are main shortcomings. Sometimes the lack of commitment of local stakeholders translates into their non-continuous involvement or reduction of their involvement throughout the project. This statement was contested by local stakeholders. They argued that often they are barely involved. They are only informed or consulted when the national stakeholders consider it necessary.

Collective Negotiation Agreement of a Water Quality Strategy

The impact of applying Companion Modelling in comparison with a pure traditional top-down planning approach is reflected in the formulation of measures by decision-makers and stakeholders. While traditionally a large portion of both national and regional funds was allocated to infrastructural projects, the proposed interventions are a combination of infrastructural, soft and institutional measures. The negotiation process for selecting potential measures during the role-playing game followed four cyclical steps: (i) prioritisation of three main challenges related to the water status in Büyük Menderes river basin, (ii) definition of main ambitions and goals, (iii) selection of two potential measures, and (iv) impact assessment using WFD Explorer.

For the collective formulation and selection of measures, stakeholders worked in small homogeneous small groups for the upstream region of Büyük Menderes river basin. These were then merged into heterogeneous groups for the downstream region. Each small group had the freedom to define their own goals and preferences on which they were choosing the proposed measures. No significant variations appeared in the identification of main issues and challenges across groups. The use of homogeneous and heterogeneous groups also did not have a significant influence. This agreement shows the benefits of the prior step to create a common ground. As a result, there was a cooperative environment in the next step, the selection of potential measures. For the upstream region, all small groups selected a combination of infrastructural and soft measures. Particularly, all groups selected the construction of a WWTP. Differences appeared in the selection of the soft measure. The group composed of representatives from the national government did not follow the rules of the game, and selected two soft measures (three measures in total). However, the other groups did not complain. The selected measures included the enforcement of improved management of manure and training for farmers on good agricultural practices. The other two small groups composed mainly by representatives of regional stakeholders selected the treatment of drainage water of farming and agriculture and training on clean production technologies in textile factories. The commodian asked then a representative of each small group to form a temporary multi-stakeholder advisory committee and negotiate a preferred strategy composed of three measures. The committee had 10 minutes to negotiate. No agreement could be reached after the designated time. It was then agreed that another 10 minutes would be added to the negotiation process. The commission did not follow the rules of the game. They decided to select another measure that had not been previously selected by the small groups: Training for farmers on good agricultural practices. Moreover, they could not agree in the selection of only three measures. As a result, the preferred strategy for the upstream region is composed of four measures. The preferred strategy was then assessed using the WFD Explorer. In the application of the role-playing game for the downstream region in heterogeneous groups differences in dependencies and hierarchical relations became more apparent. The representatives of the national stakeholders assumed a leading role. The involvement of the irrigation unions and fish cooperatives reduced gradually. The final negotiation for the preferred strategy was held by a representative of the DSI Regional Directorate (Figure 5.5) and of a local university. In this case, an agreement could be reached in the established time (10 minutes). The resulting strategy, after its assessment using the simulation model, comprised also a combination of an infrastructural and a soft measure: construction of an advanced WWTP in an industrial area, and the reallocation of the olive oil industry into an industrial zone with a WWTP.

5.4 Application Example 2: Surabaya Watershed Water Quality Study

5.4.1 Study Area

In Indonesia, water quality is categorised as poor. Domestic sewage, solid waste disposal, industrial effluents and inappropriate land use are identified as the primary pollution pressures (ADB, 2016b). According to the Indonesian Ministry of Environment (2013), approx. 14,000 tons of human excrement is left improperly treated on a daily basis. Only 34% of the water is treated in WWTPs in urban settings (ADB, 2015). On Java, industrial waste water has decreased in quality in the last decades. One last example is that the number of critical watershed areas is also rising rapidly, being Java, Sumatra and Kalimantan the most affected regions. Bad water quality combined with a disturbed hydrological cycle can be a significant source of health problems. The various measures undertaken by the Indonesian Government demonstrate however its commitment towards improving water quality in Indonesia, and to achieve SDG Targets 6.3 and 6.6 by 2030. An example is the increased number of septic tanks in households (40.67 % in 2006; 60.33% in 2011) (Ministry of Environment, 2013). The national government recognises that besides structural and institutional measures, a change in behaviour is of crucial importance to save the environment in Indonesia. These facts reveal that managing water quality and sustainably protecting the ecosystem requires the active engagement of different stakeholder groups and their ownership in the agreed solutions, as well as the use of data, assessment models and monitoring tools.

The Surabaya watershed is the delta catchment area of the Brantas river basin (Figure 5.7). Surabaya city, the capital of East Java, is located in this watershed. Brantas river basin has an approximate area of 11,800 km2 and it is located in East Java province. Population in Brantas basin has increased rapidly from 8.37 million (1960) to 16 million (2008) from which Surabaya counts for approximately 2.5 million. The Brantas river originates from the Arjuno volcanic massif and the mainstream traverses nine regencies and five municipalities (Valiant, 2013). Downstream, Brantas River is divided into two branches after the Mlirip gate: the Surabaya and Porong rivers. The basin has a tropical monsoon climate and an average rainfall of 4300 mm/year. Agriculture is the main livelihood activity in the region. Rice production in the Brantas basin represents 30% of East Java total rice production

(Blomquist et al., 2005). Surabaya is also an important industrial hub for domestic trade. Surabaya city together with Malang city contributes up to 50% of the gross domestic product of East Java province (Kemper et al., 2007). However, pollution coming from upstream developments, improper use of pesticides, rapid urbanisation and industrialisation of the Surabaya region has a significant impact on the water quality. Water quality in downstream areas is categorised as poor. BOD concentrations range from 10-20 mg/l in the Surabaya River while upstream BOD varies from 8-15 mg/l. Unfortunately, the situation is exacerbated during dry periods when water stress occurs (Usman, 2000). Besides the negative environmental effects, water quality is another source of disputes among stakeholders. An illustrative example is that industries and local communities have continuous arguments on who should pay for the water pollution.

The overall problem in Surabaya watershed can be categorised as unstructured (Hommes, 2008), as there are significant disagreements between stakeholders caused partly due to a limited knowledge about the system.

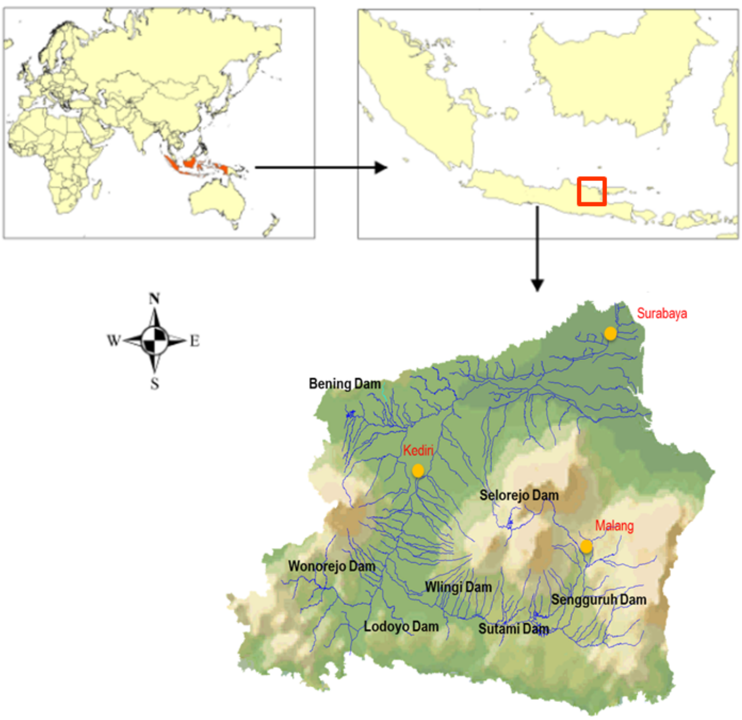


Figure 5.7 Surabaya watershed (adapted from: Subijanto, 2015)

5.4.2 Adapted Approach

Specific Use

Managing water quality in Indonesia follows the regulation No. 82/2001 (i.e. management of water quality and control over water pollution). It defines four water quality classes ranging from standard drinking water (Class 1), water usable for recreational purposes, hot-water fish cultivation and animal husbandry (Class 2), water usable for agriculture and farming (Class 3) and, lastly water usable for irrigation (Class 4). Today water quality in Surabaya watershed is classified as class 3. The regional WRM authorities aim to improve water quality from class 3 (BOD <=6 mg/L) to class 2 (BOD<=3 mg/L). The expected output of applying a participatory modelling approach was an increased consensus for joint action to reach this water quality goal in the Surabaya.

Considering that the adapted Companion Modelling approach targets mainly decision makers and local stakeholders with minimal literacy, technical knowledge and skills (Section 5.2), another approach was required to also engage those stakeholders at the grassroots level, i.e. local community members. Therefore the adapted approach applied in this case combined the use of participatory modelling, by means of Companion Modelling combined with simulation modelling (Section 5.2), and the negotiated approach, developed by Both Ends and Gomukh Environmental Trust (2011). The combination of participatory modelling and the Negotiated Approach had the primary purpose to transform the non-cooperative environment into a dialogue platform that would facilitate dialogue among stakeholders, especially by reducing their disputes regarding the system and water quality situation. This would create the basis for the collective action required to reach the water quality goal in the future.

The Negotiated Approach

The negotiated approach helps in empowering local communities through a long term involvement in all aspects of WRM practices (Both Ends and Gomukh Environmental Trust, 2011). It conceives participation as a process of negotiation. Negotiation is viewed as a creative interactive process that encourages innovation and change. Improving decision-making processes goes hand in hand with recognizing the (sometimes conflicting) interests and perceptions of all stakeholders, including disadvantaged groups, and considering their local knowledge, practices and experiences. The negotiated approach guideline highlights that "The negotiations consist of a dialogue intended to resolve disputes and to reach agreements on courses of action. To make such an approach successful in reaching win–win situations requires an open, although carefully structured process and a paradigm shift in the thinking of all stakeholders" (Both Ends and Gomukh Environmental Trust, 2011). The approach defines seven main tasks for empowering local communities so they are able to participate in the planning and decision-making process. These tasks are in line with the IWRM principles and planning cycle (GWP, 2000; Van Beek and Arriens, 2014), and are the following: (i) preparing the process, (ii) reaching and maintaining agreement on the design of the process, (iii) joint fact-finding and situation analysis (problem analysis), (iv) identifying and analysing possible solutions, (v) forging agreement, (vi) representatives communicating with their constituencies, (vii) monitoring implementation of agreements; and (viii) strengthening the capacity of participants.

Capacity development and negotiation support though join data collection are critical elements of the negotiated approach applied in the Surabaya watershed case. The livelihood analysis and activity analysis were used as part of the approach to engage stakeholders, detect water-related problems, defining needs and possible implementing solutions based on their perceptions and knowledge, especially those of local communities and the surrounding industries. These are tools commonly used at the early stages of the negotiation approach (Mustikasari, 2011). The well-being of community members, their vulnerability and capacity to cope with adversities, and their strategies towards water issues were investigated using a livelihood analysis. Its process followed seven steps: (i) identification of vulnerable groups, (ii) formulation of relevant issues and information desired, (iii) composition of questionnaires and training of enumerators, (iv) sample selection and interviews, (v) elaboration, (vi) summary and conclusion, and (vii) a focus group discussion. A more quantitative activity analysis was then performed to study the production processes of the main industries based on a selection of critical activities in the area. Field surveys, literature review and consultations with technical experts were used for collecting information. This process ultimately helped in creating a multi-stakeholder dialogue between local communities and the private sector.

Stakeholder Engagement Structure

The stakeholder engagement process included the main components of the adapted Companion Modelling approach. It incorporated various loops for individual and collective learning (Étienne, 2013), and all stakeholders had a similar level of participation. The outputs from the livelihood analysis and activity analysis served to build a diagram of interactions that illustrated the interactions between stakeholders and resources or among stakeholders (Figure 5.8). Main stakeholders are presented with white boxes. Resources are displayed on the right side as grey boxes. The interactions between stakeholders and between stakeholders and resources are illustrated with arrow. The type of action is indicated for each arrow. Results from the livelihood analysis and activities analysis were also used to construct the role-playing game.

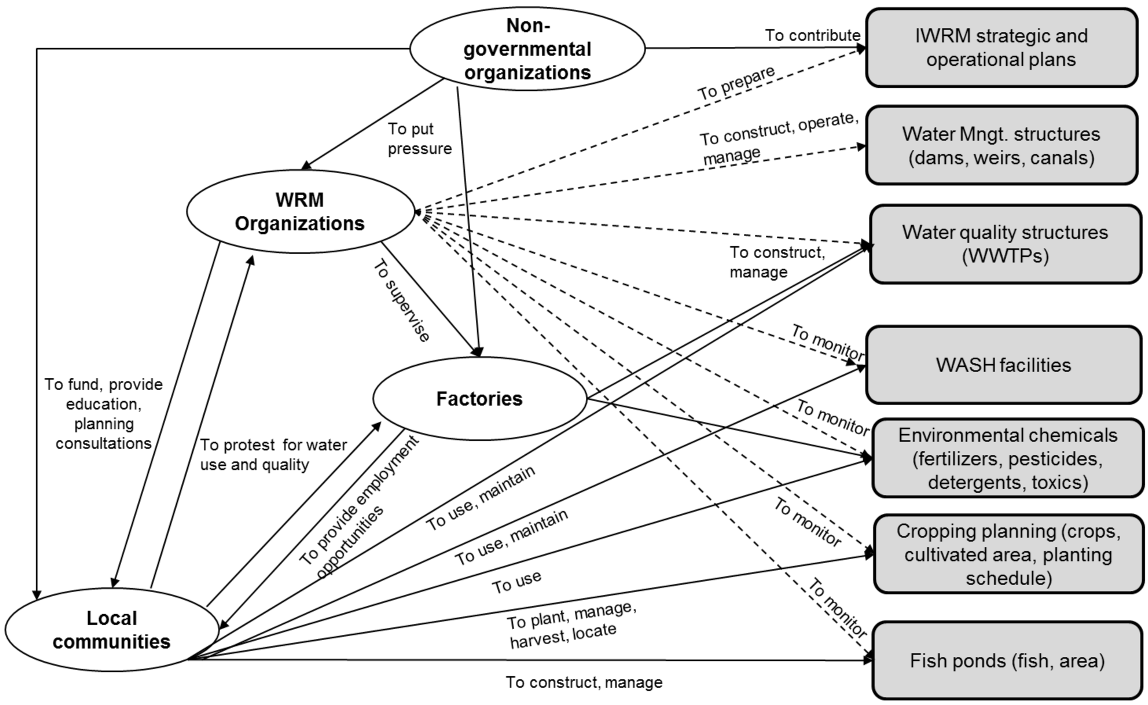


Figure 5.8 Extract of diagram of interactions of Surabaya watershed

Four stakeholder groups were involved in the Surabaya watershed study. These included: local communities, industries, NGOs, dam operators and regional water authorities. A total of 40 stakeholder representatives actively participated in the 10-month study. The selection of participants was based on the outcomes from the Livelihood Analysis and Activities

Analysis and the multi-agent systems model. The following selection criteria were considered:

1. More than 30 industries are located along the Surabaya river and its tributaries. Their selection for this study was based on the following criteria: scale, employment capacity and historical discharge quality data availability.
2. Selection of communities was based on these criteria: vulnerability and willingness to participate. Selected communities were: Balongbendo, Penambangan, Cangkring Anglers, Paguyuban Warge Stren, Wonorejo and Bogempinggir. Two requirements were considered for the selection of participants for the role-playing games: (i) they have basic knowledge in local water quality problems (commonly village administrators), and (ii) not afraid of speaking up during the sessions.
3. Selected operators and water management authorities included: Jasa Tirta 1, EPA, BBWS public water supply company and governors.

The stakeholder engagement process is displayed in Table 5.3. It considers the timing of participation and the levels of participation for each stakeholder group as structuring elements.

Modelling Approach

The participatory modelling approach for the Surabaya watershed incorporated three main elements: A quick Scan model (i.e. MS Excel), a complex simulation model (i.e. RIBASIM) and a role playing game.

Computer-based Simulation Models

The step-wise simulation modelling approach commenced with the use of Google Earth Engine (GEE) combined with a simple MS Excel quick scan model and evolved towards a complex water balance and quality simulation model using RIBASIM.

A simplified model for performing a quick scan of the system (i.e. water availability and quality) was co-developed jointly with local stakeholders. GEE was used as the geographic information system. Locations of main infrastructures, water users and sources of pollution (i.e. point and diffuse sources) were identified using the model.

Table 5.3 Stakeholder engagement structure for Surabaya watershed study based on levels of participation and modelling phases. The table uses a set of abbreviations. The Village names are Balongbendo (Ba), Penambangan (Pe), Cangkring (Ca), Anglers (An), Paguyuban Warge Stren (Pa), Wonorejo (Wo), and Bogempinggir (Bo). Industries names are PT. Adiprima Surabaya (AS), PT. Mountain Dream (MD), PG. Gempol Kreb (GK), PT. Alu Aksara Pratama (AAP), PT Wings Suraya (WS), PT. Surabaya Metabox (SM), PT. Suparama (Su), and PT. Miwon (Mi).

Level of participation	Timing of participation (modelling phases)					
	Data Collection	Model Identification	Model Construction	Model Verification & Validation	Model use	Measures Formulation & Strategy Design
Ignorance						
Awareness						
Information			An, Pa, Wo, Bo AS, MD, AAP, WS, SM, Su, Mi			
Consultation	Ba, Pe, Ca AS, MD, GK, AAP	All All All	ECOTON	An, Pa, Wo, Bo AS, MD, AAP, WS, SM, Su, Mi ECOTON, KLH All		
Discussion	ECOTON	ECOTON			An, Pa, Wo, Bo AS, MD, AAP, WS, SM, Su, Mi ECOTON, KLH All	
Co-design						An, Pa, Wo, Bo AS, MD, AAP, WS, SM, Su, Mi ECOTON, KLH
Co-decision-making	All					All

Legend
- Local communities (green)
- Factories (blue)
- Non-governmental organizations (yellow)
- Operators and governmental authorities (purple)

A water balance and quality quick scan model using MS Excel software package was developed with these input data. The model provided monthly information regarding water consumption, BOD concentrations and environmental flows in the selected locations. The experience with the MS Excel quick scan model was used to develop the more complex simulation model. RIBASIM model package (van der Krogt and Boccalon, 2013) was used for further developing the hydrological relations for water availability and allocation, as well as water quality (i.e. BOD concentrations).

Due to water quality data scarcity, the simulation model was constructed with historical data from 2010 to 2014 with a monthly time step. Hydrological data was based on observed discharges, water levels and Mlirip dam operation rules. This information was obtained from Jasa Tirta 1 organisation. This semi-public organisation is responsible for the management of the Brantas watershed (flood control, water quantity and quality monitoring, construction and O&M of structural measures). The model is composed of irrigation, fishpond, public water supply and general district nodes. Their location was obtained from GEE. Only major farming areas in the Brantas Delta that are supplied from irrigation canals were included in the model. Smallholder farms could not be included due to lack of historical data. The same approach was followed for fisheries. Domestic and municipal public water supply for Gresik and Surabaya urban and peri-urban areas were considered for the study. A total of nine industrial areas were selected for the model. These included those dedicated to the production of food, soap and detergents, paper and building materials. Existing infrastructural facilities such as dams, bifurcations, flood control and barrages were also included in the model. Water quality data in the Mlirip reservoir and the industrial hub was based on monitored BOD concentrations provided by EPA (institution responsible for maintaining and improving the water quality in Surabaya watershed) and BBWS Brantas (public authority responsible for IWRM in Brantas basin). Estimations based on literature were made for domestic and irrigation waste water (Bohl et al., 2002; Fuhrmeister et al., 2015).

The Surabaya River Game

The role-playing game had three primary objectives: (i) reduce disputes among stakeholders by collectively understanding stakeholders' perceptions, behaviours, positions, concerns and interests regarding the watershed issues in the basin, (ii) facilitate the exchange of points of view, knowledge and experiences, and initiate collective learning (required for building a common negotiation ground), and (iii) build trust on the simulation models and designed strategies. The game was composed of four elements: environmental settings, player components, rules of operation and input to the game (Eden and Ackermann, 2013). The environmental information described the physical system in the area (i.e. geography, morphology, hydraulics, hydrology and water quality). Information was extracted from the MS Excel and RIBASIM models; therefore, it showed the "real" problems in Surabaya watershed. The physical and social systems were connected to players (stakeholders) and their roles. The game comprised five players: communities, industries, PDAM (drinking water company), BBWS Brantas, Jasa Tirta 1 and EPA. Game cards were distributed to assign roles to participants. However, governors, operators and selected stakeholders maintained their "real" roles, to ensure a good connection with the "real" social and institutional systems. The game also incorporated specific tools for information visualisation, player interaction and records. A laptop was used to introduce the role-playing game, running the simulation models and presenting their simulation outputs. Information was shared among participants using a projector and a screen. Game cards included function, financial resources and draw lots cards. Other material included a notebook and pens for taking notes of the stakeholders' dynamics during the session.

The rules of the game reflected the institutional structures and social relations in reality (Figure 5.8). It was designed to be open, transparent and autonomous. At the beginning of the game, participants shared their roles. They had the freedom to have an active or somewhat passive attitude during the game. They could explain their positions and interests, and propose potential actions using function cards. Communities could propose appropriate interventions to the management players using demonstration cards. They were also able to contest proposed measures from other players using the same demonstration cards. Some function cards were limited by the hydrological conditions in the system, which varied in each round after running the simulation model. For instance, the flushing river card could only be used if the water storage in the Mlirip dam had reached its threshold level and opening the gates would not cause floods downstream. Finally, the approval of interventions was constrained by the budget available. An investment plan needed to be formulated, discussed and agreed before a preferred strategy would be approved.

Organising Team and Means

The organising team comprised a commodian (referring to the individual specialised in Companion Modelling), the international non-governmental organisation (i.e. Both Ends), the local non-governmental organisation (i.e. ECOTON), and Jasa Tirta 1 organisation. The commodian was responsible for designing and applying the adapted Companion Modelling approach as well as responsible for the modelling. Both Ends provided guidance on the concept of the Negotiated Approach and its application. ECOTON applied the negotiated approach in the Brantas basin. As part of the implementation of the Negotiated Approach, ECOTON played an essential role in performing all field activities (e.g. livelihood analysis and activity analysis) with the commodian, providing local knowledge about the Surabaya watershed, engaging the different stakeholder groups and leading the stakeholder engagement sessions. Finally, Jasa Tirta 1, was responsible for informing about the governmental policies and practices regarding water quality in the region.

The study was ten months in duration. It commenced in March 2015 and finalised in January 2016. The total budget allocated to conduct the research study was 15,000 EUR.

5.4.4 Results and Discussion of the Evaluation Process

Real World Representation and Shared Understanding of the System

The participatory modelling approach helped to create a common ground for the negotiation process on how to manage the water quality in the watershed sustainably and inclusively. Modelling results suggest that the water status in Surabaya watershed is not functional. The average BOD concentrations in three different locations of the watershed are 5.8 mg/l (see baseline graph in Figure 5.9). All stakeholders agreed that the water status in the watershed was not good and that their actions might contribute to it. Community members recognised their limited knowledge on water quality issues and the inter-linkages with their daily life actions. For instance, they recognised that they were not aware of the effects throwing domestic waste into the river had on health and pollution of water for downstream users. They also admitted their insufficient knowledge in maintaining WWTPs, which explains the low performance of small WWTPs in the region. Industry representatives identified their lack of technical expertise as the leading cause of water pollution. Both stakeholder groups agreed that the lack of knowledge was a significant barrier to their involvement in processes of planning and decision-making. Although dialogue platforms exist in Surabaya watershed, the level of participation of local communities and factories is low. Following Choguill (1996) ladder of community participation, local participation can be categorised as "diplomacy". The participation of industries is even a level lower, "informing". Dam operators and regional water authorities identified three additional issues: (i) poor maintenance of sanitation facilities by local communities, (ii) limited budget for watershed management, and (iii) complexity of organising communities living at the riverbank. The poor maintenance of sanitation facilities caused a reduction of investments in new facilities. Limited national and regional budget is allocated to environmental protection and ecosystem conservation. Local authorities face therefore major difficulties in the implementation of green solutions. Finally, numerous large communities live on the riverbank. They do not only have a negative impact on water quality due to solid disposal into the river, but they also suffer from seasonal fluvial flooding and other disasters, and health problems. Re-allocation of those communities represents a major challenge for the regional government. By the end of the first role-playing session, all stakeholders had a shared understanding of the physical system as well as the main concerns and issues faced by all stakeholder groups. The organising team had a good understanding of the interactions and dynamics among stakeholders.

Stakeholder Response to Model Results: Identification of Water Quality Solutions

The gained knowledge of the socio-physical system during the first role-playing game session was reflected in the formulation of potential measures and the evaluation of their socio-economic and environmental impacts. For the first time all stakeholders recognised the need for a combination of institutional and physical measures, without leaving out integrated solutions that require the collaboration of various stakeholder groups.

The creation of a coalition against river pollution was conceived as a viable solution to strengthen the communication among stakeholders. The position of NGOs that allows them to work jointly with local communities, negotiate with industries and access decision-making processes makes them the most appropriate to take the role as mediators. Additionally, three physical measures were formulated to improve water quality from class 3 to class 2. These were: (i) construct four small WWTPs in areas near urban and industrial areas that should be O&M by local communities and industries, (ii) improve the performance of existing water treatment plants by updating its technology, and (iii) construct a large WWTP in the middle reach of Surabaya watershed or downstream. For all cases, it was stated that both local communities and industries should reduce their waste disposal up to 50%. The impact of these physical measures was evaluated using RIBASIM. Figure 5.9 displays the cases that were evaluated. The water quality results are shown for three locations in the watershed: a main industrial zone upstream, the Mas 4 outlet and the Wonokromo outlet.

The comparative impact assessment of the different cases shows that the co-construction of a large scale WWTP in the middle reach of Surabaya river is the most effective measure for reducing water pollution. The implementation of such measure requires, however, high capital expenditures and operating expenses. A study performed under the Surabaya Sewerage and Sanitation Development Program (SSDP) shows that the overall performance of existing large scales WWTPs cannot meet the design quality standards due to inadequate inlet maintenance, casual use of any additional land and pollutant overloading. Prihandrijanti et al. (2008) argue that instead, decentralised WWT systems are more feasible economically with a higher cost-benefit ratio. This ambiguity caused that, even though participants shared a common understanding of the status of water quality in the basin, an agreement for the preferred strategy could not be reached. A more extensive analysis and additional sessions were requested for the design of the preferred strategy.

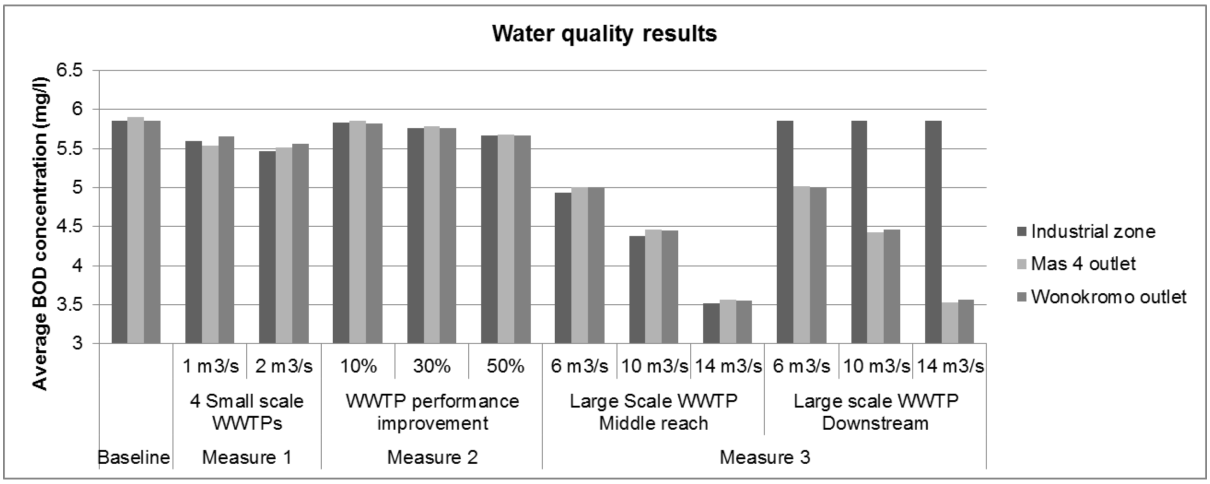


Figure 5.9 Water quality results of potential measures for Surabaya watershed

The Modelling Approach of Participatory Modelling

Data collection is frequently a bottle-neck in the modelling process, causing delays in model development. In many contexts, data is power. It is also frequent that a one-way data collection method is applied. Stakeholders are solely asked to provide data and are not involved in further modelling stages. For these reasons, decision-makers and stakeholders are often hesitant about sharing data. This also became apparent in this study. At the beginning of the study, when the organising team asked for data to decision-makers and stakeholders for the pre-construction of the role-playing game, this was rather incomplete. However, when they became aware of their further involvement in the development of the Ms Excel and RIBASIM models and during the role-playing game sessions for the formulation and selection of potential measures, they showed interest in sharing their knowledge and data to validate and improve the models. The participatory modelling approach thus helped in ensuring that data collection would not become a "bottle-neck" for the study. Moreover, selecting an appropriate time step for the role-playing game can become a challenge. The game rounds need to be sufficiently representative in the model simulations. If the time step is too short, many rounds will be required, which might cause that participants get bored. If the time step is too long, some system dynamics could be missed, such as impacts of wet-dry seasons or years. The selection of the game duration is recommended to be linked to a "real" planning process. In the Surabaya River game, the simulation period was five years, as it is the duration of the operational planning phase.

5.5 Method Evaluation and Key Features

The second method introduced in the previous sections of this chapter is evaluated using the analytical framework (Chapter 3). First, a comparative assessment between both applications, Turkey and Indonesia, is presented in Table 5.4. This is followed by a general evaluation of the method (Table 5.5), where key features are highlighted in orange..

The competitive interaction context where the method is applied requires the application of a participatory modelling approach. The low cooperation between involved stakeholders (i.e. unilateral action and ad hoc coordination) constraints the level of participation, at least at the early stages of the project. The key features of the new method:

- *Context:* Mainly suitable for unstructured problems characterized by high disagreements and disputes among stakeholders, normally caused by limited knowledge on the system.
- *Application*: It is applied in complex medium and large river basin systems. The basins are characterised by a poor water quality status, high urbanisation rates, data scarcity, complex institutional setups, power asymmetries between agencies and stakeholders, and reluctance to engage local stakeholders.

- *Specific use:* The primary purpose of this method is to enhance cooperation via collective reflection, collaborative learning and dispute resolution. When accomplished, the method supports the decision-making process by structuring collective action.
- *Modelling approach:* The method includes complex computer-based simulation models, a role-playing game and potentially an agent-based model. In contrast with "common" Companion Modelling, the approach does not make use of a created virtual world. Rather, the construction of the virtual world for the role-playing game is based on the "real" problems in the basin and potential interventions. The simplified rules and structure of the role-playing game help stakeholders to better understand the functioning of the "real" system in an easy manner. Human agent interactions, dynamics and resources are analysed using the outcomes of the role playing game. Computer-based simulations are mainly used for providing more detailed information about the physical system. Merging both outputs helps in having a shared representation of the socio-physical systems and their interactions.
- *Stakeholder engagement:* The method is designed to be used in top-down and bottom-up planning processes. The ARDI method helps structuring the stakeholder engagement process. This needs to be adapted considering the planning process followed. In bottom-up processes, a similar level of participation for all stakeholders is encouraged. In large river basins, a more top-down approach is frequently applied, due to its complexity and the large number of stakeholder groups. In these cases, structuring stakeholder participation and negotiation process is recommended (e.g. circles of influence). The use of the Negotiated Approach, in combination with the participatory modelling approach, is recommended when involving disadvantaged groups (e.g. local communities) with low literacy and none or limited technical skills..

Table 5.4 Assessment of the Companion Modelling approach applied in Turkey and Indonesia

Factors	Parameters		Büyük Menderes case Turkey	Surabaya case Indonesia
Context and application	Problem type	Problem structure Scale of action Time horizon	Semi-structured Regional Medium term	Semi-structured Regional Medium term
	Domain		Integrated River Basin planning	Watershed management (water availability and quality)
	Interaction context	Cooperative Competitive	Competitive	Competitive
Specific use	Participatory/ Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	Primary purpose: Enhanced cooperation Secondary purposes: Model improvement and collaborative learning	Primary purpose: Enhanced cooperation Secondary purposes: Collaborative learning
	Planning/Management cycle phase		Early stages of the planning and decision making process	Early stages of the planning and decision making process
Information handling	Model characterisation	Model system focus Model type	Socio-physical system models Analytical models	Socio-physical system models Analytical models
	Modelling tool / Software platform		Combination of hydrology and water quality models, MAS and role-playing game	Combination of hydrology and water quality models, MAS and role-playing game
	Information type		Combination of system interactions and complex processes	Combination of system interactions and complex processes
	Information delivery medium	Virtual/web Face-to-face	Face-to-face	Face-to-face
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Participatory	Participatory
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	National ministries, regional governmental agencies, universities, private sector, farmers and fisheries cooperatives	Local communities, industries, regional governmental agencies
	Model users	Direct/Indirect Technical skills	Indirect Relatively high technical skills	Mainly indirect. Universities were direct users. Low technical skills
	Participation mode	Only modellers (no participation) Individuals Groups	Varying from only modellers and groups. Homogeneous groups for model construction (ecology and hydrology) and Heterogeneous groups for model use.	Varying from only modellers and heterogeneous groups.
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	(Figure 5.3) Circle A: up to co-design Circle B: up to discussion	Participatory modelling is combined with the negotiated approach for empowering local communities, so they can have a similar participation than other stakeholders (Table 5.3)
	Timing of participation	Data collection Model definition Model construction Model validation Model use Measure formulation Strategy design	Up to model use (tested using measures; however, further development is required for using it in decision making processes)	Up to measure formulation (tested using measures; however, further development is required for using it in decision making processes)
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Unilateral action and coordination (See interactions in Figure 5.5)	Unilateral action and coordination (See interactions in Figure 5.8)
Modelling / organising team	Team		The team included a hydrology and ecology modelling teams and an organizing/ participatory modelling team	The team included a hydrologist, ComMod modeller, Negotiated Approach facilitator
Means	Timing		16 months	10 months
	Financial resources		400k EUR (upscaling project)	15k EUR (pilot project)

Table 5.5 Evaluation of the Adapted Companion Modelling approach

Factors	Parameters		Adapted Companion Modelling
Context and application	Problem type	Problem structure Scale of action Time horizon	Unstructured Medium and large river basins Short or medium terms
	Domain		Integration of domains related to complex basin management
	Interaction context	Cooperative Competitive	Competitive Stakeholders commonly have conflict of interests. In cases where there is a cooperative context, ComMod helps collective action (primary purpose) by reducing the existing conflicts among stakeholders.
Specific use	Participatory/ Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Enhance cooperation via collective reflection, collaborative learning and dispute resolution. *Secondary purposes:* Support of the decision-making process with collective action.
	Planning/Management cycle phase		Early phases of the planning cycle
Information handling	Model characterisation	Model system focus Model type	Socio-physical system models Analytical models
	Modelling tool / Software platform		Include: (i) complex computer-based simulation models, (ii) role-playing game (the virtual world represents the real system, problems and stakeholders) and (iii) an Agent-based model.
	Information type		Combination of system interactions and complex processes
	Information delivery medium	Virtual/web Face-to-face	Face-to-face Virtual platforms are sometimes used, mainly for interactive computer simulation sessions.
Stakeholder involvement structure	Participatory method	Participatory Collaborative	**Participatory modelling**
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	ARDI method followed Local stakeholders, economic bodies, regional authorities, universities and research institutes and NGOs
	Model users	Direct/Indirect Technical skills	Stakeholders are direct users during the role-playing game and the development of the model. Users can be direct or indirect when using the computer-based simulation model.
	Participation mode	Only modellers (no participation) Individuals Groups	Combination of all participation modes
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	In bottom-up processes, a similar level of participation for all stakeholders is encouraged. In large river basins, a more top-down approach is frequently applied, due to its complexity and the large number of stakeholder groups. In these cases, structuring stakeholder participation and negotiation process is recommended (e.g. circles of influence).
	Timing of participation	Data collection Model definition Model construction Model validation Model use Measure formulation Strategy design	All
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Low cooperation (mainly coordination)
Modelling / organising team	Team		Commodians, researchers and academics and NGOs
Means	Timing		2-5 years (average)
	Financial resources		More resources required than the "common" ComMod

5.6 Conclusions

In this chapter, the appropriateness of an adapted participatory modelling method that combines the key features of Companion Modelling and simulation modelling was demonstrated. The key features of Companion Modelling approach when applied to WRM were first presented. An exploration of ten cases using six parameters (i.e. context and application, specific use, information handling, stakeholder involvement structure, organising team and means) was performed. These key features were then applied for the design of an adapted Companion Modelling approach that uses also simulation modelling for enhancing multi-stakeholder collaboration in complex river basins. The approach is applied in a top-down water quality planning process in Turkey and a bottom-up process in Indonesia. The study uses the continuous involvement of stakeholders in the modelling process to support the creation of a common understanding of the river basin system (collaborative learning). This is particularly critical for creating a common ground for the negotiation process. Cooperation among participants increased as they gradually learnt about the perceptions, behaviours, positions, interests of other stakeholders. The co-construction and use of two simulation models for the physical system in combination with a role-playing game helps to build trust of the simulation models and the results, and understand the interaction and dynamics among stakeholders. Ultimately, the process can lead to collective exploration of water management strategies. By the end of the process in Turkey, a set of potential interventions was collectively formulated and their impacts in water quality analysed using the simulation models. The construction of WWTPs in combination with technical trainings and institutional measures are the most accepted solutions for achieving water security and sustainable development in the basin. More detailed technical and investments analysis is however expected. In the case in Indonesia, the use of the negotiated approach for empowering local communities in combination with the participatory modelling approach that combined a quick scan, a complex simulation model and role-playing game helped in actively engaging stakeholders in the modelling process, regardless of their differences in technical knowledge, background and skills. For local stakeholders, the approach created a neutral environment and knowledge exchange platform. This helped them gain a better understanding of the roles and responsibilities of decision-makers and other stakeholders, their concerns, positions and interests. It also facilitated changes in perceptions, mental models and behaviours of governmental authorities regarding the potential benefits of involving local communities and the private sector in watershed management.

Overall, the participatory modelling method illustrated in this chapter helps improving water quality and the protection and restoration of ecosystems by transforming non-cooperative environments into multi-stakeholder cooperation contexts with the support of modelling tools.

6

FAST INTEGRATED SYSTEMS MODELLING FOR PROJECT PRIORITISATION

In this chapter the third collaborative modelling method, namely Fast Integrated Systems Modelling (FISM), is described as part of Research Question 3: *How can participatory and collaborative modelling approaches be applied with existing and newly developed computer-based simulation models?* The approach is applied in Bangladesh. The approach is followed for constructing a FISM model in a collaborative modelling way as part of the development of the Bangladesh Delta Plan 2100. The results of the evaluation are presented in Chapter 8.

This chapter is based on:

Basco-Carrera L, van Beek E, van Deursen W.P.A, Slager K, Al Hossain B.M.T, Oliemans W, Choudhury G.A, Haasnoot M. (2018) Fast Integrated Systems Modelling for Collaborative Decision Making under Uncertainty; the Bangladesh Delta Plan 2100 case. Environmental Software and Modelling (publication in progress)

6.1 Introduction

Water resource planners aim to achieving water security for their stakeholders. Planning includes analysing and communicating about uncertainty. The nature of uncertainty can be caused by an imperfection of knowledge about a system (i.e. epistemic uncertainty), due to the inherent variability or unpredictability of the system (i.e. ontological uncertainty) or when a certain quantification cannot get better with additional sampling (i.e. statistical uncertainty) (Refsgaard et al., 2007; Voinov et al., 2016; Walker et al., 2003). Epistemic uncertainty can be further classified as substantive, strategic and institutional (Bijlsma et al., 2011). Other authors consider ambiguity as another dimension in the nature of uncertainty (Brugnach et al., 2008; Dewulf et al., 2005).

Adaptive plans need to consider directions, extents and time frames of changes that in most cases are unknown. Magnitudes and directions of processes such as climate change and socio-economic developments are very uncertain. The planning for water resources management therefore needs to be a cross-domain concept that considers not only the physical system but also society as a whole. This needs to be addressed in a balanced and integrated analysis. Moreover, water is a substance that is moving through landscapes, countries and regions, without taking notice of artificial borders. This means that interventions in one location in a water system can have positive or severe implications at other locations. Water being polluted upstream is less useful downstream, and flood retention upstream may decrease flood risk downstream, for instance. A good integrated water resources management (IWRM) plan needs to address this spatial inter-relation. The use of computer-based simulation models that describe the relations is therefore critical in IWRM. The formulation and integration of measures and the prioritization of investments are important steps in the planning process. They can condition the implementability of an IWRM plan. The acceptance of the preferred strategy and the commitment of national and local decision-makers and stakeholders to implement, monitor and evaluate the plan are critical. Therefore, the active engagement of decision-makers and stakeholders in planning and decision-making processes is imperative for developing sustainably (United Nations, 2016). However, when engaging stakeholders, planners and analysts need to consider how to communicate the uncertainty associated to the models they use in their analysis, models being just a representation of the real system. As Brugnach et al. (2007) indicates, today there is still a lack of confidence among policy makers to incorporate modelling information into policy formulation. Engaging different stakeholders in the modelling and planning process adds ambiguity, which is caused by many people having different views and beliefs (Brugnach et al., 2008; Dewulf et al., 2005; Voinov et al., 2016). Such reasons beg for the development and use of suitable methods and tools to address the different nature of uncertainty. They need to be able to (i) assess interventions, actions and their combination in pathways over time, (ii) translate scientific knowledge about uncertainties and models into readily digestible and trustworthy information, as well as to (iii) communicate this information to decision-makers and stakeholders. In fact, these are key requisites for strengthening decision-making and the implementation of robust adaptive IWRM plans.

