Global Water Partnership

Collaborative modelling

– Engaging stakeholders in solving complex problems of water management

Analytical models play an ever-increasing role in the complex world of water resources planning and management. They support key decision-making for managing flood risk, building dams, managing groundwater, and bringing together the social, economic, and environmental issues and challenges of integrated water resources management (IWRM).

But models only provide us with one view of the world. There are 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.

This paper argues for bringing 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. This approach is called 'collaborative modelling'.

This Perspectives Paper was prepared by Laura Basco Carrera and Guillermo Francisco Mendoza.
It is intended to galvanise discussion within the network and the larger water and development community.

www.gwp.org www.gwptoolbox.org

About Global Water Partnership

The Global Water Partnership (GWP) vision is for a water secure world.

Our mission is to advance governance and management of water resources for sustainable and equitable development.

GWP is an international network that was created in 1996 to foster the application of integrated water resources management: the coordinated development and management of water, land, and related resources in order to maximise economic and social welfare without compromising the sustainability of ecosystems and the environment.

The Network is open to all organisations which recognise the principles of integrated water resources management endorsed by the Network. It includes states, government institutions (national, regional, and local), intergovernmental organisations, international and national non-governmental organisations, academic and research institutions, private sector companies, and service providers in the public sector.

The Network has 13 Regional Water Partnerships, 85 Country Water Partnerships, and more than 3,000 Partners located in 183 countries.

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Linking ecosystem services and water security – SDGs offer a new opportunity for integration (2016)
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Acknowledgements

I have spent many years designing ways to integrate stakeholder participation, technical analysis, and modelling in water resources planning. Often, great technical models have been produced only to be rejected by stakeholders, who either could not understand the model construction or, more frequently, opposed the values of the model builders. Thus, these models' legitimate uses – identifying trade-offs and facilitating water resources decision-making – were compromised, or 'duelling models' emerged that hindered planners' ability to identify and negotiate trade-offs. In the last several years, collaborative modelling has grown out of the practical, on-the-ground needs of water resources planners and decision-makers trying to reach implementable and workable decisions while including a variety of stakeholders. Rapid advances in software and hardware have underpinned this growth. Today, collaborative modellers use interactive technologies to fulfil the governance and integrated water resources management principles that so many advocate. These technologies are opening new windows into practical methods for water resources planners and decision-makers worldwide to overcome the frequent stalemates of the past and to improve the culture of water resources decision-making. Guillermo F Mendoza, US Army Corps of Engineers, and Laura Basco Carrera, Deltares, the Netherlands, are part of a new generation of water resources planners using collaborative modelling to help decision-makers in many parts of the world. We hope this GWP Perspectives Paper helps open up such new windows to those unfamiliar with collaborative modelling.

Dr Jerome Delli Priscoli
Chair of GWP Technical Committee

1 What is collaborative modelling?

Collaborative modelling is gaining momentum in water resources planning. It is about bringing 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 parties are involved in river basin 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 list of possible interventions.

These two paths often run parallel and tend only to cross at the beginning of the process when data are 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, collaborative modelling builds stronger connections between technical experts and stakeholders. It is a structured process designed to bring technical and social paths closer together in the search for solutions. Stakeholders formally learn more about the models, how they are developed and used, and their potential and limitations. And modellers spend time away from their computer screens, listening to stakeholders and seeking ways of building criteria that are of interest to stakeholders into their models. As a result, stakeholders feel part of the process as their knowledge, interests, and needs are actively considered and valued. Together, modellers and stakeholders share learning, build consensus, and trust in the solutions developed and in the decision-making process.

This Perspectives Paper proposes collaborative modelling as a framework to support water resources decision-making, particularly where there are:

- diverse and conflicting stakeholder interests; and
- conflicting facts, limited knowledge or high uncertainty about the system of interest.

We argue that this provides a practical approach to integrating water resources planning with stakeholder engagement, conflict management, model development, and decision analysis. Systematic approaches are needed that incorporate both technical and social solutions. Collaborative modelling achieves this by formally including stakeholders in the modelling and assessment process.

