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Water and Environmental Systems Management Under Uncertainty: From Scenario Construction to Robust Solutions and Adaptation

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Abstract

This paper presents and discusses concepts, models, and methods for defining strategies, plans, and actions to achieve the sustainable development of water and environmental systems in a context of uncertainty. The complexity of such systems, including human and natural landscapes and their interactions, is a tremendous challenge with regard to decision-making processes. The future that is now being designed involves a myriad of uncertainties, climate and non-climate related, that request comprehensive decision frameworks involving multiple processes (institutional, political, social, economic, biophysical, etc.) to prevent disagreements and barriers from impeding the achievement of sustainable decisions. When it comes to assessing responses to future scenarios (or different states of the world), the idea of robustness can include introducing the concept of adaptation. New terms such as “multiple plausible futures” and “deep uncertainty” have been emerging. How past frameworks should give rise to new frameworks so that decisions to be taken on water and environmental systems management and infrastructure planning are adapted to uncertain future conditions are the main issues tackled. The limitations on predicting the future and controlling and managing water and environmental systems mean that policy makers and society in general, especially knowledge-producing centres, need to shift from rhetoric to intervention, to tackle the many changing tendencies of today. Deciding now, at the present time, which has already been the future, the future of the next generations is an intricate and demanding task.

Keywords Water and environmental systems of the future · Uncertainty and decision making · Scenario generation · Flexibility · Adapting to new drivers of changes

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1 Introduction

The role of rivers in the birth and growth of civilizations is unquestionable. They made human sedentism possible, along with a community life that was creating mechanisms of cooperation and development, giving rise to the societies of today. They provided the water needed for farming to develop; they made the first industrial achievements and recreational activities possible; their natural beauty and the features of their courses captured the imagination of many peoples; they provided a source of identity for human settlements and exceptional communication routes between different geographic areas. Furthermore, they gave rise to the beliefs and spiritual attitudes of the people who were settling close to them as better living conditions became established. A reasonable balance between uses and resources was sustained for many hundreds of years, which preserved the conditions in which a rich wildlife and well-adjusted ecosystems were able to thrive.

However, rivers are not static systems – just think of the seasonal changes in which placid rivers suddenly turn into overwhelming and destructive currents. Measures were taken very early on not only to create conditions to use the resources of rivers but also to ensure that the consequences of natural phenomena could be controlled. Therefore, so that the resources could meet communities' needs, especially for agriculture, the first infrastructure elements and rules for their allocation and use began to emerge. Dams were built which initially made it possible to control natural phenomena and helped to support subsistence agriculture. They gradually evolved to produce energy, supply water, and intensive irrigation, and eventually provided a setting for large-scale leisure activities. This meant that the territory was reformatted with disruptions to the natural environment being introduced. The different interventions in and uses of rivers caused them to become polluted and fragmented, very often jeopardizing the vibrant ecosystem activity essential for a healthy life; their biodiversity has been damaged, food security has been called into question, and many situations have led to people being displaced.

The range of activities related to rivers and water bodies in general and their associated ecosystems is such that their protection and development require comprehensive oversight. The multifaceted conditions that can endanger the health of water and natural environmental systems and their influence on the progress of societies, including protecting people and property from the effects of extreme events, must now be considered in a new framework. Changes can be seen in various components (hydrological, biochemical, geomorphological, environmental, economic, social, regulatory, etc.). How to achieve progress while at the same time building sustainable solutions is today a more difficult challenge than ever, one that must be faced in a context of multiple uncertainties.

The literature is full of articles that set out the key points along the way that has brought us to the situation existing today (Pahl-Wostl 2020). It is clear that the strictly technical approach was understandably prominent (Pahl-Wostl et al. 2011) when it came to solving well-defined problems that needed urgent answers. Examples include those related to the concentration of the population in urban areas and the intensification of agriculture and industry that occurred in the last two centuries. The need to provide more water resources to meet growing demands and health and sanitation requirements meant that it was crucial to find and apply appropriate solutions. River basins also needed intervention to protect towns, cities, local areas, and their people and assets from intense sporadic hydrological events. As time went by, it became clear that interventions to solve specific problems and adopted only for technical reasons were not the way to proceed. The importance of gathering various types of knowledge and making structured decisions became clear. Managing water as a resource came to be contextualized in a wider, more comprehensive insight. This is exemplified by the importance given to understanding the behaviours and functions of different habitats and establishing their relationship with the hydrological features of the environments to which they belong. A transformational attitude began to emerge. A new model that considered demand-side water management and the integrative features of the Water Framework Directive (WFD, 2000) was developed.