Participatory and collaborative modelling has emerged to strengthen the collaboration between modellers, decision-makers and stakeholders to manage water resources in a more sustainable manner. This paradigm stresses the value of informed decision-making and inclusive development by facilitating the involvement of stakeholders in the modelling process (Akhmouch and Clavreul, 2016; Hare, 2011; Hare et al., 2003; Voinov and Bousquet, 2010). Various approaches, methods and tools exist to communicate uncertainty. Voinov et al. (2016) describes three broad phases in participatory and collaborative modelling approaches that relate to the treatment of uncertainties: (i) evaluation of input data (quantitative and qualitative), (ii) study of the propagation or generation of uncertainties during the modelling process, and (iii) analysis of outputs (model results). Bayesian modelling using Bayesian Networks is a well-known method for communicating about modelling assumptions and uncertainty as it helps to define transparently the conditional probabilistic relations between variables in a certain network (Carmona et al., 2013; Castelletti and Soncini-Sessa, 2007). Simulation approaches such as Monte Carlo Simulation are techniques commonly used to study the uncertainty propagation by models (Castelletti et al., 2012; Loucks et al., 2005). Sensitivity analysis is commonly used to analyse the uncertainties of model outputs (Loucks and Van Beek, 2017; Loucks et al., 2005). Other methods and tools help communicating epistemic uncertainty related to predicted outcomes and scenarios. Scenario exploration is a stand method used to build scenarios jointly with stakeholders by means of exploring a set of storylines. Meta models or "quick scan" models are also often used to carry out exploratory analyses and support long term decisions by taking into consideration uncertainties (Davis and Bigelow, 2003; Haasnoot et al., 2014; Wieland and Gutzler, 2014).

This chapter describes a collaborative modelling approach to develop a Fast Integrated Systems Model (FISM), that helps studying and communicating uncertainty related to the modelling process and adaptive planning. It integrates and simplifies interactions and relevant feedbacks among complex systems into a fast, low-resolution model.

6.2 Method

The use of simplified versions of complex quantitative models to improve the use of modelling tools in decision-making processes has received more attention in the last few years. These models are faster to develop and use, and can be adapted to the needs of decision-makers and stakeholders. Keeping them simple facilitates the involvement of stakeholders in the modelling process, the communication of associated uncertainty (Hall et al., 2014), and improves the credibility of their results (Wieland and Gutzler, 2014). Examples can be found of the use of such meta- and "quick scan" models in data-rich contexts and regions where there are many models available for simulating rainfall-runoff (Jakeman and Hornberger, 1993), analysing airport policies (Kwakkel et al., 2010; van Grol et al., 2006), assessing flood risks (Ward et al., 2011) and screening of management actions (Haasnoot et al., 2014; van der Most et al., 2002; Van Schijndel, 2006), amongst others. However, their use in data scarce dynamic environments presents a challenge. These environments are commonly characterized by limited system knowledge due to lack or limited data availability and accessibility. Also, multi-stakeholder partnerships and co-evolution are a pre-requisite, as there is community-based adaptation. In these particular contexts, the use of a collaborative approach for developing a simplified FISM model can be beneficial.

The collaborative modelling approach followed to develop FISM(s) is conceived as an interactive, iterative and adaptive process in which stakeholder participation is complemented by the use of computer-based models and communication tools. It is suitable for high-level reasoning and communication, exploratory analysis and long term decision support that takes into consideration the uncertainties. It supports the quantification and prioritization of possible projects and interventions by quantifying policy-relevant impacts of these interventions under various scenarios about the future. The approach integrates and simplifies existing complex quantitative models to develop a fast, low-resolution, dynamic model. This is done jointly with stakeholders and decision-makers. Specifically, it integrates and simplifies interactions and relevant feedbacks among complex systems into a FISM model that is intended to mimic the behaviour of complex (detailed) models, called the base model (Davis and Bigelow, 2003; Walker and van Daalen, 2013). Such models are also known as 'low resolution models', 'repro models' or 'fast and simple models'. FISM builds upon the concept of collaborative prototyping: start simple, understand the system and gradually increase complexity. FISM(s) can therefore be built with widely available software packages as Excel as a front end, or more sophisticated tools, such as Python or PC Raster, depending on the needs of the process (resolution in time, space and system processes to be included). Given the collaborative modelling approach followed, there is a high level of stakeholder participation in the development and use of the modules and the resulting FISM(s). The approach also helps creating a collaborative environment by means of team work and a continuous, structured collaborative prototyping process.

Collaborative modelling helps making decisions and communicating uncertainties to decision-makers and stakeholders regarding model development and use, and regarding future developments. The approach provides a stakeholder engagement structure that allows the continuous involvement of different stakeholder groups at different stages of the modelling and planning process. The scale, domain and complexity of the social and institutional system are conditioning factors for designing the engagement process. Stakeholders can have similar or different levels of participation. In the last case, the differences in the levels of participation of stakeholders may require the design of more structured engagement processes (e.g. circles of influence approach). Technicians and modellers are intended to work on the development of the FISM engine, including the selection and simplification of detailed, complex models, their integration into the FISM engine, model validation and re-formulation following the outputs from fit for purpose. Commonly, the modelling team requires the creation of a multi-disciplinary group composed of engineers, computer scientists, economists and sociologists. They can establish a single heterogeneous group or various sub-groups. Each sub-group is then responsible for a component of the computational framework. Policy and decision-makers and planners are intended to work mainly in the design and use of the user interface, as they will be direct users. They define the SIs and DSIs and specify the scenarios, potential interventions, strategies they want to evaluate. The collaboration between the modellers and the decision-makers is critical, as the engine calculates the impacts of the interventions and strategies in terms of the SIs and DSIs; and feed these back to the user interface. Finally, the organizing team plays a key role in managing the process and defining a capacity development procedure to ensure collective learning (i.e. social and shared learning) (Collins and Ison, 2009; Evers et al., 2012; Hare, 2011; Hare et al., 2003; Pahl-Wostl et al., 2007) and achieve a cooperative environment.

The implementation of the collaborative modelling approach follows four key steps (Gupta et al., 2012; Haasnoot et al., 2014; Jakeman et al., 2006; Walker and van Daalen, 2013):

1. Definition of model purpose and context
2. Conceptualization of the system
3. Implementation in the model i.e. FISM
4. Discussion and evaluation of the model

6.2.1 Definition of Model Purpose and Context

A key first step for the model design and development phase is to analyse what is exactly expected from the FISM: *Is it fit for the purpose?* This will determine the accuracy, performance of the FISM, as well as its computational framework and stakeholder engagement process. Generally, a FISM is recommended to be used to support decision-makers and stakeholders with the impact assessment of their decisions. That is, the model is used to scan a large number of potential decisions, and help in selecting the right policy options for the right reasons. This modelling purpose can, however, vary depending on the local policy context and decision-making process. Some exemplary questions that help defining the design of the model(s) are:

- What questions would you like the model to answer?
- What output indicators do you want to see? What is used for evaluation of policies?
- What input indicators are needed? From what changing conditions would you like to see the impact? What policy actions or interventions would you like to test?

The answers to the aforementioned questions help determining if the model(s) is accurate enough. The quality of the FISM can be assessed by answering the following question: *Does the FISM lead decision-makers to the same decisions as would be made if using the complex models?* The target to be reached is thus a set of decisions, which corresponds to the decisions that would be made on basis of the complex models.

6.2.2 Conceptualization of the System

The selection of the right policy options generally requires the integration of solutions and prioritization of investments. The approach is structured to provide information on the state of the water resources system, and evaluate the impact of projects, strategies and investments and their impact on the national or regional socio-economic development goals and targets by means of both State and Decision Support Indicators.

- State Indicators (SIs) illustrate the state of the water resources system according to its main functions. These include indicators such as flood extent, groundwater levels or the salinity level in regional rivers.
- Decision Support Indicators (DSIs) illustrate how successfully the water resources system and investments that are in it contribute to reaching the policy goals. Examples are food security or agricultural productivity. The FISM enables the evaluation of interventions under multiple scenarios, and selection of those interventions that perform best considering these DSIs.

6.2.3 Implementation in the Model

The DSIs and SIs determine what complex, detailed models should be considered to construct the FISM. The outputs from the "Definition of Model Purpose and Context" phase guide the accuracy of the model(s). This information is essential for defining the computational framework for the development and use of the FISM(s). The computational framework quantifies the information needed for the decision-making process by means of models and databases. There are three main components of a computational framework. First, it contains a natural water resources system model. It may include the hydrology of the main rivers, regional natural systems, water quality and others. Second, the associated activity modules determine the water demand and user impacts. Possible modules are: agriculture, urban development, navigation and environment. The third component is the impact modules, expressed in DSIs. Economic, finance and social models are commonly used as impact modules.

The technical infrastructure of a FISM model, similar to other Decision Support Tools (DST), is discerned into two components: a graphical user interface and the engine. The graphical user interface, often named the dashboard, is used for exploring model results. It is a simple interface that is preferably built with widely available software packages as Excel and PCRaster grid commands (Utrecht University, 1995). Other more sophisticated tools such as Python programming can be used depending in the needs of the decision-making process (see e.g. the Planning Kit or Delft FEWS; (Basco-Carrera et al., 2017a; Loucks and Van Beek, 2017; Van Schijndel, 2006)). The user interface allows the user to specify scenarios, select individual or combinations of potential interventions in different locations and implement them in the short, medium or long term, as well as to visualize model results in the form of spatial-temporal maps and graphs for a selected region. The engine contains the models and related databases that calculate the values of the SI's and DSI's under the specified scenarios and interventions. The models used are generally simplified versions from existing complex, detailed models. Two types of models are used: process-based models and statistical-based models. Process-based models in FISM describe the basic system processes but are simplified to reduce data need and running time. These models are preferred to be used for the construction of FISM models. Statistical-based models are statistically derived from the results of complex, detailed models. These are used within the space of the complex model application (interpolation rather than extrapolation). These models however present important shortcomings such as the failure to tell a (transparent) story and support policy makers with robust logic for their choices that can be explained to others. They can be perceived as a black box. Moreover, they have the weakness to represent problems with multiple components and the boundary of input (Bigelow and Davis, 2003). Often fuzzy system dynamics is used for integrate different modules, and to give an adequate measure of the uncertainties surrounding the model results (Wieland and Gutzler, 2014). FISM also incorporates other methods and tools used in collaborative modelling approaches. It makes use of economic and financial analyses to assess the benefits and costs of alternative decisions and investments. The assessment of the impacts might require the use of a model for evaluating alternatives and arriving at a decision. Criteria identified with the participation of stakeholders need to be combined into the FISM(s). Several Multiple Criteria Decision Analysis (MCDA) techniques exist for this purpose (Greco et al., 2005) including the weighted summation technique, the Analytic Hierarchy Process method (Hajkowicz, 2008; Saaty, 2008) and scorecard analyses (Loucks and Van Beek, 2017; Loucks et al., 2005).

6.2.4 Discussion and Evaluation of the Model

The evaluation of the FISM did not follow the traditional model calibration and validation mechanisms that use metrics such as R2 or Nash-Sutcliffe coefficients (McCuen et al., 2006; Willmott, 1981). The FISM is used to explore the future and therefore there is no truth against which model can be validated. It is a policy model that simulates situations that have not existed or observed in the past (possible futures and policy options that have not been implemented yet). The evaluation focused if the FISM is suitable for the model purpose and context defined in the first phase of the project. The performance of the model was assessed based on reflecting on the following questions: *Does the model produce credible outcomes with sufficient accuracy for the screening and ranking of promising actions? What detail or difference in the outcomes would result in different decisions?*

6.3 Application Example: Bangladesh Delta Plan 2100

6.3.1 Study area

Bangladesh is located in South Asia. It shares borders with India and Myanmar (Figure 6.1). Its geographical location raises important concerns in terms of natural resources management, as the country's water availability and use depends significantly on the upper riparian countries. Today, Bangladesh suffers of water scarcity in the North-West regions during the dry season and of floods during monsoon in South-West (Brammer, 1990; Mekonnen and Hoekstra, 2016). Over the years, many of the distributaries, directly dependent on the flow of Ganges and the Brahmaputra, have been silted-up and de-linked from its sources. Moreover, around 20% of the country undergoes threats of inundation under average flooding situations and in extreme events. In Haor regions in the North-East, flash floods bring in huge damage to agricultural crops and other valuable assets. In the coastal regions, a lot of the coastal polders, as well as the flat and un-protected areas are severely impacted during cyclones and storm surge events (GED, 2017). Water pollution is also a critical national issue, in particular around the big cities (Nickson et al., 1998; Smith et al., 2000). The major rivers (e.g. Brahmaputra, Ganges and Meghna) are highly dynamic and erosion in prone. Around 50-60 thousand persons are forced to migrate due to erosion. Climate change, sea level raise and saltwater intrusion are salient challenges in Bangladesh. In socio-economic terms, Bangladesh is one of the most populous countries in the world, with more than 162 million people living in it. It is projected that by 2025 the population will be around 178 million and by 2050 it will be around 202 million. Building a climate resilient society is a big challenge. Bangladesh needs to strengthen its capacity for dealing with long term climate change and uncertainty, and hence implement flexible strategies for sustainable development, while ensuring cooperation with its neighbouring countries. The implementation of IWRM concept in the development projects is essential, as well as resolving social conflicts and disputes among decision-makers and stakeholders. Although the challenges are many and important; the country is equally characterized by its resilience, the ability to adapt to changing climatic and economic conditions and profit from the abundant natural resources available in the delta (CSIRO, 2014; GED, 2017).

The Bangladesh Delta Plan 2100 (BDP2100) is a joint project of the governments of Bangladesh and the Netherlands to assist the Bangladesh government addressing these issues and challenges (GED, 2017). It aims to create a long term holistic and vision-based plan for the Bangladesh delta. This long-term vision, combined with the use of scenarios, allows planning to be adaptive and dynamic by taking into account uncertainties in future developments in climate change, socio-economic development, population growth and regional cooperation. It focuses on important governance and institutional challenges, related to the national planning process, legal and other institutional arrangements, performance of implementing agencies and capacity building, prioritization and decision-making as well as funding and financial mechanisms.

Figure 6.1 The Bangladesh territory and its administrative divisions (source: Media Bangladesh)

6.3.2 Stakeholder Engagement Structure

To develop a FISM, a stakeholder engagement structure was designed to ensure a collaborative environment between modellers, scientists, economists, planners and decision-makers throughout the modelling process. The structure followed the circles of influence approach (Cardwell et al., 2008). However, it only comprised two circles of influence: the model construction team (Circle A) and the decision-makers (Circle D). Both stakeholder groups worked jointly for a period of 10 months. The decision-makers and planners worked mainly in the design of the user interface, as well as in the formulation of DSIs, SIs, measures and strategies, and the evaluation of the FISM. This stakeholder group included representatives from the General Economic Division of the Bangladesh Planning Commission, BDP2100 team, Bangladesh Water Development Board and the Water Resources Planning Organization. Stakeholders part of Circle A worked in the selection of the detailed, complex models and their integration into the FISM engine. They helped stakeholders from Circle D in the formulation of SIs and measures, evaluation of the FISM and were responsible for its re-formulation when needed. Two persons from the modellers team also helped in developing the user interface. This inter-disciplinary group was conformed of professionals from the Center for Institute of Water Modelling, Environmental and Geographic Information Services, the Institute of Water and Flood Management from the Bangladesh University of Engineering and Technology, Witteveen+Bos, Ecorys, Delft University of Technology and Deltares.

A collaborative modelling approach was followed to develop a FISM as well as to support communication of uncertainties in climate change, sea level rise, socio-economic development, population growth and regional cooperation. As aforementioned in the Method Section, the approach followed four key steps:

1. Definition of model purpose and context
2. Conceptualization of the system
3. Implementation in the model i.e. FISM
4. Discussion and evaluation of the model

6.3.3 Definition of Model Purpose and Context

The aim of the FISM is to support the evaluation and comparison of policy actions and strategies for Bangladesh to generate information for investment planning under uncertain changing conditions in a transparent manner. This requires an integrated analysis as various relevant sectors are involved and interact via different parts of the system in space and time. It also requires a model that is able to do simulations in a limited time as multiple combinations and sequences of actions need to be explored under multiple futures. To be useful in interactive decision-making processes, the model should report on the projects and interventions in seconds and minutes rather than hours. Therefore, what is actually needed is a fast, integrated and dynamic model: a FISM.

The policy actions and strategies to be evaluated are a mix of detailed feasibility studies, concept notes and programmes. A number of these measures have been assessed by using detailed, complex models. Typically, these studies, notes and programmes are difficult to compare for a number of reasons: different consultants, tools, data and assumptions or different evaluation criteria. Moreover, most proposals are generally focussed on one particular sector or policy goal and do not take into account the interactions with other interventions and sectors. The FISM supports the: (i) assessment of impacts of combinations of measures on a consistent set of policy indicators; (ii) assessment of the synergy, competition or overlaps across measures; and (iii) prioritization of measures from a list of multiple possible measures. In Figure 6.2, the use of the FISM in the policy planning process and the responsible agencies is illustrated. Typically, this framework would take place for the BDP2100 update, every new Five Year Plan (FYP), and for the annual review process (GED, 2015, 2017; Islam, 1974).

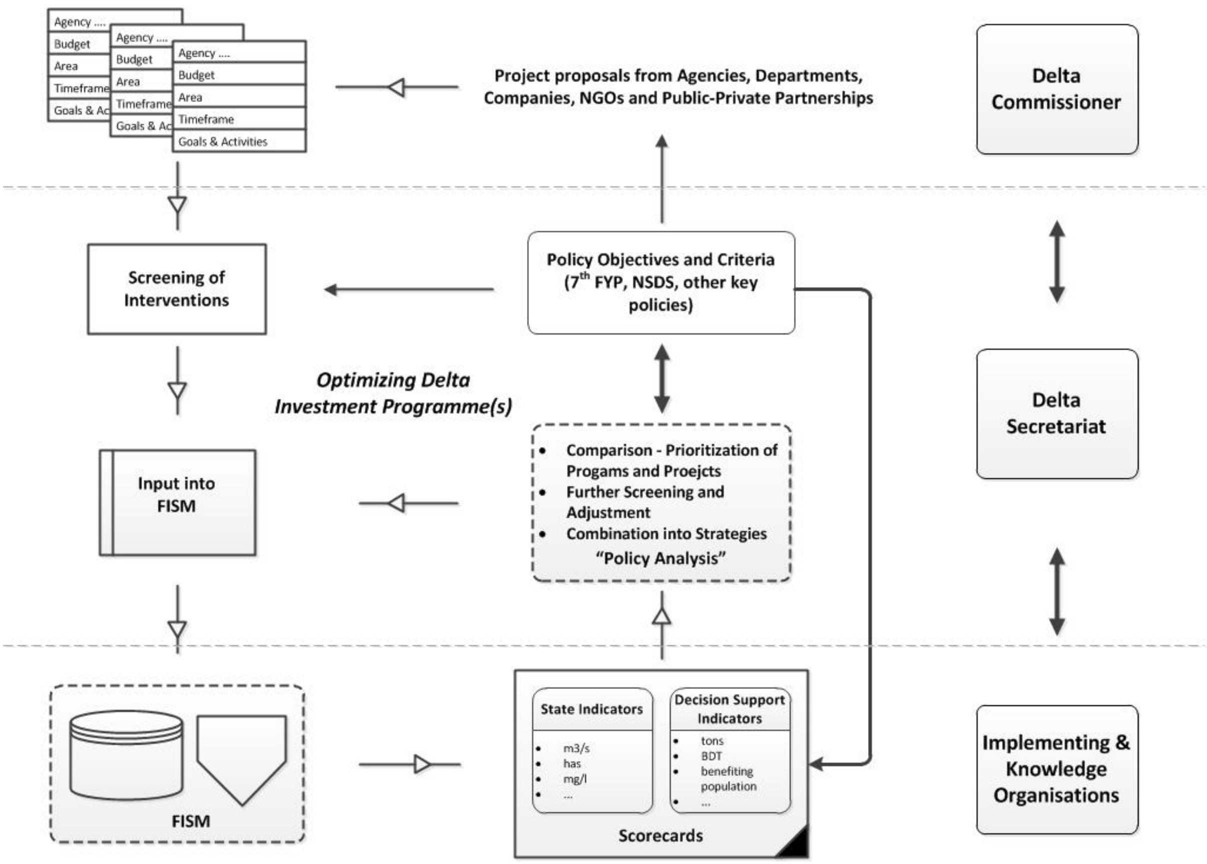


Figure 6.2 The FISM in the policy planning process in Bangladesh

The collaborative modelling approach followed to develop the FISM is applied in a structured form by means of eight iterative steps:

1) Specify the region
2) Determine the Decision Support Indicators (SIs)
3) Determine the State Indicators (SIs)
4) Specify the measures
5) Specify the strategies
6) Comparative assessment of strategies and investments
7) Comparative impact assessment of scenarios
8) Observations and recommendations for decision-making

6.3.4 Conceptualization of the System in State and Decision Support Indicators

An iterative participatory approach was used to design and determine the DSIs and SIs that would be included in the FISM.

Based on the scope of the FISM and considering the targets defined in the BDP2100 (GED, 2017), Seventh Five-Year Plan (GED, 2015) and the Sustainable Development Goals (United Nations, 2016), a first inventory of SIs and DSIs was prepared by the modelling team. The shortlisting, selection and refinement of the indicators were conducted by the planners of BDP2100, decision-makers and involved stakeholders. The final list of SIs and DSIs, and the corresponding units, is presented in Table 6.1.

6.3.5 Implementation in FISM

The computational set-up of FISM for BDP2100 followed a structure composed of five primary elements:

- A network model that describes the hydrodynamic performance of the main river system of Bangladesh;
- A regional, grid-based model that describes the water balance (surface and ground water) of identified (hydrological) regions;
- Aggregated sector modules that describe the performance of the various sectors (e.g. agriculture, fisheries, navigation);
- A set of impact modules for demand and socio-economic impacts, and the formulation of DSIs;
- A set of issue-specific process modules for the generation of SIs.

Table 6.1 State and Decision Support Indicators used in the Bangladesh Delta Plan 2100

DECISION SUPPORT INDICATORS		
A	Sustainable economic development	
A.1	Sector productivity	
A.1.1	Agriculture (rice, wheat, sesame, oil seeds, potato and sun flowers)	Million tons; tons/ha
A.1.2	Fisheries (aquaculture and capture)	Million tons; tons/ha
A.1.3	Energy	MW
A.2	Economic loss due to floods, droughts, water logging and salinity	
A.2.1	Agriculture	Tk
A.2.2	Fisheries	Tk
A.2.3	Energy	Tk
A.2.4	Housing	Tk
A.2.5	Critical infrastructure	Tk
B	Livelihood security and health	
B.1	Food security (focus only on amount, not access)	
B.1.1	Rice	%
B.1.2	Wheat	%
B.1.3	Fish	%
B.2	Safe drinking water	
B.2.1	Urban	%
B.2.2	Rural	%
B.3	Population affected by floods, droughts, salinity	# affected; % population
C	Poverty reduction, equity and gender	
C.1	Income distribution	
C.1.1	Gini coefficient	-
C.1.2	Employment rate: Rural (agriculture and fisheries) – Urban (industries)	%
C.2	Poverty specified population affected by floods	# affected; % population
D	Environmental sustainability	
D.1	Ecosystem sustainability	
D.1.1	Environmental flows below threshold	Days
D.1.2	Min flow for connectivity floodplain/beel to main river	Min flow for connectivity - Ha as function of water flow

STATE INDICATORS		
E	Flood attenuation and storm surge regulation	
E.1	Peak main river discharge and water level	m3/s and m
E.2	Riverine flood extent, duration and depth	ha, days and m
E.3	Extreme cyclone flood extent	ha
E.4	Flash flood extent	ha
F	Waterlogging and drainage congestion	
F.1	Drainage and flood recession rate	days and m
G	Water retention and production	
G.1	Dry season river flow and no-flow duration	m3/s and days
G.2	Floodplain water storage	m3
G.3	Groundwater fluctuation and depletion rate	m and m/year
G.4	Annual groundwater recharge rate	m3/ha
G.5	Meteorological drought	days
G.6	Agricultural drought – extent, duration and intensity	days, mm
G.7	Hydrological drought	Days
G.8	Area under irrigation coverage: ground/ surface water	ha (ground/ surface water)
G.9	Irrigation wells falling dry in dry season and shallow depth	days and area
G.10	Drinking water wells falling dry in dry season	days (decade)
H	Salinity control	
H.1	Max. inland intrusions length and area affected (surface water)	km and km2
H.2	Maximum salinity level in groundwater and soil salinity coverage and level	dS/m
H.3	Surface water salinity concentration and spatial variation	dS/m

The sector and impact modules are a combination of a fast and simplified spatio-temporal process model and statistical relations between variables (e.g. expert-judgment rules, transfer functions, lookup tables). The calculation modules are set up to be run in a separate fashion, using serial processing and fuzzy system dynamics (Wieland and Gutzler, 2014). The computational framework from calculation modules ranged from simple Microsoft Excel Worksheets to PCRaster grid commands. For integrating certain modules, was used to develop certain cause-effect relations from scratch. The number of dependent software libraries is kept as low as possible to keep the FISM easily transportable to any kind of desktop and laptop computer in Bangladesh. The main modules of the FISM are given in Figure 6.3. The main spatial calculation unit used is "Upazila level"[9]. This level was selected due to its relevance for decision-making in Bangladesh and data availability.

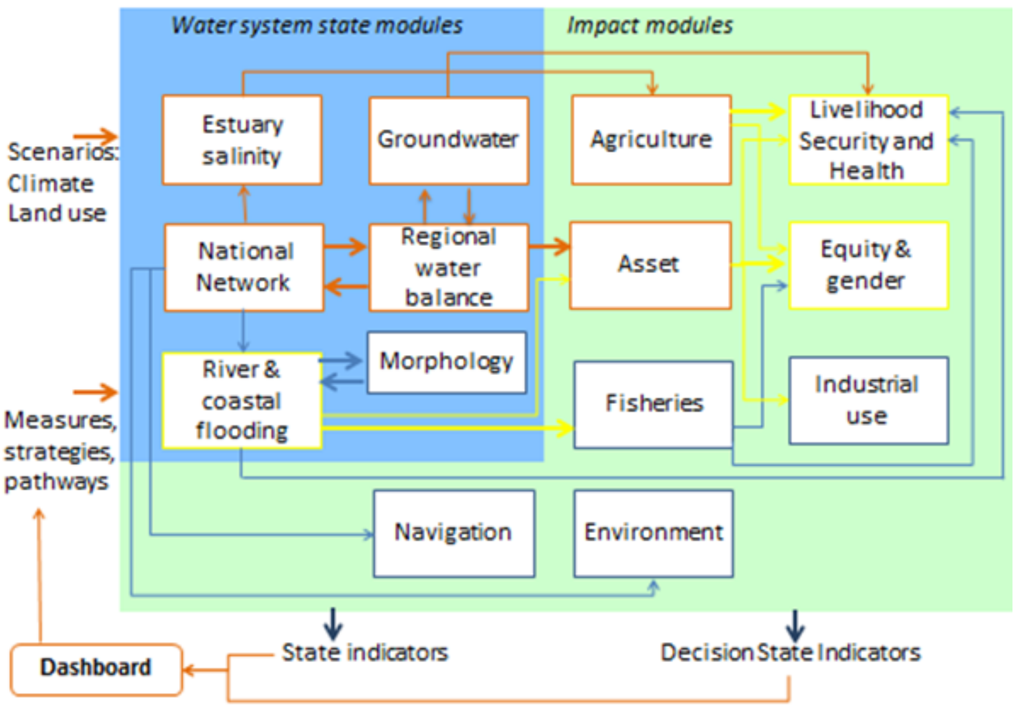


Figure 6.3 General set-up of the computational framework. Red lines represent completed modules. Yellow lines are modules partly implemented. Blue lines represent modules and relations only conceptually implemented

Two pilot regions were used to test and evaluate the FISM. These are the Barind and Coastal Zone regions (Figure 6.1). The Barind region is the south part of the North-West

[9] Upalizas are geographical regions in Bangladesh used for mainly administrative purposes. They function as sub-units of districts. Their functionality can be seen to be analogous to that of a county or a borough in other countries.

region of Bangladesh. It is a dry area with in the west part the High Barind Tract area and the east the Atrai river. The dry conditions made it one of the poorest regions of Bangladesh. This region is characterized by the tendency of high extraction of groundwater and diversion of river water for irrigation purposes. The reduction of Ganges water during the dry period and inadequate surface water is further creating problems as aquifers do not get adequately recharged. In the North-West region the existing water scarcity may be intensified due to effects of climate change. Climate models suggest that there will be longer dry seasons and shorter wet seasons and that the discharge will increase only in the wet season. The Coastal pilot covers the area of the West and East Ganges tidal plain and the Meghna Deltaic plain. The Ganges area has long drainage routes of low gradient and very little fresh water flow from the parent river. Many districts are at risk from cyclone and storm surges. This region is recognized as the polder area of Bangladesh. Those polders face the sea are subject to erosion and migration of rivers. Siltation of some rivers is causing navigation problems. Water logging is another major problem. Sea level rise is likely to cause significant changes in river salinity in the South-West coastal area of Bangladesh during the dry season by 2050, which will likely lead to significant shortages of drinking water in the coastal urban areas, scarcity of water for irrigation for dry-season agriculture and significant changes in the coastal aquatic ecosystems. These challenges in both regions are addressed in the FISM.

Scenarios and Measures

Four diverging scenario narratives were collaboratively developed with stakeholders from Circles A and D (Figure 6.4). These were formulated following the IPCC (IPCC, AR5) climate scenario approach and included in FISM. These scenarios are concentrated around two key drivers: (i) future water conditions based on transboundary developments and climate change, and (ii) economic development and related land use changes (GED, 2017).

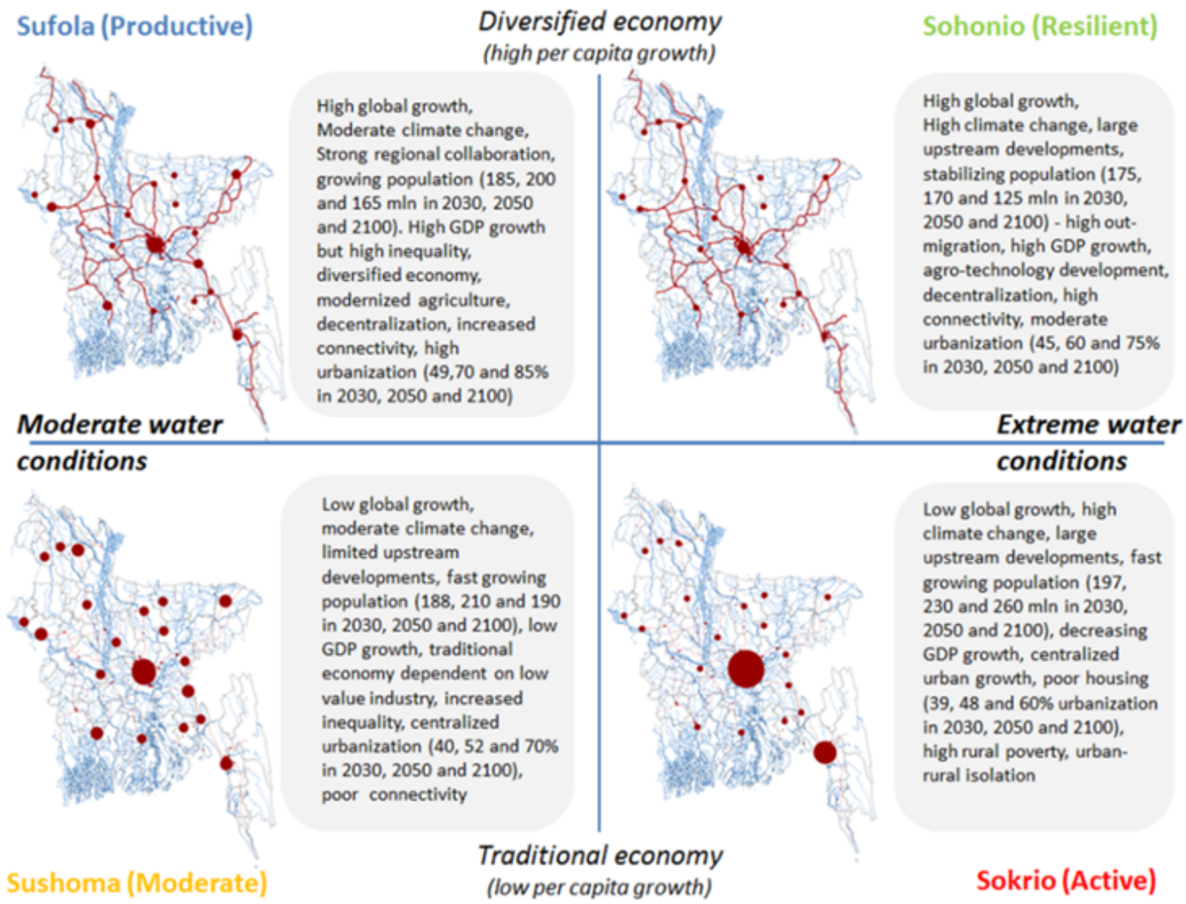


Figure 6.4 Scenario narratives used in FISM (source: GED, 2017)

A total of 10 measures and 28 specifications were included in FISM. These were subject to detailed feasibility studies, and impacts of the measures had been determined using the complex, detailed models. The FISM engine and user interface were developed to support decision-makers and stakeholders in (i) assessing the impact of individual measures and strategies considering different scenarios and based on a consistent set of policy objective indicators i.e. DSIs and SIs, (ii) assess the synergy, competition and overlaps across measures, and (iii) prioritize investments based on economic and financial factors. During the evaluation, the application of different integrated strategies and their impacts under different scenario conditions in both selected pilot regions was used to test the performance of the FISM and evaluate the approach followed. The results from FISM were compared with the outputs from the complex, detailed models.

Table 6.2 Measures included in the FISM for the Barind and Coastal pilot regions

PILOT REGIONS	MEASURES
Barind	• Revitalization of regional rivers through river management, flood control defences improvement and wetland restoration (in Chalan Beel) • Increased surface water irrigation, through supplementary and full irrigation • Replace of Boro rice with wheat in the cropping pattern • Promotion of precision irrigation to increase irrigation efficiency • Promote Managed Aquifer Storage and Recharge at private and community level
Coast	• Agriculture intensification through more salt tolerant varieties (up to 3 ppt), or improved drainage, or improved irrigation, or improved irrigation and drainage • Improved drainage through installing pumping capacity, or dredging and excavation, or tidal river management, or enhanced operation and maintenance • Development of the Ganges barrage to enhance freshwater flows to the South Central river system to reduce salinity intrusion in support of agriculture and environmental objectives • Promotion of Managed Aquifer Storage and Recharge at private and community level • Improving the durability of rural housing by conversion from 'Katcha to Pucca'

FISM User Interface

The dashboard of the pilot version of the FISM is developed in Microsoft Excel 2010 with Visual Basic for Applications (VBA) as scripting programming language to enable more intuitive interactivity with the dashboard. It is customizable to be easy-to-use for novice as well as advanced users. It entails four main components. The main overview screen helps exploring spacio-temporal impacts of scenarios and/or strategies on the different DSIs and SIs. A section of the dashboard is dedicated to define and customize new strategies based on a set of measure types. A pathway panel in the dashboard keeps track of the intended time order of the selected strategy and a central scorecard provides summary indicator statistics. Colours indicate the relative scoring. A more detailed scorecard is available in a separate sheet. Strategies for the specific pilot areas and the impacts on indicators for different areas are provided in maps within one dashboard. The main sections of the user-interface are displayed in Figure 6.5.

6.4 Method Evaluation and Key Features

The FISM that uses collaborative modelling is evaluated using the analytical framework (Chapter 3). A general evaluation of the method is presented in Table 6.3.The most characteristic features are highlighted in orange.

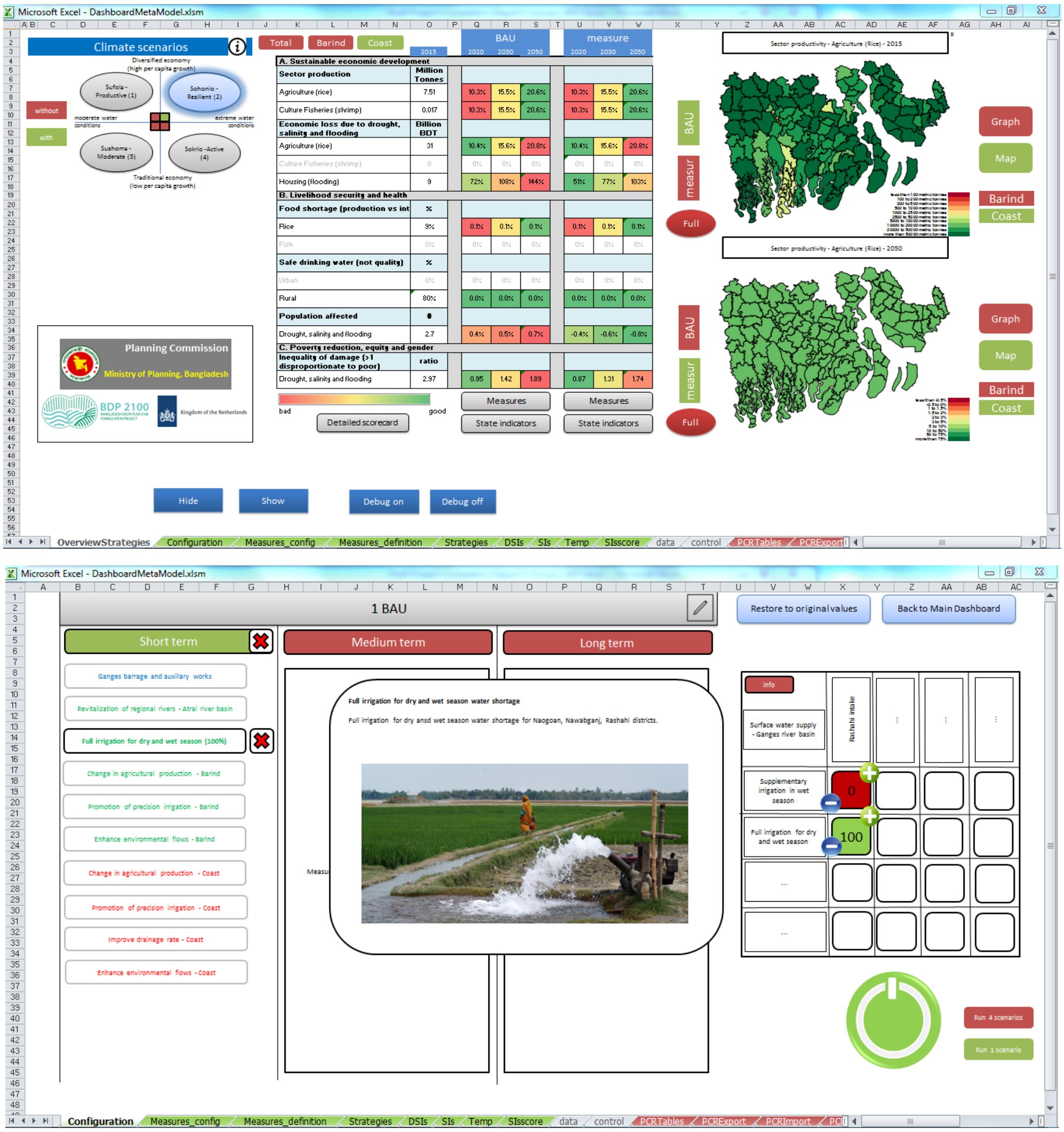


Figure 6.5 FISM dashboard showing an example strategy case

The application of FISM requires of a cooperative environment, where participants agree to share their detailed models and/or the results to construct the FISM model. Collaborative modelling is therefore the encouraged approach used for developing a FISM model. The key features of the new method are:

- *Application*: It follows a multi-sectorial and multi-disciplinary approach, as the approach focuses on the integration of different domain in a temporal and spatial manner.
- *Specific use:* The primary purpose of this method is to support decision-making, particularly in the later stages of the planning process i.e. strategy design and investment planning. The collaborative modelling process also helps collaborative learning. Participants, via their continuous involvement and as direct users of the FISM model, develop knowledge of the system in an integrated and adaptive manner. Moreover, they learnt to transform water-related processes and issues into economic and social indicators, relevant for decision-making.
- *Modelling approach:* .The approach integrates and simplifies existing complex quantitative models to develop a fast, low-resolution, dynamic model. This is done jointly with stakeholders and decision-makers. Specifically, it integrates and simplifies interactions and relevant feedbacks among complex systems into a FISM model that is intended to mimic the behaviour of complex (detailed) models. Regarding the software platform, FISM can be built with widely available software packages as Excel as a front end, or more sophisticated tools, such as Python or PC Raster, depending on the needs of the process (resolution in time, space and system processes to be included).