Box 1 An early example of collaborative modelling

Negotiating a treaty between the USA and Canada to manage the water levels of the Great Lakes, which form the border between the two nations, was never going to be easy. Ocean-going vessels that travel up the St Lawrence River from the Atlantic Ocean to the Great Lakes generate some US$3.4 billion in business revenues in the USA. A feasibility study (IUGLS, 2012) undertaken to support the negotiations aimed to establish lake levels that provide benefits for navigation, hydropower and ecological interests, recreation, and in tackling coastal flood risks.

Technical experts from both nations contributed a wealth of information, but this seemed to hinder rather than help the decision-making process. The bottleneck was not technical; it was more to do with conflicts among at least five different sector interests. Moreover, these interests involved two nations, a dozen states and provinces, tribal governments, and local and city governments. A collaborative modelling approach brought the stakeholders and the technical experts together. It helped the planning process to move in a more structured manner from a discussion about facts and figures to the more important practice of negotiating and reconciling the desires of local and regional interest groups.

Source: Bourget (Ed.) (2011).

2 Why does collaborative modelling matter?

Collaborative modelling matters when resources are scarce or benefits are increasingly reduced as this creates potential for conflict among users who end up competing for limited resources. It is particularly important for the water sector where benefits to people, industry, agriculture, energy, amenity, and the environment can be at odds.

Even as recently as the 1950s, planning and managing water was relatively straightforward. Water was more plentiful, demand was relatively low, and the rules for sharing water were simple. Governments took a 'top-down' approach to managing water resources and responded to shortages by increasing the supply. There was little incentive to engage in cross-sector discussions over water sharing or to consult water users about allocation.

But as populations have grown and livelihoods improved, lifestyles have become more water rich, and the demand for water has substantially increased. This becomes a problem when water shortages occur and there is not enough water to meet the demand. The challenge then for sustainable development is how to allocate limited water resources among the many competing uses and users of water to meet the needs of all while maintaining healthy and diverse ecosystems and delivering water security (GWP, 2014). At this point, serious conflicts can arise and water users begin to take a strong interest in how water resources are managed and allocated and want to have a say in how this is done.

Involving stakeholders is now becoming an accepted means of improving decision-making. Indeed, this is now enshrined in the United Nation's 2030 Development Agenda, which recognises the importance of water security in all aspects of development and the need for cooperation and integration among planners and stakeholders to meet the Sustainable Development Goals (SDGs). Water's importance is recognised in SDG 6, known as the 'Water Goal', which says that we must *"ensure availability and sustainable management of water and sanitation for all"*.

SDG 6 recommends a holistic approach as the most effective means of making the best use of available water resources. For many, this means major changes in the way water resources are planned and managed, from the conventional 'silo' approach, where each sector – public water supply, agriculture, energy, industry, and environment – all make separate plans, to one where sectors plan and manage water resources together. This is the essence of integrated water resources management (IWRM) (see Box 2).

Box 2 IWRM is ...

"... a process which promotes the coordinated development and management of water, land, and related resources to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems."

Source: GWP (2000).

In IWRM, planning is based on river basins rather than on administrative boundaries, and water users participate in decision-making about how resources are developed and allocated. This ensures that any proposed developments encompass a wide variety of competing interests, perspectives, and values. In many countries, water resources planners have responded to the challenge of IWRM by involving stakeholders in the planning process. But all too often this has meant stakeholders are simply offered a menu of options at the end of a planning process undertaken by technical experts. This has left many stakeholders with little understanding of and trust in what was on offer.

In parallel with these developments, computing power that was once only available to the best-resourced organisations and institutions, is now readily available everywhere. More and more people are becoming familiar with computers and modelling systems, and mobile internet has meant that information can be accessed or transmitted from almost anywhere in the world. In addition, technological advances in remote sensing have greatly improved data collection in data-poor areas for use in global models.

Such developments have led local experts and water managers in developing countries to use analytical modelling techniques. By using this technology, these experts are able to inject more quantitative information into water resources decision-making, and to enhance stakeholders' ability to visualise and communicate.

At Stockholm World Water Week 2016, the World Water Council highlighted the need for 'beautiful' infrastructure designs and plans to address our future challenges. Through this approach, communities would seek to achieve truly integrated economic, social, and environmental objectives; this differs from the more traditional approach of maximising economic benefits while reducing or mitigating social and environmental impacts. In other words, environmental and social interests also become explicit objectives, and not essentially constraints to finding solutions.