However, the levels of complexity of water and environmental systems management have increased in recent times. The constraints on predicting the future mean that policy makers, society, and especially knowledge-producing centres, need to shift from rhetoric to intervention to tackle the many tendencies that are changing today (Pahl-Wostl 2020).

The working hypotheses that have prevailed in traditional management until recently must clearly be questioned. It must be possible to decide what our water and natural environmental systems should look like in the future. Thus it should be emphasized how climate change represents an enormous challenge to produce analytical insight for all levels of decisions (Marchau et al., 2019).

The literature has recently been focusing on how to incorporate uncertainty into decision-making processes related to planning infrastructure and managing water resources and associated ecosystems (protection and management of their services) (Maier et al. 2016; Moallemi et al. 2018, Marchau et al., 2019, Loucks 2022). Deciding now, in this present time which has already been the future, the future of those who will come after us, is an intricate task. It is essential to understand that decisions taken today must be based on "anticipating" the changes in future conditions. This is the main motivation for the next sections.

This paper provides a novel, integrated synthesis of knowledge available in several forms of literature (papers, books, and reports), relevant to analysing the challenges and limitations still found in water and environmental systems management, particularly with respect to uncertainty issues in decision-making processes. It contributes with an overview of essential concepts, models, and methods, having in mind readers less familiar with these subjects and interested in exploring them.

Its structure is as follows. The next section looks at the future challenges of water and environmental system management and discusses the main issues and concepts for developing decision-making frameworks under uncertainty. Subsequently, models and methods for tackling real-world problems are systematized and commented on. In the conclusions, the main takeaways from this paper are highlighted and the limitations of frameworks for managing water and environmental systems of the future are acknowledged.

2 Main Issues and Challenges for Future Water and Environmental Systems Management

The future that is now being formatted involves numerous uncertainties, both climate and non-climate related (Zeferino et al. 2014; Heidrich et al. 2016, Burnham, 2016, Pianosi and Wagener 2016). These require comprehensive decision frameworks involving multiple issues (institutional, political, social, economic, biophysical, etc.) to prevent disagreements and barriers to reaching sustainable decisions. Water companies and utilities worldwide are increasingly asked to find approaches capable of providing water of good quality, meeting reasonable pressure requests, and handling demand uncertainty in a sustainable and cost-effective manner (Pollard et al. 2004; Roach et al. 2015). Water resources authorities are periodically asked to develop management plans at the river basin level (the WFD planning cycle is 6 years). These involve setting strategic decisions for allocating water resources (human and non-human uses), devising flood and quality protection measures, and enhancing ecosystem services. Approaches such as IWRM – Integrated Water Resources Management need crucial changes to consider "strategic adaptation plans" as noted by Roach et al. (2016). Different initiatives worldwide show the importance of inclusive initiatives like the "Water and Sanitation for All" proposed by the UN under the Sustainable Development Goals, for whose success suitable decision-making frameworks are needed.

Awareness of the complexity in the field of water resources and environmental systems management is growing, along with the limited ability to predict and shape the information required to formulate future interventions, mainly with regard to long-term decisions. The decisions to be taken correspond to outlining problems with a myriad of objectives, as mentioned above, but in new, difficult contexts. In Fig. 1a comprehensive framework is depicted for implementing a decision-making process to address a specific problem, taking into account uncertainty issues. An overview of the different aspects focused on in this figure are discussed next, and a more thorough analysis to detail aspects related to real-world applications is dealt with in the next section.