Table 6.3 Evaluation of FISM using collaborative modelling

Factors	Parameters		FISM using Collaborative Modelling
Context and application	Problem type	Problem structure Scale of action Time horizon	Semi-structured All scales, from national to local Short, Medium and Long time horizons
	Domain		Multi-sectorial and multi-disciplinary approach. Integration of different domains.
	Interaction context	Cooperative Competitive	Cooperative
Specific use	Participatory/ Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Decision-making, with a special focus on investment planning *Secondary purposes:* Collaborative learning about the system in an integrated and adaptive manner
	Planning/Management cycle phase		Late phases of the planning cycle, strategy design and investment planning
Information handling	Model characterisation	Model system focus Model type	Socio-physical system models Analytical models
	Modelling tool / Software platform		Software platform: Excel, Python, PC Raster Modelling tools: Detailed physically-based and economic models. Also social models can be included. Fuzzy system dynamics help creating connections between models.
	Information type		Combination of system interactions and complex processes
	Information delivery medium	Virtual/web Face-to-face	Face-to-face The dashboard can be transformed into a online software platform
Stakeholder involvement structure	Participatory method	Participatory Collaborative	**Collaborative modelling**
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	Circle of Influence approach recommended in large scale studies Decision-makers with knowledge on investment planning (like Ministry of Economy and Finance), water resources planners and managers, modellers and technicians and stakeholders
	Model users	Direct/Indirect Technical skills	Stakeholders are direct users of the FISM model
	Participation mode	Only modellers (no participation) Individuals Groups	Combination of all participation modes
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	Up to co-design. In some cases, it can scale up to co-decision-making
	Timing of participation	Data collection Model definition Model construction Model validation Model use Measure formulation Strategy design	All
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Collaboration
Modelling / organising team	Team		Modellers from different disciplines, economists, planners, decision-makers, statisticians, and stakeholders
Means	Timing		1 month- 3 years
	Financial resources		Depending on the available detailed models and design of the dashboard.

6.5 Conclusions

This study has illustrated a collaborative modelling approach to develop a simple model to be used for collaborative decision-making under uncertainty. The approach followed structured the involvement of decision-makers, planners, modellers and other stakeholders in the development and use of a fast, integrated and dynamic model i.e. FISM. The model is generally developed from simplified versions of existing complex, detailed models. A collaborative prototyping process is followed to guide the modelling process and structuring the stakeholder engagement process. The approach involves high levels of participation and collaboration between involved stakeholders. The FISM helps the integration of physical and socio-economic systems in a modelling framework to support the evaluation and development of sustainable strategies and policy actions, and ultimately the prioritization of investments. It also makes it possible to consider quantitatively main alternatives for multiple futures, required for robust and adaptive decision-making. To test the approach, it has been applied in the development and use of a FISM for the Bangladesh Delta Plan. FISM was collaboratively constructed with Excel and PCRaster grid commands to help decision-makers, planners and stakeholders to evaluate and prioritize future investment decisions and plans. Its integrated approach helps better understanding the system complexity, and managing and communicating uncertainties related to the system, the modelling process and ambiguities from different stakeholder views. The approach is most suited in contexts characterized by limited system knowledge due to lack or limited data availability and accessibility, and/or complex hydrology of the river(s). It is therefore suggested to further apply the FISM approach in other policy domains and regions.

7

Crowdsourcing and Interactive Modelling for Quick Adaptation and Visualisation

In this chapter the fourth participatory modelling method is presented. It combines the use of crowdsourcing and Interactive Modelling. More specifically, stakeholders are involved in data collection via crowdsourcing and in model development and validation using the Interactive Modelling approach. Its implementability is described through its application in Tanzania. This is the last method designed and implemented as part of Research Question 3: *How can participatory and collaborative modelling approaches be applied with existing and newly developed computer-based simulation models?*.

This chapter is based on:

Gebremedhin, E.T., Basco-Carrera, L., Jonoski, A., Winsemius, H., Iliffe, M., 2018. Participatory Mapping and Urban Flood Modelling. Environmental Modelling & Software (in publication progress).

7.1 Introduction

The Sendai Framework for Disaster Risk Reduction 2015-2030 adopted by the United Nations and led by United Nation International Strategy for Disaster Reduction (UNISDR) highlights the significant role of stakeholders and the use of modelling tools in Disaster Risk Reduction (DRR) (UNISDR, 2015). Risk assessment consists of firstly, simulating flooding by using different data, including elevation and observed river flow data during floods in the area (Kollinger et al., 2003). The outputs are then used for flood risk mapping (Lin et al., 2006). Therefore, the involvement of local stakeholders becomes a necessity for an accepted and fully supported model results. It is also valuable in the formulation of numerous flood risk management alternatives, and the identification and evaluation of policies (Maskrey et al., 2016). This makes participatory modelling a powerful tool for informed decision support systems (Voinov and Bousquet, 2010).

From local to global problems, citizens are trying to be engaged as stakeholders in planning decisions that have an impact on them and their communities. Consequently, the interaction of people with models and in decision-making is evolving. This requires an improvement in the traditional model development approach as citizens are progressively becoming aware of the fact that they are capable of providing input to the development of models and in the planning process (Voinov et al., 2016). Additionally, flood related problems are frequently associated with several objectives and are multi-disciplinary (Almoradie et al., 2015; Jonoski and Evers, 2013). As a result, involvement of stakeholders in developing models and DSSs has become of key importance.

Recently, to foster stakeholder involvement in environmental modelling, participatory modelling has been applied in several cases; such as: improving partnerships and conflict management (Martínez-Santos and Andreu, 2010; Suwarno and Nawir, 2009); environmental planning (Beierle and Konisky, 2000; Ritzema et al., 2010); flood risk management (Almoradie et al., 2015; Evers et al., 2016; Evers et al., 2012; Jonoski and Evers, 2013); and groundwater modelling (Tidwell and Van Den Brink, 2008). As part of this PhD, an extensive study was carried out to study the first projects/studies where Interactive Modelling was applied in the Netherlands. The participatory and collaborative modelling framework (Chapter 3) was used for the analysis. The cases studied include the MIPWA groundwater case (Basco-Carrera et al., 2017), AZURE groundwater case and the Delta

Program Rivers (Warren, 2015). Results of literature review and the extensive study show that in many cases the participatory modelling approach has been used in the application phase rather than in the actual model development. Specifically, little has been done using the knowledge of stakeholders in data collection, development and improvement of an urban flood model. This might be particularly important in areas where there is little or no technical data available to build a hydrodynamic model.

Developing urban flood model requires various types of data, such as rainfall, high resolution Digital Terrain Model (DTM), drainage network layout, boundary conditions, etc.. Due to the complex nature of urban settings, development of the urban flood model also requires detailed information about various infrastructures, including roads, buildings and waterways which affect the flow in the city. Many countries do not have accurate flood models due to non-availability of such required data. Furthermore, developing such computer-based models demands certain skills and knowledge regarding representation of the real physical system in the model. This can be the biggest challenge in many countries. Finally, in addition to lack of technology and skills, poor collaboration among stakeholders additionally hinders the development of these types of models in data scarce environments. Participatory modelling is then proposed to alleviate some of these problems, but it needs to be planned and applied carefully. This means that there should be a clear stakeholder engagement structure, based on extensive analysis of stakeholders and their skills and level of understanding about the system in question. This is a pre-requisite for quality assurance of the developed model (Martínez-Santos and Andreu, 2010). In short, the work presented here demonstrates that with a well-structured participatory modelling approach it is possible to develop inclusively an urban flood model, even in data scarce environments.

OpenStreetMap (OSM) is one of the recent geo-spatial developments being used worldwide with a strong focus on community participation. It has a goal of developing open editable map of the world to overcome the lack of geo-information that exists in most part of the globe (Haklay et al., 2014). This study describes how OSM data can be used as an input for developing an urban flood model in Dar es Salaam with the support of local communities in order to compensate for the existent shortage of technical data. Results from the study corroborate the findings from many researchers who argue that involving communities in map development not only solves the problem of data scarcity, but it also empowers and motivates the community (Panek and Sobotova, 2015; Perkins, 2007; Weiner et al., 2002; Wood, 2005). Participatory mapping can therefore result in capacity development and enriching open source data for developing urban flood models.

In this study, a method on how to develop an urban flood model using automated schematisation based on community mapped data is presented. The focus of the study is to obtain potential model improvements by working together with the local stakeholders, following a participatory modelling approach.

7.2 Method

This study formulates a new participatory modelling method that integrates the development of a flood model with community-based data collection. It develops and applies a framework for participatory urban flood modelling, in which an iterative data collection process that involves the community and the stakeholders plays a major role. The work aims at developing a hydrodynamic model to build a 1D-2D coupled urban flood model for Dar es Salaam. This modelling approach combines a one dimensional (1D) model to simulate the flow through the drains, rivers and streams, with a two dimensional model (2D) to represent the flow over the surface, around the buildings over the floodplain.

The new framework for participatory urban flood modelling represents an interactive process that provides guidance on how to collect and improve OSM data through community mapping (crowdsourcing). It provides a practical approach on how experts can interact with the community members/citizens (Figure 7.1). The main objective of the framework is interactive data collection for purposes of model schematization and simulation. This process includes data quality control, identification of data gaps and other issues.

Community Mapping

Community mapping or "crowdsourcing" has been widely used for data collection. It has been especially successful for OSM development in many countries, including in Africa. Some exemplary cases include: mapping of Kibera informal settlement in Kenya (Panek and Sobotova, 2015), mapping the newly created nation in South Sudan (Haklay et al., 2014); and iCitizen, mapping service delivery in South Africa. Furthermore, mapping urban areas using crowdsourcing has become a successful way to develop an open source data for slum and informal settlements.

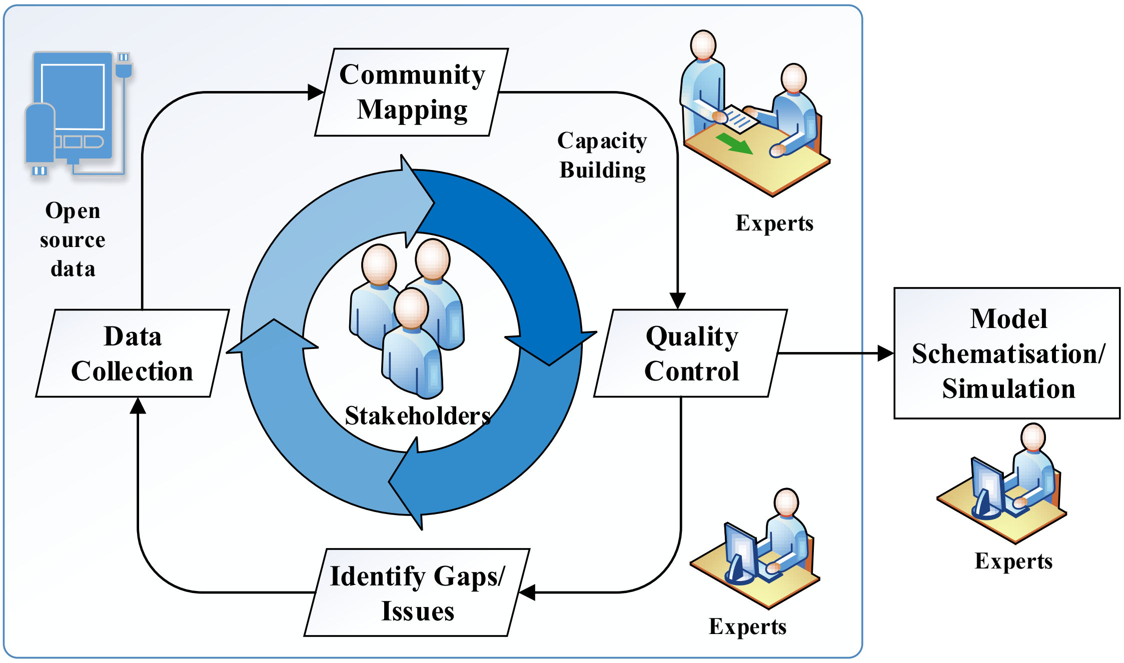


Figure 7.1 Framework for participatory urban flood modelling

"Crowdsourcing" is a process of attaining information from many involved contributors ('crowd'), regardless of their skill level and background (Haklay et al., 2014). One of the biggest successes of this data collection technique is being able to work collaboratively with non-technical members of the community. This includes people who have extensive knowledge of the area, such as the location of infrastructure (e.g. waterways, roads and buildings). Some of the advantages of crowdsourcing are: affordability (cheap cost), accessibility, faster way of collecting data, and its variety. However, it has its own major shortcomings. As the less qualified, the collected data may have quality issues. One way of monitoring this problem is applying proper training and data quality control, so that the collected data can be filtered and useful. "Mappers" need to clearly understand "what, where, how and why" to map a certain feature. Clarifying the idea on how water moves in the city can help the mappers to understand why those features have to be mapped and incorporated into the flood model. Another shortcoming of this approach, is the fact that the participation is often limited to one-way data collection (Voinov et al., 2016). It is rare that the participants in data collection eventually get to discuss the obtained results. In this work, an iterative data collection approach is presented that can improve data quality and allows the participants to see and discuss the obtained results.

Data Collection

A major challenge for stakeholder participation is launching and maintaining the participatory process (Almoradie et al., 2015). For successful data contribution and usage of OSM, the data collection process requires an established community mapping in the area. Information from OSM is used for developing the 1D-2D urban flood model. Therefore the focus of the community mapping is on identifying as well as gathering new data (e.g. information about features such as various waterways, buildings and roads).

In the study, the iterative modelling process commenced with the construction of an initial model (i.e. first prototype) using the existing OSM data. Assumed values for the missing information about the existing waterways were applied. The second iteration step aimed to improve the model started with the engagement of local stakeholders though interviews. The initial model results were validated by local stakeholders during and after the stakeholder workshop. A reconnaissance survey and field visits to the flood prone areas with the mapping group facilitated the data validation process by comparing existing OSM data and field data. Missing data were added to OSM or were corrected. As a result, the participatory mapping approached facilitated the improvement of data quality.

Quality Control and Identification of Gaps

Quality control is one of the most significant steps in data collection, particularly to ensure that collected information is reliable and accurate. It can be obtained by going through the iterative process and by acquiring a large response rate from the contributors (Haklay et al., 2014). In the Dar es Salaam case, the first quality control phase is conducted by the established community mapping for OSM. Tools are used afterwards to improve data quality. . The Java OSM editor can be used to filter recurring errors. The process is combined with field visits carried out by the community mapping. Data check, analysis and resurveying helps the mapping team to identify gaps and correct errors in their mapping. The assistance of OSM mapping expert is recommended.

Model Schematisation and Simulation

Data collected and validated is used for preparing the model schematisation. It represents the relevant physical features in a schematic form (as close to reality as possible).The process of refining the model through data preparation and schematisation is iterative.

In the study, model schematisation included identifying external forces, setting up the cross-section profiles, preparing the network layout and its various structures. The schematisation technique depends on the type of software package that is used to construct the urban flood model. There are various hydrodynamic models that simulate a flow through an urbanised area (e.g. SWMM, HEC-RAS, MIKE URBAN and D-Flow FM). The framework presented in this study uses OSM data for establishing semi-automated schematisation of urban flood model using D-Flow Flexible Mesh.

7.3 Application Example: Manzese Ward Flood Risk Assessment

7.3.1 Study Area

Dar es Salaam is the largest city in Tanzania, with a population of 4.4 million. It is also the country's economic centre. Over the last twenty years, the land use has been significantly changed, primarily with urbanisation, resulting in informal and unplanned urban settlements with poor infrastructure (Kombe, 2005). This is leading to high vulnerability to flooding. Rapid urban growth and lack of resources still remain critical issues for the city (Hambati, 2017; Hambati and Gaston, 2015). Various recent studies and projects were carried out to provide an accurate assessment of the system and provide some strategies and solutions to these challenges. In 2015, Hambati and the community hazard mapping team conducted a flood assessment in Dar es Salaam (Hambati and Gaston, 2015). The result of the assessment shows that flooding (i.e. pluvial and fluvial floods) represents the primary hazard in Dar es Salaam. Additionally, an extensive technical assessment to study the flooding condition in Dar es Salaam was conducted by Deltares in 2016, with the financial support of World Bank (WB) project named "Challenge Fund I" (Winsemius et al., 2016). The project outcome shows that the city is prone to a regular flooding. Even though the city has a flood early warning (forecasting) system, few flood warnings and response actions are taken by the local authorities and stakeholders. Lack of planning and coordination among the stakeholders combined with limited budget allocated to preparedness and response are key challenges that the local authorities and stakeholders face. In particular, the majority of the budget is allocated to recovery, rather than preparedness. This shows a lack of proactive measures. Data scarcity aggravates the situation. Despite the recent initiatives to enhance the coordination among stakeholders and communities, considerable work still remains towards continuous collaboration and participation among the stakeholders.

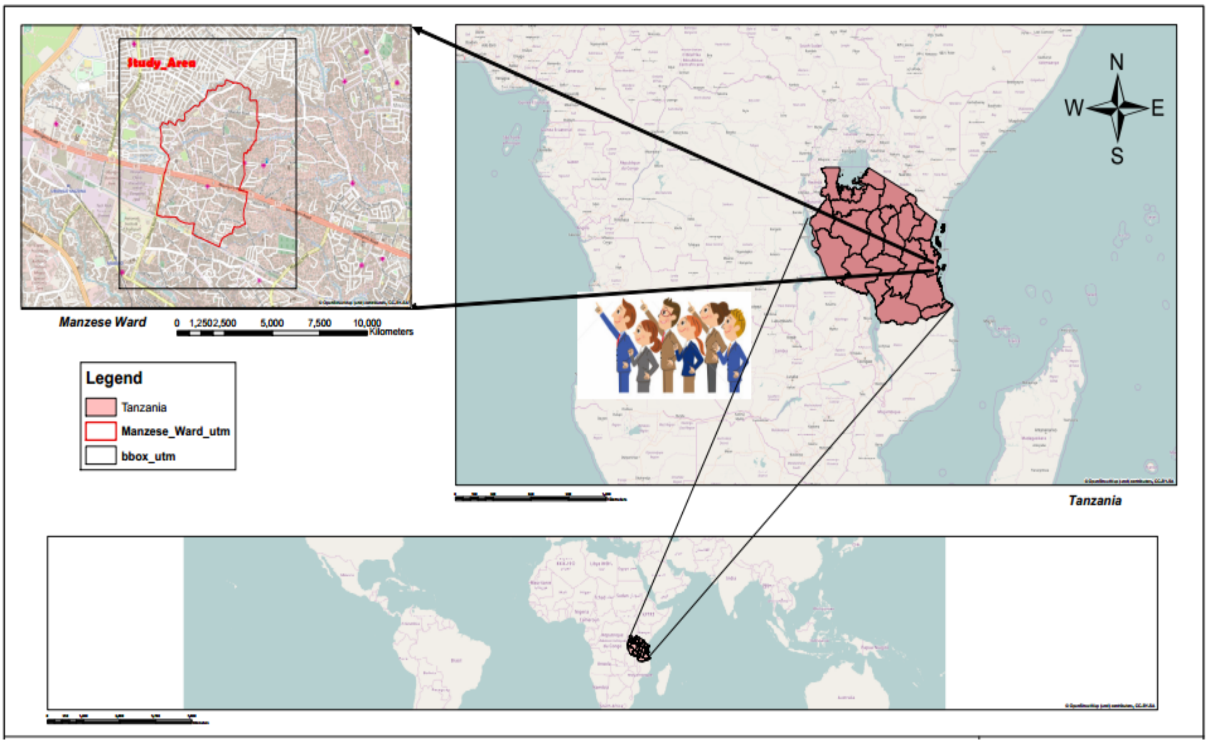


Figure 7.2 Location of Manzese ward and the model domain area, Dar es Salaam, Tanzania

Manzese ward in Dar es Salaam is selected as a pilot area to establish this study (Figure 7.2). This Ward not only suffers from lack of infrastructure but also from poor waste management, leading to high flood vulnerability.

7.3.2 Participatory Urban Flood Modelling Approach

Mapping cities with the knowledge of the locals has spread widely in different places through participatory mapping approach (Chambers, 2006), including in Tanzania. In Dar Es Salaam in particular, the coordination with stakeholders and the communities for managing and planning the city has been adopted since 1992, with the technical assistance from UNCHS (Halla, 1994). This engagement was proven to be effective during the community mapping initiative in Tandale, in Dar es Salaam, as part of the community mapping project in 2011 (Iliffe, 2015). In Manzese Ward, the Ramani Huria community mapping project implemented in 2015 supported the consolidation of the mapping community and the extension of the OSM for the area. The project was supervised by the

World Bank and Tanzania Red Cross Society (TRCS) and it aimed at mapping most of the city through public participation.

The participatory modelling employed in this study builds on these prior experiences with community mapping. Similar organizational and individual stakeholders have been mobilised, now with the objective of developing an improved urban flood model. The adopted participatory urban flood modelling framework for Manzase Ward is illustrated in Figure 7.3. Principal element of the participatory approach is structuring the involvement of local stakeholders in the process of model development.

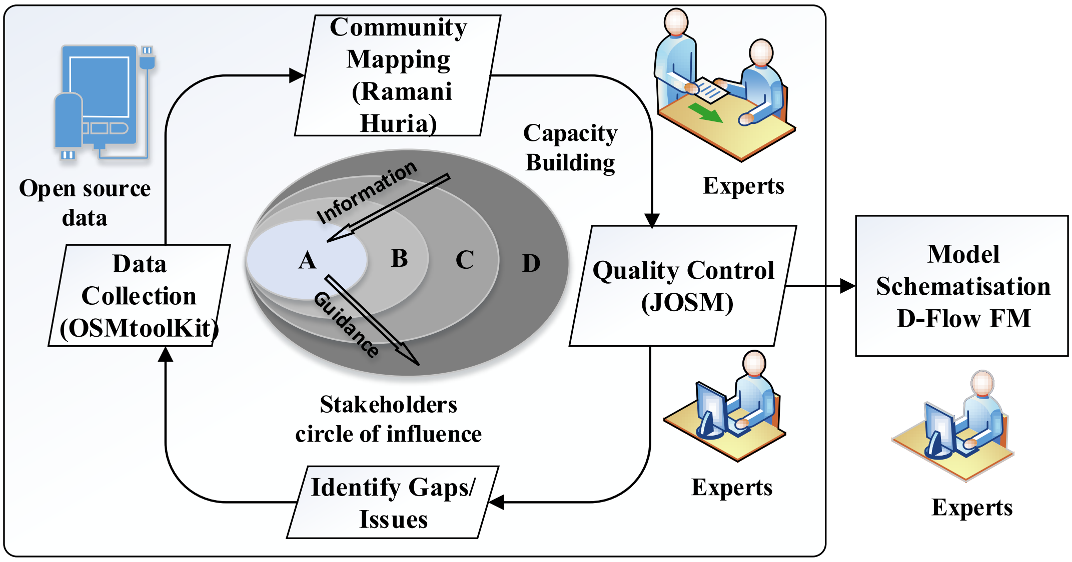


Figure 7.3 Manzese Ward Participatory Urban Flood Modelling Framework

The circles of influence approach was used for this purpose, based on the results of the stakeholder analysis (Cardwell et al., 2008). Four circles were distinguished as well as the relationship among them. These include: (I) Circle A: Modelling team and organising team, (II) Circle B: Model user and improvement team, (III) Circle C: Consulting and Mappers team, and (IV) Circle D: Decision-makers (Table 7.1). 25 participants were involved from 13 organisations, including a private construction company(Silcon Builders Limited), TRCS (Disaster Risk Management (DRM)), WB, HOT (Humanitarian OpenStreetMap Team), RCCC/ARC, Tanzania Meteorological Agency, Ardhi University, University of Dar Es Salaam, Ministry of Water Resources, Ruvu river basin, Disaster Management Department, Centre for Community Initiative (NGO), Kinondoni Municipal councils, Dar Es Salaam city council, Ardhi University and Dar Es Salaam Region Office.

Table 7.1 Circles of Influence approach used in Manzese Ward

Circle	Stakeholders' group
A	▪ Red cross ▪ Deltares
B	▪ World Bank ▪ Universities (Dar Es Salaam & Ardhi)
C	▪ World Bank ▪ HOT ▪ Universities (Dar Es Salaam & Ardhi) ▪ Non – governmental organisations ▪ Citizens organisations
D	▪ Provincial administrative authority ▪ Provincial water resources authority

Dar es Salaam Community Mapping

The consolidation of the Dar as Salaam community mapping is supported by the Zuia Mafuriko and Dar Ramani Huria project. "Dar Ramani Huria" is a Swahili term for "Dar Open Map". The initiative engages community members and local university students (i.e. University of Dar es Salaam and Ardhi University). The mapping team has the responsibility to map residential neighbourhoods, roads, rivers/streams, floodplains in the vicinity and other relevant critical infrastructure.

In the study, the OSMtoolkit was developed with their inputs to support their task of mapping critical infrastructure. It provides guidance on the specific characteristics and features that need to be mapped. The first prototype was developed by the Deltares experts with the established OSM carried out by Ramani Huria community based mapping in Manzese ward (Figure 7.4). Validation of the information and collection of new data to improve the model was carried out following the participatory data collection framework. A set of tools were developed and used to support the data collection process. The OSMtoolKit facilitates the collection of local waterways infrastructures and JOSM editor tool helps uploading collected data by the mapping team into the OSM platform.

Stakeholder Workshop

The stakeholder workshop held on 21-23 of February 2017 in Dar Es Salaam had three main objectives. First, it was designed to be an interactive environment to further develop the technical knowledge regarding participatory mapping using OSM and urban flood modelling using D-Flow-FM. Secondly, it created the suitable inclusive environment to enhance the collaborative work between local stakeholders, mappers, modellers and the organising team. This propitiated the exchange of technical and local knowledge between them. Finally, the workshop focused mainly on continued training of the participants on what type of data to collect and how to bring an open source data, such as OSM into an urban flood model.

Having a good insight of the existing technical and local knowledge about the area and the systems, including their understanding about hydrology and flood modelling, was a pre-requisite for designing the workshop. A semi-structured questionnaire survey was used to collect this information. This was followed by an extensive analysis of the survey results.

A total of 25 water professionals and local stakeholders filled in the survey. Respondents had diverse backgrounds: community representatives with a social science background, disaster managers, university professors and urban planners with extensive experience on mapping. The survey results showed that only 5 respondents had certain knowledge in hydraulics and hydrology. All participants are to some extent familiar with mapping. The majority (80%) had experience in mapping for data collection themselves.

Initial Model Schematisation

The initial model was constructed based on available OSM data, rainfall data time series from 1988 up to 2015 that were obtained from the Tropical Rainfall Measuring Mission (TRMM), two boundary inflows (i.e. Ng'ombe River and Mbokamu stream) that were developed using a unit hydrograph. The model also included a 2m resolution Digital Terrain Model (DTM) developed using PARTERRA GEE, spatially variable roughness based on the land use cover and 0.012 manning roughness values for the 1D open channels.

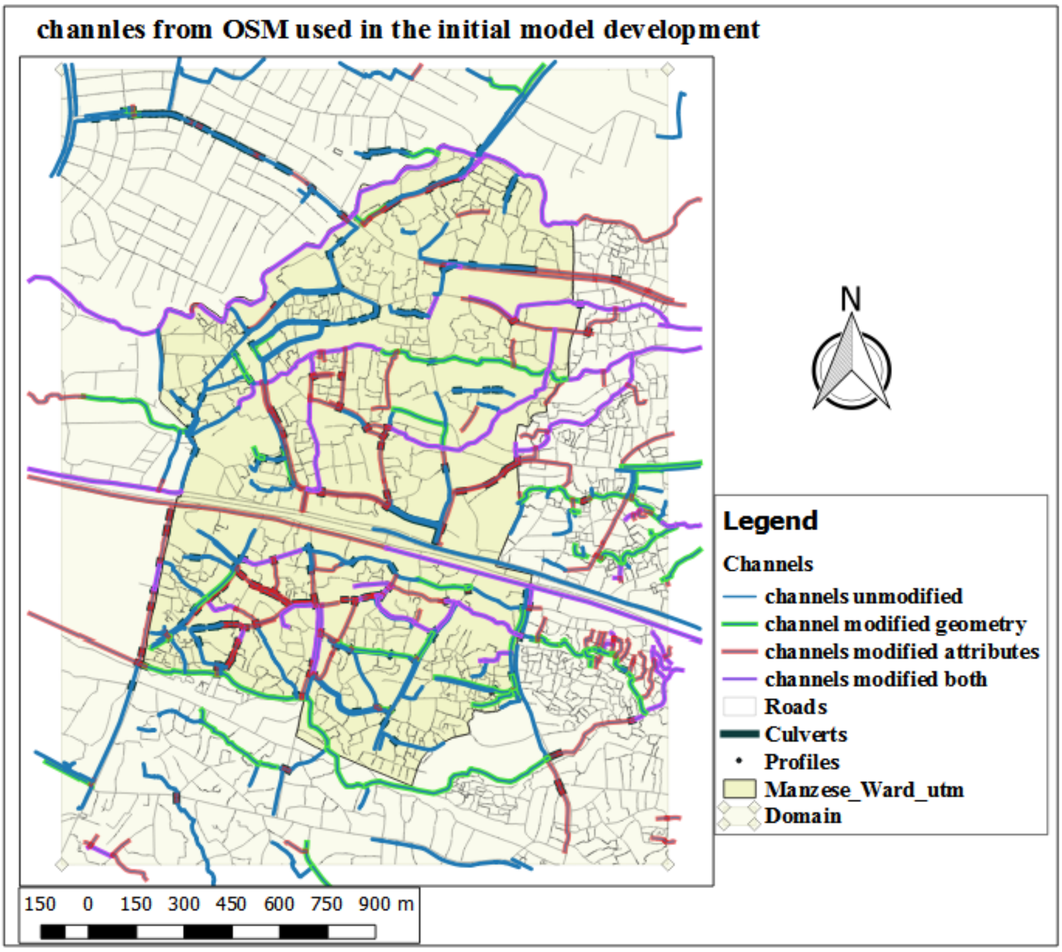


Figure 7.4 Initial OSM data used for the development of the first model prototype

The osm2dh tool was used to obtain data from OSM and provide an automated D-Flow FM schematised model. Its configuration allows obtaining the values for key attributes from the OSM datasets. The user can provide a default value for the missing information of various waterways. The available attributes of waterways or channel elements in OSM include ditch, stream, river and drain. Assumed values were provided to missing data, for instance to waterways depths and widths (as OSM only uses a rectangular profile type). Figure 7.4 illustrates the channels' status in the initial urban flood model for Manzese ward. Channels labelled in blue contain unmodified values. Green coloured channels are characterized with proper attributes, but assumed values were used for missing values. Red channels are defined with modified attributes. Lastly, both attributes and the geometry were modified for those channels coloured in purple. After engaging local stakeholders in mapping and modelling, the default values for some of the waterways and unmapped channels were improved.

The initial model setup was tested for 2D flow simulation and later coupled with the 1D drainage networks. The time step (Dt) was set to 30sec. Flexible mesh size was max 25m – min 6.25m and Dx was based on the flexible mesh cell size. A 100-year return period design storm with 3-hourly rainfall, and discharge from upstream was used for 24 hours of simulation time.

7.3.3 Evaluation Process

Three data collection methods were used in this study: interviews, a reconnaissance survey and a workshop to collect and validate data and model outputs. Interviews were conducted with community members to gather information about flood prone areas and the location of infrastructure. A reconnaissance survey was conducted to validate the OSM data of the case study area. The interviews were also used to identify and analyse dependencies between the stakeholders, investigate possible beneficiaries from the study and improve the stakeholder engagement process for data collection and model development. A stakeholder workshop was used to provide training to the mappers, modellers and community members about (i) flood modelling, (ii) types of features that affect the flow in an urban environment, and (iii) the characteristics and methods to map certain features such as drains, ditches, elevated roads and buildings.

7.3.4 Results and Discussion of the Evaluation Process

Overview of the Stakeholder Workshop

The workshop comprised training and several different working sessions. On the first day of the training, the research and organising team demonstrated and explained how flood moves in the city and through an urbanised area. Games –like representations- were used for illustration of how water moves in channels. Additionally, the team explained and discussed the type of models that can be implemented in an urban setting. This included the importance of representing channel drainage flow in a 1D model and overland flow in a 2D model. With this understanding, a discussion among the participants initiated, regarding mapping important features for urban flooding. Clear understanding was established about where to map and what detail to map, in order to validate and improve the flood model.

One main activity of the workshop was the analysis of different scenario cases. It started with an exercise in building the 2D model with the available data, followed by an exercise of analysing changes with various grid resolutions. The results with the 2D model were evaluated and that led to the completed 1D-2D flood model development with D-Flow FM. Participants were asked to investigate where the channels and river geometry was modified and where the channels with missing dimensions are located. The OSM data that were used to build the initial model were first presented (Figure 7.4) and discussed among the participants. The participants were then asked to split into two small groups. The first group, namely the "modeller group" focused on building the 1D-2D flood model. The second group, namely the "mapper group" focused on identifying locations for data collection and validation. The application of the participatory modelling approach structured the data collection phase. On the second day, while the modeller's group prepared schematisation of the initial model, the mappers group selected an area where the representations of the channel in the OSM were incorrect. On the last day, the participants were out for field work to investigate and validate the data used to build the initial model.

Reconnaissance Survey

Selection of area for reconnaissance survey, implemented by the mapper's group was based on two main conditions: first, using their knowledge of the local area, the mapper's team were able to identify some drainage channels that were not being displayed in the OSM and non-existing drainage lines were mistakenly mapped; secondly, as the initial model was built using assumed default cross-section for the rivers (5 m width and 2 m depth), it was important to validate the assumption applied to Ngombe River. By going into the study area, the drainage channels could be checked and the assumption could be validated and corrected if required. Additionally, the organising team pointed out that, in the OSM, the model domain area showed 848 intersections between roads and waterways, however, only 290 were shown as culverts. As a result, validation with field work was necessary to check if there is a culvert at the intersection, or if there is no intersection at all. The field work was facilitated with the drone image of Manzese Ward captured by WB and the paper map of the drainage network prepared by the organising team using the OSM. Consequently, the drainage lines close two Ngombe River were selected to carry out the reconnaissance survey.

Figure 7.5 Selected area for reconnaissance survey

In Figure 7.5, the drainage lines and the river location selected for field visit are presented: point A shows the location of the drainage line missing from the map; point B and D show the drainage lines that actually do not exist but created a looped drainage network; and point C represent the location of Ngombe River. On the third day, participants went to the selected locations for data collection and validation. In order to save time and cover more ground, the participants split into two groups. The first group, went to the location represented by A & B, while the second group went to point C and D.

Field investigation helped to obtain new data about the river and the drainage lines and this data were applied in the model. The findings from the reconnaissance survey include: i) a trapezoidal drainage line that had not been mapped at point A was identified; ii) the drainage lines that were seen at point B and D do not exist; and iii) the river is wider and deeper than the assumed values.

Referring to the framework for participatory urban flood modelling, the next step would be model schematisation using the collected new data. For this purpose, the collected data had to be updated in OSM platform and converted into a D-Flow FM file format. However, the OSM attributes and the developed Osm2dh tool only support a rectangular cross-section at this time. As a result, the improvement was implemented in the following ways: i) the collected cross-section of a trapezoidal channel was converted into a rectangular cross-section, by considering the conveyance capacity of the channel; ii) the drainage lines at point B and D were removed from the OSM and iii) the new "real" assumed cross-section for river (10 m width and 3 m) was applied.

Model Improvement

The second (improved) model was schematised using the data obtained from the reconnaissance survey with the help of the local stakeholders. The results obtained from the second model were compared with those if initial model, to evaluate the improvement obtained with the applications of the participatory modelling approach. The first comparison was regarding the drainage channels that were mapped, but do not exist in the area, which created a loop in the drainage lines. The second comparison was carried out on Ngombe River with the newly assumed cross-section (width and depth).

Case I: Improvement in Channels

Figure 7.6 shows the drainage channels before (left) and after (right) improvement. The time series of water depth taken at points B & C for the initial model are presented in Figure 7.6 a & b and after the improvement in Figure 7.6 c & d. As aforementioned, at point A and C there were drainage channels connecting the side channels which created a looped network. This looped channel is created due to a mapping mistake. The reason for this mistake may be the following: usually community mapping uses a satellite or drone image to develop the OSM. Depending on the timing of taking such an image, some areas might show shading. This shading could be confusing and might seem like a drainage line, leading to a wrongly mapped channel. Unlike urban drainage line that drains out the coming flow, the looped network creates storage. This results in accumulation of water until it reaches the full capacity of the drainage channel (peak depth 0.17m, Figure 7.6 a). After the improvement (Figure 7.6 b), those channels were removed and the water drained to the lowest point after it reached only 0.01m. As part of the improvement, the new trapezoidal channel located down below point A, has also been mapped and included in the second model.

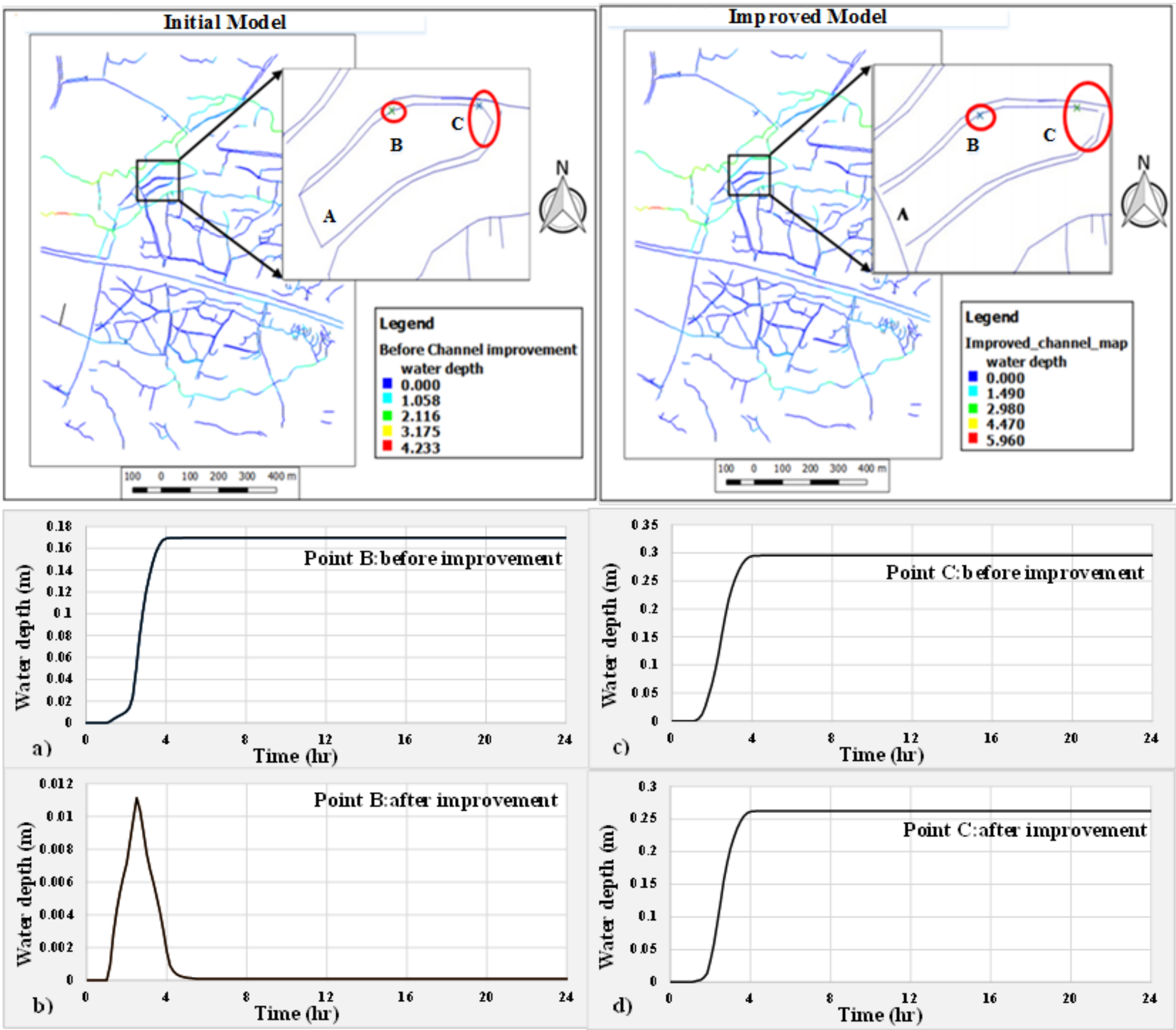


Figure 7.6 Comparison of water depth in the drainage lines before and after the improvement

Furthermore, at point C, before the improvement, the water depth reached 0.30m and stayed that way till the end of the simulation (Figure 7.6 c). After the removal of the locking channel, even though the water depth was reduced to 0.26m (Figure 7.6 d), it again stayed like that till the end of the simulation. This is because there is no drainage network that is connected to this drainage line, to drain the water. In fact, this is happening physically in that drainage channel, as one of the major problems in the area is lack of proper drainage network due to unplanned infrastructure and settlement.