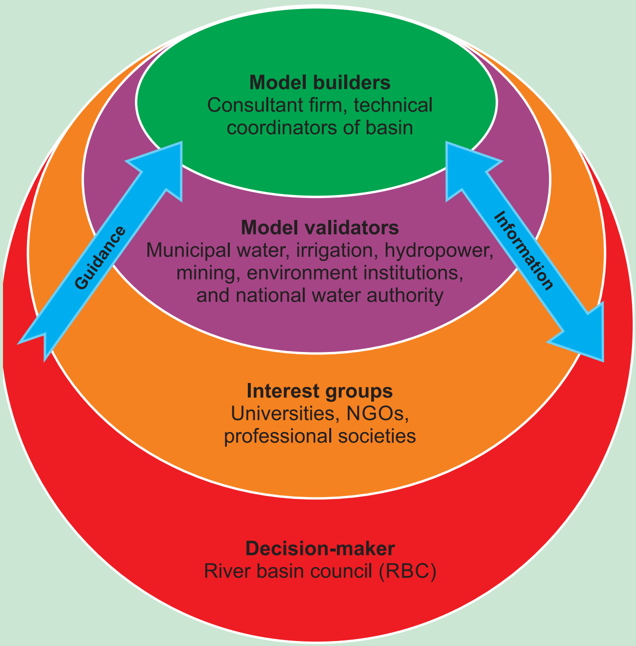
For this new approach, we need new types of models that can integrate and balance multiple objectives, and which reflect the diversity of stakeholder values. We also need to bring in stakeholders during the modelling process rather than at the end. This is the essence of

Box 3 Collaborative modelling to develop IWRM plans for river basins in Peru

In 2009, the Government of Peru passed a new water law and set out an ambitious plan to develop locally driven solutions for water sustainability using the principles of IWRM. This plan had to be validated by river basin councils and approved by the National Water Authority (ANA). The Government envisaged that the plan would incorporate *"social, cultural and environmental values with the goal to maximise social and economic well-being without compromising the sustainability of vital ecosystems"* (RRHH del Perú, 2009).

Using participatory approaches to develop plans, gain approval within a reasonable time frame, and put plans into practice while honouring financial commitments proved challenging. A collaborative modelling approach, using 'shared vision planning', and partially financed by loans from the World Bank and the Inter-American Development Bank, was proposed and applied in six pilot basins along the arid Pacific coast. Over a period of 24 months, a collaborative modelling approach was used to structure each basin vision statement, assign stakeholder-defined objectives that measured success, formulate investment activities and actions, evaluate trade-offs, and inform the project priorities.

Participants were organised into distinct working groups defined by 'circles of influence' (Cardwell et al., 2008; Mendoza et al., 2013) that define roles, commitments, communication channels, rules of engagement, and the two-way flow of technical information among interest groups, model builders, and analysts. The circles of influence concept enforces a change in approach and puts model builders at the inner/lowest level, to be directed by stakeholders and decision-makers, who are at the highest level. Stakeholders therefore become the model and process validators that drive technical analysis. River basin councils formally approved each phase of this collaborative process, informed by a decision support model, and agreements on the *status quo*, possible actions, and the selection of priority activities.



Source: Adapted from Mendoza et al. (2013).

collaborative modelling, which is proposed as an approach to help interest-based negotiation in order to avoid sub-optimal outcomes and to promote plan acceptability and completeness. This approach offers a means of integrating divergent sources of knowledge and values, building credibility in the information produced, confronting and managing disputes and conflicts, and translating complex scientific information and data into understandable information that can enhance dialogue among stakeholders.

But in setting out these objectives, this new approach raises 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? And how should this information be communicated?

3 What is the appropriate solution?

A variety of approaches and methods for participatory planning and decision-making have been developed for IWRM, mainly due to the increasing focus on public participation. Indeed, a lot of research has been undertaken to improve stakeholder participation in planning and decision-making. But far less research has been undertaken to improve conventional analytical models within a participatory setting.