In Fig. 1, the information presented on the right-hand side means that different levels of uncertainty can emerge at different times in the decision-making process. The uncertainty reflects the lack of or imperfect nature of knowledge with respect to external conditions and the characteristics of the systems to be worked on, as well as to the consequences of the solutions that may be implemented. Climate change adds fundamental challenges for defining analytical insight in all types of decisions. The implications of these new visions for the management of water and environmental systems have led to the development of a number of conceptual frameworks. In fact, making decisions considering perfect knowledge about the issues at stake, and thus resorting to deterministic approaches, is out of question today. Different approaches can be followed to tackle uncertainty issues, which has led to the emergence of new terminology such as "multiple plausible futures" and "deep uncertainty". Following the synthesis of deep uncertainties presented by Haasnoot et al. (2014) they are severe uncertainties that can appear "from multiple possible futures without knowing relative probabilities" (Lempert 2013); "from multiple world-views including different values to evaluate the systems" (Rotmans and De Vries 1997); and "from policy responses to environmental events and trends (Haasnoot et al., 2012) that cannot be considered independently" (Hallegate et al., 2012). This raises the problem of dealing with different states of the world or scenario uncertainty (Maier et al. 2016).

After the specification of the problem, objectives and constraints for its resolution must be established. Then alternative options must be built and evaluated in light of the objectives to fulfil (Fig. 1). Constraints could include physical aspects, technology availability, institutional barriers, legislation, and budgetary aspects. A spectrum of options may be considered as alternatives. It may be about policies, strategies, plans, designs, actions, etc.

There is an increasingly acute perception of lack of knowledge regarding the future behaviour not only of hydrological and other environmental variables (exogenous climate

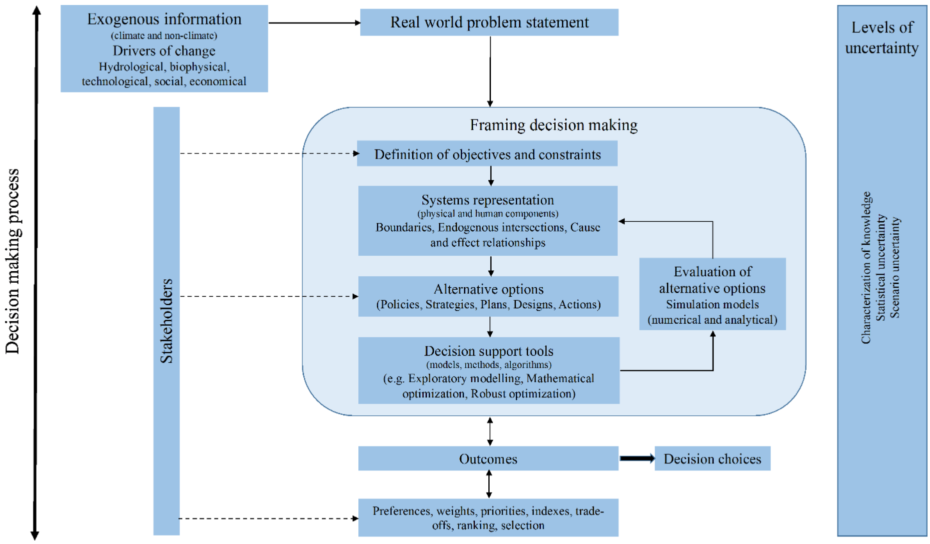

Fig. 1 Comprehensive framework for a decision making process accounting for uncertainty issues

and non-climate information) but also of the general response of environmental systems to new stimuli (internal functioning and endogenous interactions very often hard to figure out). In addition to these aspects, greater difficulty in devising information for decision-making processes can also derive from multiple possible drivers of change (Fig. 1):

- economic and population growth;
- technological developments (in the energy and agriculture sectors, or in wastewater treatment, for instance);
- land-use changes;
- new lifestyles and standards of living;
- costs and benefits from preventing consequences of adverse changes;
- unexpected implementation of new policies (marked by new geographies of poverty, migration, and the emergence of new economic powers);
- variability of stakeholder preferences with regard to outcomes not only from systems responses, but also for defining objectives and constraints, and alternatives;
- intricate societal responses engendered by such a wide range of trends and drivers of change.

The outcomes resulting from the decision framework used are also related to the exogenous information and how alternative options impact the system, given its endogenous functioning (Fig. 1). A feedback loop should be considered so that the evaluation of alternatives can drive the review of the various steps of the process. The outcomes are organized for the final disposition of the decision process, considering the preferences and weights assigned to each objective (here, the important role of stakeholders is stressed). Deep uncertainty approaches can promote the evaluation of trade-offs between solutions obtained through the range of plausible futures. In the end, alternatives can be rated, ranked, or selected depending on the tools used to support decision-making (e.g. exploratory modelling and scenario development, simulation models and sensitivity analysis, mathematical optimization, multiobjective programming, multicriteria decision analysis, robust optimization). This is an iterative process that can include the re-examination of different issues of the decision procedure.