Case II: Improvement in the Ngombe River

Generally, after incorporating the new data, the maximum water depth in the river is higher than that developed initially. This is because there is more area in Ngombe River, as the cross-section is higher after the improvement. The initial model result of Ngombe River showed maximum water depth of 2.35m. After the improvement, the second model, resulted a maximum water depth of 3.85m. In Figure 7.7 a, and Figure 7.7 b, flood inundation before and after is presented. As a result of the incorporation of the new data, inundated area is smaller than before. This is more visible at the downstream of Ngombe River, where it is shown that less number of houses are flooded after model improvement. In the initial model, maximum water depth of 2.214m was recorded. (Figure 7.7 a).

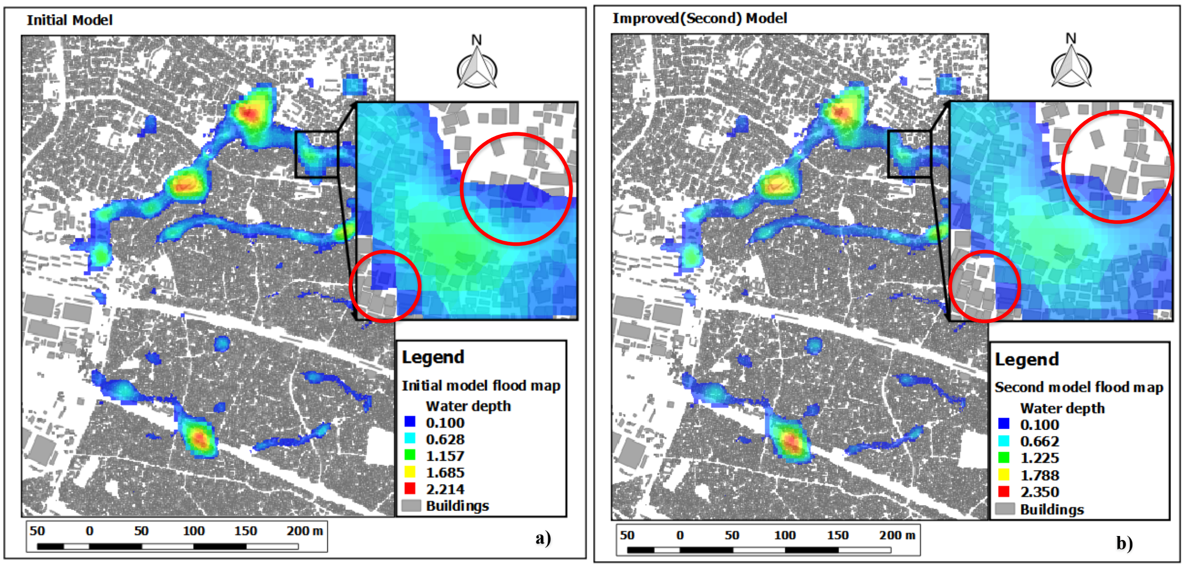


Figure 7.7 Flood inundation map for the initial (a) and the improved model (b)

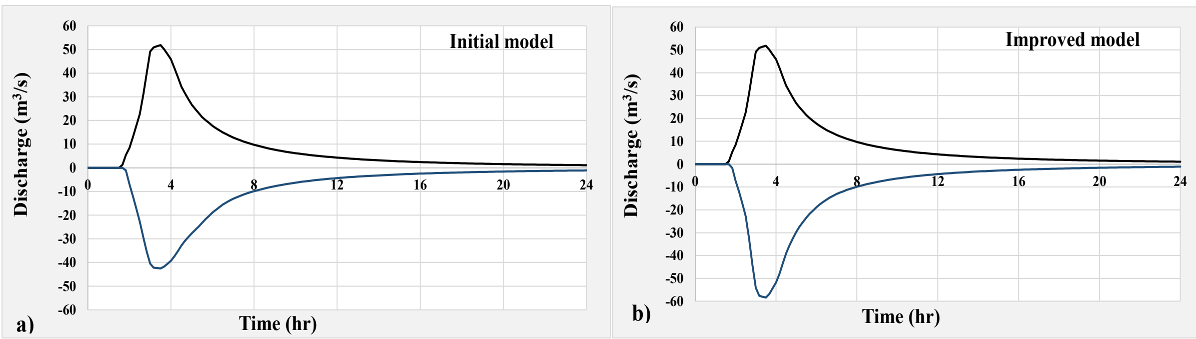


Figure 7.8 Discharge flow in the upper and outflow in the mid reach of Ngombe River for the initial (a) and improved (b) model

After model improvement, the second model resulted in a maximum water depth of 2.35m (Figure 7.7 b). The maximum water depth is in fact registered in the river. In the initial model, the river has a smaller cross-section and more water spreads as overland flow. However, after the improvement, the river channel has higher capacity, covering more water, and the maximum water depth is also higher. This reduces the amount of water that goes to the floodplain area, which is also noticeable in Figure 7.7, that shows lower water depths in these areas for the improved model.

Besides the comparison of the water depths in the river and the floodplains, discharge at Ngombe River was also evaluated. Having the same boundary inflow to the river in the upper reach, the outflow at the mid reach shows higher discharge in the second model. Figure 7.8 shows the resulting discharge inflow and outflow for both cases. As it can be seen, for the same inflow (51 m^3/s), the initial model outflow was 43m^3/s and the second model resulted in 58 m^3/s. This is because the flow is directly related to the cross-section area, the higher the cross-section, the higher the carrying capacity. As aforementioned, there is more area in Ngombe River, as the cross-section is larger than the initial assumption.

As can be seen from this study, even complex urban flood model development can be supported in a data scarce environment with a structured participatory mapping and modelling approach. The results from the initial and the second model have shown how the local stakeholders can contribute in the iterative model improvement process.

Moreover, due to lack of observed hydrological data, calibration and validation of the developed model have not been carried out. Although there are advantages of using OSM in data scarce environments, in this case most of the data is still missing and there is inaccuracy and miss-representations of some features. For instance, the size of the drainage channels on some locations was inaccurate. However, regardless of these limitations, the level of improvement achieved with only one workshop and subsequent data gathering campaign shows the potential for further model improvement by collecting data with the help of the local stakeholders.

7.4 Method Evaluation and Key Features

This method that integrates crowdsourcing and Interactive Modelling is evaluated using the participatory and collaborative modelling framework (Chapter 3). Table 7.2 presents the results of the evaluation of the method and its application in Dar es Salaam. The most characteristic features are highlighted in orange.

Participatory or collaborative modelling can be used when applying this method. The key features of the new method are:

- *Application*: DRR projects/studies, the interaction context is generally much more cooperative than in IWRM and related projects/studies. The problem structure is therefore commonly semi-structured. The method is commonly applied in high-tech projects/studies.

- *Specific use:* the primary objective of the participatory modelling and mapping approach is model improvement by improving its quality with the support of stakeholders, and as a result enhance integration and acceptance. Secondly, the participatory modelling approach initiates collaborative learning in which capacity development can be obtained.
- *Modelling approach:* The method combines the use of OSM for data collection and complex physical system models that help representing the system. For Interactive Modelling, communication and rapid visualization tools are essential.
- *Stakeholder engagement*: It is recommended to create different working groups such as the "mapping team" and the "modelling team". The stakeholder engagement structure is critical to ensure a good working space and collaborative environment. Such structure allows the active involvement of very different stakeholder groups in the project/study (incl. local communities and citizens).

In terms of future research directions, the initiated work should be further improved through mapping and improving more areas in the OSM. In this study, the collected data for improvement only covers waterways infrastructures. Therefore, for future model improvements, information about buildings and roads should also be updated. Furthermore, the database in OSM could also include other types of structures according to the local conditions. The 1D channel can be according to the type that is actually presented on the ground, instead of representing all the channels as having rectangular cross sections. This may be specifically relevant for the Ngombe River, as the assumption of uniform cross-section for a natural river is not ideal. Community mapping campaigns can be extended to surveying the actual river cross-sections and their incorporation in the model.

Table 7.2 Evaluation of Crowdsourcing and Interactive Modelling

Factors	Parameters		Crowdsourcing & Interactive Modelling	Dar es Salaam case Tanzania
Context and application	Problem type	Problem structure Scale of action Time horizon	Semi-structured Different scales Different time horizons	Semi-structured Local (city, ward level) Medium (20 years)
	Domain		Different domains	Flood Risk Management
	Interaction context	Cooperative Competitive	Cooperative environments	Cooperative environment
Specific use	Participatory/ Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Model improvement *Secondary purpose:* Collaborative Learning	*Main purpose:* Model improvement *Secondary purposes:* Collaborative learning
	Planning/Management cycle phase		Situation analysis and Strategy design. Commonly high-tech projects.	Situation analysis
Information handling	Model characterisation	Model system focus Model type	Physical system models Analytical models	Physical system model and tools Analytical model
	Modelling tool / Software platform		Combination of OSM and complex models. Communication and visualization tools are critical for interactive modelling.	Crowsourcing for data collection. For modelling: D-Flow Flexible Mesh flood model, PARTERRA-GEE tools, Crayfish QGIS plugin, OSMToolKit and JavaOpeenStreetMap
	Information type		Complex processes	Complex processes
	Information delivery medium	Virtual/web Face-to-face	Combination	Face-to-face sessions, workshops and a reconnaissance survey
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Can vary, participatory and collaborative modelling are possible	Participatory modelling
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	The approach allows to have very different stakeholder groups involved (incl. local communities and citizens)	(Section 7.3.2)
	Model users	Direct/Indirect Technical skills	Commonly, direct users	Direct.
	Participation mode	Only modellers (no participation) Individuals Groups	All participation modes are possible	Stakeholders were grouped into the Mapping and the Modelling teams. Experts helped both teams
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	All levels are possible	Stakeholders actively participated in consultation, discussion and to some extend co-designing.
	Timing of participation	Data collection Model definition Model construction Model validation Model use Measure formulation Strategy design	All timings are possible	The participation ranges from accessing data from OSM, model schematizing, identification of areas where validation and mapping is required for improvement and finally to discussing scenario cases.
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Commonly, coordination and collaboration	Collaboration
Modelling / organising team	Team		Experts in OSM and complex models required	Project leaders, community representatives, urban planners, and disaster risk managers.
Means	Timing		-	10 months
	Financial resources		-	USD 150k

7.5 Conclusions

This study examined and demonstrated the potential urban flood model development and improvement using OSM data following applications of participatory mapping and modelling approach. The use of the developed framework for participation in the case study area promoted interaction and involvement of the locals, including the community members and stakeholders. It was used for ensuring the active participation of key stakeholders in data collection and building trust and ownership of the data for the flood model. Moreover, it facilitated the co-production and sharing of knowledge regarding the urban flood model, contributed to increased flood resilience, and strengthened collaboration between governmental, technical and scientific institutions, civil society organisations and local communities.

The approach provided novel and quite promising results regarding the use of participatory modelling and mapping approach for urban flood model development. Such participation on modelling have been predominantly used by stakeholders in other environmental models. This study demonstrates the potential of the approach in achieving improvements in hydrodynamic urban flood model development in data scarce developing countries.

8

SELECTION AND EFFECTIVENESS OF PARTICIPATORY AND COLLABORATIVE MODELLING METHODS

This chapter presents first an overview of the methods used and adapted as part of this Ph.D. thesis. In particularly, an assessment is conducted to analyse the methods and their (most suitable) application considering four main parameters given/constrained by the context and situation (i.e. specific use – purpose, systems analysis, planning cycle phases, and technical knowledge and skills required). Moreover, the chapter includes an analysis of the added value of participatory and collaborative modelling in WRM, including its effectiveness and challenges. The outputs of this chapter help addressing Research Question 4: *What is the added value of applying participatory and collaborative modelling to support water resources planning and management?*.

This chapter is partly based on:

Basco-Carrera, L., van Beek, E., Jonoski, A., Benítez-Ávila, C., Guntoro, F.P., 2017. Collaborative Modelling for Informed Decision Making and Inclusive Water Development. Water Resources Management 31(9) 2611-2625.

Basco-Carrera, L., Dahm R., Gebremedhin E., Naffaa S., and Winsemius H., 2018. The role of participatory and collaborative modelling in water resources management. Opinion paper (publication in progress)

Basco-Carrera L., Mendoza G., 2017. Collaborative Modelling. Engaging stakeholders in solving complex problems of water management. Global Water Partnership. Perspectives Paper No. 10

8.1 Methods General Overview

The research conducted as part of this Ph.D., which is presented in the previous Chapters and Sections, is used as a basis for providing a general overview of the participatory and collaborative modelling methods presented. The 20 parameters used in the generic framework for participatory and collaborative modelling (Table 3.1) help evaluating existing participatory and collaborative modelling approaches, methods and tools, as well as to generalize case-specific approaches. Some of these parameters can also be used as criteria for the selection of the suitable approach, method and/or tool in a particular context and/or situation. Other parameters help evaluating or designing the approach. Some can be even used as performance indicators. The "interaction context," for instance, is a parameter given by the context and/or situation. It is an external factor that is given at the start of the project. However, it can change over time. The "model users", on the other hand, is a parameter that often can be decided by the organizing and modelling team or the involved stakeholders.

In this section, four main parameters given/constrained by the context and situation are selected to provide a general overview of the methods presented and their (most suitable) application. These four main parameters are: (i) specific use – purpose, (ii) systems analysis, (iii) planning cycle phases, and (iv) technical knowledge and skills required. All methods are then categorized into participatory modelling and collaborative modelling. The general overview include the general approaches and tools used by the participatory and collaborative modelling community (e.g. Group Model Building, Interactive Modelling) and the methods used and adapted in this Ph.D. research (i.e. Methods 1-4). The first general approaches and tools are coloured in orange. The methods used and adapted during this research are coloured in red (see figures in sections below).

8.1.1 Specific Use

The specific use, particularly the purpose of using participatory or collaborative modelling, is an important factor when deciding the approach, method or tool(s) to use. Figure 8.1 illustrates the suitability of the methods and approaches studied based on their specific use. The four purposes included in the generic framework for participatory and collaborative modelling (Table 3.1) are used for categorizing the approaches and methods. These are: decision-making, collaborative learning, mediation and model improvement.

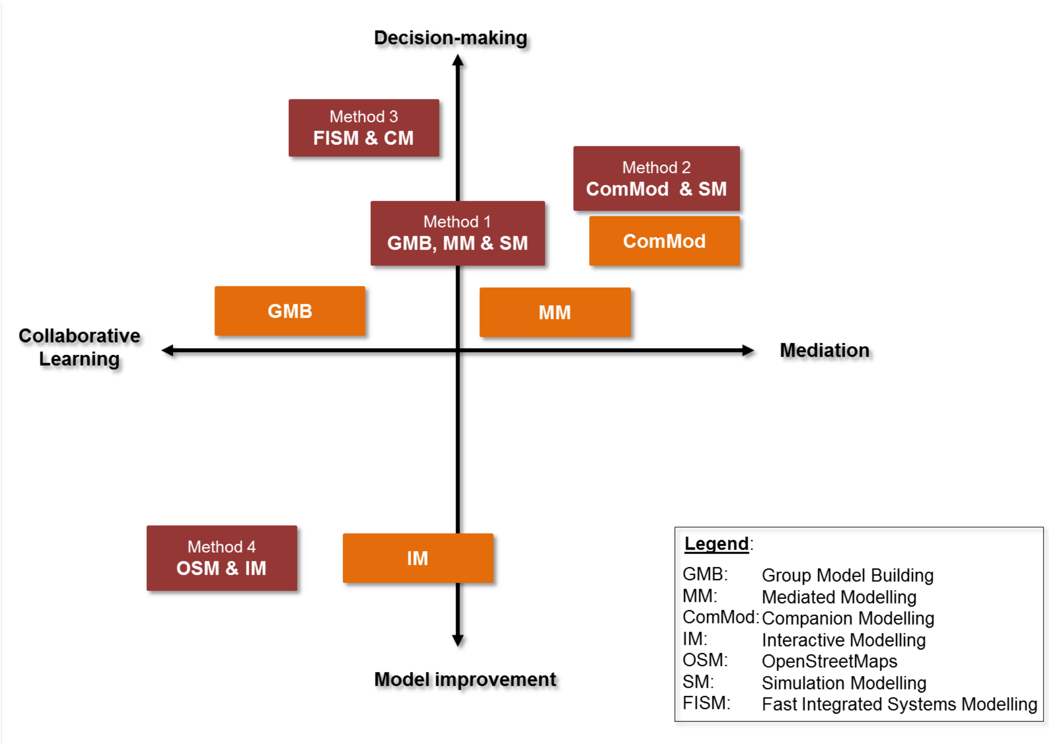


Figure 8.1 Methods general overview based on specific use

Interactive Modelling is mainly used for model improvement. Its combination with crowdsourcing (Method 4; presented in Chapter 7) enforces collaborative learning. Stakeholders involved in the Tanzanian case perceived that this method helped gaining a good understanding of the models and tools developed and used during the project. They also highlighted its benefit in terms of integrating local and technical knowledge via shared learning, a form of collaborative learning.

Many researchers question the difference between Group Model Building and Mediated Modelling due to their high similarities (see Chapter 4). However, when analysing the specific use of both approaches, their differences become more apparent (Figure 8.1). Group Model Building is mostly suited for cooperative environments. As a result, its specific use is commonly collaborative learning. On the other hand, Mediated Modelling is mostly suited for non-cooperative environments. Its primary purpose is mediation by means of collaborative learning. Although both approaches can be used in decision-making processes, the stress of both approaches remains in the joint development of a systems analysis/dynamics model. Method 1 (Chapter 4) developed as part of this research, which combines the use of Group Model Building and Mediated Modelling with simulation modelling, is more adapted to complex decision-making processes related to water resources management.

Companion Modelling and its combination with simulation modelling (Method 2; Chapter 5) is most suitable for non-cooperative environments. It is commonly used as a means towards enhancing the dialogue between individuals and/or stakeholder groups. Its primary use is enhanced cooperation by means of mediation. While Companion Modelling is frequently used in local and regional scales such as at community level, Method 2 is adapted to be applied in bigger scales such as complex large and medium river basins.

Method 3 (i.e. FISM and collaborative modelling) is the method most appropriate for decision-making. It is particularly suitable for designing and testing alternative strategies and prioritizing investments. The results from stakeholders' perceptions questionnaire show that collaborative learning is a secondary output when applying this method. Involved stakeholders and decision-makers do not only gain understanding of the system(s) in an integrated manner, they also learn about the needs, interested and perceptions of other decision-makers and stakeholders.

8.1.2 Systems Analysis

The focus of the system(s) that aims to be modelled can also determine the selection of the approach, method or tool(s). In the generic framework (Table 3.1), four types of model system focus are included: physical system models, single actor decision models, individual actor impact models, social system models or combinations of them. In this section, however, the methods and approaches are categorized based on the system(s) analysed. These include: (i) physical system, (ii) social interactions, and (iii) economic system. Figure 8.2 presents the general overview of the different approaches and methods based on the system of analysis.

Companion Modelling and Method 2 are commonly used for the analysis of the physical system, as well as the social interactions. Both aim to enhance cooperation by means of first having a good overview of the social interactions between the stakeholders involved. A role playing game or an agent-based model are commonly used for assessing the social interactions. The simulation model is used to better analyse the physical system. As stakeholders get a better insight on the social interactions and the physical system, dialogue is boosted and possible points of cooperation are identified.

Interactive Modelling is primarily used for assessing the physical system. It allows the fast and interactive use, manipulation of the model, as well as the fast visualization of the system dynamics. The engagement of local stakeholders in data collection via crowdsourcing, improves the analysis of the physical system, but it can also provide additional information related to for instance, the economic system (e.g. critical infrastructure, land cover, etc.).

Method 3 based on FISM and collaborative modelling allows the integration of all three systems: economic system, physical system and social interactions. Specifically, it integrates and simplifies interactions and relevant feedbacks among complex systems into a FISM model that is intended to mimic the behaviour of complex (detailed) models (Chapter 6).

The flexibility of the tools used in Group Model Building and Mediated Modelling allow that any type of system can be modelled. As highlighted in Chapter 4, examples of system dynamic models modelling the behaviour of the economic system (global and/or local), social interactions and its relation with decision-making, as well as models representing the physical system can be found in literature. Moreover, their tools also allow the integration of different sorts of models, which can model different systems. These integrated models are also often named as meta-models. The method developed as part of this thesis, Method 1, allows a more detailed analysis of the physical system, as it combines the use of systems analysis and dynamics with complex, detailed physical-based model(s).

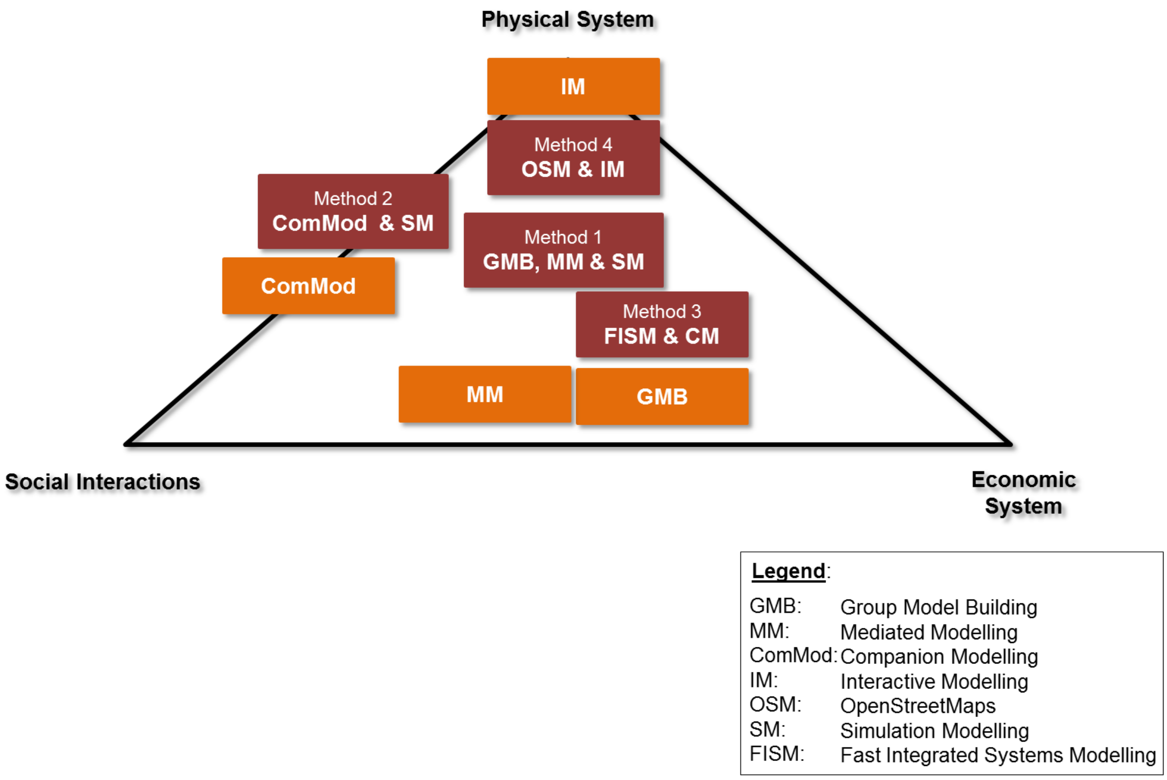


Figure 8.2 Methods general overview based on system of analysis

8.1.3 Planning Cycle Phases

Often there is the perception that all methods and tools can be used interchangeably. However, when analysing their use and timing in terms of the planning cycle, their differences are significant. Indeed, the development and use of approaches, methods and tools is specific to certain stages of the planning and decision processes and corresponding modelling phases. Figure 8.3 displays the IWRM planning cycle (boxes and arrows in black). The different methods and tools studied as part of this Ph.D. study are included in additional boxes next to the planning phases, when they are commonly used. Results from the analysis show that most methods and tools are commonly used in the early and middle stages of the planning process i.e. situation analysis and measure formulation. Their use for implementation, monitoring and evaluation is rather limited.

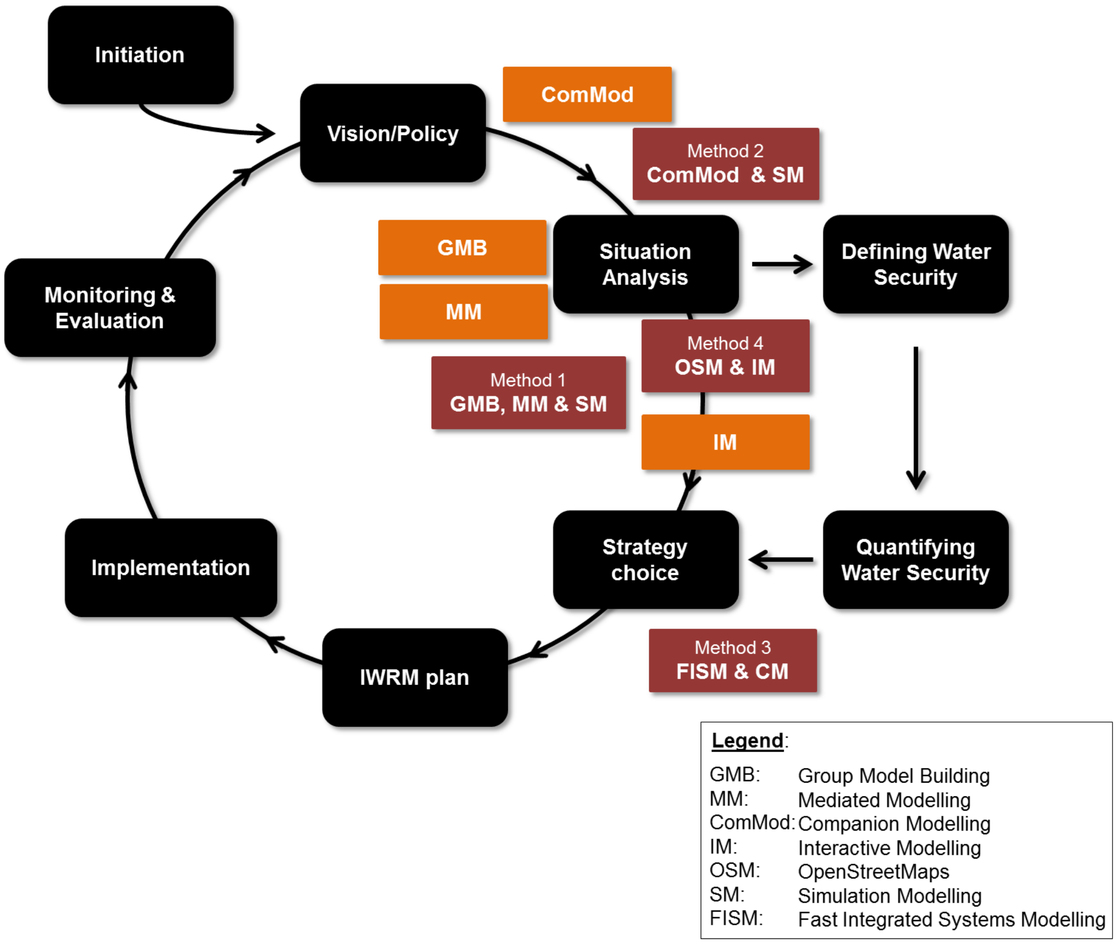


Figure 8.3 Methods general overview based on planning cycle phases

Companion Modelling stresses the analysis of the social interactions, not only at individual level but also considering the institutional setup and policies being in place. These are critical elements when it comes to competitive environments. Companion Modelling is therefore suitable to be applied in the early stages of the planning process, when the enabling conditions are being analysed. The use of the simulation model, agent-based model and the role playing game in the situation analysis phase help better understanding the physical system and the social interactions when analysing it. Companion Modelling can also be used for to achieve joint action. In this cases, its use extends up to strategy building, action planning and in some occasions implementation.

Group Model Building, Mediated Modelling and the Method 1 developed as part of this thesis are mainly used for situation analysis. Although their scripts and guidelines include up to measure formulation and policy design, the steps and tasks are much more detailed for the situation analysis phase. The combination of systems analysis and dynamics with complex, detailed simulation models allow not only a more exhaustive analysis of the system, but also the testing of the measures proposed.

Interactive Modelling is also commonly used for situation analysis. However, the high-tech models and tools used, allow the exhaustive analysis of measures and alternative strategies. The use of crowdsourcing adds to the deeper analysis of the system.

Finally, FISM focuses more on the water security phases as well as on the middle phases of the planning cycle. Commonly, FISM requires detailed, complex models that are used to analyse the system(s) in great detail. FISM makes use of these models, by integrating them. For this method, the definition of model purpose and context is a primary step (Section 6.2.1). This is linked to the policy and vision planning phase, as well as to defining water security. In the phase namely, quantifying water security, the DSIs and SIs are defined (Section 6.2.2). Finally, the method helps in the evaluation of possible alternative strategies under different scenarios and the prioritization of investments (Section 6.2.3). This is the last step prior to finalizing the IWRM plan.

8.1.4 Technical Knowledge and Skills required

The technical knowledge and skills of the decision-makers, stakeholder and technicians that will be involved in the participatory or collaborative modelling process are essential factors that can constrain the selection of the approach, method and tool(s) used. Some methods and tools require higher technical knowledge and skills than others. An indirect objective of participatory and collaborative modelling is the development of knowledge and skills of the participants. As a result, it is common that involved decision-makers, stakeholders and technicians increase their knowledge and skills by the end of the project/study. The initial knowledge and skills of the participants, however, need to be carefully studied at the beginning of the project/study. It is critical that participants feel comfortable with the methods and tools developed and used during the entire modelling and planning process. Otherwise, there is a high risk that they feel lost, and as a result, they lose interest and commitment. It is therefore recommended to start with those methods and tools that suit the initial knowledge and skills of the participants. If needed, these can then be made more complex or other (more complex) tools can be selected, once the participants have gained the required knowledge and skills. Figure 8.4 presents the categorization of the methods and tools studied in this Ph.D. research based on their required level of technical knowledge and skills.

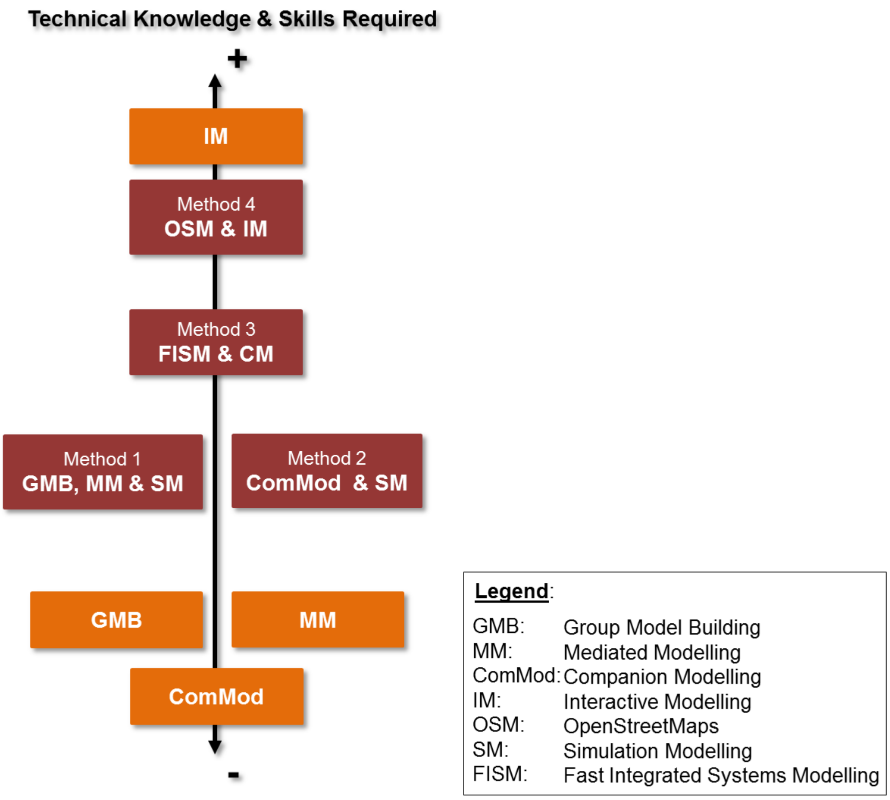


Figure 8.4 Methods general overview based on technical knowledge and skills required

Companion Modelling is the approach that requires less technical knowledge and skills. Its simple design allows the active participation of local stakeholders e.g. local communities that in some cases have very low literacy rates.

Group Model Building and Mediated Modelling are tools that can be used in environments where participants do not have or have very limited technical knowledge and skills. A distinction needs to be made between systems analysis and system dynamics. Systems analysis makes use of Causal-Loop Diagrams (Section 3.3.3), which do not require any modelling and technical skills. However, the use of system dynamics requires a higher (but still limited) level of technical knowledge and skills (Section 3.3.5). These models are developed from scratch based on the knowledge from the participants. This facilitates the understanding of the model and its functioning and the trust in it and its results.

When Companion Modelling, Group Model Building and Mediated Modelling are combined with simulation modelling (Methods 1 and 2), the required level of technical knowledge and skills increases. Participants need to understand the data, equations and assumptions included in the complex, detailed model(s), as well as the functioning of the model per se. The complexity addressed by the model also needs to be explained to participants, so they feel comfortable working with such a tool. The use of communication and visualisation tools is recommended to facilitate the understanding of the participants.

The development of a FISM model commonly requires the integration of detailed, complex models. A good understanding of the FISM model goes hand in hand with having a good understanding of the complex models. The technical knowledge and skills to understand the FISM model are thus quite high. However, the collaborative prototyping used for the development of the FISM model facilitates the acquisition of knowledge and skills by the participants. Collaborative prototyping is based on the concept: start simple, understand the system and gradually increase complexity. FISM(s) can therefore be built with widely available software packages like Excel as a front end, or more sophisticated tools, such as Python or PC Raster, depending on the needs of the process (Chapter 6). Moreover, the approach allows the differentiation of stakeholder groups. Stakeholders and decision-makers can decide to what extend they want to be involved in the development of the FISM model. They can decide to just be involved in the use of the model. This implies that they only require of limited technical knowledge to understand the dashboard.

Interactive Modelling uses quite high-tech software packages and tools. Its development and use therefore require high technical knowledge and skills. It is recommended that researchers, university students and scientists are involved in the modelling process. The use of crowdsourcing using OSM; however, allows the active participation of other stakeholders that do not have high technical skills. Mapping critical infrastructure in the field is not a difficult task. However, its complexity remains in what exactly to map and how to map it in an accurate manner. Also, even though the process of uploading the mapped information in OSM is not difficult, knowledge on the use of computers and internet platforms is critical. In the case of Tanzania, for instance, local communities were involved in mapping. However, this was possible thanks to the World Bank project, called

Ramanihuria, which has focused on developing the mapping capacities using OSM of local communities in Dar es Salaam for more than four years.

8.1.5 Participatory Modelling and Collaborative Modelling

In this section, we categorize the methods and tools developed and used as part of this Ph.D. in regards to participatory and collaborative modelling (Figure 8.5).

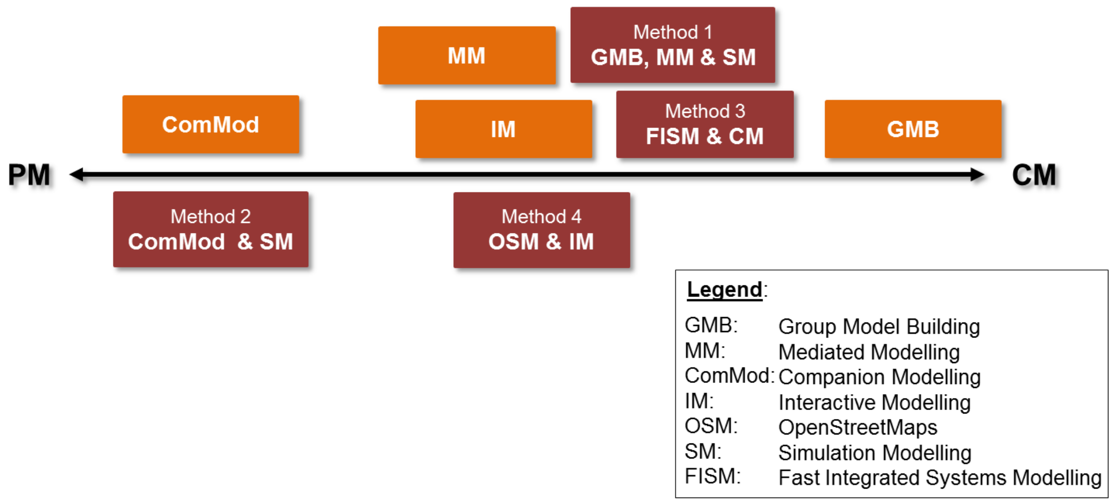


Figure 8.5 Method general overview based on participatory modelling and collaborative modelling

Companion Modelling and Method 2 are classified as participatory modelling. Stakeholders involved are not directly involved in the development of the agent-based model and role-playing game. They can be involved in some of the model development phases; however, this is not an established rule. Besides its level of participation, the type of cooperation is also low, as these methods are mainly applied in non-cooperative environments.

Mediated Modelling is also categorized as participatory modelling. Although participants are involved in highly in the development of the model (high level of participation), the type of cooperation between them is very low, i.e. unilateral action or cooperation. As a result, the high level of participation is used to increase the type of cooperation among involved stakeholders.

Interactive Modelling can be applied as participatory or collaborative modelling, depending on the context, situation and technical skills of participants. In the Netherlands, Interactive Modelling was applied in a collaborative modelling way thanks to the cooperative environment and the high sense of trust that stakeholders have in the technical experts and modellers (Warren, 2015). In Tanzania, on the other hand, the level of participation was lower, due to the context and limitations in terms of means. The use of participatory mapping using crowdsourcing allows the more active participation of stakeholders. As a result, their level of trust and ownership increases. The use of crowdsourcing increases the level of participation and the cooperation between involved stakeholders. This can lead to collaborative modelling.

FISM commonly requires a collaborative modelling approach. A FISM model requires the integration of various complex, detailed models. The collaboration between research institutes, universities and other organizations that have these models or have the capacity to develop them is essential. The levels of participation of all involved stakeholders are also high. They are involved in the development of the complex models, in the integration of these into the FISM model and/or in the development of the customized dashboard.

Group Model Building is the approach that is most collaborative. By contrast to Mediated Modelling, it is used in cooperative environments. Commonly, participants are from the same organization or stakeholder group. As a result, they share a common vision and values. The type of cooperation is therefore very high (i.e. collaboration or joint action). The tools and software platform used allows the development of the model from scratch and its development is based on the knowledge from the involved stakeholders. The resulting level of participation is also very high (i.e. co-design or co-decision making). Its combination with a simulation model increases the technical complexity of the modelling process. Stakeholders involved therefore require certain technical knowledge. Otherwise, trainings and capacity development sessions need to be organized. Depending on the context, the level of participation might be lower than when only making use of systems analysis and/or dynamics.

8.2 Effectiveness of Participatory and Collaborative Modelling

Many articles have been published on the use of participatory and collaborative modelling approaches for environmental modelling and natural water resources over the last few years. Still, there is limited information available on their effectiveness in formal decision-making and planning processes, particularly when using computer-based simulation models. There is need to better understand the perceived benefits and challenges of using participatory and collaborative modelling in WRM by local stakeholders, rather than by enthusiastic members of the academic community. To better understand the role of participatory and collaborative modelling a set of different questionnaires were developed for the application of each of the methods and cases. The diversity of opinions held by local stakeholders on this topic for the four participatory and collaborative methods that were tested, is presented in the following sections of this chapter. It is important to highlight that the questionnaires were not designed to get statistically significant results, nor was it pre-tested, as proper surveying would do. The questionnaires used are included in the Annexes C-F.

8.2.1 Method 1: Simulation Modelling and System Dynamics

This collaborative modelling method makes use of simulation modelling and system dynamics with the aim to better perform an integrated analysis of the system jointly with stakeholders (Chapter 4). An evaluation of the impacts of using the method for river basin planning in comparison with traditional water resources planning approaches is presented in this section. For this, the study case in Indonesia is used. The Pemali Comal River Basin Territory in Indonesia was divided into two areas. In the Eastern region the collaborative modelling approach was applied for river basin planning, while in Western region, traditional planning methods were used. The collaborative modelling area comprised Pemalang, Pekalongan and Batang districts, and Pekalongan city. Similarly, Tegal and Brebes districts and Tegal city composed the conventional planning area. Three mechanisms were used for data gathering: (i) project documents, (ii) semi-structured interviews with decision-makers and local stakeholders, and (iii) semi-structured questionnaires with decision-makers, local stakeholders, and the modelling and organising team. The semi-structured interviews were designed following the Protocol of Canberra (Jones et al., 2009). The outcomes served for adapting the collaborative modelling approach to the local context and conditions. Semi-structured questionnaires were used for evaluating the progress and experiences from participants during the modelling and planning processes. In particular, two semi-structured questionnaires (i.e. pre-evaluation and post-evaluation forms) were distributed to 29 stakeholder representatives from Circles A and B (Section 4.3.3). Both forms were designed using some of the contingencies for

Group Model Building interventions (Akkermans and Vennix, 1997). In the collaborative modelling area, an additional evaluation of the collaborative modelling approach and outcomes was carried out (Annex B).

The results of the evaluation of the collaborative modelling approach suggest that the preparation of the master plan was effective, and it served to support informed and inclusive planning and decision-making. Stakeholders and decision-makers of the collaborative modelling area evaluated the general process and outcomes in a positive way. Collaborative modelling has proved to be effective for structuring unstructured problems and the process has resulted in satisfactory outcomes.