Decision support systems (DSS) is one area that has attracted attention. Typically, DSS are customised models designed to serve as a link between analytical models for IWRM and the decision-making processes that determine preferred courses of action. The idea behind DSS is that decision-makers and stakeholders (or their

Box 4 Collaborative modelling to develop an adaptive IWRM plan in Bangladesh

Bangladesh faces many challenges – pressure on land use, climatic impacts, environmental protection, governance, globalisation and macro-economic development. The Bangladesh Delta Plan 2100 (BDP 2100) is being prepared as an integrated, adaptive, holistic and long-term strategic plan to help deal with the challenges of future land and water management, water security, food security, economic growth, and resilience to catastrophic natural hazards. The plan provides guidance to the Government of Bangladesh, and specifies a series of short- and long-term steps which target the development of a safe, resilient, and prosperous delta. The backbone of this management plan is a robust water system.

A fast-integrated systems model (or meta-model) using Microsoft Excel and PCRaster was developed for rapidly assessing and prioritising interventions under various future scenarios. Government agencies and stakeholders were involved in all modelling phases using a collaborative modelling approach. This included activities to parameterise the systems, simplify complex models, define physical state and decision support (socio-economic) indicators, formulate scenario conditions, identify possible measures based on the BDP 2100 investment plan, design the user interface, and test the model.

This active engagement was critical for ensuring the continuous improvement of the model based on the new demands of local planners and stakeholders. The collaborative modelling approach enhanced trust and acceptance for the model and its outputs and created a sense of ownership among the stakeholders involved. These are all critical elements for generating legitimacy and inclusive development within a management plan.

advisors) can use a system to assess a range of interventions before selecting their preferred option. However, in many instances the systems are not used for this purpose. There are several reasons for this:

- DSS focus on specific objectives and criteria but these can both evolve over time and change depending on the decision-making process (Bousset et al., 2005; Medema et al., 2008; Mintzberg, 1978).
- Many DSS developments focus on software structure, the user interface, and visualisation capabilities, rather than their participatory use (Refsgaard et al., 2005; Serrat-Capdevila et al., 2011).
- DSS often puts modellers at the centre of the decision-making process. Developments take place behind the scenes, even in those instances when there is stakeholder interaction during data collection and when results are shown and discussed (Bourget, [Ed.], 2011; Loucks et al., 2005). Consequently, stakeholders perceive models as 'black boxes' about which they have little familiarity, understanding, and trust.

In response to these concerns, collaborative modelling was conceived to help strengthen stakeholder ownership of DSS and other IWRM analytical tools. One of the earliest versions of collaborative modelling was shared vision planning (SVP) developed by the US Army Corps of Engineers and used to resolve conflicts between the USA and Canada over the Lake Ontario–St Lawrence Seaway problem (see Box 1). The concept of shared vision planning is often referred to in the GWP ToolBox.

The lessons learned from shared vision planning helped to formulate a set of 'best practices for collaborative modelling' (see section 4.2). At the same time, the scientific community began researching collaborative modelling, focusing on system dynamics and conceiving 'group model building' as a method of intervening in the practices of business organisations. By the turn of this century, group model building was also being applied to natural resources management.

The idea behind these approaches was to increase stakeholder involvement during the modelling process. This implies that stakeholders should determine what should be quantified, and be involved in data collection and validation activities to build trust in the data, and in the analysis of issues and potential interventions. Collaborative modelling was not intended to supplant political processes inherent to decision-making; rather it was designed to enhance the quality and value placed upon scientific information informing the processes. This improves the credibility attached to decisions, which may in turn make them easier to implement.

At its best, collaborative modelling combines collective model design with real-time peer review processes, helping to navigate the uncertain terrain between political and technical aspects of decision-making. An important secondary outcome is collective learning about other stakeholder objectives from a holistic point of view, capacity development, and stakeholder empowerment that occurs during the initiatives.

Today, the concept of collaborative modelling is much broader than its predecessor, shared vision planning. It now brings together a range of other approaches and tools used by researchers and practitioners worldwide for integrated and adaptive IWRM planning (see Table 1). Collaborative modelling comprises the development and use of computer-based models and analytical tools in combination with communication, visualisation and facilitation tools, and mental and cultural models.