The sustainability of environmental systems depends to a very great extent on how to adapt in terms of infrastructure and management of resources, and how to respond to societal problems arising from the combined effects of environmental and social developments. The involvement of stakeholders (Fig. 1) is especially important in the development of this new framework, as, indeed, are the levels of institutional, social, economic, political, and technical-scientific integration, which are essential aspects to be taken into account.

Inspiring approaches emerged from different areas and their terminology, systematization, objectives encompassed, opportunity, and challenges for applicability to real-world problems have recently been and will certainly be in the coming years, the subject of a large number of research publications. Literature contributions like those of Roach et al. 2016, Maier et al. 2016, Marchau et al., 2019, Loucks 2022 and their references provide a broad spectrum of analyses, models, and methods on the scope of decision making characterized by deep uncertainty.

The move from deterministic approaches to approaches considering different levels of uncertainty includes several steps in real-world applications. This subject is explained in more detail in Sect. 3.

3 Decision-support Processes for Dealing with Uncertainty

Although the future is uncertain, and many of its facets are even deeply uncertain, resource conditions must continue to improve to meet the challenges of their future management, always striving to ensure the sustainability of any intervention. Therefore, an understanding of what is needed to develop the most appropriate strategies, plans, and actions to deal with such complex futures must be the issue. In fact, investments and policies are very often responsible for complicated consequences. They can be the kickstart for long-term socio-economic reorganizations beyond their lifetimes. Future developments must be based on sound planning strategies. These aspects should be the stimulus to find and deal with uncertainties during the whole decision process. From the input data, type and parameters of simulation models, construction of metrics to evaluate different options, the type of decision models, and different approaches for them to handle uncertainty issues, there is a long way to go before convergence with the appropriate framework is applied. Some reflections on these issues are presented next.

3.1 Simulation Models

Simulation models are part of the decision process (Fig. 1). In fact, models that accurately represent the different components of environmental systems are vital to enable the evaluation of the impacts of the decisions to be implemented. Challenges from using different simulation approaches are questioned and highlighted. The need to address uncertainty (in terms of its source, degree, and nature) in the modelling of systems is crucial when it comes to any intervention they might be subjected to.

Uncertainty can be associated with all types of information, from a lack of understanding of biophysical changes in environmental systems or social systems (thus postulating inadequate cause-and-effect relationships) as well as from different types of parameters to be considered. Handling the uncertainty representation (Amaranto et al. 2022) associated with environmental systems in terms of the various parameters that characterize them and the input variables of the physical models that represent them (Fig. 1 and details in the next section), is widely discussed in the literature (Beven et al., 1992, Montanari 2005, Pianosi and Wagener 2016).

Water resources and environmental systems decision problems must rely on simulation models capable of determining the effects of the different potential drivers of change. The different options to design infrastructure for flood protection, water storage, supply, and drainage, as well as for ecosystem protection and enhancement, and land uses in times of uncertainty, have led to an important body of literature (Marchau et al., 2019).

However, the conceptualization of models to show how phenomena are described requires a clear definition of a model's purpose and a definition of its structure (cause-and-effect relationships) for an accurate representation (more theoretical or more conceptual) of the system under analysis. Appropriate data for parameter calibration must also be available. All these highlighted aspects can be subject to some degree of uncertainty.

Additionally, for handling the complexity of water and environmental systems, the intricacy associated with integrated approaches that simultaneously include various types of models (for the different components, physical and social) can create additional challenges when it comes to solving decision models. When a large number of simulations are needed with such complex models, particularly if simulation models are embedded into optimization/decision models, execution times may turn out to be prohibitive. Metamodels can help to overcome such limitations. They represent/mimic an approximate perspective of real-world phenomena. They are usually knowledge-based and statistically-supported models and they are hard to construct. Keeping them fast enough while simultaneously accurately representing the behaviour of the systems is really challenging. Haasnoot (2013) built a metamodel to help explore adaptation pathways for the management of the Rhine delta under future conditions. Beh et al. (2017) used a metamodel to solve water supply problems.

Tscheikner-Gratl et al. (2019) present a new discussion on uncertainty issues related to the calibration of fully integrated models for catchment studies and the linking of separate sub-models.