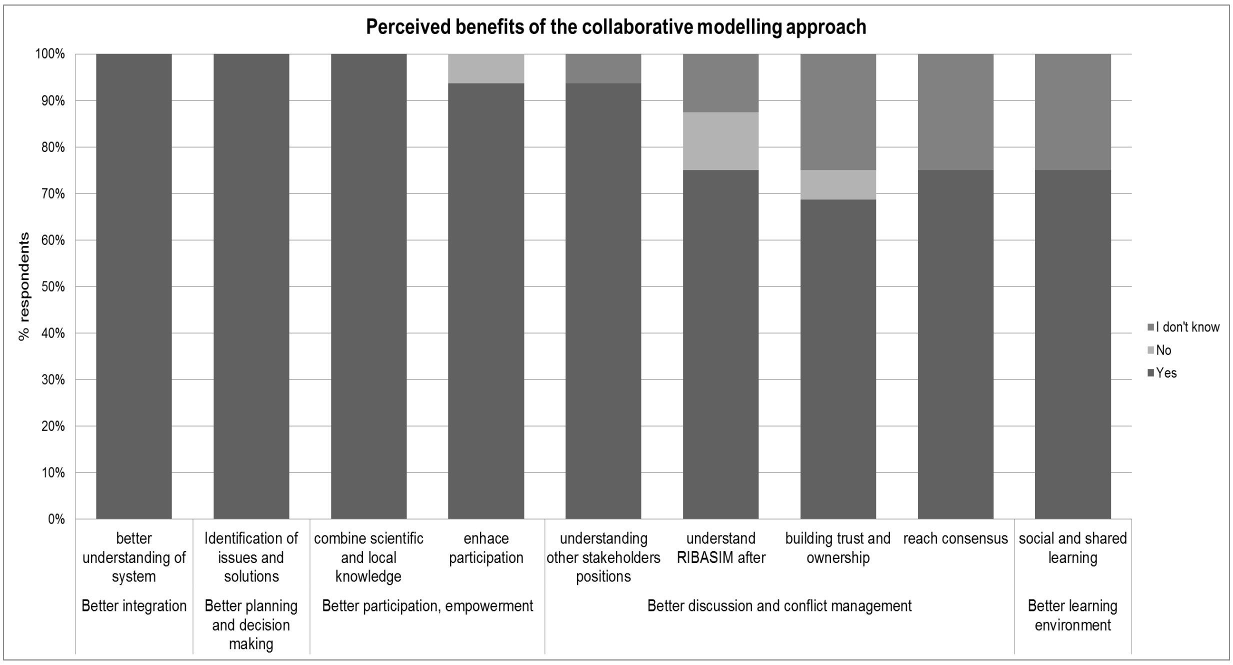


Figure 8.6 Perceived benefits of the collaborative modelling approach

Integrated Approach

An integrated river basin master plan needs to tackle the water-related issues in the basin in an integrated manner to secure water for all. The integrated approach is also conceived as a facilitating instrument to enhance group learning and thus enhance cooperation among stakeholders. The results of the comparative analysis corroborate these findings (Figure 8.6). The collaborative modelling approach helped stakeholders gain an improved insight into the inter-linkages between issues. The results of the post-evaluation form in both areas show that more than 92% of respondents are aware of the inter-connections between problems. However, when asked to explain some of the (cause-effect) relations, stakeholders from the conventional planning area had difficulty in describing these. Less than 18% could actually describe more than two inter-connections. In the collaborative modelling area, stakeholders (even those stakeholders with less technical background) could explain not only the connections between the majorities of problems but also explain the problems faced by other stakeholders. Stakeholders and decision-makers corroborated that the joint identification and analysis of future problems using system dynamics helped to create awareness of future collective problems.

Shared Learning: Better Understanding of the System and Evidence-based Solutions

Engaging stakeholders in model development and technical analysis fostered shared learning. 70% of the stakeholders and all the modelling team agreed that the collaborative modelling approach contributed towards shared learning. It helped decision-makers and stakeholders having a good understanding of the functioning of the system and the impacts of possible interventions. Risks and costs could then be minimised. Collaborative modelling created a better learning environment for technicians to learn about the different systems by recognising the local knowledge and experience from the decision-makers and stakeholders. Moreover, the joint and iterative construction of the RIBASIM model served to create awareness and consensus regarding the functioning of the different systems, water availability in the basin, water users, and present and future water-related problems. Moreover, constructing a simple model and then improving it over time with input from stakeholders and experts helped the process of getting familiar with system dynamics and RIBASIM.

Furthermore, collaborative modelling helps to develop the technical capacity of stakeholders. Only 43,7% of the stakeholders had heard about RIBASIM before commencing the project. Further, none of them were familiar with the application. This result is surprising as RIBASIM had been used for the preparation of the strategic integrated river basin master plan in Pemali Comal, prior to this project. This might imply that a pure traditional planning approach was used for its preparation. Most stakeholders had however a better understanding of the functioning of system dynamics and RIBASIM model thanks to the use of collaborative modelling. They felt confident to be able, with some technical support, to develop such models and use them for planning purposes.

The impacts of using collaborative modelling versus a traditional planning approach are also reflected in the formulation of measures by decision-makers and stakeholders. In line with the major problems identified, structural measures were most prominent in both regions. In the East, O&M (40%), the use of Decision Support Systems (33,3%), regulations and licensing (40%) and awareness raising (13,3%) were most valued. By contrast, conservation and land use measures (41,7%), enhanced cooperation (41,7%) and better WRM (33,3%) were the most demanded measures in the West, where traditional methods were applied. This demonstrates that in the conventional planning area, stakeholders could perceive that the traditional planning approach did not enhance cooperation among stakeholders, so the disputes between stakeholders remained. Moreover, improving WRM is a very generic solution. One could argue that decision-makers and stakeholders did not have a good understanding of the physical, socio-economic and institutional system to find more detailed solutions. By contrast, in the collaborative modelling area, enhancing cooperation is not perceived as a major issue and the proposed solutions concerning the improvement of WRM are much more concrete. Stakeholders and decision-makers perceived more the benefits of soft measures and institutional mechanisms, rather than just grey infrastructure.

Enhanced Use of Participatory and Modelling Tools

Collaborative modelling enhances the use of participatory, modelling and communication tools for inclusive and informed decision-making. 93,3% of respondents in both areas considered the use of planning support tools as important for better planning and decision-making processes (Geurts and Mayer, 1996). Group discussions is the most demanded participatory technique, with 66,7% in the collaborative modelling area and 58,3% in the conventional planning area. The need of local knowledge from other stakeholders through group discussions and public consultation meetings was perceived as significantly important (46,7%). Not surprisingly, the use of Decision Support Systems and modelling tools was requested much more in the collaborative modelling area (60%) versus the conventional planning area (25%). Stakeholders in the collaborative modelling area provided also detailed information on the type of technical studies required (e.g. water quality, coastal zone management), scenarios and river basin simulations. These technical studies were requested by stakeholders with both technical and non-technical backgrounds (e.g. water users associations). Both perceived the advantages of using computer-based models for obtaining a better understanding of the system, the water-related issues and testing of possible measures.

Tackling Uncertainty to Build Trust and Ownership

Collaborative modelling helped in enhancing trust in the models, gaining acceptance of the model results. This built ownership of the models and tools, as well as of the measures proposed and the integrated river basin master plan for Pemali Comal. Uncertainty related to data accuracy and completeness was one of the key factors affecting trust. Although the functioning of the model was explained in several occasions, for some stakeholders it was not sufficient to obtain a good understanding of the model. For others, the collaborative modelling approach allowed them to spend time comprehensively discussing the model and its results. The iterative process helped them building ownership. Building trust and ownership was thus directly related to the time spent in developing knowledge and learning.

Customisation and Use of free-available Modelling Tools is critical

A best practice identified by Langsdale et al. (2013) is to select software that is easy to learn and can be made available to all. The use of system dynamics for problem identification and measures formulation supported this practice; however, difficulties were encountered in customizing RIBASIM due to its "rigid" user-interface. RIBASIM was developed as a decision-making tool for technicians. Its configuration is not sufficiently adequate for engaging all stakeholder groups in its construction and use. Respondents recommended that making RIBASIM more user-friendly considering the needs, skills and backgrounds of stakeholders and making it freely available would both increase and enhance its use in decision-making processes.

Acceptance requires an Inclusive well-structured Stakeholder Engagement Process

Early and continuous engagement of stakeholders is of key importance in collaborative modelling. The selection of appropriate stakeholder group representatives to create an appropriate working group is often considered as trivial; however this study has demonstrated its relevance. Local NGOs participated in the study; however their involvement was restricted to Circle C (Section 4.3.3). Not incorporating and not considering sufficiently all forms of stakeholder knowledge and their concerns, especially from NGOs, had an impact on the Indonesian Constitutional Court revoking the 2004 water resources law in 2015 due to disagreements arisen mainly by local NGOs on the maintenance of clean water access. The integrated river basin master plan can thus not be endorsed and implemented; instead it needs to be prepared again under a new legislation.

8.2.2 Method 2: Companion Modelling and Simulation Modelling

An evaluation of the impacts of using this participatory modelling method was performed in the Indonesian case (Section 5.4). The evaluation consisted in reviewing (i) project documents, (ii) survey questionnaires and (iii) interviews. Field surveys and semi-structured interviews were conducted as part of the livelihood analysis and activities analysis (Annex B). These were recorded and translated into English by the local NGO, ECOTON. A questionnaire to evaluate the participatory modelling approach was given to the participants of the first role-playing game. Overall, the evaluation was carried out based on the results of the interviews and survey questionnaires with 40 stakeholder representatives and the organising team. The aim of the evaluation was not to test a predefined theoretical model of how the system functions but to learn social behaviours and dynamics in line with field surveys. The following questions were investigated: (i) which players played the dominant roles in the role-playing game? (ii) how do players interpret their roles in the game?, (iii) what were the reactions of players to the changes in water system?, (iv) when, why and where did the conflicts arose?, and (v) when, why and among whom were the agreements reached?. Data was clarified using post-interviews with regional authorities and operators, and used to finalize the diagram of interactions of Surabaya watershed. In the next section, the results of this evaluation process are presented.

The evaluation of the design and application of the participatory modelling approach conducted by the organising team and local stakeholders shows promising results (Figure 8.7). The use of simulation models helped in reducing the different understandings of the functioning of the physical system. Social learning, in the like of the role-playing game, was critical for gaining knowledge on the mental models, interactions and dynamics of the different stakeholders. Many stakeholders did not perceive the role-playing game as an entertaining tool but instead as one that can be used in formal WRM processes. Finally, the negotiated approach helped in developing the capacity of local communities and empowered them to actively and fruitfully participate in the planning and decision-making processes. It also enhanced the collaboration between grassroots stakeholders.

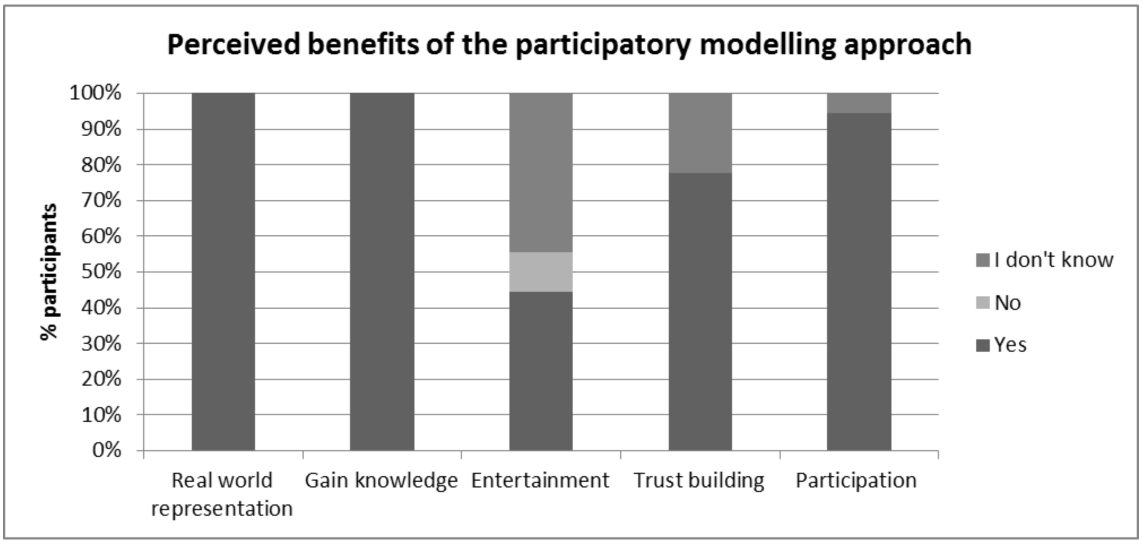


Figure 8.7 Perceived benefits of the participatory modelling approach in Surabaya watershed

Real World Representation and Shared Understanding of the System

Informed decision-making and planning is essential for lowering investment risks. A critical challenge is the acceptance of the models and tools used, as well as their results. Ensuring that involved stakeholders agree that the model shows a relatively similar representation of the real system is a critical step. The second principal step is to provide a shared understanding of the system to create a common ground for negotiation among stakeholders. There is a clear perception that the model schematisation and outputs are a good approximation to the real system. The participatory modelling approach helped to create a common ground for the negotiation process on how to manage the water quality in the watershed sustainably and inclusively. For the construction of the role-playing game and the simulation models, the livelihood analysis and activities analysis were conducted to identify the main issues and challenges in the Surabaya watershed. Also interviews with decision-makers were conducted. This information was first validated during the first role-playing game and later used for creating a collective understanding of the system among stakeholders.

Stakeholder Participation and Trust Building

The interactive setup of the stakeholder sessions was new for many stakeholders. Local communities and industries engaged in the early stages of the study. The commitment of operators and water managers, however, increased gradually throughout the study. Their interest and willingness to participate increased with the construction and use of the RIBASIM model. 78% of stakeholders agreed that the open and transparent participatory modelling process helped in building trust towards the data and models used (Figure 8.7). They also indicated that they felt confident that their knowledge was taken into account when developing the models and in the formulation of potential measures and design of strategies. As a result, 95% of stakeholders confirmed that they would be willing to continue participating in the participatory modelling sessions.

Social Learning: Better Participation and Cooperation

The majority of stakeholders (95%) corroborated that collaborative modelling contributed towards social learning and had a significant effect in terms of consensus building. The comparison between the mental models and the quantitative models became an essential element for creating a cooperative environment, as the information provided by the model was considered as being neutral during the discussions. Participatory modelling facilitated that stakeholders and decision-makers could learn from the concerns, needs and interests of other stakeholders. They could finally visualise and understand the socio-physical problems faced by other stakeholder groups. The process helped reaching the required level of consensus and trust for addressing the collective problems for the present and future situations and finding collective, sustainable solutions.

Acceptance requires an Inclusive well-structured Stakeholder Engagement Process

As highlighted in the evaluation of the previous method, the early and continuous engagement of stakeholders is of key importance in participatory and collaborative modelling. Key findings from the previous case in Indonesia (Chapter 4) showed the relevance of involving local NGOs in water resources planning and management. This lesson learnt was considered in the design and implementation of the adapted Companion Modelling approach. The approach aimed to empower the local NGOs so they could play an important role in data collection and the modelling process. It also enhanced the involvement of other not-well represented groups such as local communities and the private sector.

A key lesson learnt of this case is that the involvement of NGOs as part of the organising team can be very beneficial for the modelling team, especially in bottom-up planning processes. It helps to provide continuous support and understanding of the local environment, as most NGO staff also work as researchers and lecturers at national or regional universities and therefore, they have considerable local and technical knowledge on IWRM. Moreover, they commonly understand and support the interests of local communities. This helps to ensure that all identified stakeholders' viewpoints are taken into account equally. Finally, local NGOs can reduce cultural barriers between the modelling team, commodians and the local stakeholders (e.g. communication –language-, session protocols). However, it is critical that they keep their neutral position throughout the process.

Customisation of Modelling Tools is critical

Following an iterative process for the development of the simulation models is particularly essential when involving local communities, as they might get easily overwhelmed if their technical knowledge is limited. This can then hamper their willingness to continue participating. It could be observed during the second role-playing game session, when the RIBASIM model was presented and used for the formulation of potential measures. Some members of the local communities found it difficult to manipulate or even understand its function. As a result, they gradually lost their interest in the role-playing game and became passive participants. In a future application, it is recommended first to have homogeneous group sessions to ensure that all stakeholders feel familiar with the models and their functionalities. Only then, sessions with heterogeneous groups are encouraged. Moreover, the use of a more user-friendly version of RIBASIM was requested by grassroots stakeholders. This would enhance its use in bottom-up planning and decision-making processes.

8.2.3 Method 3: Collaborative Modelling and FISM

The evaluation of FISM using collaborative modelling was performed using a post-questionnaire at the end of the study with 12 professionals involved in the development of FISM in Bangladesh. The questionnaire comprised seven questions. The first question asked for the familiarity of the responders with the approach, and how that knowledge and experience was gained. The set of questions dealt with the benefits and challenges of engaging stakeholders in water resources planning and management, and the use of modelling tools. The questionnaire finalised by asking the needs for advancements in WRM, and the value of participatory and collaborative modelling (Annex B).

Results from the evaluation show that only 50% of respondents were familiar with the term "collaborative modelling". 75% respondents answered the final question of the questionnaire about the benefits of participatory and collaborative modelling, after its definition was presented in two steps. The key component of stakeholder engagement was first introduced, and later on the use of modelling tools in planning and decision-making processes. It can be concluded, that most stakeholders are much more familiar with the concept (definition) of participatory and collaborative modelling than with the terminology per se.

Benefits and Challenges of Stakeholder Engagement

Stakeholder engagement is in the core of participatory and collaborative modelling. The largest benefits of stakeholder engagement in water resources planning and management are seen in the integration of cross-sector perspectives and local knowledge. The use of collaborative modelling had an effect on the perceived benefits. Proposing innovative measures, strategies and actions because of a better understanding of the functioning of the system, developing capacity (collective learning) and raising awareness are perceived as major contributions of stakeholder engagement in the planning process. By contrast, cost saving is perceived as factors with less potential. Lack of political will and leadership followed by low capacity to engage in consultations due to limited education or trainings are identified as the major factors that limit the engagement of stakeholders in the planning process.

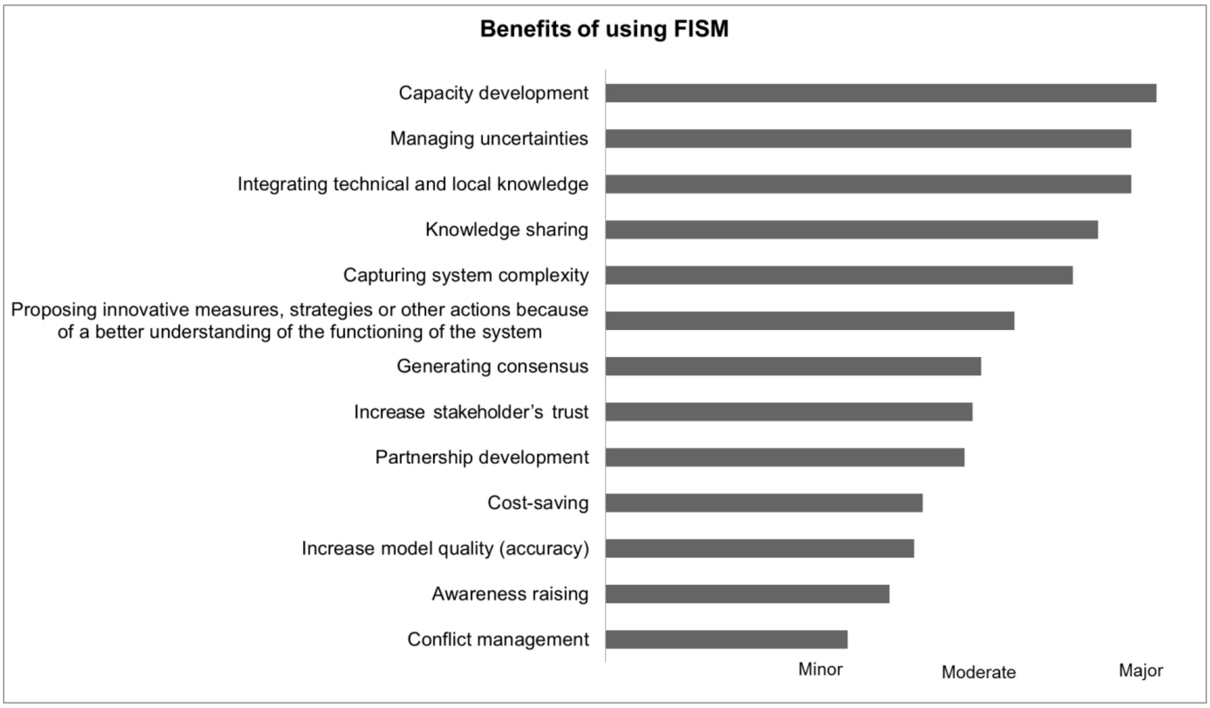


Figure 8.8 Benefits of FISM

Benefits and Challenges of FISM

Modelling is the second major pillar of participatory and collaborative modelling. In the evaluation process, respondents were asked to rank the major benefits and challenges of using modelling tools for planning and manage water resources. There is a clear perception that the co-construction process of FISM supports capacity development (Figure 8.8). This is particularly important, as the low technical capacity of local organisations is perceived as the major cause of the limited use of modelling tools in the planning processes. The FISM approach supports better understanding, managing and communicating uncertainty. Moreover, it is perceived as a good tool to integrate technical knowledge and local knowledge. This helps capturing the complexity of the system(s).

Benefits of Collaborative Modelling

The last question of the evaluation process referred to the benefits of collaborative modelling. The results are presented in Figure 8.9. The evaluation results show positive results on the use of collaborative modelling for the development and use of FISM. The major benefit perceived by the modellers involved in the development and use of the FISM is that collaborative modelling improves the decision-making process by making it more informed and inclusive. The approach allows having an integrated understanding of the system in terms of processes and inter-connections over space and time. A secondary benefit is the integration of local knowledge and technical expertise via a structured stakeholder engagement process. In the case of the preparation of the Bangladesh Delta Plan 2100, the Circles of Influence approach was followed. The gained understanding of the local knowledge as well as the views, perceptions and needs of other stakeholders helps generating consensus, and as a result, multi-stakeholder cooperation.

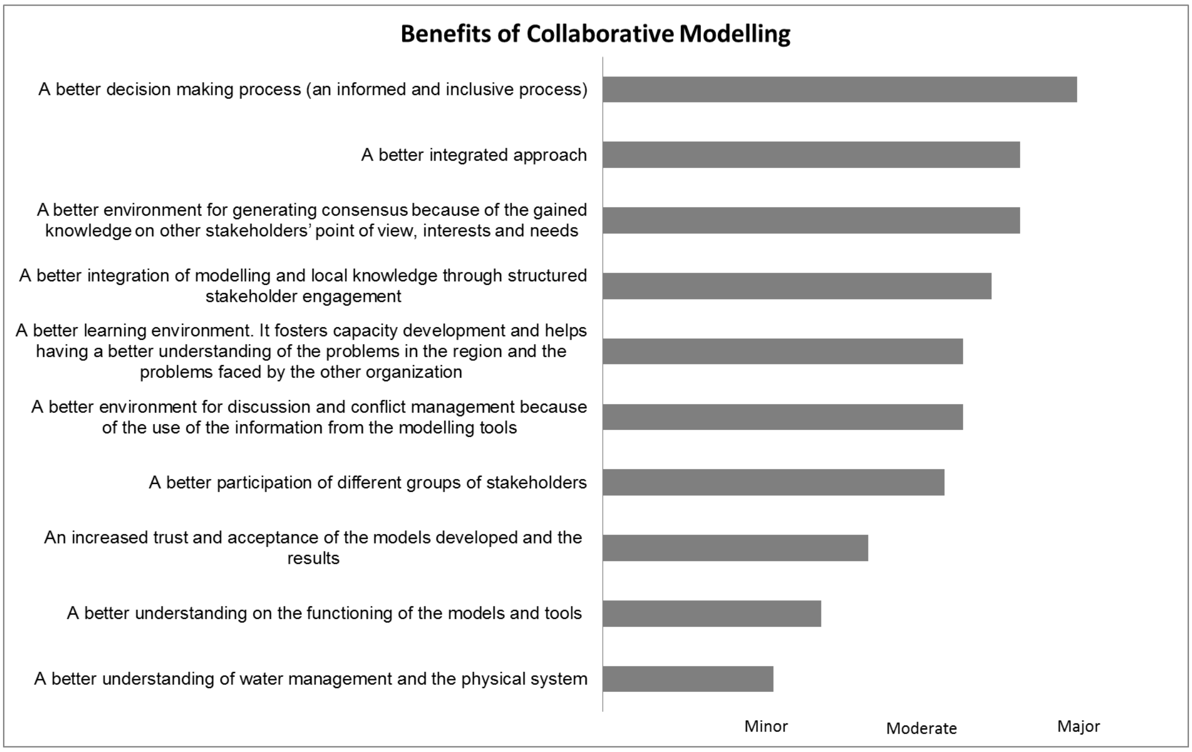


Figure 8.9 Benefits of FISM using collaborative modelling

Better Decision-Making

Participants ranked the benefit "The use of participatory and collaborative modelling leads to better decision-making" highest. Collaborative modelling is able to address a key challenge of decision-making processes: decision goals might evolve over time. The flexible structure of a collaborative modelling process helps incorporating this adaptability. This results in an increased use of modelling tools in decision-making processes (i.e. informed decision-making), and enhanced engagement of stakeholders (i.e. inclusive process).

Decision-making in WRM requires the formulation and integration of measures and the prioritisation of projects. 31% of respondents argue that the development and use of modelling tools with stakeholders allows the assessment of the impacts of the potential measures before these are actually implemented. The increased transparency of the planning and modelling process allows them to have more clarity of the planning and decision-making processes.

Integrated Approach

Water Security and IWRM require an integrated approach. This was ranked as a key benefit of using collaborative modelling. Both can help gaining an improved insight into the inter-linkages between issues and solutions. FISM using collaborative modelling helps building consensus among stakeholders on a common vision, the functioning of the system(s), the problem(s) at stake and solutions.

Inclusive Process and Social Learning

There is a very clear perception that this method allows an inclusive decision-making process. It helps structuring the engagement of stakeholders in the modelling process, as well as in the various stages of the planning process. This engagement structure boosts social learning: the collective - rather than individual - process of learning, knowledge co-creation and accumulation of wide experiences to generate a broader knowledge and evidence base upon which decisions can be taken (Wehn et al., 2017). Stakeholders get a better understanding about the local situation and how it can be progressed and transformed. This often results in changes in in mental models, beliefs, perceptions and - as a result – practices (Hurlbert and Gupta, 2015; Mostert et al., 2007b; Pahl-Wostl et al., 2007; Standa-Gunda et al., 2003; Voinov and Bousquet, 2010).

Multi-stakeholder Cooperation

As a secondary outcome, participatory and collaborative modelling creates a better environment for discussion and conflict management. The neutral atmosphere created by the use of modelling tools helps changing the mental models of stakeholders regarding the functioning of the water resources system and the problems faced by other stakeholders, and as a result generating consensus among stakeholders.

8.2.4 Method 4: Crowdsourcing and Interactive Modelling

The crowdsourcing and Interactive Modelling method was evaluated by the 23 stakeholders involved using pre- and post- questionnaires. The structure of the questionnaires was similar to the one used for Method 3 and it also comprised seven questions (Annex F). In the

Dar es Salaam case, the period between the pre- and post- questionnaires was of one week. This is the time required to present the developed first model prototype and its validation.

Results from the evaluation show that 43% of respondents were already familiar with the terminology before the study started. This percentage increased up to 58% by the end of the project. As well as for the Bangladesh case (Method 3), most stakeholders are much more familiar with the concept (definition) of participatory and collaborative modelling than with the terminology "participatory modelling".

Benefits and Challenges of Stakeholder Engagement

The largest benefits of stakeholder engagement in flood risk management are seen in the integration of cross-sector perspectives and in proposing innovative measures, strategies and actions in the pre-questionnaire. The use of participatory modelling had some effect on the perceived benefits. Besides these two factors, capacity development (collective learning) is also perceived as major contribution of stakeholder engagement in the planning process at the end of the project. By contrast, cost saving is perceived as factor with less potential. In terms of challenges, lack of political will and leadership and lack of funding to support stakeholder engagement are major factors that limit the engagement of stakeholders in decision making and management processes. Low capacity to engage in consultation processes, due to lack of education or skills, is also perceived as an important challenge. On the other hand, distance between stakeholder cores and time are not perceived as critical barriers.

Benefits and Challenges of Modelling Tools

Similar to stakeholder engagement, there is a clear perception that modelling tools are the means for developing innovative measures, strategies and actions because they help better understanding the functioning of the system. Stakeholders also perceive that combining participatory mapping and Interactive Modelling, following a participatory modelling approach, helps integrating technical and local knowledge.

The fact that international consultants do not involve local stakeholders in the modelling process, and that models are too expensive to buy and maintain are also important challenges frequently faced by decision-makers and stakeholders. After actively participating in the participatory modelling process, none of the respondents considered that as a challenge anymore, as the software used is open access (freely available). Most respondents agree that Interactive Modelling is most suited in high-tech environments, which requires stakeholders with technical skills and knowledge. As a result, the low technical capacity of local organizations and stakeholders is perceived as an important challenge. Also, even though crowdsourcing allows different types of stakeholder groups to be involved in data collection, training and working sessions are necessary so they can learn which data to gather, as well as how to gather it and upload it in OSM.

Benefits of Participatory Modelling

As illustrated in Figure 8.10, there is a positive perception on the use of participatory modelling to guide the Interactive Modelling and crowdsourcing process. Prior to experiencing participatory modelling, most respondents perceived that participatory modelling would provide benefits in terms of getting a better understanding of models and tools, as well as of getting better understanding of the physical system and how to manage it. The results of the post-questionnaires show that both factors remain the primary benefits. Respondents identified other major benefits after having experienced participatory modelling. The approach helps understanding the system in an integrated manner. It also helps the integration of local and technical knowledge from the different stakeholder groups that got involved in the project. Finally, most respondents share the common perception that following a participatory modelling approach allows having a better environment for generating consensus, as involved stakeholders gained understanding of the views, perceptions and needs of other stakeholders.

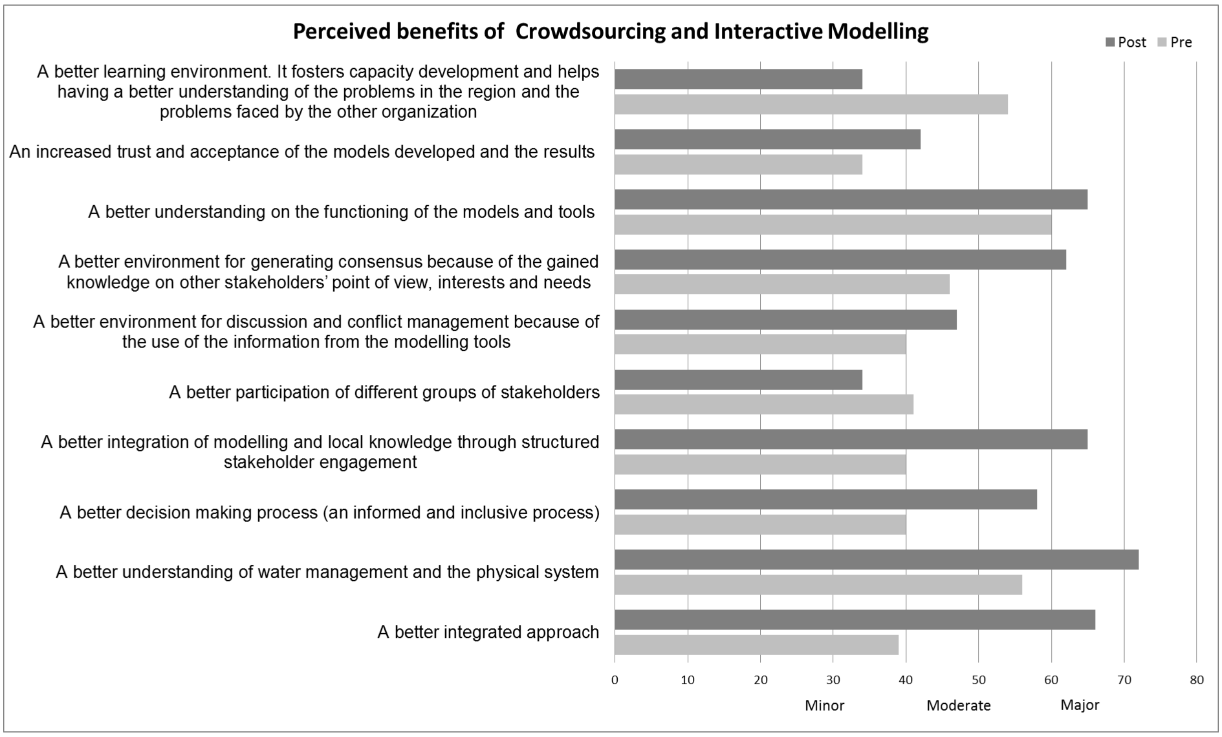


Figure 8.10 Benefits of participatory modelling using crowdsourcing and Interactive Modelling

Better Understanding of the System

Better understanding of the system was considered as a key benefit of using participatory modelling. The use of Interactive Modelling allows the rapid visualization of the physical system using advanced modelling tools. Crowdsourcing is an inclusive method that requires of field work for data collection. The combination of data collection in the ground and the modelling process enhances the understanding of the system as a whole but it also permits the validation and the improvement of the model with "real" ground data.

Integrated Approach

Urban flood modelling and DRR in general require a good understanding of many different factors that are critical in an urban setting. Information, knowledge and expertise on: rainfall, rivers and canals, water logging as a result of drainage congestion, hazards, critical infrastructure and other assets, land use, economic activities in the area, etc., are some of the relevant factors that need to be carefully studied when performing an urban flood modelling assessment. The modelling task associated to the assessment requires therefore considerable amount of data that cannot be collected only with global datasets and models. Instead, local data and knowledge are essential. The integration of such information to facilitate the visualization and understanding of the urban system in an integrated manner is of key importance. The results of the pre- and post- questionnaires (Figure 8.10) show the benefits of following a participatory modelling approach for crowdsourcing and Interactive Modelling. The active and structured participation of different stakeholder groups in combination with the various models and tools allows the better integration of all available information and knowledge, resulting in a good integrated approach.

Better Understanding of Models and Tools via Shared Learning

The structure of the participatory modelling process facilitates the active involvement and collaboration between stakeholder groups: while the mappers are busy collecting data based on the modelling requirements specified by the modelling team, the modelling team learn more about the system and can improve the performance of the model thanks to the data collected by the mappers. These all are also engaged in the planning process with decision-makers and other institutional stakeholders. This creates the enabling conditions for shared learning. Local stakeholders e.g. mappers and decision-makers learn how the system(s) is represented by the model. They learn the modelling steps, the data and information that is required. Similarly, modellers learn from local stakeholders and decision-makers about the "real" system. This active participation with defined roles enhances the collaboration between stakeholder groups. As a result, participatory modelling makes the modelling process more efficient when compared to traditional planning and modelling processes. It improves model performance. Data collection does not become a bottle-neck in the modelling process, model validation requires less duration and model quality increases considerably.

Enhanced Cooperative Environment

The combination of crowdsourcing and Interactive Modelling allows the enhanced collaboration between different stakeholder groups ranging from technicians, modellers, decision-makers and local communities. As highlighted in Table 7.2, the primary purpose of this method is model improvement. The secondary purpose is collaborative learning. It can therefore be quite surprising for some readers that most respondents considered that participatory modelling allows having a better environment for generating consensus, as this is not considered as a primary or secondary purpose. However, the results of the study demonstrate that a great benefit of collaborative learning is enhanced cooperative environment. The structured stakeholder engagement process facilitates the collaboration between different stakeholder groups. Each stakeholder group gains a better understanding of the views, perceptions and needs of other stakeholders. Establishing different working teams with concrete roles and tasks, and making clear the links between tasks, inputs and outputs between working teams creates a cooperative working space. Moreover, as these teams learn more about the models and tools, and the system throughout the modelling process, they also gain a better understanding of possible ways of collaboration and joint solutions.

8.2.5 Challenges of Participatory and Collaborative Modelling

In this section, the overall challenges of participatory and collaborative modelling are introduced. These were obtained from the lessons learnt when designing and applying participatory and collaborative modelling in the various cases.

Institutions face several challenges in putting collaborative modelling into practice. The challenges identified by participatory and collaborative modellers include a lack of capacity to undertake participatory and collaborative modelling, the need for trust, technical constraints, difficulties in defining the rules for decision-making, a reluctance to accept participatory processes, and the busy schedules of decision-makers. In this section these challenges are analysed.

Lack of Capacity

Agencies and institutions rarely have all the skills and experience necessary to cope with all four pillars of collaborative modelling. Some may have strong skills and experience in water resources planning; some may have expertise in developing models and analytical tools for decision analysis; some may have implemented effective methods for stakeholder participation; and others may have used methodologies to enhance negotiations among competing interests. But in practice, expertise in one or two of these areas is not enough. If agencies and institutions wish to engage effectively in participatory and collaborative modelling, they must explore ways of acquiring sufficient capacity to support all four pillars of the process.

The Need for Trust

Planners typically view problem solving as something to be addressed in a highly structured way. In semi-structured or unstructured contexts, planners often bring experts into participatory processes to provide advice, resolve conflicts and assess whether a problem can be structured. These experts perform initial assessments to help planners understand the problem and its various stakeholders. Participatory and collaborative modelling requires a different approach that builds trust between technical and social experts, an understanding of each other's roles, and continual joint-learning among the interdisciplinary team engaged in what will be an unfamiliar process. This is unlikely to exist at the start of the collaborative modelling process and it takes time to develop and change long established working practices and attitudes.

Socio-technical constraints

Model developers are technical people who typically see their role as supporting institutions with the quality controlled and assured information needed to inform planning or decision-making. These developers work with subject matter specialists to build models and undertake analysis. They develop models that provide an 'accurate' representation of reality and transform data, via a series of mathematical relationships, into information that can demonstrate the impacts of proposed interventions. In semi-structured or unstructured problems, there can be uncertainty and mistrust in both the data and the system relationships, and so decisions will likely depend on negotiated outcomes. Because of this, stakeholders and decision-makers may wish to guide and influence the development of decision support tools. All this uncertainty can take modellers well beyond their 'comfort zone'.

In a participatory or collaborative modelling process, decisions are typically constrained by divisive values or conflicting interests. There will be gaps in data sets and uncertainties inherent in the modelling process. The priority for technical analysis is to obtain sufficient technical rigour to analyse credible trade-offs that are understood and acceptable to stakeholders and decision-makers. The technical team therefore has a new role in navigating a path through the model requirements to ensure precision and accuracy. Experienced modellers will also bring their own set of value judgements and belief systems to the table and these too can be explored as part of the collaboration.

Difficulties in Defining the Rules for Decision-Making

Decision rules can be easily defined for structured problems: they might include cost–benefit and discounted cash-flow analyses, restricted by social, cultural, and environmental constraints. But when planning semi-structured and unstructured problems, decision analysis procedures are likely to be poorly formulated, and it is difficult to define and quantify the critical assessment indicators.

A Reluctance to accept Participatory Processes

Planners and decision-makers often resist collaborative or participatory processes unless they are clearly necessary, as they can delay or extend the planning process. Planners may also avoid participation because they have limited experience and understanding of how to structure the processes that socialise decision-making, reduce opposition, and achieve societal buy-in to improve the timeliness of project implementation. Indeed, there is often an urgency to take decisions and act irrespective of the levels of uncertainty or division, which can preclude collaboration.

Involving stakeholders in a planning process is often approached with caution because it requires expert facilitation and carries the risk of delaying the planning process, especially when there are budgetary and time constraints. Moreover, stakeholders can be difficult to manage especially when benefits to their interests are at stake. However, it has been shown that extended participatory processes can lead to reduced implementation times, and most importantly provide buy-in to the final decision process.

The busy Schedules of Decision-Makers

Decision makers do not always have the capacity to take part in collaborative processes. They tend to be busy people with limited time available to engage in collaborative modelling activities, even though they may intuitively agree with its aims and appreciate its benefits. Nevertheless, interest from decision-makers is essential for conducting a collaborative modelling process. There is no guarantee of success with collaborative planning, and the process usually takes longer than the conventional alternative. But the expectation is that when decisions are made, they will be easier to implement when there is high-level stakeholder 'buy-in'. Committed individuals, or 'champions', within agencies can play an important role in generating interest among decision-makers.

8.2.6 Stakeholder Perceptions Summary and Conclusions

There seems to be a general consensus on the importance of stakeholder engagement and the use of modelling tools in the planning and decision-making processes in WRM. Despite most stakeholders being not very familiar with the terminology "participatory and collaborative modelling", almost of them are aware of its concept: involving stakeholders in the modelling process.

The evaluation of the first method demonstrates that the collaborative modelling approach helps better planning and decision-making. It facilitates the integration of data and information with decision-making using modelling tools and stakeholder participation and negotiation for river basin planning. Group Model Building and Mediated Modelling facilitate the understanding and assessment of the system in an integrated manner. Collaborative learning and the neutral atmosphere created by the use of modelling tools helps changing the mental models of stakeholders regarding the functioning of the water resources system and the problems faced by other stakeholders. All these factors enhanced stakeholder trust in the model and its results, and strengthened the sense of ownership of the integrated river basin master plan for Pemali Comal River Basin Territory.