The Global Water Partnership (GWP), national policies, and development agencies, such as the World Bank and the Asian Development Bank, promote IWRM as a means for sustainable development. Given that IWRM integrates diverse stakeholder interests, which can often lead to complex and conflictive decision-making, participatory frameworks are recommended to support the planning process. The inclusion of collaborative modelling provides a practical framework to minimise any disagreement over the facts and quantify understanding and impacts on these diverse interests.

4 How can collaborative modelling support decision-making?

Collaborative modelling is a component within a broader formal planning process. It begins with identifying the problem, moves into formulating and assessing recommended measures, and ends with implementation. It 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

Table 1 Types of collaborative modelling approaches

Types of collaborative modelling	References
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 management decisions on water resources. The framework was devised and piloted on five river basins of the US East Coast, following the most severe flood ever recorded in the 1960s that led to conflict between states and cities. SVP integrates seven steps of planning into a structured collaborative process called the 'circles of influence'; this drives technical analysis and the development of a decision support system.	Bourget (Ed.) (2011); Cardwell et al. (2009); Creighton and Langsdale (2009); Langsdale et al. (2013); Mendoza et al. (2013)
Interactive modelling 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 within 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)
Fast-integrated systems modelling integrates and simplifies interactions and relevant feedbacks among complex systems into a fast, low-resolution model (for example in Microsoft Excel) necessary for high-level reasoning and communication, exploratory analysis and long-term decision support that takes uncertainties into consideration. The collaborative development of this simple model promotes common understanding of integrated systems, to better support evidence-based stakeholder dialogue.	Davis and Bigelow (2003); Haas-noot et al. (2014)
Group model building and **mediated** modelling are types of participatory modelling using system dynamics. Causal loop diagrams, and/or stocks and flows are developed together with stakeholders and used to describe cause–effect relationships and feedback loops between factors and systems. The approach enhances team learning and creates a shared social reality that results in a shared understanding of the problem and the development of potential solutions. Simplified processes of group model building 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 normally used as input for more complex simulation models. These models 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.	Antunes et al. (2006); Richard-son and Andersen (1995); Stave (2010); Van den Belt (2004); Vennix (1996, 1999); Vennix et al. (1992); Videira et al. (2003); Videira et al. (2009) Bourget (Ed.) (2011); Cockerill et al. (2007); Tidwell and Van Den Brink (2008); Van den Brink (2009)
Bayesian modelling is typically used in decision-making processes which consider probabilities of occurrence. This approach supports decision-making under conditions of uncertainty as it helps define the conditional probabilistic relations between variables in the network. The uncertainties associated with these probabilities are presented in a transparent way and analysed together with stakeholders.	Carmona et al. (2013); Castelletti and Soncini-Sessa (2007)
In **companion modelling**, stakeholders are typically involved in the co-construction of computer-based simulation models, agent-based models and in role-playing games for natural resource management, par-ticularly at the community level. In other cases, it is more convenient for stakeholders to make use of the agent-based model as an analytical tool (participatory simulation) rather than to actually build it. In both approaches, the aim is to enhance shared learning dialogues.	Briot et al. (2007); Castella et al. (2005); Étienne (2011); Guyot et al. (2005); Lonsdale et al. (2004); Souchère et al. (2010)
Collaborative modelling using networked environments for stakeholder participation combines participatory processes supported by a socio-technical framework. Simulation models are developed with a focus on social learning to elevate awareness of flood risk and facilitate planning activities. The process is supported by a web-based collaborative platform.	Evers et al. (2012); Jonoski and Evers (2013)

Source: Adapted from Basco-Carrera et al. (2017).

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, 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.