3.2 Levels of Uncertainty and Scenarios

In Fig. 1 it is shown that uncertainty levels have to be analysed at different points in the decision process. Figure 2 shows the conceptualized paradigms for modelling the future (Mair et al. 2016). The first paradigm, representation 1 (black line) in Fig. 2a, is based on the best available knowledge. It means that there is enough knowledge to characterize the conditions to which the system will be submitted and anticipate its responses (Maier et al. 2016). This is applicable to cases of low uncertainty.

Paradigm 2 (blue representation in Fig. 2a) performs the statistical characterization of knowledge, still considering the assumption of stationarity. Probabilistic distributions allow the statistical characterization of the information required to use simulation/decision support models that will in each case provide the results, which are themselves capable of being

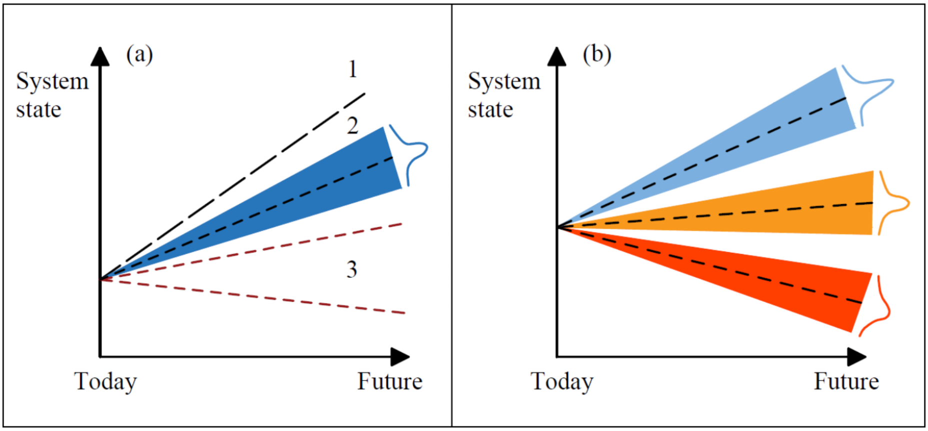

Fig. 2 (a) Representation of future modelling paradigms; (b) Combination of paradigms. (Adapted from Mejia-Giraldo and McCalley 2014 and Maier et al. 2016)

treated statistically. The literature reports several ways to statistically use these results for decision-making purposes. In many cases, decisions were based on results corresponding to different levels of probability. Mean values were sometimes used and sometimes the worst situation in terms of implementation requirements was considered (offering more assurances for the risk-averse decision makers), or even the one that decision makers perceived as corresponding to the most appropriate estimation. After characterization, probabilistic distributions can also serve to generate a large number of snapshots, using various methods (Monte Carlo simulation, Latin hypercube, etc.). These can be used to analyse solutions for different realizations of the variables at stake. These approaches, appearing under the so-called "statistical uncertainty", can also lead to selecting snapshots (leaving only a number that is still statistically representative of the whole set) through reduction techniques (Heitsch and Romisch 2003; Magini et al. 2019), and establishing their corresponding probabilities/weights. This paradigm conceptualizes future behaviours based on the imitation of past behaviours, according to the available knowledge.

Both paradigms seek to answer the question 'What is going to happen?', assuming that historical trends will continue into the future.

The hypothesis of stationarity was accepted until it recently began to be called into question (Milly et al. 2008). In fact, the idea that there could be probabilities linked to future events encountered in the characterization of environmental systems has been strongly questioned, indicating that different conceptual approaches should be created. The challenges are different today. This means that there can be limitations on the use of risk analysis when knowledge is limited or absent. As an example, it can be hypothesized that the future might involve hydrological regimes that no longer statistically correspond to what is known today about existing historical series. The idea of multiple plausible futures (also referred to in the literature as "states of the world" Maier et al. 2016) is intrinsically linked to the building of scenarios that will make it possible to assess what the outcome of the solutions to be implemented might be (Fig. 1). Creating scenarios involves coherently proposing various hypothetical circumstances for the future that encompass a range of plausible conditions, using different assumptions and perspectives regarding the past, present, and future.