Results from the second method show its suitability for managing water quality in complex river basins in an inclusive manner and its substantial benefits in developing stakeholders' capacities and creating a cooperative environment. The approach helps to improve the use and quality of computer-based models and to structure the involvement of local stakeholders from the grassroots level in managing water quality. It enhances collective reflection and helps in reducing disputes by sharing and developing knowledge of local communities, the private sector, planners, decision-makers and technicians, and with the use of technical data and modelling tools. Ultimately, the participatory modelling approach aims at supporting that the enabling conditions are in place for collective action in the future.

The use of collaborative modelling for developing a FISM model shows promising results when applied in decision-making processes. Its integrated approach helps better understanding the system complexity, and managing and communicating uncertainties related to the system, the modelling process and ambiguities from different stakeholder views. Its flexibility allows the integration of different (physical, economic and/or social) models. The approach is most suited in contexts characterized by limited system knowledge due to lack or limited data availability and accessibility, and/or complex hydrology of the river(s).

The fourth method combines the use of crowdsourcing for participatory mapping and Interactive Modelling for quick model adaptation and visualization. The participatory modelling approach used for a flood risk assessment in Dar es Salaam, Tanzania, shows significant benefits in regards to model improvement, the primary purpose of this method. In comparison with the other methods, the use of crowdsourcing allows the constant collection of data based on the needs of the models and tools. This improves substantially the development and validation of the models and tools, and as a result their performance. The structured stakeholder engagement process, organized in different working teams, facilitates the active participation of different working groups and the integration of local and technical knowledge and information. This leads to a good integrated approach and a cooperative environment.

Overall, participatory and collaborative modelling helps improving decision-making employing an inclusive and informed process. Stakeholder engagement and the use of modelling tools are effective means to conduct integrated studies and propose innovative measures, strategies and actions. Both approaches support the development of stakeholders' capacities and skills via collaborative learning. The use of participatory and collaborative modelling tools helps in improving the model performance, tackling and communicating uncertainties and capturing the system's complexity. The combination of local and technical knowledge helps better understanding the functioning of the system and enhances the sense of trust and acceptance of the modelling tools and their results. This results in a greater engagement, consensus and commitment of stakeholders in the implementation of water security. However, significant differences can be observed when applying participatory modelling or collaborative modelling regarding model trust and ownership. Collaborative modelling increases significantly the trust and sense of ownership of the models and its results, as stakeholders are active and directly involved in model construction and use. By contrast, participatory modelling does not have a significant effect on increasing the ownership of the models. There is a better modelling process due to the interventions of stakeholders thought the process. However, their mainly indirect involvement does not boost trust and ownership in a significant manner.

Participatory and collaborative modelling supports informed and inclusive decision-making, planning and management processes. However, sustainable WRM can only be achieved if there is a strong political will and commitment to apply and implement IWRM policies and projects, considering the results of the modelling tools and with the support of local stakeholders.

9

CONCLUSIONS AND REFLECTION

9.1 Overview of the Presented Research

This Ph.D. thesis has addressed an important issue in water security, the use of computer-based models for informed planning and decision-making processes. New scientific and technological advances have allowed a better understanding of water resource systems. They have brought with it the possibility to support planning and decision-making processes by providing quantitative information by means of computer-based models, open and big data, drones, etc. The use of mobile phones, GIS apps, networked environments, interactive touchscreens and similar technologies also offers great possibilities to the way one can communicate and disseminate the information. It is evident that scientific and technical knowledge can substantially improve informed decision-making; however, its use in actual decision making processes remains a challenge. A key aspect of increasing its use is the involvement of decision-makers and stakeholders. Today it is globally acknowledged that sustainable development goes hand in hand with inclusiveness (Akhmouch and Clavreul, 2016; European Communities, 2003b; GWP, 2000). The United Nations and all Member States (2016) recognise via the sustainable development agenda 2030 the need for strengthening the participation of local communities, the creation of multi-stakeholder partnerships, the expansion of international cooperation and capacity building support for improving water security. Boosting the use of computer-based models thus requires the involvement of stakeholders in the modelling processes and in various stages of the planning and decision-making processes. Only then can decision-makers and stakeholders have a sense of trust in and ownership of the models and results. This will consequently improve their commitment to develop and implement water management strategies to secure water for all. Over the last decades, the scientific community has put considerable efforts in the development of DSSs and participatory approaches and tools to address this challenge. Unfortunately, the development of DSSs has been mainly carried out by scientists and technicians. The use of participatory tools has enhanced the engagement of stakeholders in managing water resources. However, their involvement is frequently limited to a set of consultations regarding water resources issues and possible solutions. The integration of both processes and the collaboration between technicians, decision-makers and stakeholders in decision-making processes is only partial.

This Ph.D. thesis has presented participatory and collaborative modelling as a suitable approach for participatory and informed decision-making in IWRM. A review of the main participatory and collaborative modelling approaches and tools being used for environmental and natural resources modelling revealed its value in involving stakeholders in the modelling process. However, there was limited knowledge on the use of both approaches with computed-based simulation models for formal, informed decision-making processes. An exploration of the key components of participatory and collaborative modelling was made based on the common elements that the majority of these approaches have and the needs of IWRM processes. These key components served as a basis for the identification of the main factors that help to determine the most suitable approach for different contexts and situations. The compilation of these factors resulted in a generic framework for participatory and collaborative modelling approaches in WRM. The framework was tested in a groundwater management case in the Netherlands (i.e. MIPWA case) before using it for identifying the key features of "participatory modelling" and "collaborative modelling" (Basco-Carrera et al., 2017b). The framework was improved and enriched with the insights of the SESYNC participatory modelling pursuit.

The framework was used in defining the generic characteristics and features of existing participatory and collaborative modelling approaches. Group Model Building, meditated modelling, and Companion Modelling are approaches evaluated with the framework (Annexes A and B). The framework also helped in generalising case-specific participatory and collaborative modelling approaches, and corresponding tools. It was applied in the Delta Program Rivers in the Netherlands to assess the Blokkendoos tool and another groundwater management case in the Netherlands (i.e. AZURE) (Warren, 2015). The main use of the framework was to design and test different approaches for specific contexts and situations and to categorise them into participatory or collaborative modelling approaches. Existing approaches were adapted, maintaining their key features and elements, so they could have a broader applicability and be used in combination with computer-based simulation models. These were applied for river basin planning in Indonesia (Chapter 4), water quality management in Turkey and Indonesia (Chapter 5), adaptive planning in Bangladesh (Chapter 6), and flood risk management in Tanzania (Chapter 6). Finally, its technical and social contributions were evaluated. For each study case, an impact assessment in terms of the modelling process, social dynamics, and planning and decision-making processes was conducted (Chapter 8).

The following section provides the key findings of this Ph.D. thesis by answering the research questions defined in the first chapter. The chapter ensues with a reflection on the research and provides a set of recommendations for future research.

9.2 Answering the Research Questions

The prime contribution of this Ph.D. study is to present how computer-based simulation models can be used in informed and participatory decision-making processes using participatory and collaborative modelling for achieving sustainable and inclusive development. In the remaining of this section, the overall objective is addressed by answering the corresponding research questions.

9.2.1 What are the key features of participatory and collaborative modelling approaches used for managing water resources?

IWRM provided another dimension to engaging stakeholders in managing water resources, in comparison to traditional WRM. Its second principle highlights the important role of users, planners and decision-makers in water development and management. Therefore, it asks for a participatory approach when applying IWRM. In this Ph.D. thesis, participatory and collaborative modelling is presented as an appropriate approach for ensuring the engagement of stakeholders in the IWRM process, by means of involving them also in the modelling process. The terms "participatory" and "collaborative" "modelling" already provide substantial information about their definition. First, "participatory" relates to participation of stakeholders, which is an essential component of participatory modelling approaches. In science, a distinction is made between the concepts: engagement, participation and involvement. The OECD (2015) defines engagement as a broad umbrella term and stakeholder engagement as the opportunity for those with an interest, or 'stake', to take part in decision-making and implementation processes. Stakeholders are distinct from simply the wider 'public' and can also include users, governments, private sectors and regulators and non-governmental organisations. Participation offers a simple structure for identifying power-based degrees of citizen involvement in decision-making (taking as a basis Arnstein's ladder (Arnstein, 1969)). Finally, stakeholder involvement implies –

explicitly or implicitly – trade-offs regarding representativeness, inclusion, or (in)equality in interactive processes (e.g., Sørenson2002; Mayer et al. 2005; Sørenson and Torfing 2007) (Chapter 1). Other modelling approaches make use of the term "collaborative". Collaboration can be defined as a level of participation (Bruns, 2003). In transboundary water management, collaboration relates to the types of cooperation between stakeholders (Sadoff and Grey, 2005). Collaboration is achieved when collective learning occurs and when the ideas and initiatives of stakeholders are adapted to achieve mutual benefits. This implies they are adapted to either secure mutual gains or to mitigate harm caused to other stakeholders. Although the differences between the two terms "participatory" and "collaborative", their inherent similarities can result in them being used interchangeably. This is in large part due to unclear distinction having been made between them in the literature. The word "modelling" refers to the modelling process, which is composed of a set of steps such as data collection, model definition, model construction, model validation and verification, as well as model use for the formulation of measures, the design of strategies and impact assessment. Ultimately, participatory and collaborative modelling aims at facilitating the involvement of stakeholders in the modelling process. The levels of participation and types of cooperation are subject to the context and situation which can change over time, while applying the approach.

This Ph.D. study focused on the possible use of participatory and collaborative modelling with computer-based simulation models. These are the modelling tools that are most frequently used in formal, informed decision-making processes. This is an area where limited research had been undertaken prior to this study. In this context, participatory and collaborative modelling is defined as an interactive and adaptive planning process in which stakeholder participation is complemented using computer-based models, and communication and visualisation tools. Participatory and collaborative modelling for policy analysis in WRM rests upon the integration of four pillars: (i) water resources planning, (ii) informed decision-making using at least computer-based models, (iii) stakeholder participation, and (iv) negotiation. These inter-linked pillars are considered the basis for effective and sustainable IWRM. In Chapter 2, a distinction is made between "participatory modelling" and "collaborative modelling". Collaborative modelling is conceived as a subset of participatory modelling. Collaborative modelling approaches are more suited to planning and decision-making processes in highly cooperative contexts with high levels of participation for key stakeholders, leading to the increased importance of negotiation within the process. By contrast, participatory modelling occurs across a wider spectrum and can involve lower levels of participation.

In sum, participatory and collaborative modelling approaches highlight the involvement of stakeholders throughout the modelling process. Their key, common features are: water resources planning, informed decision-making using at least computer-based models, stakeholder participation, and negotiation.

9.2.2 What are the main methods and tools used in participatory and collaborative modelling? And how can these be evaluated to determine for which situations they are most suitable?

Participatory and collaborative modelling comprises different types of approaches, methods and tools. Some are extensively used for WRM. Others are just emerging. In this Ph.D. thesis, a distinction between the concepts: “approach”, “method” and “tool” is made (Box 1 at page 25). Participatory and collaborative modelling is conceived as a process. The approach defines the way this process is designed, structured and organised considering the context, situation, planning, decision-making and negotiation processes. The tools used in the process encompass modelling, communication and visualisation tools. Seven of the most characteristic types of participatory and collaborative modelling approaches are identified in Chapter 3. The development and use of methods and tools is specific to certain stages of the planning and decision processes and corresponding modelling phases. The use of crowdsourcing is an innovative method for participatory mapping. More traditional methods for data and information acquisition include interviews and surveys. Other tools and methods help process orchestration (e.g. role-playing games). A distinction is made between qualitative and quantitative modelling. The use of Causal Loop Diagrams, decision tree analyses or concept mapping are some of the tools used for modelling qualitative data and information. Other tools provide a conceptual quantification of data and information. This is the case of fuzzy cognitive mapping, scenario exploration or social network analysis. Finally, numerous are the tools used for quantitative modelling (Chapter 3).

The existence of these approaches and tools is critical for the use of participatory and collaborative modelling for IWRM. One should however keep in mind that a large toolset is available for supporting the participatory and collaborative modelling process. It is essential to select the right tool or a combination of them for each specific context, situation and decision-making process and which existing approach(es) is most suited to the given context, considering the trade-offs. It is important to avoid that the selection is driven by the objectives and specifics of the problem at stake and not necessarily by the experiences of the organising team. This demands a systematic analysis of the conditions related to the problem being addressed as well as the enabling environment. A generic framework therefore was developed (Table 3.1) that contains the main parameters that help in determining the most suitable approach for different contexts and situations in WRM. These main factors include: context and application, specific use, information handling, stakeholder involvement structure, modelling and organising team and means. Each parameter is composed of various sub-parameters. All these critical aspects that need to be considered for the design of a participatory modelling or collaborative modelling approach can be summarised with the following question:

> *Who (which group of stakeholders) needs to be involved in which steps of the planning process (timing), to what extent (level of involvement) and how (participatory approach, communication techniques and visualisation tools)?*

The framework helps to (i) define the generic characteristics and features (trade-offs) of existing participatory and collaborative modelling approaches and tools; (ii) generalise case-specific participatory and collaborative modelling approaches, and corresponding tools; and finally, (iii) categorise the previous approaches, (i) and (ii), into participatory or collaborative modelling approaches (Chapter 3). The framework needed to be tested before using it to identify the key features of participatory modelling and collaborative modelling. Three different participatory and collaborative modelling cases were used to test its efficiency. A groundwater management case in the Netherlands (i.e. MIPWA case) was used for the initial testing (Basco-Carrera et al., 2017b). Its final validation and refinement occurred after applying it to evaluate two Interactive Modelling study cases in the Netherlands (Warren, 2015).

The analysis of the key features of participatory and collaborative modelling using the generic framework shows that both approaches are most appropriate for semi-structured and unstructured problems. These are characterised by lack of scientific certainty about the system and/or low degree of consensus regarding values, norms, standards, beliefs and ambitions among stakeholders. Collaborative modelling is more suitable for highly cooperative contexts, as it comprises high levels of participation of key stakeholders. These are commonly involved in co-deciding and/or designing. Other interested stakeholders can be involved in lower levels of participation. An important difference between both approaches is the model users and as a result the methods and tools used. As participatory modelling occurs across a wider spectrum, involved stakeholders can have lower levels of participation. Hence, they can be direct or indirect users of the participatory modelling tools. This provides some freedom in the selection of the modelling tools, as well as on how to involve stakeholders in the development and use of these tools. Often model construction is performed by the modelling team. By contrast, in collaborative modelling key stakeholders are commonly direct users. The selection of the modelling tool or platform (including its visualisation) is therefore directly linked to the knowledge and skills of these stakeholders. The direct or indirect use of models and tools relates to the modelling and organising team. Due to the more active involvement of stakeholders, collaborative modelling approaches often require a bigger team, for instance, the addition of a dedicated process manager. Team members also require more modelling and facilitation skills in comparison to participatory modelling. Finally, collaborative modelling is frequently more resource intense, as it requires longer duration and more resources.

Further elaboration of this research question is being carried out in the following research question, where approaches and tools are tested in practical research studies in the fields of river basin planning, water quality management, adaptive planning and flood risk management.

9.2.3 How can participatory and collaborative modelling approaches be applied with existing and newly developed computer-based simulation models?

The involvement of stakeholders in the planning and the development and use of the models was a condition 'sine qua non' for addressing the second research objective. The toolset composed of different approaches, methods and tools as well as the generic framework, provides the basis for developing and using computer-based simulation models in an inclusive way. The adapted approaches, developed as part of this thesis, contain the four key components of participatory and collaborative modelling. Their design is based on the enabling conditions and situation of the system, as well as the decision-making and planning processes. They include the use of computer-based simulation models, other qualitative or quantitative tools, and communication and visualisations tools. Stakeholder involvement is structured considering the social and institutional dimension. The negotiation process during the co-construction of the model and its use for the formulation of possible solutions considers the principles of conflict management and dispute resolution. The analysis of positions, interests, roles and dependencies as well as hierarchical and power relationships among decision-makers and stakeholders is strongly considered for structuring the stakeholder involvement and negotiation processes.

Any new approach needs to be tested and refined before it can be widely used. Four different IWRM domains were used to test the development and use of computer-based simulation models under the umbrella of participatory and collaborative modelling. These are: (i) river basin planning with particular focus on water stress, (ii) water quality management, (iii) adaptive planning to ensure national water security, and (iv) flood risk management. The contexts and situations may vary widely across different regions, and differences will likely exist between the different participatory and collaborative modelling approaches. As such, the adapted participatory and collaborative modelling approaches were applied in three different continents, i.e. Africa, Asia and Europe. They were applied for river basin planning in Indonesia (Chapter 4), water quality management in Turkey and Indonesia (Chapter 5), adaptive planning for national water security in Bangladesh (Chapter 6), and flood risk management in Tanzania (Chapter 7).

In this Ph.D. thesis, four participatory and collaborative modelling approaches are presented that allow the co-development and use of computer-based simulation models with decision-makers and stakeholders for participatory planning and informed decision-making. Each approach is composed of a simulation model and other qualitative or quantitative modelling tools. The selection of the modelling tools and design of the approach followed the structure of the generic framework presented in Chapter 3. The approach also helps in structuring the involvement of stakeholders and defines the negotiation process. The different approaches are described in the following paragraphs.

IWRM, including river basin planning, requires integrated analysis of the system. The shared understanding of the system (physical and socio-economic dimensions), in an integrated manner, is therefore essential. This shared understanding is particularly relevant in those river basins characterised by water stress, and as a result in disputes between water users. System dynamics and Causal Loop Diagrams are modelling tools widely used in participatory and collaborative modelling to articulate and understand the causal interactions that describe the problem(s) behaviour changes over time. The combination of a water balance and allocation model with system dynamics and Causal Loop Diagrams is therefore a good modelling approach for performing an integrated analysis of the water resources system over time and the formulation of potential measures. In relatively cooperative environments, it is recommended to use Group Model Building to structure the involvement of stakeholders. When little consensus among stakeholders occurs, the use of Mediated Modelling is encouraged.

A pacification strategy is sometimes necessary prior to making decisions. It is particularly relevant, for instance, in strongly centralised governmental contexts where there is mistrust and lack of cooperation between national authorities and regional stakeholders; or in bottom-up planning and management processes where there needs to be the active participation of local communities and the private sector. Multi-stakeholder cooperation, and, as a result, collective action becomes particularly relevant in the implementation phase. The national and regional governments often lack the resources and capacity to implement, operate, maintain and monitor all assets and interventions. The Companion Modelling approach supports collective reflection and the integration of knowledge on the physical and social systems by settling existing disputes between stakeholders. In these contexts, having a good understanding of the social system is critical for understanding and resolving such disputes. The use of Companion Modelling with computer-based simulation models and role-playing games is an appropriate solution for enhancing multi-stakeholder cooperation as a step prior to decision-making. The use of the negotiated approach is suggested (Both Ends and Gomukh Environmental Trust, 2011) for empowering local communities and facilitating their involvement in the planning and decision-making processes.

Not all strategies are viable. Many IWRM plans contain a long list of measures (namely "wish list" in colloquial terms) as the preferred strategy. Good plans, however, require the integration and prioritisation of projects and managing uncertainties. The selection of criteria needs to be combined into an integrated model for evaluating the impacts of the designed strategies under possible futures. This becomes particularly relevant in national water security plans, as they require the use of different models to study the different problems at stake. FISM is an appropriate approach to build integrated models from existing complex, detailed models jointly with stakeholders and decision-makers. These existing models are used as components (modules) that are coupled to represent new and, more complex systems. The approach also permits the assessment of integrated solutions based on different scenarios and a set of physical, socio-economic and financial criteria. Therefore, the use of FISM models is recommended in later stages of the planning process, to manage and communicate uncertainty and integrate and prioritise projects.

Each quantitative model has a certain running time. It can vary from seconds or minutes to days and even months. The involvement of stakeholders in the modelling process requires the use of fast systems that allow stakeholders to interact with the tool as they use it. Interactive Modelling addresses this challenge by providing extremely fast and accurate dynamic visualisation of a system. Touchscreens are often used to facilitate the active participation of stakeholders. Stakeholders can also interact and make direct changes to the tool and model as they use it as well as see the results of their changes almost instantly. It is recommended to be used in environments where stakeholders have technical knowledge and skills, and are familiar with technology. Interactive Modelling can be combined with the use of mobile phones and crowdsourcing to involve stakeholders and the crowd in collecting data.

Results from all these cases show that modelling is a main element of participatory and collaborative modelling. It creates the enabling conditions for shared learning. On one hand, decision-makers and stakeholders learn from the modelling team how the simulation model represents the system(s). They also learn the modelling steps, the data and information required and formulas used to represent the water cycle and the natural resources. Assumptions are formulated and agreed collectively. The uncertainty associated with the data and model assumptions is acknowledged and discussed. Moreover, they learn how to manipulate the model during its construction and use. On the other hand, the knowledge of the modelling team about the system(s) is usually limited; however, they need this information for constructing the model. Participatory and collaborative modelling facilitates that the modelling team learns about the physical, social, institutional and economic system(s), water-related problems, main drivers for development and growth, possible interventions, available financial mechanisms, amongst others. Only with the combination of both, technical and local knowledge, an accurate model can be constructed. The use of computer-based models with participatory and collaborative modelling has also resulted in improved model performance. Data collection does not become a bottle-neck in the modelling process. Model validation requires less duration. In comparison with traditional planning and modelling processes, the use of participatory and collaborative modelling makes the modelling process more efficient. It also has a positive effect on the models and results obtained. Stakeholders increase their trust in them. Stakeholders are familiar with the model's components, features and functioning. This strengthens the sense of ownership of the co-developed models and their results, and boosts informed decision-making. Still, the use of existing computer-based simulation models can have important drawbacks. The freedom of stakeholders to intervene in the development of the model(s) or manipulate it is more restricted than other participatory and collaborative modelling tools in which the model can be created completely from scratch. Moreover, it is technically more intense. The effective involvement of stakeholders in the development of the model and/or its direct, interactive use asks for the customisation of the model and the user-interface based on the background, skills and needs of the involved stakeholders, as well as the use of free-available (even open source) software and visualisation and communication tools.

9.2.4 What is the added value of applying participatory and collaborative modelling to support water resources planning and management?

Participatory and collaborative modelling can contribute to achieving sustainable and inclusive development by means of help strengthening the ownership of computer-based simulation models and enhance their use in the decision-making processes. Assessing their value is a required step prior to their establishment. The assessment, presented in Chapter 8, focused on their effectiveness in terms of the planning and decision-making process, the modelling process, and the social and institutional dynamics.

A challenge of decision-making processes is that the goals might evolve over time. The structure of DSSs makes it difficult to incorporate this adaptability. By contrast, participatory and collaborative modelling can assimilate those changes, as it is a process rather than a tool. This results in an increased use of methods and modelling tools for formulating evidence-based solutions and making lower risk investments. Some approaches help to tackle water-related issues in the basin in an integrated manner (e.g. Method 1; Chapter 4). The co-development of the model helps in building consensus among stakeholders on a shared vision, the functioning of the system(s) and the problem(s) at stake. The creation of a shared understanding is particularly important for establishing a 'common ground' in the negotiation process (e.g. Method 2; Chapter 5). Participatory and collaborative modelling can also help communicating uncertainty to decision-makers and stakeholders. Approaches, such as FISM (Application in Bangladesh; Chapter 6), as well as Group Model Building and Mediated Modelling (Application in Indonesia; Chapter 4), can represent the changes of system(s) behaviour over time. The scenario exploration method helps in setting "storylines" for the future with stakeholders, considering the associated uncertainty. The formulation and integration of measures and the prioritisation of projects are critical elements in the planning process. They can condition the implementability of an IWRM plan. The acceptance of the preferred strategy and the commitment of national and local decision-makers and stakeholders to implement, monitor and evaluate is critical. Modelling with stakeholders presents two main benefits in this regard. First, it allows the assessment of the impacts of the potential measures before they are actually implemented. Decision-makers and stakeholder can themselves evaluate (as indirect or direct model users) if the proposed measures perform as expected or instead a new strategy needs to be designed to achieve the desired goal. The second benefit of participatory or collaborative modelling is transparency. The increased transparency of the planning and modelling process allows stakeholders to have more clarity of the system(s) and of the needs and interests of the other participating stakeholders. This strengthens their sense of ownership of the agreed solution. They feel that they are able to exert sufficient influence and control over the decision-making process and its outcomes, which enhances their willingness to continue being involved in the implementation phase. This commitment is essential for the sustainable management of water resources.

Finally, applying participatory and collaborative modelling to support water resources planning and management contributes to relevant societal aspects. Its use boosts inclusive development by structuring the involvement of stakeholders during the various stages of the planning process. Participatory and collaborative modelling permits the participation of different stakeholder groups to be similar during the modelling process, or vary depending on their background and skills (using e.g. the Circles of Influence approach). It also structures the negotiation process, particularly when applying collaborative modelling approaches. The neutral atmosphere created by the use of modelling tools helps in changing the mental models of stakeholders regarding the functioning of the water resources system and the problems faced by other stakeholders. Through social learning, stakeholders learn about the perceptions, beliefs, concerns and interests of other stakeholders. This becomes critical for transforming the potential initial disputes into a more cooperative environment. Supporting negotiation and increasing the type of cooperation among stakeholders results in enhanced commitment and engagement, and provides power balance among stakeholders. This engagement is essential for launching and maintaining the participatory decision-making process.

In conclusion, participatory and collaborative modelling supports and ensures availability and sustainable management of water resources for all inclusively using multi-stakeholder engagement, cooperation and capacity development, and the use of data and modelling tools.

9.3 Reflection and Recommendations for Future Research

WRM is a broad field. It requires securing water and sanitation for all, improving water quality, protecting and restoring ecosystems, increasing disaster-risk resilience, while supporting sustainable development and economic growth. This Ph.D. research shows promising results in enhancing the use of computer-based simulation models in informed decision-making processes. Augmenting their use goes hand in hand with the sense of ownership that decision-makers and stakeholders have of the model(s) and resulting outputs. Ownership can only be obtained with a high degree of trust. A process that integrates the modelling process with the involvement of stakeholders to increase the sense of trust is therefore needed. The participatory and collaborative modelling approaches presented in this Ph.D. thesis help addressing these requirements. These Ph.D. outputs serve to provide recommendations for future research and applications.

1. Usability and enrichment of the generic framework

Some directions regarding the design and applicability of the generic framework should be explored in the future. This Ph.D. research has demonstrated the strength of using the proposed generic framework to evaluate a set of participatory and collaborative modelling approaches and to design new approaches in the field of WRM. To confirm the generic applicability of the framework, it must be applied to other participatory and collaborative modelling approaches and additional case studies in other contexts and situations.

The generalisation of an approach based on the assessment of various similar applications using the generic framework seems a reasonably straightforward process. The framework, however, requires detailed information of 20 different parameters for each case evaluated. In many instances, information about certain parameters is lacking. This results in having to increase the sample size to reduce the uncertainty. This Ph.D. thesis has defined 10 cases as the minimal sample size to be able to generalise an approach (used for evaluating Group Model Building, Mediated Modelling and Companion Modelling). However, some can reason that the evaluated sample is still too small and that more research is required. Another possible development is the design of an adapted and more specific (sub-) framework to evaluate the variety of participatory modelling tools (including computer-based models, visualisation and communication tools). Finally, the proposed framework (in and of itself) does not provide detailed guidance about the selection of the most suitable approach. Once further approaches and tools have been analysed, a possible future research direction would be the development of a more detailed decision path based on a selected set of parameters.

2. Further assessment of the designed participatory and collaborative modelling approaches

Each designed method has been applied in one or more study cases. Although this is sufficient for evaluating its effectiveness, further assessment is required for the eventual generalisation of each of the methods. The six parameters used for evaluation may vary widely across different regions and subtle differences will likely exist between the different participatory and collaborative modelling approaches. As an example, the cooperative, participatory and high-tech context in the Netherlands allowed for the application of a collaborative Interactive Modelling approach characterised by high levels of participation and type of cooperation (Warren, 2015). However, these conditions are not always common in other regions of the world. In this light, further application and analysis in other cases is recommended to validate the approaches.

3. Design of new participatory and collaborative modelling approaches for water resources management

There is a great variety of participatory and collaborative modelling approaches, methods and tools. This Ph.D. thesis centres on the adaptation of existing approaches and methods to comply with the features of a computer-based simulation model and its modelling process. Thus, two possible future research directions are foreseen. On the one hand, the use of other methods and tools can be investigated and complemented with the selected simulation model for the five water resources domains covered in this Ph.D. research: integrated river basin planning with emphasis on water stress (water balance and allocation model), water quality management (water quality and ecology model), adaptive planning to national water security (meta-model) and flood risk management (hydrodynamic model). On the other hand, it is recommended the design of new approaches for other computer-based models such as data-driven (statistical) and optimisation models, when possible.

4. Customisation of the model and user-interface; and development of open access models

The customisation of the model engine and especially, the user-interface, as well as having free-available models are essential conditions expressed by almost all stakeholders that participated in this Ph.D. thesis. These could not be completely tackled in this Ph.D. thesis. . An important limitation of computer-based simulation models is that changes in the model code, engine or interface require a considerable amount of time and resources. Although some developments are in progress, the timeframe of this Ph.D. research did not allow the use of the new developments in the study cases (except for Dflow FM that is open access). It is therefore particularly relevant to continue with the new developments and their testing and application in these and/or other study cases in the future.

5. Creating incentives for sustainable data collection

In this Ph.D. thesis, the involvement of local communities, citizens and stakeholders in the collection of data via crowdsourcing is proposed. Data collected is then uploaded to OSM and can be validated, modified and enriched by them or other stakeholders over time. This method is beneficial in terms of the modelling process, as the data needed for constructing computer-based simulation models is high. It also allows the engagement of local stakeholders early in the planning process, which translates into an increased commitment and sense of ownership of the data collected and model developed. Other advantages include the lower cost, speed and potential scalability. However, engaging the "crowd" for sourcing data requires incentive mechanisms such as reputation systems, social mechanisms, gamification, and financial and career rewards (Katmada et al., 2016). It is encouraged to perform a research study on the use of incentives for crowdsourcing under the umbrella of participatory and collaborative modelling for informed, participatory decision-making in WRM.

6. Establishment of a Collaborative Modelling CoP

Participatory and collaborative modelling supports bridging the gap between science, policy and practice, which is essential for sustainable development. This Ph.D. study has allowed us to meet and work together with many researchers, practitioners, planners, consultants, decision-makers, developing organisations and other local stakeholders that work or are interested in using participatory and collaborative modelling for WRM. A required future step is the establishment of a global Collaborative Modelling Community of Practice (CoP) that will enhance even more multi-disciplinary and cross-sectorial collaboration and boost the new collaborative modelling knowledge agenda.

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REFERENCES

Abbott, M., Jonoski, A., 2001. The democratisation of decision-making processes in the water sector II. Journal of hydroinformatics 3 35-48.

Abelson, J., Forest, P.-G., Eyles, J., Smith, P., Martin, E., Gauvin, F.-P., 2003. Deliberations about deliberative methods: issues in the design and evaluation of public participation processes. Social science & medicine 57(2) 239-251.

ADB, 2015. Making it happen: Technology, finance and statistics for sustainable development in Asia and the Pacific. Asia-Pacific Regional MDG Report 2014/15. Asian Development Bank (ADB), United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP) and the United Nations Development Programme (UNDP), Bangkok

ADB, 2016a. Asian Water Development Outlook 2013. Strengthening Water Security in Asia and the Pacific. Asian Development Bank, Mandaluyong City, Philippines.

ADB, 2016b. Indonesia: Country water assessment. Asian Development Bank. Mandaluyong City, Philippines.

ADB, 2016c. River Basin Management Planning in Indonesia: Policy and Practice. Asian Development Bank, Mandaluyong City, Philippines.

Akhmouch, A., Clavreul, D., 2016. Stakeholder engagement for inclusive water governance:"Practicing what we preach" with the OECD water governance initiative. Water 8(5) 204.

Akkermans, H.A., Vennix, J.A., 1997. Clients' opinions on group model-building: an exploratory study. System Dynamics Review 13(1) 3-31.

Almoradie, A., Cortes, V., Jonoski, A., 2015. Web-based stakeholder collaboration in flood risk management. Journal of Flood Risk Management 8(1) 19-38.

Alter, S., 1980. Decision support systems: current practice and continuing challenges. Addison-Wesley Reading, MA.

Andersen, D., Richardson, G., 1997. Scripts for group model building. System Dynamics Review 13(2) 107-129.

Andersen, D.F., Vennix, J.A., Richardson, G.P., Rouwette, E.A., 2007. Group model building: problem structuring, policy simulation and decision support. Journal of the Operational Research Society 58(5) 691-694.

Antunes, P., Santos, R., Videira, N., 2006. Participatory decision making for sustainable development—the use of mediated modelling techniques. Land Use Policy 23(1) 44-52.

Armour, A., 1995. The citizens' jury model of public participation: a critical evaluation, Fairness and competence in citizen participation. Springer, pp. 175-187.

Arnstein, S.R., 1969. A ladder of citizen participation. Journal of the American Institute of planners 35(4) 216-224.

BAPPENAS, 2008. Rencana Pembangunan Jangka Panjang (RPJP) Nasional 2005-2015.

Barnaud, C., 2013. La participation, une légitimité en question. Natures Sciences Sociétés 21(1) 24-34.

Barreteau, O., Bousquet, F., 1999. Jeux de rôles et validation de systèmes multi-agents. JFIADSMA. Ingéniere des systèmes multi-agents. Hermes Science Publications 99(1) 67-80.

Barreteau, O., Bousquet, F., Étienne, M., Souchère, V., d'Aquino, P., 2014. Companion modelling: a method of adaptive and participatory research, Companion Modelling. Springer, pp. 13-40.

Barreteau, O., Bousquet, F., Millier, C., Weber, J., 2004. Suitability of Multi-Agent Simulations to study irrigated system viability: application to case studies in the Senegal River Valley. Agricultural Systems 80(3) 255-275.

Barreteau, O., Bousquet, F., Weber, J., 1997. Modes de gestion et viabilité des périmètres irrigués: questions de représentation. In F. B. Weill (Ed.), Tendances nouvelles en modélisation pour l'environnement (pp. 153-159). Elsevier, Paris.

Barreteau, O., Garin, P., Dumontier, A., Abrami, G., Cernesson, F., 2003. Agent-based facilitation of water allocation: Case study in the Drome River Valley. Group Decision and Negotiation 12(5) 441-461.

Basco-Carrera, L., del Callejo-Veracc, I.G., van Beek, E., Mendoza-Bruckner, C., Werner, M., 2017a. Stakeholder participation and capacity development as key elements for Disaster Risk Reduction in Bolivia: A framework for early warning based on forecasting requirements. Background paper of State of DRR at Local Level Report. A Report on the Patterns of Disaster Risk Reduction Actions at Local Level, UNISDR, Geneva.

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017b. Collaborative modelling or participatory modelling? A framework for water resources management. Environmental Modelling & Software 91 95-110.

Beierle, T.C., Konisky, D.M., 2000. Values, conflict, and trust in participatory environmental planning. Journal of Policy analysis and Management 587-602.

Belete, G.F., Voinov, A., Laniak, G.F., 2017. An overview of the model integration process: From pre-integration assessment to testing. Environmental Modelling & Software 87 49-63.

Bell, S., Morse, S., 2013. Measuring sustainability: Learning from doing. Routledge.

Berendrecht, W., Snepvangers, J., Minnema, B., Vermeulen, P., 2007. MIPWA: a methodology for interactive planning for water management, MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, pp. 74-80.

Bigelow, J.H., Davis, P.K., 2003. Implications for model validation of multiresolution, multiperspective modeling (mrmpm) and exploratory analysis. Rand Corp Santa Monica CA.

Bijlsma, R., Bots, P., Wolters, H., Hoekstra, A., 2011. An empirical analysis of stakeholders' influence on policy development: the role of uncertainty handling. Ecology and society 16(1).

Biswas, A.K., 2004. Integrated water resources management: a reassessment: a water forum contribution. Water international 29(2) 248-256.

Blomquist, W.A., Dinar, A., Kemper, K., 2005. Comparison of institutional arrangements for river basin management in eight basins. World Bank Policy Research Working Paper No. 3636.

Bohl, H., Bonnett, G., Fanning, D., Rayment, G., Davidson, A., 2002. Biological oxygen demand and sugars in irrigation water runoff from sugarcane fields, Proceedings-Australian Society of Sugar Cane Technologists. PK Editorial Services; 1999, pp. 297-303.

Boisseau, S., 2005. Co-evolution of a research question and methodological development: an example of companion modeling in northern Vietnam. Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management in Asia. Int. Rice Res. Inst.

Borowski, I., Hare, M., 2007. Exploring the gap between water managers and researchers: difficulties of model-based tools to support practical water management. Water Resources Management 21(7) 1049-1074.

Bosch, O.J., Nguyen, N.C., Maeno, T., Yasui, T., 2013. Managing complex issues through evolutionary learning laboratories. Systems Research and Behavioral Science 30(2) 116-135.

Both Ends, Gomukh Environmental Trust, 2011. Involving communities. A Guide to the Negotiated Approach in Integrated Water Resources Management. Both Ends, Amsterdam, the Netherlands.

Bots, P.W., Bijlsma, R., Von Korff, Y., Van der Fluit, N., Wolters, H., 2011. Supporting the constructive use of existing hydrological models in participatory settings: a set of "rules of the game". Ecology and Society 16(2) 19

Bots, P.W., van Daalen, C.E., 2008. Participatory model construction and model use in natural resource management: a framework for reflection. Systemic Practice and Action Research 21(6) 389-407.

Bourget L. (Ed.), 2011. Converging Waters: Integrating Collaborative Modeling With Participatory Processes to Make Water Resources Decisions. Institute for Water Resources, U.S. Army Corps of Engineers.

Bousquet, F., 2005. Companion modeling and multi-agent systems for integrated natural resource management in Asia. Int. Rice Res. Inst.

Bousquet, F., Barreteau, O., Le Page, C., Mullon, C., Weber, J., 1999. An environmental modelling approach: the use of multi-agent simulations. Advances in environmental and ecological modelling 113 122.

Bousquet, F., Trébuil, G., 2005. Introduction to companion modeling and multi-agent systems for integrated natural resource management in Asia. Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management in Asia 1-20.

Bousset, J.-P., Macombe, C., Taverne, M., 2005. Participatory methods, guidelines and good practice guidance to be applied throughout the project to enhance problem definition, co-learning, synthesis and dissemination. SEAMLESS.

Brammer, H., 1990. Floods in Bangladesh: geographical background to the 1987 and 1988 floods. Geographical journal 12-22.

Briot, J.-P., Guyot, P., Irving, M., 2007. Participatory simulation for collective management of protected areas for biodiversity conservation and social inclusion. AIS-CMS 7 183-188.

Brown, J., 2002. The world café: A resource guide for hosting conversations that matter. Whole Systems Ass.

Brugnach, M., Dewulf, A., Pahl-Wostl, C., Taillieu, T., 2008. Toward a relational concept of uncertainty: about knowing too little, knowing too differently, and accepting not to know. Ecology and society 13(2).

Brugnach, M., Tagg, A., Keil, F., de Lange, W.J., 2007. Uncertainty matters: computer models at the science–policy interface. Water Resources Management 21(7) 1075-1090.

Bruns, B., 2003. Water tenure reform: Developing an extended ladder of participation. Politics of the Commons: Articulating Development and Strengthening Local Practices, Chiang Mai, Thailand.

Campbell, D., 2001. The long and winding (and frequently bumpy) road to successful client engagement: one team's journey. System Dynamics Review 17(3) 195-215.

Cardwell, H., Langsdale, S., Stephenson, K., 2008. The shared vision planning primer: How to incorporate computer aided dispute resolution in water resources planning. Institute for Water Resources, Alexandria, IWR Report.

Carmona, G., Varela-Ortega, C., Bromley, J., 2013. Participatory modelling to support decision making in water management under uncertainty: Two comparative case studies in the Guadiana river basin, Spain. Journal of environmental management 128 400-412.

Castella, J.-C., Trung, T.N., Boissau, S., 2005. Participatory simulation of land-use changes in the northern mountains of Vietnam: the combined use of an agent-based model, a role-playing game, and a geographic information system. Ecology and society 10(1) 27.

Castelletti, A., Galelli, S., Ratto, M., Soncini-Sessa, R., Young, P.C., 2012. A general framework for dynamic emulation modelling in environmental problems. Environmental Modelling & Software 34 5-18.

Castelletti, A., Soncini-Sessa, R., 2006. A procedural approach to strengthening integration and participation in water resource planning. Environmental Modelling & Software 21(10) 1455-1470.

Castelletti, A., Soncini-Sessa, R., 2007. Bayesian Networks and participatory modelling in water resource management. Environmental Modelling & Software 22(8) 1075-1088.

Chambers, R., 1994. The origins and practice of participatory rural appraisal. World development 22(7) 953-969.

Chambers, R., 2006. Participatory mapping and geographic information systems: whose map? Who is empowered and who disempowered? Who gains and who loses? The electronic journal of information systems in developing countries 25(1) 1-11.

Checkland, P., 1999. Systems thinking. Rethinking management information systems 45-56.

Chen, Q., 2014. Cellular automata and artificial intelligence in ecohydraulics modelling. CRC Press.