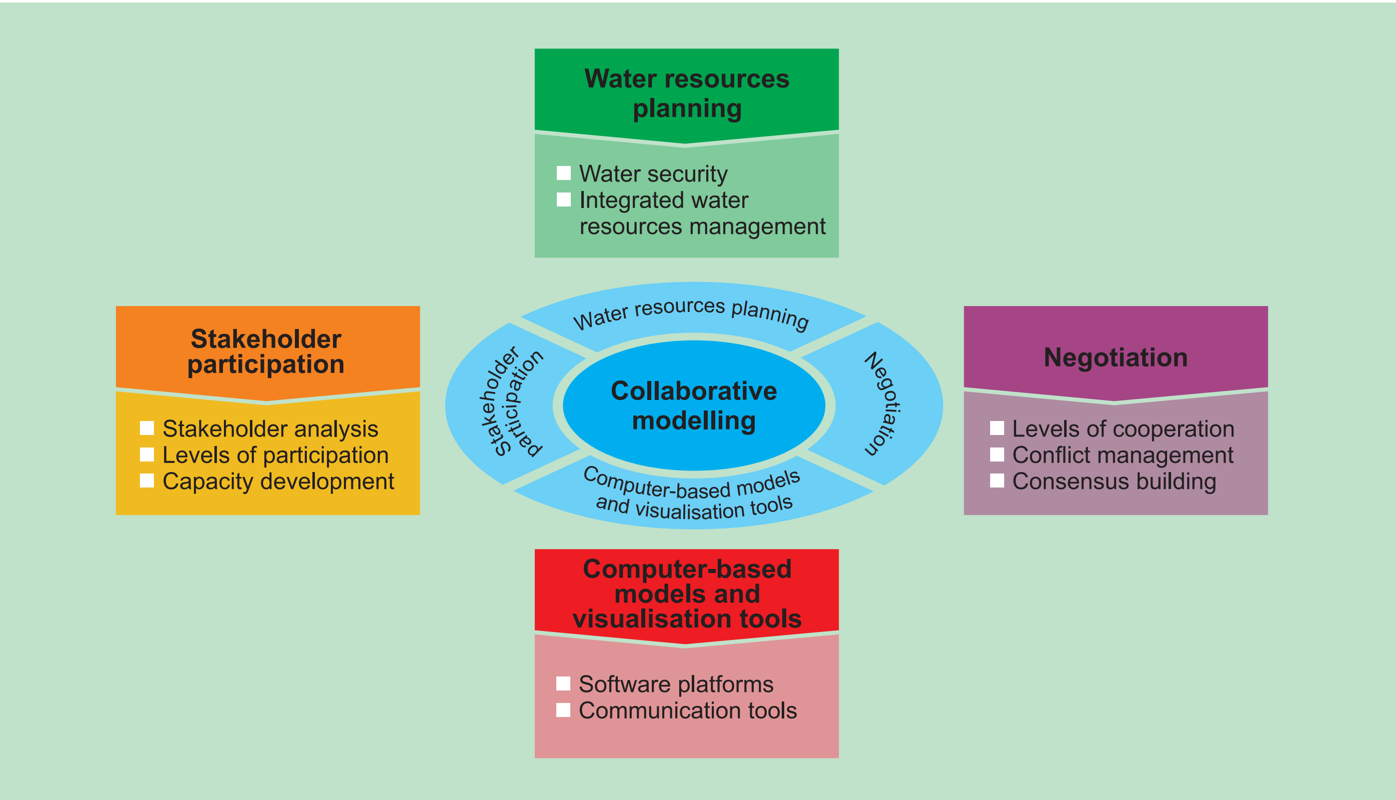
> **Box 5 From Bangladesh ...**
>
> "To create legacy and contribute to long-term sustainability, it is important that stakeholders are involved in the process to develop the meta-model. When people are familiar with the tools and techniques and know how to use them, they feel more ownership over the meta-model themselves."
>
> Md. Taibur Rahman, PhD, Assistant Project Director at Delta Plan 2100 Project, and Senior Assistant Chief, General Economic Division, Bangladesh Planning Commission

4.1 Key components

Collaborative modelling for policy analysis and decision support rests upon the integration of four key pillars (see Figure 1):

- **Water resources planning** – an iterative decision- or policy-making process commencing with a problem statement that determines activities required to achieve the desired objectives in a timely manner.
- **Computer-based models and visualisation tools** – to inform the relationships among the various interest groups and assess the impacts of a decision or policy.

Figure 1 Key components of collaborative modelling for policy analysis



Source: Basco-Carrera et al. (2017).