The shift from using point estimates from probabilistic distributions to using scenarios (representing different states of the world, Cunha et al. 2019), the evaluation of the robustness (Giudici et al. 2020) of the decisions to be implemented (in terms of strategies and plans and actions) has been taking shape and is being prioritized, in both scientific and institutional terms. The evaluation of the solutions, considering their performance across all the scenarios considered, is replacing the old approach to decision making as the one that works best for the statistically more likely future (Lempert and Groves 2010).

When it comes to assessing responses to future scenarios, the idea of robustness can relate to the concept of adaptation. Adaptation will have to take place in a context of increased demand for water, localized population growth, scarce resources, aggressive economic development, new forms of energy production and agricultural practices, urban concentration, and, in addition to all this, a situation of ensuring environmental flows and an increasing number of environmentally legitimized uses, etc. (Burnham et al. 2016). There could be a need to cope with multiple evolutionary paths found over time, which give rise to new paths (Trindade et al. 2019; Buurman and Babovic 2016).

Thus, coping with uncertainty gives rise to paradigm 3 in Fig. 2a (representation 3 with red lines), involving the “exploration of plausible multiple futures” (Maier et al. 2016). The concept of deep uncertainty can be introduced and exploratory scenarios can be proposed in an effort to answer the question ‘What can happen in the future?’ In fact, in terms of decision support models, deep uncertainty is described as having the following characteristics (Maier et al. 2016 referring to Lempert and Groves 2010, and Walker et al. 2013): “[being] a situation where the analysts do not know, or at least the different parties interested in the decision do not reach a consensus as to: (1) the appropriate models to describe the interactions between system variables; (2) the probabilistic distributions to represent the parameters of the models; and (3) how to assess the appropriateness of the results of the alternative solutions involved.” There will therefore be solutions featuring different trends arising from a number of plausible futures, which result from different assumptions when representing the conditions of the systems being studied.

The three paradigms can be combined as in Fig. 2b).

This systematization will allow the construction of an essential work base that includes uncertainty in the development of the responses that have to be created for future unknown conditions. There must be an awareness that definitive approaches will never be available. The information, the scientific technical knowledge, and the social perception as they exist today must be organized as well as possible, even at the risk of unsatisfactory hypotheses or gross approximations coming to light in the future. It is a quality of human action to meet the challenge of devising and anticipating ways of doing things. The opposite would be inaction.

3.3 Decision Support Models and Methods Under Uncertainty

Approaches based on estimates from historical series come to nothing if the future is different from that represented by those series. It can even be said that a small deviation under the conditions laid down can have major consequences for the outcome of the implemented decisions.

In the literature (Walker et al. 2013) four possibilities have been considered for this purpose. The first two include:

- Planning to resist what would be the worst-case scenario from the standpoint of decision makers. These would be extremely costly decisions and we might end up with the problems mentioned above. The solutions implemented might not work when the so-called “black swans” (big surprises) happen (see Bellomo et al. 2013).
- Planning for the resilience of systems. Solutions should be built that will allow the rapid retrieval of systems for any future situation. This approach is usually applied to short-term decisions.

In Walker et al. 2013, and in Maier et al. 2016, and also in the most recent contributions to the literature, the idea is that the decisions to be implemented ought to lead to robust results (e.g. Roach et al. 2016; Watson and Kasprzyk 2017). The evaluation of robustness will always be linked to the good performance of the solution under multiple future conditions. Thus, there are two other approaches, static robust approaches, and dynamic robust approaches:

- Static robust solutions are those that work with a satisfactory level of efficiency (with a range of levels of satisfaction to be tried) for a wide and varied number of hypotheses and models constructed based on the best available knowledge and what we can sense about the future (Cunha and Sousa 2010; Zeferino et al. 2012). Tools are used to define the solution that best serves a plausible set of proposed future scenarios simultaneously. This approach, used by a large number of authors, does not include the idea of adaptation along the planning lifespan.
- Dynamic robust approaches overcome the limitations relating to the adaptive characteristics of the solutions outlined in the previous approach. In this case, the solutions are designed so that they can be re-examined and adapted over time as new information becomes available, and several directions of development are possible. The systems, therefore, become less vulnerable to possible future changes. Decision makers will be able to accommodate differences in understanding the systems and their dynamics, and the various established intervention priorities, which might become clearer as time passes. Physical, environmental, social, and economic, as well as governance and policy-making issues in general, can be covered here. These solutions are characterized by prudence and flexibility. There is a clear shift from the paradigm based on forecasting and planning, relying on currently available knowledge, to the management paradigm through learning (Larson et al. 2015), embedding in the systems the ability to react to moments of unpredictability and unanticipated risks (Marques et al. 2018; Cunha et al. 2019). Various options can be developed, and over time it is possible to move from one option to another if new information gathered in the meantime suggests this should happen.