Chen, Q., Mynett, A.E., 2006. Modelling algal blooms in the Dutch coastal waters by integrated numerical and fuzzy cellular automata approaches. Ecological modelling 199(1) 73-81.

Chen, S.H., Pollino, C.A., 2012. Good practice in Bayesian network modelling. Environmental Modelling & Software 37 134-145.

Choguill, M.B.G., 1996. A ladder of community participation for underdeveloped countries. Habitat international 20(3) 431-444.

CIRAD, 2004. http://cormas.cirad.fr/ComMod/en/. Last accessed in November 2017.

CIRAD, 2015. www.commod.org/en/. Last accessed in November 2017.

CL, 2009. www.gdrc.org/kmgmt/c-learn/. Last accessed in November 2017.

Clavel, L., Ducrot, R., Sendacz, S., 2008. Gaming with eutrophication: Contribution to integrating water quantity and quality management at catchment level. IWRA, 13ème congrès mondial de l'eau, Montpellier 2008(1-4).

Cleaver, F., 1999. Paradoxes of participation: questioning participatory approaches to development. Journal of international development 11(4) 597.

Cockerill, K., Tidwell, V.C., Passell, H.D., Malczynski, L.A., 2007. Commentary: cooperative modeling lessons for environmental management. Environmental Practice 9(01) 28-41.

Collins, K., Blackmore, C., Morris, D., Watson, D., 2007. A systemic approach to managing multiple perspectives and stakeholding in water catchments: some findings from three UK case studies. Environmental Science & Policy 10(6) 564-574.

Collins, K., Ison, R., 2009. Jumping off Arnstein's ladder: social learning as a new policy paradigm for climate change adaptation. Environmental Policy and Governance 19(6) 358-373.

Cook, C., Bakker, K., 2012. Water security: Debating an emerging paradigm. Global Environmental Change 22(1) 94-102.

Costanza, R., Voinov, A., 2003. Landscape simulation modeling: a spatially explicit, dynamic approach. Springer Science & Business Media.

CSIRO, 2014. Bangladesh Integrated Water Resources Assessment. CSIRO, WARPO, BWDB, IWM, BIDS and CEGIS. Bangladesh.

Daniels, S.E., Walker, G.B., 1996. Collaborative learning: improving public deliberation in ecosystem-based management. Environmental impact assessment review 16(2) 71-102.

Davis, P.K., Bigelow, J.H., 2003. Motivated metamodels: Synthesis of cause-effect reasoning and statistical metamodeling. No. RAND/MR-1570. Rand Corporation, Santa Monica, CA.

de Bruijn, K.M., Cumiskey, L., Dhubhda, R.N., Hounjet, M., Hynes, W., 2016. Flood vulnerability of critical infrastructure in Cork, Ireland, E3S Web of Conferences. EDP Sciences, p. 07005.

de Niet, A., Meijers, E., Schep, S., 2014. Accurate Prediction Of Ecological Quality Ratio With Product Unit Neural Networks. 11th International Conference on Hydroinformatics HIC 2014, New York City, USA.

De Stefano, L., 2010. Facing the water framework directive challenges: a baseline of stakeholder participation in the European Union. Journal of environmental management 91(6) 1332-1340.

Deltares, 2012. Water Security Atlas. Atlas Ketahanan Air. Java Water Resources Strategic Study. Deltares, DHV, MLD, Wiratman & Associates, Indonesia.

Deltares, 2016a. DELWAQ. http://oss.deltares.nl/web/delft3d/delwaq.

Deltares, 2016b. Final Report River Basin Explorer: a modelling tool for River Basin Planning in Turkey. Deltares, Witteveen+Bos, Regional Water Authority Peel and Maasvallei and DKM: The Netherlands.

DeSario, J., Langton, S., 1999. Citizen participation and technocracy. The Science of Public Policy: Essential Readings in Policy Sciences I 2 396-407.

Dewulf, A., Craps, M., Bouwen, R., Taillieu, T., Pahl-Wostl, C., 2005. Integrated management of natural resources: dealing with ambiguous issues, multiple actors and diverging frames. Water science and technology 52(6) 115-124.

Douglas, M., Wildavsky, A., 1983. Risk and culture: An essay on the selection of technological and environmental dangers. Univ of California Press.

Ducrot, R., Chagas de Carvalho, Y.M., Jacobi, P.R., Clavel, L., Barban, V., Madazio, V., Rabak, C., Reydon, B.P., Bussmeyer Arruda, F., Ramos, H.H., 2007. Building capacities to tackle the infrastructural and environmental crisis in São Paulo: Role-playing games for participatory modelling. Butterworth, J., Ducrot, R., Faysse, N., Janakarajan (eds). Peri-urban water conflicts–Supporting dialogue and negotiation. Technical Paper Series 50: 77-112.

Dukhovny, V.A.a.S., V.I.,, 2005. Integrated Water Resources Management. Experience and lessons learned from Central Asia -towards the Fourth World Water Forum. Global Water Partnership.

Dürrenberger, G., Dürrenberger, G., Dürrenberger, G., 1997. Focus groups in integrated assessment: A manual for a participatory tool. ZIT-Center for Interdisciplinary Studies in Technology, Darmstadt University of Technology.

Edelenbos, J., Klijn, E.-H., 2006. Managing stakeholder involvement in decision making: A comparative analysis of six interactive processes in the Netherlands. Journal of Public Administration Research and Theory: J-PART 417-446.

Edelenbos, J., van Schie, N., Gerrits, L., 2008. ``Democratic anchorage of interactive governance: developing institutional interfaces in water governance'', Proceedings 2008 conference of the Political Science Association. http://www. psa. uk/proceedings. aspx.

Eden, C., Ackermann, F., 1998. Analysing and comparing idiographic causal maps. Managerial and organizational cognition: Theory, methods and research 192-209.

Eden, C., Ackermann, F., 2013. Making strategy: The journey of strategic management. Sage.

ESRI, 2009. World Terrain Base. Retrieved May 4, 2016, from http://services.arcgisonline.com/ArcGIS/services/World_Terrain_Base/MapServer?wsdl.

Étienne, M., 2011. Companion modelling. A participatory approach to support sustainable development. Versailles, Quae.

Étienne, M., 2013. Companion modelling: a participatory approach to support sustainable development. Springer Science & Business Media.

Etienne, M., Du Toit, D., Pollard, S., 2011. ARDI: a co-construction method for participatory modeling in natural resources management. Ecology and Society 16(1).

European Commission, 2010. Büyük Menderes River Basin Management plan. Republic of Turkey Ministry of Environment and Forestry, Directorate General for State Hydraulic Works in cooperation with Dutch DLG Government Service for Land and Water Management, UK Environment Agency and the Slovak Water Research Institute.

European Communities, 2003a. Economics and the environment: the implementation challenge of the Water Framework Directive. Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance Document 1. Office for Official Publications of the European Communities.

European Communities, 2003b. Public Participation in Relation to the Water Framework Directive. Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance Document 8. Office for Official Publications of the European Communities.

Evers, M., Jonoski, A., Almoradie, A., Lange, L., 2016. Collaborative decision making in sustainable flood risk management: a socio-technical approach and tools for participatory governance. Environmental Science & Policy 55 335-344.

Evers, M., Jonoski, A., Maksimovič, Č., Lange, L., Ochoa Rodriguez, S., Teklesadik, A., Cortes Arevalo, J., Almoradie, A., Eduardo Simões, N., Wang, L., 2012. Collaborative modelling for active involvement of stakeholders in urban flood risk management. Natural Hazards and Earth System Science 12(9) 2821-2842.

Farolfi, S., Müller, J.-P., Bonté, B., 2010. An iterative construction of multi-agent models to represent water supply and demand dynamics at the catchment level. Environmental Modelling & Software 25(10) 1130-1148.

Faysse, N., Bustamante, R., Del Prado, A.D.N., Cuba, P., Alcoba, R.G.A., Rojas, V.C., Ariel, J., Terrazas, I., Lizárraga, A., Betancourt, B.P., 2007. Supporting local organisations in peri-urban Cochabamba, Bolivia. Peri-Urban water conflicts supporting dialogue and negotiation 2: 25-47.

Ficek, A., 2014. What we learned from using tablet computers for data collection. https://www.pdastats.com/news/archives/589: Published July 29, 2014. Accessed October 3, 2017.

Fischer, F., 2000. Citizens, experts, and the environment: The politics of local knowledge. Duke University Press.

Fischer, F., Bruhn, J., Gräsel, C., Mandl, H., 2002. Fostering collaborative knowledge construction with visualization tools. Learning and Instruction 12(2) 213-232.

Fuhrmeister, E.R., Schwab, K.J., Julian, T.R., 2015. Estimates of nitrogen, phosphorus, biochemical oxygen demand, and fecal coliforms entering the environment due to inadequate sanitation treatment technologies in 108 low and middle income countries. Environmental science & technology 49(19) 11604-11611.

Fung, A., 2006. Varieties of participation in complex governance. Public administration review 66(s1) 66-75.

Gearin, E., Kahle, C., 2001. Focus Group Methodology Review and Implementation. Kruger, R. Analysis: Systematic Analysis Process.

GED, 2015. The Seventh Five Year Plan. Bangladesh Planning Commission. General Economics Division. Bangladesh.

GED, 2017. Bangladesh Delta Plan 2100. Bangladesh Planning Commission. General Economics Division. Bangladesh.

Georgakakos, A.P., 2007. Decision support systems for integrated water resources management with an application to the Nile basin. Elsevier: Amsterdam, The Netherlands.

Geurts, J., Mayer, I., 1996. Methods for participatory policy analysis: Towards a conceptual model for research and development. WORC report 9612.

Gill, P., Stewart, K., Treasure, E., Chadwick, B., 2008. Methods of data collection in qualitative research: interviews and focus groups. British dental journal 204(6) 291-295.

Giupponi, C., Sgobbi, A., 2008. Models and decisions support systems for participatory decision making in integrated water resource management, Coping with Water Deficiency. Springer, pp. 165-186.

Glykas, M., 2010. Fuzzy cognitive maps: Advances in theory, methodologies, tools and applications. Springer.

Goodchild, M.F., 2007. Citizens as sensors: the world of volunteered geography. GeoJournal 69(4) 211-221.

Gray, S.A., Gray, S., De Kok, J.L., Helfgott, A.E., O'Dwyer, B., Jordan, R., Nyaki, A., Analyzing, F., 2015. Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. Ecol. Soc 20(2) 11.

Greco, S., Figueira, J., Ehrgott, M., 2005. Multiple criteria decision analysis. Springer's International series.

Grey, D., Sadoff, C.W., 2007. Sink or swim? Water security for growth and development. Water policy 9(6) 545-571.

Grimble, R., Chan, M.K., 1995. Stakeholder analysis for natural resource management in developing countries, Natural resources forum. Wiley Online Library, pp. 113-124.

Gunderson, L.H., 2003. Adaptive dancing: interactions between social resilience and ecological crises. Navigating social-ecological systems: Building resilience for complexity and change 33-52.

Gupta, H.V., Clark, M.P., Vrugt, J.A., Abramowitz, G., Ye, M., 2012. Towards a comprehensive assessment of model structural adequacy. Water resources research 48(8).

Gurung, T., Bousquet, F., Trébuil, G., 2006. Companion modeling, conflict resolution, and institution building: sharing irrigation water in the Lingmuteychu Watershed, Bhutan. Ecology and society 11(2).

Guyot, P., Drogoul, A., Lemaître, C., 2005. Using emergence in participatory simulations to design multi-agent systems, Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems. ACM, pp. 199-203.

GWP-ToolBox, Global Water Partnership (GWP) www.gwp.org/ToolBox/. Last accessed in October 2017.

GWP, 2000. Integrated water resources management, TAC Background Papers. Global Water Partnership (GWP).

GWP, 2012. Increasing Water Security - A Development Imperative, TAC Background Papers. Global Water Partnership (GWP).

Haasnoot, M., Van Deursen, W., Guillaume, J.H., Kwakkel, J., Van Beek, E., Middelkoop, H., 2014. Fit for purpose? Building and evaluating a fast, integrated model for exploring water policy pathways. Environmental Modelling & Software 60 99-120.

Hajkowicz, S.A., 2008. Supporting multi-stakeholder environmental decisions. Journal of environmental management 88(4) 607-614.

Haklay, M., Antoniou, V., Basiouka, S., Soden, R., Mooney, P., 2014. Crowdsourced geographic information use in government, Report to GFDRR (World Bank). London.

Hall, D.M., Lazarus, E.D., Swannack, T.M., 2014. Strategies for communicating systems models. Environmental Modelling & Software 55 70-76.

Halla, F., 1994. A coordinating and participatory approach to managing cities: The case of the sustainable Dar es Salaam project in Tanzania. Habitat international 18(3) 19-31.

Hambati, H., 2017. The vulnerability of urban communities to flood hazards in Tanzania: A case of Dar es Salaam city. Tanzania Journal for Population studies and Development 21(1).

Hambati, H., Gaston, G., 2015. Revealing the Vulnerability of Urban Communities to Flood Hazard in Tanzania: A Case of the Dar es Salaam City Ecosystem. International Journal of Geospatial and Environmental Research 2(1) 3.

Hanssen, L., Rouwette, E., Van Katwijk, M.M., 2009. The role of ecological science in environmental policy making: from a pacification toward a facilitation strategy. Ecology and society 14(1) 43.

Haraldsson, H., 2005. Developing methods for modelling procedures in System Analysis and System Dynamics. Department of Chemical Engineering, Lund University.

Haraldsson, H.V., 2004. Introduction to system thinking and causal loop diagrams. Department of Chemical Engineering, Lund University.

Hare, M., 2011. Forms of participatory modelling and its potential for widespread adoption in the water sector. Environmental Policy and Governance 21(6) 386-402.

Hare, M., Letcher, R., Jakeman, A., 2003. Participatory modelling in natural resource management: a comparison of four case studies. Integrated Assessment 4(2) 62-72.

Hassenforder, E., Smajgl, A., Ward, J., 2015. Towards understanding participatory processes: Framework, application and results. Journal of environmental management 157 84-95.

Heller, R., 2010. A Cost-Benefit Analysis of Face-To-Face and Virtual Communication: Overcoming the Challenges. Gap Inc. Graduate Research Assistant for CAHRS.

Hisschemöller, M., 1993. De democratie van problemen: de relatie tussen de inhoud van beleidsproblemen en methoden van politieke besluitvorming. VU uitgeverij.

Hommes, S., 2008. Conquering complexity: dealing with uncertainty and ambiguity in water management. University of Twente.

Hovmand, P., Rouwette, E., Andersen, D.F., Richardson, G.P., Calhoun, A., Rux, K., Hower, T., 2011. Scriptapedia: a handbook of scripts for developing structured group model building sessions.

Hurlbert, M., Gupta, J., 2015. The split ladder of participation: A diagnostic, strategic, and evaluation tool to assess when participation is necessary. Environmental Science & Policy 50 100-113.

Iliffe, M., 2015. Starting Ramani Huria – Mapping The Flood Prone Areas In Dar es Salaam, Mark's Brain.

Islam, N., 1974. Five-year plan of Bangladesh: Perspectives and problems. World development 2(4-5) 49-53.

Ison, R.L., Collins, K.B., Wallis, P.J., 2015. Institutionalising social learning: Towards systemic and adaptive governance. Environmental Science & Policy 53 105-117.

Jakeman, A., Hornberger, G., 1993. How much complexity is warranted in a rainfall-runoff model? Water resources research 29(8) 2637-2649.

Jakeman, A.J., Letcher, R.A., 2003. Integrated assessment and modelling: features, principles and examples for catchment management. Environmental Modelling & Software 18(6) 491-501.

Jakeman, A.J., Letcher, R.A., Norton, J.P., 2006. Ten iterative steps in development and evaluation of environmental models. Environmental Modelling & Software 21(5) 602-614.

Janssen, M., 2002. Complexity and ecosystem management: the theory and practice of multi-agent systems. Edward Elgar Publishing.

Jeuken, A., Haasnoot, M., Reeder, T., Ward, P., 2015. Lessons learnt from adaptation planning in four deltas and coastal cities. Journal of Water and Climate Change 6(4) 711-728.

Jolk, C., Greassidis, S., Jaschinski, S., Stolpe, H., Zindler, B., 2010. Planning and decision support tools for the integrated water resources management in Vietnam. Water 2(4) 711-725.

Jones, N., Ross, H., Lynam, T., Perez, P., Leitch, A., 2011. Mental models: an interdisciplinary synthesis of theory and methods.

Jones, N.A., Perez, P., Measham, T.G., Kelly, G.J., d'Aquino, P., Daniell, K.A., Dray, A., Ferrand, N., 2009. Evaluating participatory modeling: developing a framework for cross-case analysis. Environmental management 44(6) 1180-1195.

Jonoski, A., 2002. Hydroinformatics as Sociotechnology. CRC Press.

Jonoski, A., Evers, M., 2013. Sociotechnical framework for participatory flood risk management via collaborative modeling. International Journal of Information Systems and Social Change (IJISSC) 4(2) 1-16.

Katmada, A., Satsiou, A., Kompatsiaris, I., 2016. Incentive mechanisms for crowdsourcing platforms, International Conference on Internet Science. Springer, pp. 3-18.

Keen, P.G., 1987. Decision support systems: the next decade. Decision Support Systems 3(3) 253-265.

Kelly, R.A., Jakeman, A.J., Barreteau, O., Borsuk, M.E., ElSawah, S., Hamilton, S.H., Henriksen, H.J., Kuikka, S., Maier, H.R., Rizzoli, A.E., 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. Environmental Modelling & Software 47 159-181.

Kemper, K.E., Blomquist, W.A., Dinar, A., 2007. Integrated river basin management through decentralization. Springer.

Koç, C., 2010. A study on the pollution and water quality modeling of the River Büyük Menderes, Turkey. Clean–Soil, Air, Water 38(12) 1169-1176.

Kolagani, N., Ramu, P., 2017. A participatory framework for developing public participation GIS solutions to improve resource management systems. International Journal of Geographical Information Science 31(3) 463-480.

Kollinger, M., Vondráček, K., Šeblová, V., Zdražil, J., Jirka, J., Vokounová, L., 2003. Flood simulation and visualization, Central European Seminar on Computer Graphics. Slovakia. Citeseer.

Kombe, W.J., 2005. Land use dynamics in peri-urban areas and their implications on the urban growth and form: the case of Dar es Salaam, Tanzania. Habitat international 29(1) 113-135.

Korfmacher, K.S., 2001. The politics of participation in watershed modeling. Environmental management 27(2) 161-176.

Kosko, B., 1986. Fuzzy cognitive maps. International journal of man-machine studies 24(1) 65-75.

Kwakkel, J.H., 2016. The Exploratory Modeling Workbench An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making.

Kwakkel, J.H., Walker, W.E., Marchau, V., 2010. Adaptive airport strategic planning. European Journal of Transport and Infrastructure Research (EJTIR), 10 (3), 2010.

Lamers, M., Ottow, B., Francois, G., von Korff, Y., 2010. Beyond dry feet? Experiences from a participatory watermanagement planning case in The Netherlands. Ecology and society 15(1) 14.

Lane, S.J., Heddle, N.M., Arnold, E., Walker, I., 2006. A review of randomized controlled trials comparing the effectiveness of hand held computers with paper methods for data collection. BMC medical informatics and decision making 6(1) 23.

Langsdale, S., Beall, A., Bourget, E., Hagen, E., Kudlas, S., Palmer, R., Tate, D., Werick, W., 2013. Collaborative modeling for decision support in water resources: principles and best practices. JAWRA Journal of the American Water Resources Association 49(3) 629-638.

Lewis, P., 1992. Rich picture building in the soft systems methodology. European Journal of Information Systems 1(5) 351.

Lin, B., Wicks, J., Falconer, R., Adams, K., 2006. Integrating one-and two-dimensional hydrodynamic models for flood simulation. River Basin Management: Progress Towards Implementation of the European Water Framework Directive 369.

Linstone H., Turoff M. (Ed), 2002. The Delphi Method: Techniques and Applications http://is.njit.edu/pubs/delphibook/.

Lonsdale, P., Baber, C., Sharples, M., 2004. Engaging learners with everyday technology: A participatory simulation using mobile phones, Mobile Human-Computer Interaction-MobileHCI 2004. Springer, pp. 461-465.

Loucks, D.P., da Costa, J.R., 2013. Decision support systems: Water resources planning. Springer Science & Business Media.

Loucks, D.P., Stedinger, J.R., Haith, D.A., 1981. Water resource systems planning and analysis. Prentice-Hall.

Loucks, D.P., Van Beek, E., 2017. Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications. Springer.

Loucks, D.P., Van Beek, E., Stedinger, J.R., Dijkman, J.P., Villars, M.T., 2005. Water resources systems planning and management: an introduction to methods, models and applications. Paris: UNESCO.

Luna-Reyes, L.F., Andersen, D.L., 2003. Collecting and analyzing qualitative data for system dynamics: methods and models. System Dynamics Review 19(4) 271-296.

Martínez-Santos, P., Andreu, J., 2010. Lumped and distributed approaches to model natural recharge in semiarid karst aquifers. Journal of hydrology 388(3) 389-398.

Maskrey, S.A., Mount, N.J., Thorne, C.R., Dryden, I., 2016. Participatory modelling for stakeholder involvement in the development of flood risk management intervention options. Environmental Modelling & Software 82 275-294.

McCuen, R.H., Knight, Z., Cutter, A.G., 2006. Evaluation of the Nash–Sutcliffe efficiency index. Journal of Hydrologic Engineering 11(6) 597-602.

Medema, W., McIntosh, B.S., Jeffrey, P.J., 2008. From premise to practice: a critical assessment of integrated water resources management and adaptive management approaches in the water sector. Ecology and society 13(2) 29.

Media Bangladesh, http://www.mediabangladesh.net/map-of-bangladesh/. Access it on February 2018.

Mekonnen, M.M., Hoekstra, A.Y., 2016. Four billion people facing severe water scarcity. Science advances 2(2) e1500323.

Mendoza, G., Cardwell, H., Guerrero, P., 2013. Integrated water resources management in Peru through shared vision planning. Free flow: reaching water security through cooperation (Eds. Griffiths and Lambert). UNESCO/Tudor Rose, London, UK. pp 136–140.

Midgley, G., 1995. Mixing methods: developing systemic intervention. Centre for Systems Studies, University of Hull Hull.

Ministry of Environment, 2013. State of the Environment Report of Indonesia 2012. Status Lingkungan Hidup Indonesia 2012. Ministry of Environment of the Republic of Indonesia. Jakarta, Indonesia. .

Mintzberg, H., 1978. Beyond implementation: An analysis of the resistance to policy analysis. École des hautes études commerciales.

Mishan, E.J., Quah, E., 2007. Cost-benefit analysis. Routledge.

Mostert, E., 2003. The challenge of public participation. Water policy 5(2) 179-197.

Mostert, E., Pahl-Wostl, C., Rees, Y., Searle, B., Tàbara, D., Tippett, J., 2007a. Social learning in European river-basin management: barriers and fostering mechanisms from 10 river basins. Ecology and society 12(1).

Mostert, E., Pahl-Wostl, C., Rees, Y., Searle, B., Tàbara, D., Tippett, J., 2007b. Social learning in European river-basin management: barriers and fostering mechanisms from 10 river basins. Ecology and Society, 12 (1), 2007.

Mouton, A.M., Van Der Most, H., Jeuken, A., Goethals, P.L., De Pauw, N., 2009. Evaluation of river basin restoration options by the application of the water framework directive explorer in the Zwalm River basin (Flanders, Belgium). River research and applications 25(1) 82-97.

Mukherjee, N., 1993. Participatory rural appraisal. Concept Publishing Company.

Mustikasari, R., 2011. A Guide for Analyzing Livelihhods and Economic Activities in the Context of a Negotiated Approach to Integrated Water Resources Management. Both Ends and Telapak. Indonesia.

Nabavi, E., Daniell, K.A., Najafi, H., 2017. Boundary matters: the potential of system dynamics to support sustainability? Journal of Cleaner Production 140 312-323.

Newig, J., Pahl-Wostl, C., Sigel, K., 2005. The role of public participation in managing uncertainty in the implementation of the Water Framework Directive. European Environment 15(6) 333-343.

Nickson, R., McArthur, J., Burgess, W., Ahmed, K.M., Ravenscroft, P., Rahmanñ, M., 1998. Arsenic poisoning of Bangladesh groundwater. Nature 395(6700) 338-338.

Novak, J.D., Cañas, A.J., 2008. The theory underlying concept maps and how to construct and use them.

OECD, 2015. Stakeholder Engagement for Inclusive Water Governance, OECD Studies on Water, OECD Publishing, Paris.

Onono, M., Carraher, N., Cohen, R., Bukusi, E., Turan, J., 2011. Use of personal digital assistants for data collection in a multi-site AIDS stigma study in rural south Nyanza, Kenya. African health sciences 11(3).

Pahl-Wostl, C., 2002. Participative and stakeholder-based policy design, evaluation and modeling processes. Integrated assessment 3(1) 3-14.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., Taillieu, T., 2007. Social learning and water resources management. Ecology and Society, 12 (2), 2007.

Panek, J., Sobotova, L., 2015. Community mapping in urban informal settlements: examples from Nairobi, Kenya. The electronic journal of information systems in developing countries 68.

Paolisso, M., 2002. Blue crabs and controversy on the Chesapeake Bay: a cultural model for understanding watermen's reasoning about blue crab management. Human organization 61(3) 226-239.

Paolisso, M., Trombley, J., Hood, R., Sellner, K., 2015. Environmental models and public stakeholders in the Chesapeake Bay watershed. Estuaries and coasts 38(1) 97-113.

Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., Deadman, P., 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. Annals of the association of American Geographers 93(2) 314-337.

Pegram, G., Yuanyuan, L., Le Quesne, T., Speed, R., Jianqiang, L., Fuxin, S., 2013. River Basin Planning Principles: Procedures and Approaches for Strategic Basin Planning. UNESCO, ADB, GIWP and WWF. openaccess.adb.org.

Perkins, C., 2007. Community mapping. The Cartographic Journal 44(2) 127-137.

Prell, C., 2012. Social network analysis: History, theory and methodology. Sage.

Prell, C., Hubacek, K., Reed, M., Quinn, C., Jin, N., Holden, J., Burt, T., Kirby, M., Sendzimir, J., 2007. If you have a hammer everything looks like a nail: traditional versus participatory model building. Interdisciplinary Science Reviews 32(3) 263-282.

Prihandrijanti, M., Malisie, A., Otterpohl, R., 2008. Cost–Benefit Analysis for Centralized and Decentralized Wastewater Treatment System (Case Study in Surabaya-Indonesia), Efficient Management of Wastewater. Springer, pp. 259-268.

R. Speed, L.Y., T. Le Quesne, G. Pegram and Z. Zhiwei, 2013. Basin Water Allocation Planning. Principles, procedures and approaches for basin allocation planning. UNESCO, Paris.

Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. Biological conservation 141(10) 2417-2431.

Refsgaard, J.C., Henriksen, H.J., Harrar, W.G., Scholten, H., Kassahun, A., 2005. Quality assurance in model based water management–review of existing practice and outline of new approaches. Environmental Modelling & Software 20(10) 1201-1215.

Refsgaard, J.C., van der Sluijs, J.P., Højberg, A.L., Vanrolleghem, P.A., 2007. Uncertainty in the environmental modelling process–a framework and guidance. Environmental Modelling & Software 22(11) 1543-1556.

Richardson, G.P., Andersen, D.F., 1995. Teamwork in group model building. System Dynamics Review 11(2) 113-137.

Richardson, G.P., Pugh III, A.I., 1981. Introduction to system dynamics modeling with DYNAMO. Productivity Press Inc.

Richardson, G.P., Vennix, J.A., Andersen, D.F., Rohrbaugh, J., Wallace, W., 1989. Eliciting group knowledge for model-building, Computer-based management of complex systems. Springer, pp. 343-357.

Ritzema, H., Froebrich, J., Raju, R., Sreenivas, C., Kselik, R., 2010. Using participatory modelling to compensate for data scarcity in environmental planning: a case study from India. Environmental Modelling & Software 25(11) 1450-1458.

Robbins, J.H., Emery, M.C., New demands, changing values: applications of connoisseurship to the assessment of personal qualities and attributes in diverse cultural and educational settings, Paper presented at the 33rd Annual IAEA (International Association for Educational Assessment) Conference, 16-21 September, Baku, Azerbaiijan.

Romney, A.K., 1999. Cultural Consensus as as a Statistical Model. Current Anthropology(S103).

Romney, A.K., Weller, S.C., Batchelder, W.H., 1986. Culture as consensus: A theory of culture and informant accuracy. American anthropologist 88(2) 313-338.

Rouwette, E., Bleijenbergh, I., Peters, V., van Mullekom, T., 2008. Consensus bouwen in een probleemwijk. Modelbouw als interventiemethode bij het bestrijden van overlast.

Rowe, G., Frewer, L.J., 2004. Evaluating public-participation exercises: a research agenda. Science, technology & human values 29(4) 512-556.

Ruankaew, N., Le Page, C., Dumrongrojwattana, P., Barnaud, C., Gajaseni, N., Van Paassen, A., Trébuil, G., 2010. Companion modelling for integrated renewable resource management: a new collaborative approach to create common values for sustainable development. International Journal of Sustainable Development & World Ecology 17(1) 15-23.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. International journal of services sciences 1(1) 83-98.

Sadoff, C.W., Grey, D., 2005. Cooperation on international rivers: A continuum for securing and sharing benefits. Water International 30(4) 420-427.

Sedlacko, M., Martinuzzi, A., Røpke, I., Videira, N., Antunes, P., 2014. Participatory systems mapping for sustainable consumption: Discussion of a method promoting systemic insights. Ecological Economics 106 33-43.

Serrat-Capdevila, A., Valdes, J.B., Gupta, H.V., 2011. Decision support systems in water resources planning and management: Stakeholder participation and the sustainable path to science-based decision making. Efficient decision support systems—practice and challenges from current to future. InTech, India.

Sharda, R., Barr, S.H., MCDonnell, J.C., 1988. Decision support system effectiveness: a review and an empirical test. Management science 34(2) 139-159.

Sieber, R., 2006. Public participation geographic information systems: A literature review and framework. Annals of the association of American Geographers 96(3) 491-507.

Simon, H.A., 1977. The structure of ill-structured problems, Models of discovery. Springer, pp. 304-325.

SLIM, 2004. Stakeholders and Stakeholding in Integrated Catchment Management and Sustainable Use of Water. SLIM Policy Brief No.2. SLIM, UK. .

Smajgl, A., Ward, J., 2015. Evaluating participatory research: Framework, methods and implementation results. Journal of environmental management 157 311-319.

Smith, A.H., Lingas, E.O., Rahman, M., 2000. Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. Bulletin of the World Health Organization 78(9) 1093-1103.

Solanes, M., Gonzalez-Villarreal, F., 1999. The Dublin principles for water as reflected in a comparative assessment of institutional and legal arrangements for integrated water resources management. Global Water Partnership Stockholm, Sweden.

Soncini-Sessa, R., Gandolfi, C., Nardini, A., Kraszewski, A., 1991. Computer-aided water reservoir management: A prototype two-level DSS, Decision Support Systems. Springer, pp. 527-574.

Souchère, V., Millair, L., Echeverria, J., Bousquet, F., Le Page, C., Etienne, M., 2010. Co-constructing with stakeholders a role-playing game to initiate collective management of erosive runoff risks at the watershed scale. Environmental Modelling & Software 25(11) 1359-1370.

Standa-Gunda, W., Mutimukuru, T., Nyirenda, R., Prabhu, R., Haggith, M., Vanclay, J.K., 2003. Participatory modelling to enhance social learning, collective action and mobilization among users of the Mafungautsi Forest, Zimbabwe. Small-Scale Forestry 2(2) 313-326.

Stave, K., 2010. Participatory system dynamics modeling for sustainable environmental management: Observations from four cases. Sustainability 2(9) 2762-2784.

Stock, C., Bishop, I.D., O'Connor, A.N., Chen, T., Pettit, C.J., Aurambout, J.-P., 2008. SIEVE: Collaborative decision-making in an immersive online environment. Cartography and Geographic Information Science 35(2) 133-144.

Subijanto, T.W., 2015. Towards Excellence River Basin Organization. Case of Brantas River Basin East Java - Indonesia. Presentation at the National IWRM Workshop, New Delhi.

Sukardi, S., Warsito, B., Kisworo, H., Sukiyoto, 2013. River Management in Indonesia. Directorate General of Water Resources, Yayasan Air Adhi Eka, Japan International Cooperation Agency.

Suwarno, A., Nawir, A.A., 2009. Participatory modelling to improve partnership schemes for future Community-Based Forest Management in Sumbawa District, Indonesia. Environmental Modelling & Software 24(12) 1402-1410.

Thiessen, E.M., Loucks, D.P., 1992. Computer Assited Negotiation of Multiobjective Water Resources Conflicts. Wiley Online Library.

Tidwell, V.C., Van Den Brink, C., 2008. Cooperative modeling: linking science, communication, and ground water planning. Groundwater 46(2) 174-182.

UN-Water, 2006. Coping with Water Scarcity-A Strategic Issue and Priority for System-wide Action. UN-Water Thematic Initiatives.

UN-Water, 2013. Water security and the global water agenda: a UN-water analytical brief. Hamilton, ON: UN University.

UNESCO, 2009. Introduction to the IWRM Guidelines at River Basin Level. Dialogue paper. UNESCO World Water Assessment Programme, International Hydrological Programme (IHP), and Network of Asian River Basin Organizations (NARBO).

UNISDR, 2015. The Sendai Framework for Disaster Risk Reduction 2015-2030. Geneva, Switzerland.

United Nations, 2016. Sustainable Development Goals. www.un.org/sustainabledevelopment/.

Usman, R., 2000. Integrated water resource management: lessons from Brantas River Basin in Indonesia, Intersectoral Management of River Basins: proceedings of an international workshop on “Integrated Water Mangement in Water-Stressed River Basins in Developing Countries: Strategies for Poverty Alleviation and Agricultural Growth,” Loksop Dam, South Africa, pp. 16-21.

Utrecht University, 1995. PCRaster Software for Environment http://pcraster.geo.uu.nl/. Last accessed in June 2015.

Valiant, R., 2013. Integrated Water Resources Management:Water for Multipurposes. Malang Indonesia: Jasa Tirta 1 Public Cooperation.

Van Ast, J., Boot, S.P., 2003. Participation in European water policy. Physics and Chemistry of the Earth, Parts A/B/C 28(12) 555-562.

Van Beek, E., Arriens, W.L., 2014. Water Security: Putting the Concept into Practice. GWP TEC Background Paper(20).

van Buuren, A., Driessen, P., Teisman, G., van Rijswick, M., 2014. Toward legitimate governance strategies for climate adaptation in the Netherlands: combining insights from a legal, planning, and network perspective. Regional environmental change 14(3) 1021-1033.

Van de Graaf, H., Hoppe, R., 1996. Beleid en politiek. Een inleiding tot de beleidswetenschap en de beleidskunde.

Van den Belt, M., 2004. Mediated modeling: a system dynamics approach to environmental consensus building. Island press.

Van den Brink, C., 2009. Land use an groundwater quality: How technical instrumentation and scientific knowledge can support groundwater planning.

van der Krogt, W.N.M., Boccalon, A., 2013. River Basin Simulation Model RIBASIM Version 7.00. User Manual. Deltares report 1000408-002.

van der Most, H., Gijsbers, P., Dijkman, J., 2002. Flood Management along the River Rhine: Decision Support Systems in a Participatory Context. In: the MULINO conference on policies and tools for the sustainable water management in the EU, Venice, Italy, November 21-23, 2002.

van Grol, R., Walker, W.E., Rahman, A., de Jong, G., 2006. Using a Metamodel to Analyze Sustainable Transport Policies for Europe: the SUMMA Project's Fast Simple Model. In: EURO 2006, 21st European Conference on Operational Research, Iceland, 2-5 July 2006.

van Schijndel, S., 2006. The planning kit, a decision making tool for the Rhine branches, Floods, from Defence to Management: Symposium Proceedings of the 3rd International Symposium on Flood Defence, Nijmegen, The Netherlands, 25-27 May 2005, Book+ CD-ROM. CRC Press, p. 299.

Veldkamp, A., Fresco, L., 1996. CLUE-CR: an integrated multi-scale model to simulate land use change scenarios in Costa Rica. Ecological modelling 91(1-3) 231-248.

Vennix, J.A., 1996. Group model building: Facilitating team learning using system dynamics. Wiley Chichester.

Vennix, J.A., 1999. Group model-building: tackling messy problems. System Dynamics Review 15(4) 379-401.

Vennix, J.A., Andersen, D.F., Richardson, G.P., Rohrbaugh, J., 1992. Model-building for group decision support: issues and alternatives in knowledge elicitation. European Journal of Operational Research 59(1) 28-41.

Vennix, J.A., Gubbels, J., Post, D., Poppen, H., 1988. A structured approach to knowledge acquisition in model development, The 6th International Conference of the System Dynamics Society.

Verburg, P.H., Rounsevell, M.D., Veldkamp, A., 2006. Scenario-based studies of future land use in Europe. Agriculture, Ecosystems & Environment 114(1) 1-6.

Videira, N., Antunes, P., Santos, R., 2017. Engaging Stakeholders in Environmental and Sustainability Decisions with Participatory System Dynamics Modeling, Environmental Modeling with Stakeholders. Springer, pp. 241-265.

Videira, N., Antunes, P., Santos, R., Gamito, S., 2003. Participatory modelling in environmental decision-making: the ria Formosa natural park case study. Journal of Environmental Assessment Policy and Management 5(03) 421-447.

Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. Environmental Modelling & Software 25(11) 1268-1281.

Voinov, A., Gaddis, E.J.B., 2008. Lessons for successful participatory watershed modeling: a perspective from modeling practitioners. Ecological modelling 216(2) 197-207.

Voinov, A., Kolagani, N., McCall, M.K., Glynn, P.D., Kragt, M.E., Ostermann, F.O., Pierce, S.A., Ramu, P., 2016. Modelling with stakeholders–Next generation. Environmental Modelling & Software 77 196-220.

Wahyudi, S.I., Ni'am, M.F., Le Bras, G., 2012. Problems, causes and handling analysis of tidal flood, erosion and sedimentation in northern coast of Central Java: review and recommendation. International Journal of Civil & Environmental Enginering 12(04) 65-69.

Walker, W.E., Harremoës, P., Rotmans, J., van der Sluijs, J.P., van Asselt, M.B., Janssen, P., Krayer von Krauss, M.P., 2003. Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support. Integrated Assessment 4(1) 5-17.

Walker, W.E., van Daalen, C.E., 2013. System models for policy analysis, Public Policy Analysis. Springer, pp. 157-184.

Walsh, M.R., 1993. Toward spatial decision support systems in water resources. Journal of Water Resources Planning and Management 119(2) 158-169.

Ward, P.J., De Moel, H., Aerts, J., 2011. How are flood risk estimates affected by the choice of return-periods? Natural Hazards and Earth System Sciences 11(12) 3181.

Warren, A., 2015. Collaborative Modelling in Water Resources Management. Master Thesis. Delft University of Technology, the Netherlands.

WEF Water Initiative, 2010. Water security: the water-food-energy-climate nexus. World Economic Forum (WEF). Washington, Island Press.

Wehn, U., Collins, K., Anema, K., Basco-Carrera, L., Lerebours, A., 2017. Stakeholder engagement in water governance as social learning: lessons from practice. Water International 1-26.

Weiner, D., Harris, T.M., Craig, W.J., 2002. Community participation and geographic information systems. Community participation and geographic information systems 3-16.

Weller, S.C., 2007. Cultural consensus theory: Applications and frequently asked questions. Field methods 19(4) 339-368.

Wendling, C., Radisch, J., Jacobzone, S., 2013. The use of social media in risk and crisis communication.

Werick, W.J., 1997. Managing water for drought: National study of water management during drought. DIANE Publishing.

Wieland, R., Gutzler, C., 2014. Environmental impact assessment based on dynamic fuzzy simulation. Environmental Modelling & Software 55 235-241.

Willmott, C.J., 1981. On the validation of models. Physical geography 2(2) 184-194.

Winsemius, H.C., Eilander, D., Ward, P.J., Diaz Loaiza, A.M.A.D.L., Chen, J., Leskens, A., Mawanda, S., Coughlan, E., Iceland, C., Luo, T., 2016. Challenge Fund: Participatory Terrain Data and Modelling - Final Report. Deltares: Delft, Netherland.

Wolf, A.T., Yoffe, S.B., Giordano, M., 2003. International waters: identifying basins at risk. Water policy 5(1) 29-60.

Wood, J., 2005. 'How green is my valley?'Desktop geographic information systems as a community-based participatory mapping tool. Area 37(2) 159-170.

Worrapimphong, K., Gajaseni, N., Le Page, C., Bousquet, F., 2010. A companion modeling approach applied to fishery management. Environmental Modelling & Software 25(11) 1334-1344.

Wortelboer, F.G., van de Roovaart, J. C., Karaaslan, Y., and Çankaya, M. E. B.,, 2015. Models for the water framework directive–Using RIBASIM and WFD Explorer. In Sustainable Watershed Management: SuWaMa 2014 conference proceedings. CRC Press. Taylor & Francis Group.

Zeitoun, M., Mirumachi, N., 2008. Transboundary water interaction I: Reconsidering conflict and cooperation. International Environmental Agreements: Politics, Law and Economics 8(4) 297-316.