- **Stakeholder participation** – to engage with representatives of sectoral interest groups affected by the decision-making process to capture their values, perceptions, performance criteria, and objectives, and validate the process.
- **Negotiation –** a dialogue among stakeholders to achieve acceptable outcomes for everyone.

PILLAR 1: WATER RESOURCES PLANNING

Collaborative modelling can be applied to many aspects of water resources planning including reforming water policy/legislation, planning projects, developing national water strategies, and negotiating multi-lateral treaties (see Box 1). It is particularly suited to planning and decision-making which has run into difficulties with opposing key stakeholder interests, or when stakeholder information is required to fill information gaps or address uncertainties.

Collaborative modelling can support complex processes of water resources planning that are influenced by diverse and sometimes conflicting stakeholder values. For example, shared vision planning was originally devised to structure stakeholder participation for planning capital investments, such as flood management reservoirs. And collaborative modelling was used in Udon Thani City in Thailand to develop an urban plan with infrastructure for flood risk reduction. It was also used in Peru to develop IWRM plans for river basins.

Planning requires a move from concisely defining a problem towards conceptualising relevant tools for analysis. These analytical, visualisation and communication tools must be designed at an appropriate level to meet the objectives of the planning process and provide sufficient credible information for developing and evaluating strategies and for decision-making. Implementation is then supported by regular monitoring and evaluation. This planning process must be fully integrated with the other three pillars of collaborative modelling.

Collaborative modelling is ideal for dealing with semi-structured and unstructured problems (Simon, 1977; Hommes, 2008). In these situations, there is little consensus among stakeholders about values, norms, beliefs and ambitions, and a lack of scientific certainty (see Box 6). In those instances where there are deep divisions among stakeholders, alternative conflict management tools and methodologies may be required.

PILLAR 2: MODELS AND ANALYTICAL TOOLS

System decision support models, visualisation and communication tools are central to collaborative modelling. Modellers and technical analysts develop, enhance, and validate their models using collaborative processes that can increase understanding and trust between stakeholders and decision-makers.

Analytical models are developed through several stages. Typically, development begins with conceptual diagrams of system relationships. Technical analysts then provide feedback on which data are available and which are lacking. Where data are missing, expert judgement is used with the agreement of stakeholders. Several models may be coupled dynamically or incorporated into generalised functional relationships through a simple interface. Economic, social, hydrological, and ecological relationships may all be required in the models.

Analytical models use data to generate possible scenarios and options, and to support strategy development and decision-making. Ideally, stakeholders should be directly involved in constructing the models, formulating scenarios and policy options for modelling, and assessing the efficacy of options against key performance criteria.

Using open source or freeware software can ease the way in which models are distributed and used by stakeholders. Accessible and easy-to-use software tools or platforms also facilitate local capacity development and ownership. In addition, visualisation and communication can enable less technically minded stakeholders to readily understand the models and the information they produce.

Analytical models are central to building consensus and assisting stakeholders to reach a common understanding about conflicting interests, values, and norms. If models are perceived to be neutral

Box 6 Structure of problems in water policy

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

Types of policy problems based on their structure:

- Structured problems – there is a high level of scientific certainty and a high degree of consensus among stakeholders.
- Semi-structured problems – there is either a low degree of consensus combined with some certainty about scientific knowledge or a high degree of consensus combined with limited scientific certainty.
- Unstructured problems – there is a low degree of consensus and a lack of scientific certainty.

Source: Adapted from Hommes (2008); Simon (1977).

and independent, this will enhance the credibility of the information they provide. As a general rule, two questions need to be borne in mind when developing a model: How is the model going to be used? And who will be using the model? Such questions shift the traditional focus of model development away from technical capabilities towards policy and decision-making. Involving stakeholders in constructing and using models can improve the quality of the modelling and decision-making processes and lead to better informed decisions.

PILLAR 3: STAKEHOLDER PARTICIPATION

Conceptually, the benefits of high stakeholder involvement during the planning process are generally accepted. Stakeholder participation can serve as a tool for achieving the sustainable use of water resources. It is both a means to an end, and an end itself insofar as it can lead to increased stakeholder empowerment and make planning and decision-making processes more transparent and democratic.