Regarding the science and engineering of adaptation, the solutions to be adopted must be intrinsically flexible (de Neufville and Scholtes 2011, Creaco et al. 2014, Basupi and Kapelan 2015, Spiller et al. 2015, Cunha et al. 2019). This means that capacity can be created to incorporate any new information that becomes available over the envisaged operational horizon. The paths to adaptation are varied, must be analysed, and can intersect over time. The success of adaptation processes lies in understanding all the aspects involved in creating mechanisms to manage the reorganization capacity of the systems in response to uncertain futures (Fletcher et al. 2017, 2019; Herman et al. 2020, Cohen et al. 2021).

There is a range of models and methods that cover the issues described (Moallemi et al. 2018, Marchau et al., 2019). The following are active areas of research on decision making in uncertain futures: multicriteria decision analysis (Sholten *at al.*, 2014, Ilaya-Ayza et al. 2017, Amorim et al. 2020, Cunha et al. 2020, Zolghadr-Asli et al. 2021); multi-/many-objective models (Giuliani et al. 2016; Trindade et al. 2017; Marques et al. 2018; Liu and Mauter 2021; Zaniolo et al. 2021); fuzzy approaches (Fu and Kapelan 2011); development of different types of metrics to evaluate the performance of different options (Herman et al. 2015; Burak and Margat 2016; Zaniolo et al. 2018; McPhail et al. 2018); definition of regret functions and robustness measures (Cunha and Sousa 2010; Zeferino et al. 2014; Creaco et al. 2016); adaptation pathways (Buurman and Babovic 2016; Manocha and Babovic 2017); analysis of typing points (Gersonius et al. 2015); use of concepts such as info-gap (Roach et al. 2016), or real options (Buurman et al. 2009, de Neufville and Scholtes 2011, Zhang and Babovic 2012, Marques et al. 2015, Manocha and Babovic 2018).

Participatory processes are important for the success of any planning process. Stakeholders are an important part of the decision-making process under uncertainty. Together with universities and other knowledge-producing centres and policy makers they can be quite influential in terms of developing actions for sustainability. Communication materials have to be prepared, and surveys and questionnaires should be developed to get agreement on the objectives to be considered, assumptions to be used and priorities to be assigned to decision making.

4 Conclusion

There are many trends and directions of change, climate and non-climate related, that will require careful preparation of new frameworks for managing the water and environmental systems of the future. The use of probabilities associated with future events, based on the historical series known today, is being widely debated and strongly challenged. Therefore, new terms such as “plausible multiple futures” and “deep uncertainty” have been appearing. Deciding in a context of such complexity could involve:

- Learning about the processes that engender the responses to external stimuli and that will be the basis for developing controlled actions for the management of environmental systems.
- Using simulation models to “accurately” represent cause and effect relationships;
- Moving from statistical uncertainty to scenario uncertainty approaches.
- Using techniques to develop future scenarios; considering different levels of uncertainty that manifest themselves at different times in the decision-making process.
- Exploring different futures and assessing the impacts of assumptions.
- Fitting uncertainty issues into the decision processes.
- Defining sustainable solutions to be economically, environmentally, and socially acceptable in the long term, and also robust across all scenarios. This means they should function satisfactorily in a wide variety of future states of the world or scenarios.

- Defining flexible solutions that must be able to adapt over time to future situations unknown today. To be adaptable, the solutions should consider a wide range of uncertainties relating to key aspects of how the systems function, and connect short-term objectives with long-term plans, leaving open options that allow today's solutions to be reviewed whenever new information becomes available.
- Including participatory processes involving stakeholders together with universities and other knowledge-producing centres and policy makers.

The work should be developed with the idea that the models will always be incomplete in processes that are hard to grasp and whose conceptualization is complicated. These limitations should always be kept in mind when developing informed decision-making processes.

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Consent to Participate Not applicable.

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