Zindler, B., Borgmann, A., Greassidis, S., Jaschinski, S., Jolk, C., Stolpe, H., 2012. Planning and Decision Support Tools for Integrated Water Resources Management (IWRM) on River Basin Level in the Southeast-Asian Region on the Example of Vietnam: Tools for Water Quantity and Quality Risk Assessment. Novel Approaches and their applications in risk assessment. InTech, Rijeka 37-58.

ANNEX A

GROUP MODEL BUILDING, MEDIATED MODELLING AND COMPANION MODELLING ASSESSMENT

Group Model Building and Mediated Modelling

Factors	Parameters		Group Model Building (GMB)	Mediated Modelling (MM)
Context and application	Problem type	Problem structure Scale of action Time horizon	Used in messy problems. Complex social problems with different views and which have relationships with other social problems. It is mostly used for problems in which there is disagreement about values and norms standards. It is commonly used when participants are part of a team and have a common goal or mission. It is not restricted to any specific scale and size. It is not particularly a geo-spatial modelling approach. It addresses long term problems by developing policy scenarios.	Used in messy problems. Complex social problems with different views and which have relationships with other social problems. It is mostly used for problems in which there is disagreement about values and norms standards. It is commonly used when there are different stakeholder groups with limited regular interaction. There isn't a common goal or mission. It is not restricted to any specific scale and size. It is not particularly a geo-spatial modelling approach. It addresses long term problems by developing policy scenarios.
	Domain		Frequently used in business applications. Although it can also be used for Natural Resources Management.	Commonly used for Natural Resources Management.
	Interaction context	Cooperative Competitive	It is primary used in cooperative decision contexts. Participants have a common goal or mission which they want to accomplish. Despite disagreement there is an open, informal atmosphere and mutual acceptance and understanding between team members.	It is often used in more competitive contexts. Participants have different interests and positions. Although they might cooperate in ad hoc occasions, there isn't an established common goal.
Specific use	Participatory/Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	The primary purpose is collaborative learning (social learning) via the construction of the system model. This might then lead to consensus building, and ultimately it might support decision-making.	The model is constructed to mediate among stakeholders. The collaborative learning process (social learning) is essential for enhancing cooperation. Ultimately, it might support decision making.
	Planning/Management cycle phase		Commonly used at planning level. It is mainly used in early stages of the planning cycle: problem definition, initial and preliminary analysis. It can also be used as a diagnostic and impact assessment method.	

Factors	Parameters		Group Model Building (GMB)	Mediated Modelling (MM)
Information handling	Model characterisation	Model system focus Model type	It is an analytical model. Its flexibility makes it applicable to different systems. It can be considered mainly as a Socio and/or Physical System Model. Both approaches can make use of qualitative (Causal Loop Diagrams) or quantitative (system dynamics using stocks and flows) models.	
	Modelling tool / Software platform		The model describes system interactions. Possible software to be used include Stella, Vensim, SystemDynamics, GoldSim, etc.	
	Information type		All type of information can be used. Important is that it has a temporal component.	
	Information delivery medium	Virtual/web Face-to-face	Frequently, these processes are based on face-to-face sessions of 2-3 days. However, web portals can also be used.	
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Can be participatory or collaborative modelling. More commonly applied as collaborative modelling.	Can be participatory or collaborative modelling. More commonly applied as participatory modelling.
	Stakeholders involved	Organisation Type of stake Background Minimal skills and knowledge	Public sector clients or clients from consultant companies. Groups between 5 and 20 persons. GMB does not make a distinction between actors involved. Rather, it assumes that all participants have the same power to decide. When using CLD minimal literacy skills can be lower than using stocks and flows. Participants' background plays a key role when deciding the type of participatory approach used for each type of demand, as well as when choosing scratch or a preliminary model as starting point.	Often different stakeholder groups are involved. A distinction between groups is required, based on the stakeholder analysis. By contrast to GMB, it might be difficult that all participants have the same level of involvement and power to decide or even speak up. More time and effort is required to ensure a common basis in terms of knowledge and skills, as the group is composed of persons with different backgrounds and skills.
	Model users	Direct/Indirect Technical skills	All participants play a key role throughout the GMB sessions in helping to develop problem definitions, identifying variables of interest, stocks and flows, defining and suggesting data sources for the model, and sometimes generating policies.	
	Participation mode	Only modellers (no participation) Individuals Groups	The participation mode varies depending on the modelling and planning steps. Some stages are conducted without stakeholder participation. Results are then presented to the involved actors. Participants can also be interviewed or	It also includes steps where only modellers are involved, individual tasks. There are also tasks in groups and plenary. However, due to the heterogeneous interests among participants, the formation of

Factors	Parameters		Group Model Building (GMB)	Mediated Modelling (MM)
			asked for advice. In most stages, are done in small groups or plenary. Divergent and convergent tasks. In GMB, group formation is often not so critical, as there is a homogeneous interest among participants.	(homogeneous/ heterogeneous) groups becomes quite essential.
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	The actors are involved in the whole process and they have the mandate to act. Power is redistributed thru negotiation between participants.	Often there is a distinction between stakeholder groups based on their knowledge, skills and dependencies. For some it can reach up to co-decision making, others might only be involved up to the co-design.
	Timing of participation	Data collection Model definition Model construction Model validation and verification Model use Formulation of measures and design of strategies	Participants are involved in all planning and modelling phases	Participants are involved in all planning and modelling phases. However, their level of participation for each phase may vary.
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Frequently participants are part of a team. This leads to collaboration up to joint action	There is little cooperation among participants. Commonly the type of cooperation among them is lower than in GBM (coordination)
Modelling / organising team	Team		It can be just a modeller, but usually the team consists of one or more modellers, a facilitator, a gatekeeper, a process coach and a recorder.	Can be initiated by a gatekeeper and a mediated modeller; however, it is recommended to expand the team (if sufficient means). The team could have a modeller/reflector, mediator, recorder, a facilitator and a process coach.
	Skills	Modelling skills Facilitation skills Knowledge acquisition	• Development of Causal Loop Diagrams and system dynamics (and associated software packages) • Facilitation skills including process structuring, conflict handling and	

Factors	Parameters		Group Model Building (GMB)	Mediated Modelling (MM)
		skills Process management skills	communication (open communication, active listening inducing cognitive conflict in order to increase vigilance). In MM, more knowledge on negotiation and mediation is required. • Concentration and team building skills • Authenticity, integrity, neutrality and attitude of inquiry • The process coach should not be a system dynamics modeller, as the role is to reflect on the group process and accurately identify what is happening for participants based on observing their behaviour and language. • The gatekeeper should know the client organization, stakeholders and institutional setting, to be able to influence the process (if required)	
Means	Timing		There are two main methodologies. The methodology used by Vennix requires between 2 and 3 sessions. The methodology used by Richardson only requires 1 or 2 sessions.	There is more flexibility on the number of sessions.
	Financial resources		-	-

Companion Modelling

Factors	Parameters		Companion Modelling (ComMod)
Context and application	Problem type	Problem structure	Semi-structured Unstructured
		Scale of action	Local or regional scales. In many cases ComMod is applied at community level.
		Time horizon	Short or medium terms: Short term: 0-10 years Medium term: 15-30 years
	Domain		Urban and rural natural resource- watershed management
	Interaction context	Cooperative Competitive	Competitive: Stakeholders commonly have conflict of interests. Stakeholders typically generate preferred solutions independently without considering the concerns and ideas of others. In cases where there is a cooperative context, ComMod helps collective action by reducing the existing conflicts among stakeholders.
Specific use	Participatory/Collaborative modelling purpose	Decision-making Collaborative learning Mediation Model improvement	*Primary purpose:* Enhance cooperation via collective reflection, collaborative learning and dispute resolution. *Secondary purposes:* Support of the decision-making process with collective action.
	Planning/Management cycle phase		Early phases of the planning cycle.
Information handling	Model characterisation	Model system focus	Socio-physical system models
		Model type	Analytical models: ComMod generally develops and make use of a conceptual model and simulation models.
	Modelling tool / Software platform		1) Agent-based model 2) Role-playing game
	Information type		Combination of systems interactions and complex processes
	Information delivery medium	Virtual/web Face-to-face	Face-to-face: Role-playing games are commonly used in face-to-face sessions. Virtual platforms are sometimes used, mainly for interactive computer simulation sessions.
Stakeholder involvement structure	Participatory method	Participatory Collaborative	Participatory modelling
	Stakeholders involved	Organisation Background	Local communities (e.g. farmers, citizens) Economic bodies (e.g. industries, companies, traders)

Factors	Parameters		Companion Modelling (ComMod)
			Regional authorities (e.g. Natural Resources managers and planners) Universities and research institutes (e.g. academics in Natural Resources Management) NGOs (local and international)
		Minimal skills and knowledge	• Social and cultural context, Welfare and livelihood activities • Natural Resource system and its main issues • Conflict management and dispute resolution tools and procedures • Economic development and processes • Institutional set up, policies, legislation and regulations • Scientific knowledge on Natural Resources, watershed Management • Social-physical interactions
	Model users	Direct/Indirect Technical skills	Direct users (role-playing games) Limited or non-technical skills are needed to participate in the role-playing game sessions. Stakeholders are direct users when using role-playing games, and commonly indirect users when using computer simulation models. Academics and research institutions can also be direct users (when they are part of the modelling team).
	Participation mode	Only modellers (no participation) Individuals Groups	Combination of all participation modes
	Level of participation	Ignorance Awareness Information Consultation Discussion Co-design Co-decision making	Level of participation varies depending on the timing of participation. However, all stakeholder groups have similar levels of participation in the various modelling phases. These generally are: Data collection includes generally consultations and discussions. Model definition ranges from consultation up to co-design. Model construction generally comprises information gathering and individual consultations. Model verification and validation is carried out via consultations and discussion. Model use (e.g. role-playing game) and outcomes are discussed among participants. Formulation of interventions can vary: discussions or co-design.
	Timing of participation	Data collection; Model definition; Model construction; Model validation and verification; Model use; Formulation of interventions and	

Factors	Parameters		Companion Modelling (ComMod)
		design of strategies	
	Type of cooperation	Unilateral action Coordination Collaboration Joint action	Low cooperation: Unilateral action or coordination
Modelling / organising team	Team		Commodians, sometimes supported by scientists with knowledge on Natural Resource Management, and local institutions.
	Skills	Modelling skills; Facilitation skills; Knowledge acquisition skills; Process management skills	• Multi-agent modelling, role-playing games; Graphic and spatial modelling; conceptual modelling for natural system • Design field surveys, interviews; brainstorm workshops or guide roundtable discussions • Cognitive science, human behaviour and interactions, mental and cultural models • Socio-physical interactions • Familiar with the ComMod approach and its application • Workshop organisation considering institutional setup and stakeholder dependencies, budgeting A process manager is commonly not required, due to the project scale and number of stakeholders involved. Generally, process management tasks are assumed by the researchers.
Means	Timing		2-5 years (average)
	Financial resources		Commonly funded by research institutions, regional governments or international organisations.

ANNEX B

EVALUATION FORMS

METHOD 1

Water Resources issues and proposed measures in Pemali Comal River Basin Territory

Organization details

First name and Surname:...

Organization:..

Address:...

Position:...

1. **What are the major Water Resources issues your organization is facing?**

Please provide a short description or list of the major Water Resources issues

2. **What are other major Water Resources issues in Batang, Pekalongan and Pemalang that other authorities and organizations are facing?**

Please provide a short description or list of the major Water Resources issues

3. Are these problems inter-connected?

Yes ☐ No☐ *How?*

4. Have you and your team been able to design (sectorial and regional) alternative strategies based on the measures your and other organizations have planned?

Remarks and lessons learned (team work, process, methods used, time, etc.)

5. Which alternative strategy do you consider as the most appropriate, from your organization point of view and the River Basin perspective?

Please provide a description of the proposed alternative strategy (combination of measures)

Proposed alternative strategy based on your organization's own interests and needs

Proposed alternative strategy based on the interests and needs of the various organizations in the River Basin (integrated and sustainable approach)

6. Is it necessary to validate the complementarity of the proposed measures and their effects?

Yes ☐ No ☐

Why is it (or not) necessary?

What are the most appropriate method(s) to validate the alternative strategy?

Please specify the validation method: (RIBASIM model, discussion in Public Meetings, etc.)

Post -Evaluation form

Evaluating the use of the Collaborative Modelling approach for the preparation of the RENCANA in Pemali Comal

7. **Integrated approach: Did the Collaborative Modelling approach help you to better understand the various Water Resources issues in the River Basin and the fact that these are inter-connected?**

Yes ❑ No ❑ *Why?*

8. **Better planning and decision-making: Did the Collaborative Modelling approach help in converting Water Resources issues into possible solutions and thus in the design of alternative strategies?**

Yes ❑ No ❑ *Why?*

9. **Better participation: Did the Collaborative Modelling approach help in combining the local knowledge from the water users and organizations and the scientific knowledge from the technical consortium through RIBASIM?**

Yes ❑ No ❑ *Why?*

10. **Better participation: Did the Collaborative Modelling approach facilitate the participation of different water users and organizations in the different stages of the planning process? Do you think they were able to express the Water Resources problems they are facing and the measures they have planned, and this information was then used for improving the RIBASIM model?**

Yes ❑ No ❑ *Why?*

11. **Better discussion and conflict management: Did the Collaborative Modelling approach help in better understanding the interests, needs and concerns of the other water users and organizations?**

Yes ❑ No ❑ *Why?*

12. **Better discussion and conflict management: Did you know about RIBASIM, as the computer-based model for water resources planning, before the workshop(s) took place?**

Yes ❑ No ❑ *Why?*

13. **Better discussion and conflict management: After the workshop(s) do you have a better understanding of the functioning of the RIBASIM model?**

Yes ❑ No ❑ *Why?*

14. **Better discussion and conflict management: Has your trust and acceptance in the model been enhanced as a result of the Collaborative Modelling process?**

Yes ❑ No ❑ *Why?*

15. **Better discussion and conflict management: Did the scientific knowledge provided by the technical consortium and the RIBASIM computer-based model help in the process of reaching consensus among water users and organizations?**

Yes ❑ No ❑ *Why?*

16. **Better learning environment: Did the Collaborative Modelling approach help the learning process on the existing problems in the River Basin and the possible measures to address them? Did the process also help learning about other's concerns and needs?**

Yes ❑ No ❑ *Why?*

METHOD 2

<u>Livelihood Analysis Interview: Local communities</u>

Natural Resource Asset:

- Water
  - What are sources for irrigation and drinking water?
  - Can farmers obtain enough water? Is there a water gap between water demand and water supply?
  - Is the quality of water good enough both for irrigation and domestic use?
  - Are there any water facilities? How do they function?
- Land
  - How many areas of land are owned by farmers?
  - What is land used for? Farming, fish ponds or other uses?
  - Which crops do farmers plant?
  - What is the annual plantation schedule?

Social Assets:

- Access to Authority
  - Can farmers reach WRM authorities? How do they achieve it?
  - How often do farmers communicate with these authorities?
  - Do farmers think that the communication channel/ platform is effective? Why?
- Local Cooperation
  - Do farmers cooperate with other locals?
  - Which partners do they cooperate with?
  - How often do farmers communicate with their partners?
  - Do farmers think that the cooperation is effective? Why?

Hopes:

- Natural Resources
    - Do farmers need water infrastructures? What kinds of infrastructural measures do they need? Why?
    - Do farmers want to learn new skills to solve current water problems? What specific skills do they need?
- Social Resources
    - Do farmers request for cooperation or a communication platform for WRM? Which stakeholders/decision-makers do they want to cooperate or communicate with? And why?
    - Do farmers want to search for other employment opportunities such as working in factories? Why?

<u>Livelihood Analysis Interview: Factories</u>

Physical System:

- Inflow
    - What is the water source for production?
    - Can factories obtain enough water? Is there a water gap between water demand and water supply?
    - Is the quality of water good enough for production?
- Production
    - What are the main products?
    - What is the production capacity?
    - What are the raw materials?
    - What is the planned production for the five coming years?
- Water Treatment Plant
    - What is the structure of the wastewater treatment plant?
    - What is the treatment capacity?
    - How much is the yearly cost for the wastewater treatment plant for Operation and Maintenance?

- Discharge
    - How much is the daily discharge?
    - Is the quality of the discharge good? (specify concentrations of at least BOD)
    - Where is the effluent channel?

Social Assets:

- Access to Authority
    - Can factories reach WRM authorities? How do they achieve it?
    - How often do factories communicate with the authorities?
    - Do factories think the communication channel/ platform is effective? Why?
- Local Cooperation
    - Is the factory involved in any local cooperation initiative?
    - Which partners do they cooperate with?
    - How often do factories communicate with their partners?
    - Do factories think the cooperation is effective? Why?

Hopes:

- Natural Resources
    - Do factories need new facilities to improve water efficiency? What kinds of facilities do they need? Why?
    - Do factories want to learn new skills to solve current water problems? What specific skills do they need?

- Social Resources
    - Do they request cooperation or communication platform for WRM? Which stakeholders/ decision-makers do they want to cooperate or communicate with? And why?
    - Can they afford the technical innovation that was mentioned in the aforementioned questions?

Questionnaire: Participatory Modelling Evaluation

1. Do you think the map that shows the location of critical infrastructure and assets is clear?

   A. Yes B. No

2. Do you understand how to use the function card?

   A. Yes B. No

3. Do you think the setting of role-playing game is close to reality?

   A. Yes B. No C. Not Sure

4. Have you learnt new knowledge from game?

   A. Yes B. No C. Not Sure

5. Do you think the game is an entertainment activity?

   A. Yes B. No C. Not Sure

6. Do you think you gained insight from other players after this game session?

   A. Yes B. No C. Not Sure

7. Do you think the game helps to build trust between players?

   A. Yes B. No C. Not Sure

8. If you have time, will you join another game session?

   A. Yes B. No C. Not Sure

METHOD 3

Collaborative modelling questionnaire

First name and Surname:...

Organization:..

How would you define yourself as an organization? Please, tick only one/two boxes

Government	[ ]
National / Federal (ministry, public agency, etc.)	
Regional / provincial	[ ]
Local	[ ]
Service provider	[ ]
Public utility	
Private operator	[ ]
Public-private partnerships - PPP	[ ]
Associations/Networks	[ ]
Water resources management institution at subnational level	[ ]
River basin organisation	[ ]
State water resource management authority	[ ]
Regional water authorities	[ ]
Civil society	[ ]
Member-based organisation	[ ]
Non-governmental organisation	[ ]
Social movement	[ ]
Community-based organisation	[ ]
Financial actors	[ ]
Donor	[ ]
Financial institution	[ ]
Investor	[ ]
Science, academia and research centres	[ ]
Advisors	[ ]
Engineering – consulting firms	[ ]
Media	[ ]
Other, specify	[ ]

Position at the organization:……………………………………………………………………………

Years of professional experience:…………………………………………………………………….

Level of education: Please, tick the corresponding boxes

	Primary school
	Secondary and high school
	Bachelor degree in a university
	Master degree
	PhD
	Other:

Background (engineering, natural sciences, social sciences, etc.): ……………………………………………

1. Are you familiar with the concept / practice "collaborative modelling"?

Yes ☐ No ☐ *If your answer is YES, please describe your interpretation of what it means for you.*

Please, indicate how you have learnt it: university, trainings, it is a common practice, etc.

Can you please describe one case or project in which participatory modelling has been applied?

2. **Where do you see the strongest benefits of stakeholder engagement in adaptive delta planning and management?** Rate the items below from 0-9, being 0 the lowest rate and 9 the highest.

	Partnership development
	Conflict management through better understanding of other's views, interests and needs
	Generating consensus
	Integrating cross-sector perspectives and local knowledge
	Increase cooperation and stakeholder's trust
	Cost-saving
	Experience-sharing
	Awareness raising
	Capacity development, collective learning
	Proposing innovative measures, strategies or other actions because of a better understanding of the functioning of the system

3. **Where do you see the strongest challenges and/or difficulties of stakeholder engagement in adaptive delta planning and management?** Rate the items below from 0-10, being 0 the lowest rate and 10 the highest.

	Lack of political will and leadership
	Lack of funding to support stakeholder engagement
	Lack of time
	Lack of motivation
	Resistance to change
	Difficulty to reach out certain types of stakeholders
	Low capacity to engage in consultation (education, training)
	Lack of citizens' concern and awareness on water issues
	Language barrier
	Geographical distance from decision-making cores
	Decision-makers' fear of losing influence and power

4. **Where do you see the strongest benefits of using modelling tools in adaptive delta planning and management?** Rate the items below from 0-12, being 0 the lowest rate and 12 the highest.

	Partnership development
	Conflict management
	Generating consensus
	Integrating technical and local knowledge
	Increase stakeholder's trust
	Cost-saving
	Knowledge sharing
	Awareness raising
	Capacity development
	Proposing innovative measures, strategies or other actions because of a better understanding of the functioning of the system
	Increase model quality (accuracy)
	Capturing system complexity
	Managing uncertainties

5. **Where do you see the strongest challenges and/or difficulties of using modelling tools for adaptive delta planning and management?** Rate the items below from 0-4, being 0 the lowest rate and 4 the highest.

	Low technical capacity of local organizations (stakeholders)
	Decisions regarding adaptive delta planning in Bangladesh are barely made based on the results from modelling tools
	The models and tools used are too high-tech. They are not selected or adapted considering the local context and situation in Bangladesh.
	International consultants do frequently not involve local organizations (stakeholders) in the modelling process
	The models (including licenses) and too expensive to buy and maintain

6. **Where do you see the strongest needs for the advancement in adaptive delta planning and management in Bangladesh?** Rate the items below from 0-5, being 0 the lowest rate and 5 the highest.

	Supporting effective implementation of a policy, reform or projects
	Ensuring proper enforcement of regulations and norms
	Raising awareness on water risks, flood warning, damages etc.
	Building/Operating/Maintaining water infrastructure
	Fostering capacity building, qualifications, training
	A better integration of modelling and local knowledge through structured stakeholder engagement

7. **Where do you see the strongest benefits of using participatory modelling for adaptive delta planning and management?** Rate the items below from 0-9, being 0 the lowest rate and 9 the highest.

	A better integrated approach
	A better understanding of adaptive planning and how the systems functions
	A better decision making process (an informed and inclusive process)
	A better integration of modelling and local knowledge through structured stakeholder engagement
	A better participation of different groups of stakeholders
	A better environment for discussion and conflict management because of the use of the information from the modelling tools
	A better environment for generating consensus because of the gained knowledge on other stakeholders' points of view, interests and needs
	A better understanding on the functioning of the models and tools used for adaptive water resources planning
	An increased trust and acceptance of the models developed and the results of the assessment
	A better learning environment. It fosters capacity development and helps having a better understanding of the problems in the region and the problems faced by other organizations

METHOD 4

Collaborative modelling questionnaire

First name and Surname:..

Organization:...

How would you define yourself as an organization? Please, tick only one/two boxes

Government	[ ]
National / Federal (ministry, public agency, etc.)	
Regional / provincial	[ ]
Local	[ ]
Service provider	[ ]
Public utility	
Private operator	[ ]
Public-private partnerships - PPP	[ ]
Associations/Networks	[ ]
Water resources management institution at subnational level	[ ]
River basin organisation	[ ]
State water resource management authority	[ ]
Regional water authorities	[ ]
Civil society	[ ]
Member-based organisation	[ ]
Non-governmental organisation	[ ]
Social movement	[ ]
Community-based organisation	[ ]
Financial actors	[ ]
Donor	[ ]
Financial institution	[ ]
Investor	[ ]
Science, academia and research centres	[ ]
Advisors	[ ]
Engineering – consulting firms	[ ]
Media	[ ]
Other, specify	[ ]

Position at the organization:...

Years of professional experience:..

Level of education: Please, tick the corresponding boxes

	Primary school
	Secondary and high school
	Bachelor degree in a university
	Master degree
	PhD
	Other:

Background (engineering, natural sciences, social sciences, etc.): ....

1. Are you familiar with the concept / practice "participatory or collaborative modelling"?

Yes ☐ No ☐ *If your answer is YES, please describe your interpretation of what it means for you.*

Please, indicate how you have learnt it: university, trainings, it is a common practice, etc.

Can you please describe one case or project in which participatory modelling has been applied?

2. **Where do you see the strongest benefits of stakeholder engagement in urban flood risk management?** Rate the items below from 0-9, being 0 the lowest rate and 9 the highest.

	Partnership development
	Conflict management through better understanding of other's views, interests and needs
	Generating consensus
	Integrating cross-sector perspectives and local knowledge
	Increase cooperation and stakeholder's trust
	Cost-saving
	Experience-sharing
	Awareness raising
	Capacity development, collective learning
	Proposing innovative measures, strategies or other actions because of a better understanding of the functioning of the system

3. **Where do you see the strongest challenges and/or difficulties of stakeholder engagement in urban flood risk management?** Rate the items below from 0-10, being 0 the lowest rate and 10 the highest.

	Lack of political will and leadership
	Lack of funding to support stakeholder engagement
	Lack of time
	Lack of motivation
	Resistance to change
	Difficulty to reach out certain types of stakeholders
	Low capacity to engage in consultation (education, training)
	Lack of citizens' concern and awareness on water issues
	Language barrier
	Geographical distance from decision-making cores
	Decision-makers' fear of losing influence and power

4. **Where do you see the strongest benefits of using modelling tools in urban flood risk management?** Rate the items below from 0-12, being 0 the lowest rate and 12 the highest.

	Partnership development
	Conflict management
	Generating consensus
	Integrating technical and local knowledge
	Increase stakeholder's trust
	Cost-saving
	Knowledge sharing
	Awareness raising
	Capacity development
	Proposing innovative measures, strategies or other actions because of a better understanding of the functioning of the system
	Increase model quality (accuracy)
	Capturing system complexity
	Managing uncertainties

5. **Where do you see the strongest challenges and/or difficulties of using modelling tools for urban flood risk management?** Rate the items below from 0-4, being 0 the lowest rate and 4 the highest.

	Low technical capacity of local organizations (stakeholders)
	Decisions regarding flood risk management in Dar es Salam are barely made based on the results from modelling tools
	The models and tools used are too high-tech. They are not selected or adapted considering the local context and situation in Dar es Salam.
	International consultants do frequently not involve local organizations (stakeholders) in the modelling process
	The models (including licenses) and too expensive to buy and maintain

6. **Where do you see the strongest needs for the advancement in flood risk management in Tanzania?** Rate the items below from 0-5, being 0 the lowest rate and 5 the highest.

	Supporting effective implementation of a policy, reform or projects
	Ensuring proper enforcement of regulations and norms
	Raising awareness on water risks, flood warning, damages etc.
	Building/Operating/Maintaining water infrastructure
	Fostering capacity building, qualifications, training
	A better integration of modelling and local knowledge through structured stakeholder engagement

7. **Where do you see the strongest benefits of using participatory modelling for urban flood risk management management?** Rate the items below from 0-9, being 0 the lowest rate and 9 the highest.

	A better integrated approach
	A better understanding of urban flood risk management and how the systems functions
	A better decision making process (an informed and inclusive process)
	A better integration of modelling and local knowledge through structured stakeholder engagement
	A better participation of different groups of stakeholders
	A better environment for discussion and conflict management because of the use of the information from the modelling tools
	A better environment for generating consensus because of the gained knowledge on other stakeholders' points of view, interests and needs
	A better understanding on the functioning of the models and tools used for flood risk management
	An increased trust and acceptance of the models developed and the results of the assessment
	A better learning environment. It fosters capacity development and helps having a better understanding of the problems in the region and the problems faced by other organizations

GLOSSARY

Approach	Way a process is designed, structured and organised considering the context, situation, planning, decision-making and negotiation processes.
Measure	Individual intervention or project, which may be infrastructure but also institutional, legal, economic, knowledge and capacity development, just to mention a few categories. A measure can be oriented at specific spatial, sector- or national-general level. Measures can be part of one strategy but can also fit in multiple strategies.
Mental Model	Mental models are cognitive representations of external reality. The core idea behind the concept of mental models is that the interaction between an individual and the real world is mediated by a mental representation which is used to simplify our understanding of how the world functions, to filter information by focussing on relevant components and to test available behaviours (via mental simulation including counterfactual) before turning them into action.
Method	A method is a way of doing something. A particular method can be supported by one or several tools. Usually, a method can be implemented with several tools-a one-to-many relationship. Some tools serve several methods.
Scenario	Coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present and future developments, which can serve as a basis for action. In this PhD thesis, scenarios are conceived also as "external contexts" that describe developments that cannot be influenced.

Shared Learning — The process of shared learning (co-learning) considers that a truly participatory effort engage stakeholders in an interactive and iterative mode, where the flow of information is arranged in both directions: from researches/ modellers to the stakeholders and vice versa. Shared learning is a form of collaborative learning.

Social Learning — Increasing the knowledge of individuals in the social context and favouring the acquisition of collective skills is considered as a process of social learning. This helps stakeholders to improve their understanding of the system complexity, of the feedbacks between natural resource dynamics and social behaviours, and also of the interactions between stakeholders who have different points of views and different power. Social learning is a form of collaborative learning.

Strategy — A strategy is a coherent combination of measures based on alternative guiding principles or cornerstones, and derived from the vision that contributes to reaching (policy) goals. A strategy can consist of a number of sub-strategies.

Tool — Modelling technique used to carry out a particular function to achieve a certain goal. It is defined, documented, not overly modified through its use. It is clearly external to its users, albeit often created by them.

ACRONYMS

ADB	Asian Development Bank
APWF	Asia-Pacific Water Forum
ARDI	Actors, Resources, Dynamics and Interactions method
AWDO	Asian Water Development Outlook
BDP2100	Bangladesh Delta Plan 2100
BE	Back-End
BOD	Biochemical Oxygen Demand
ChaRL	Challenge and Reconstruct Learning
CLD	Causal Loop Diagrams
ComMod	Companion Modelling
CoP	Community of Practice
COPP	Comparison of Participatory Processes
DB	Databases
Dflow FM	Delft flow Flexible Mesh
DPR	Delta Programme Rivers in the Netherlands
DRR	Disaster Risk Reduction
DRM	Disaster Risk Management
DSIs	Decision Support Indicators
DSS	Decision Support Systems
DTM	Digital Terrain Model
FABE	Front- and Back-End
FE	Front-End
FISM	Fast Integrated Systems Modelling
FRM	Flood Risk Management
GIS	Geographical Information Systems
HOT	Humanitarian OpenStreetMap Team
IAIM	Individual Actor Impact Models
IRBMDMP	Integrated River Basin Management and Development Master Plan

IWRM	Integrated Water Resources Management
JOSM	Java Open Street Map
MAS	Multi-Agent System
MCDA	Multiple Criteria Decision Analysis
NGO	Non-Governmental Organization
MM	Mediated Modelling
NHI	National Hydrological Instrument in the Netherlands
ODK	Open Data Kit
O&M	Operation and Maintenance
OSM	Open Street Map
PDAs	Personal Digital Assistants
PP-GIS	Public Participation Geographical Information Systems
PSM	Physical system models
UNISDR	United Nation International Strategy for Disaster Reduction
RCCC/ARC	Red Cross Climate Centre and Red Crescent Movement
SADM	Single-Actor Decision Models
SDGs	Sustainable Development Goals
SIs	State Indicators
SPSM	Socio-Physical System Models
SSM	Social System Models
SVP	Shared Vision Planning
TRCS	Tanzania Red Cross Society
WB	World Bank
WFD	Water Framework Directive
WRM	Water Resources Management
WWTP	Waste Water Treatment Plant

LIST OF PUBLICATIONS

Journal Papers

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017b. Collaborative modelling or participatory modelling? A framework for water resources management. Environmental Modelling & Software 91 95-110.

Basco-Carrera, L., van Beek, E., Jonoski, A., Benítez-Ávila, C., Guntoro, F.P., 2017. Collaborative Modelling for Informed Decision Making and Inclusive Water Development. Water Resources Management 31(9) 2611-2625.

Basco-Carrera, L., Meijers, E., Sarısoy, H.D., Şanli, N.O., Coşkun, S., Oliemans, W., Van Beek, E., Karaaslan, Y., Jonoski, A., 2018. An adapted companion modelling approach for enhancing multi-stakeholder cooperation in complex river basins. International Journal of Sustainable Development & World Ecology, 1-18.

Basco-Carrera, L., Yangyue, Y., Rini, D.S., Mostert, E., Nooy, C., van Beek, E., 2018. Beyond the usual suspects: Local communities and the private sector engaged in modelling water quality (publication in progress).

Basco-Carrera L, van Beek E, van Deursen W.P.A, Slager K, Al Hossain B.M.T, Oliemans W, Choudhury G.A, Haasnoot M. (2018) Fast Integrated Systems Modelling for Collaborative Decision Making under Uncertainty; the Bangladesh Delta Plan 2100 case. Environmental Software and Modelling (publication in progress)

Basco-Carrera, L., Dahm R., Gebremedhin E., Naffaa S., and Winsemius H., 2018. The role of participatory and collaborative modelling in water resources management. Opinion paper (publication in progress)

Basco-Carrera, L., ter Maat J., Altamirano M., Escaniua M.L., Ancheta C., van Beek E., 2018. Fast Integrated Systems Modelling: A Method for Prioritizing Low-Risk Investments (publication in progress).

Wehn, U., Collins, K., Anema, K., Basco-Carrera, L., Lerebours, A., 2017. Stakeholder engagement in water governance as social learning: Lessons from practice. Water International 1-26.

Voinov A., Bommel P., Paolisso M., Elsawah S., Glynn P., BenDor T., Sterling E., Schmitt Olabisi L., Basco-Carrera L., Le Page C., Brunacini J., Singer A., Young L., Jenni K., Gray S., Kolagani N., Zellner M., Prell C., Hubacek K., Laursen B., Giabbanelli P., Jetter A., Sun Z., Jordan R., 2018. Tools and methods in participatory modeling: selecting the right tool for the job. Environmental Modelling & Software (https://doi.org/10.1016/j.envsoft.2018.08.028)

Jordan, R., Gray S., Zellner M., Glynn P.D., Voinov A.,Heledin B., Sterling E.J., Leong K., Schmitt Olabisi L., Hubacek K., Bommel P., BenDor T.K., Jetter A.J., Laursen B., Singer A., Giabbanelli P.J., Kolagani N., Basco-Carrera L., Jenni K., Prell C., 2018. 12 Questions for the participatory modeling community. Earth's Future (https://doi.org/10.1029/2018EF000841)

Gebremedhin, E.T., Basco-Carrera, L., Jonoski, A., Winsemius, H., Iliffe, M., 2018. Participatory Mapping and Urban Flood Modelling. Environmental Modelling & Software (publication in progress).

Warren, A., Basco-Carrera, L., Mostert, E., Van Beek, E., 2018. Model-Supported Collaborative Planning in the Netherlands (publication in progress).

Basco-Carrera, L., Benítez-Ávila, C., 2018. Group Model Building vs. Mediated Modelling for Water Resources Management (publication in progress)

Other publications

Basco-Carrera, L., Mendoza, G., 2017. Collaborative Modelling. Engaging stakeholders in solving complex problems of water management. Global Water Partnership. Perspectives Paper No. 10

Basco-Carrera, L., Rini D.S, 2018. Multi-Stakeholder Partnerships: Collaborative Modelling as a Mechanism for Sustainable Development. Encyclopedia of the UN Sustainable Development Goals. Partnerships for the Goals. Springer Nature (publication in progress)

Contributor to Book Chapter "Project Planning: Putting It All Together" in Loucks, D.P., & van Beek, E. (2017). Water Resources Systems planning and management: An introduction to methods, models and applications. Springer.

Conference presentations

Basco-Carrera L. Collaborative Modelling for Sustainable Water Resources Management. World Water Forum 7. Session "Village of Best Practices". South Korea, April 2015 [oral presentation]

Haasnoot M., van Deursen W., Basco-Carrera L., Kwakkel J., and Middelkoop H. Model Requirements for Decision Support Under Uncertainty in Data Scarce Dynamic Deltas. 8th International Congress on Environmental Modelling and Software. France, July 2016 [oral presentation]

Basco-Carrera L. Inclusive Water and Energy Nexus in Bangladesh. World Water Week. EYE ON ASIA. Session "Powering up the Region – Balancing Water and Energy Use in Asia". Sweden, August 2016 [oral presentation]

Basco-Carrera L., Oliemans W., van Beek E., van Deursen W., Slager K. and Haasnoot M. Meta modelling for adaptive planning in Bangladesh. Decision Making under Deep Uncertainty. Fourth Annual Workshop. US, November 2016 [poster]

McEvoy S. and Basco-Carrera L. Third European Climate Change Adaptation Conference. Session "Participatory modelling in climate change adaptation – methods and experiences". United Kingdom, June 2017 [moderation]

Basco-Carrera L. and Mendoza G. Insights on Collaborative Modelling for Water Resources Management. World Water Week. Session "How to Empower Stakeholders reducing and reusing water; Collaborative Modelling". Sweden August 2017 [oral presentation]

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"If you want to go fast, go alone. If you want to go far, go together" – African Proverb

BIOGRAPHY

Mrs. Laura Basco Carrera is a Water Resources Management adviser. She has international experience in projects and research related to water security, IWRM, adaptive planning, water allocation modelling, policy analysis and stakeholder engagement. She holds a BSc. and MSc. Eng. in Industrial Engineering from Polytechnic University of Catalonia, Spain, where she specialised in the field of Business Management. She has gained expertise in the field of Renewable Energies during her studies MSc. Eng. Mechanical and Process Engineering at Technische Universität Darmstadt, Germany (graduated with honours). Laura became interested in international cooperation and sustainable development when she was working for two NGOs, FUNDEO (2009-2010) and Engineers without Borders Germany (2011-2012), in Latin America and Africa.

Since 2012 she is working at a Dutch-based Research Institute, Deltares, where she has worked in several international projects related to IWRM, water security, climate change and participatory planning. She has supported and provided advice to national and regional governments, NGOs and financial organisations such as the World Bank and the Asian Development Bank in more than 19 countries in Europe, Latin America, Africa and Asia (including Bolivia, Venezuela, Ghana, Kenya, Turkey, Bangladesh, Indonesia, Egypt and the Philippines). Laura is also interested in capacity development as a means towards sustainable development. Therefore, since 2014, she has provided capacity building courses and trainings on IWRM at IHE Delft and in other countries. Since 2016, she is leading the collaborative modelling group at Deltares; and is currently establishing the Collaborative Modelling Community of Practice.

Finally, in her free time Laura is involved in initiatives that aim to empower young people in the water sector. She was in the management board of the youth-led organisation, Water Youth Network, from 2013 till 2018. She commenced as team leader of the Event Management Working Group. In 2015 she became a member of the advisory board as business manager. A year later she started coordinating the IWRM thematic group, which is composed of more than 40 members from all over the world.

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The SENSE Research School declares that **Laura Basco Carrera** has successfully fulfilled all requirements of the Educational PhD Programme of SENSE with a work load of 65.2 EC, including the following activities:

SENSE PhD Courses

- SENSE summer academy (2014)
- Environmental research in context (2014)
- Research in context activity: 'Co-organizing session on 'Water Security for the Future' and acting as international coordinator of the Young Water Leaders' Summit (YWLS) as part of the International Water Week Singapore (2014)'

Selection of other PhD and Advanced MSc Courses

- Professional proposal and grant writing, IHE Delft (2014)
- Mediation for water conflict management, IHE Delft (2014)
- QGIS basic course, IHE Delft (2015)

External training at a foreign research institute

- Innovations in Collaborative Modelling, Michigan University, United States of America (2016)

Seletion of management and Didactic Skills Training

- Board member of Water Youth Network (2013-2018)
- Supervising 5 MSc students and 1 BSc student with thesis (2015-2017)
- Assisting in the MSc course 'River Basin Modelling' (2015)
- Teaching in the MSc course 'Water resources development and EIA' (2015)

Other activities

- Writing a perspective policy paper and a chapter in the Encyclopedia of the UN SDGs
- Contribute to the preparation of book 'Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications'(2017)

Oral Presentations

- *Inclusive water and energy nexus in Bangladesh.* World Water Week, 28 August - 2 September 2016, Stockholm, Sweden
- *Collaborative modelling for sustainable water resources management.* World Water Forum 7, 12-17 April 2015, Daegu, South Korea
- *Three presentations at* 9th International Congress on Environmental Modelling and Software, 24-28 June 2018, Fort Collins, Colorado, United States of America

SENSE Coordinator PhD Education

Dr. Peter Vermeulen

UNESCO IHE DELFT

UNIVERSITY OF TWENTE.

Safe access to water is essential for sustainable development. Building resilience towards disaster risks and ensuring water availability by balancing the many competing uses and users of water, while maintaining healthy and diverse ecosystems, are critical elements to ultimately deliver water security. In this Ph.D. thesis, participatory and collaborative modelling is presented as a means towards sustainable development, as it supports informed decision-making and inclusive development. How to develop and use computer-based simulation models is analysed following a participatory or collaborative modelling approach for managing water resources, so their use can be enhanced, and the ownership of the development strengthened. Four methods are presented to engage stakeholders in the development and use of computer-based simulation models. These approaches are tested in nine study cases, from which this thesis focuses on five of them. The covered themes and countries include river basin planning in Indonesia, water quality management in Turkey and Indonesia, adaptive planning in Bangladesh, and flood risk management in Tanzania. Results of the research show that the use of participatory and collaborative modelling makes the modelling process more efficient. Together, modellers and stakeholders share learning, build consensus, have a sense of ownership of the models, tools and solutions developed and trust in the decision-making process.

This book is printed on paper from sustainably managed forests and controlled sources