Participation is also a process that enhances the capacity of individuals to improve their own lives, and this in turn can facilitate social change. Bringing stakeholders together around a table can foster consensus among competing organisations by opening channels of communication, generating mutual understanding, and enabling the negotiation of alternative solutions. Through building trust, ownership, and consensus, legitimacy and support for the planning process and its outputs can be increased.

In practice, however, structuring stakeholder processes is frequently the most difficult aspect of planning. The effectiveness of a participatory process is heavily influenced by the specific characteristics, interests, concerns, and needs of those involved. Stakeholder willingness to participate is important but it is not sufficient. What is critical is that the more influential stakeholders permit, facilitate, and encourage the involvement of others (Voinov et al., 2016).

In general, collaborative processes should be structured so that roles, stakes, levels of participation, and responsibilities are all understood. Different stakeholders will likely have different levels of formal education and opportunities to participate. Technical analysts, for example, will understand data and modelling, whereas stakeholders will understand their own sector and interests. Participatory processes must be structured to efficiently and effectively progress planning, modelling, and negotiations. Conflicts can occur, and so rules will be needed to secure a path forward (Bots and van Daalen, 2008). For instance, the scope of a planning project may need to be revisited if a conflict cannot be resolved.

PILLAR 4: NEGOTIATION

Collaborative modelling is used to support negotiations for policy- and decision-making. But this can be a complex process and include disputes among stakeholders which will require negotiation in order to reach resolution and achieve cooperation (Grey and Sadoff, 2007). In these situations, 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.

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.

4.2 Lessons learned and best practices

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 collaborative modelling as a viable way of making progress.

Every 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. And, typically, a neutral party is required to perform stakeholder analyses.

Best practice recommendations gleaned from collaborative modelling experiences documented by Korfmacher (2001), Voinov and Gaddis (2008) and Langsdale et al. (2013) include:

- Garner support from decision-makers.
- Identify who to invite to the process.
- Select software that is easy to use and can be made available to all.
- Approach the project with humility, being open to the inputs and wishes of stakeholders.
- Design and execute a process where stakeholders are valued for their contributions.
- Ensure the model and modeller can rapidly accommodate modifications and new alternatives.
- Frequently ask the team and all the participants throughout the process, 'Who will use the model?' and 'How will it be used?'
- Build a simple model early in the process, and improve it over time with input from stakeholders and experts.
- Engage stakeholders in iterative model development and technical analysis to foster shared learning.
- Choose modellers with collaborative skills and diverse modelling abilities, and facilitators with the ability to understand and appreciate what modelling can provide.

5 What are the challenges for collaborative modelling?

Institutions face several challenges in putting collaborative modelling into practice. These include a lack of capacity to undertake 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. These challenges are analysed in turn in this section.

5.1 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 collaborative modelling, they must explore ways of acquiring sufficient capacity to support all four pillars of the process.

5.2 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.

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.

5.3 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 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.

5.4 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.

5.5 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[1], and most importantly provide buy-in to the final decision process.

5.6 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.

6 Conclusions

Collaborative modelling adds effort to the already burdensome task of water resources planning. However, there are many water resources problems that cannot be solved by technical analysis alone, as the Lake Ontario–St Lawrence Seaway treaty negotiation aptly demonstrates (see Box 1).

As water resources become increasingly scarce, planning to solve both current and future water management problems become ever more complex and requires more sophisticated tools and approaches. Collaborative modelling is one approach that has the potential to solve problems. It takes advantage of the unprecedented computing power and access to information many people now enjoy, and has the capacity to deliver multi-objective outcomes in environments of competing interests.

Collaborative modelling holds the promise of widely acceptable decisions in divisive and uncertain environments. Furthermore, it can facilitate 'buy-in' to implement the decisions taken. In short, collaborative modelling can help to operationalise IWRM, leading to the development of plans that satisfy economic, social, and environmental objectives. Its ability to integrate decision support models, collaborative processes, planning procedures, and negotiation strategies is the critical foundation for achieving this vision.

[1] A US Federal Energy Regulatory Commission study (USGAO, 2001) reviewed 20 case studies where the participatory hydropower licensing took on average eight months longer during the initial 'pre-filing' phase but led to overall faster completion of final licensing for a total average of 56 months versus 79 months with reduced stakeholder participation.

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