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Degree of Master of Science

Navigating uncertainty and multifunctionality for resilience: Bridging decision making and finance for water infrastructure in the Orange-Senqu River Basin

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:

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The Orange-Senqu River Basin provides critical resources to Lesotho, South Africa, Namibia and Botswana, but uncertain climate projections, multiple possible development futures, and a financing gap create challenges for water infrastructure decision making. In contrast to conventional predict-plan-act methods, an emerging decision paradigm based on socio-ecological resilience supports decisions that are appropriate for uncertainty and leverage social, ecological and economic multifunctionality. Concurrently, the financial sector plays a powerful role in sustainable infrastructure development but remains disconnected from discourse in socio-ecological resilience. At the time of research, a project to transfer water from Lesotho to Botswana through South Africa was at pre-feasibility stage. This case was analysed through documents and interviews to investigate how uncertainty and multifunctionality are conceptualised and considered in decisions for the resilience of water infrastructure and to explore bridging concepts to finance. Stakeholders conceptualised uncertainty as risk, ambiguity and ignorance and multifunctionality as politically-motivated shared benefits. Numerous efforts to adopt emerging decision methods that consider these terms were in use but required compromises to accommodate the persistent, conventional decision paradigm, though a range of future opportunities were identified. Bridging these findings to finance revealed opportunities to consider a more comprehensive scope of risk, leverage risk mitigation measures, diffuse risks and benefits over space, time and to diverse actor groups, and to clarify roles to achieve multiple objectives for resilience. In addition to insights into how multiple decision paradigms interact in real-world decision contexts, the research highlights untapped potential at the juncture between socio-ecological resilience and finance.

Keywords: socio-ecological resilience, water infrastructure, finance, decision making, uncertainty, multifunctionality, southern Africa, Orange-Senqu River Basin

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Abbreviations

CBA – Cost-benefit analysis
CRDP – Climate Resilient Development Pathways
CRIDF – Climate Resilient Infrastructure Development Facility
DAPP – Dynamic Adaptation Policy Pathways
DWA – Department of Water Affairs
DWS – Department of Water & Sanitation
ERA – Environmental Risk Assessment
ESKOM – Electricity Supply Commission (of South Africa)
GCF – Green Climate Fund
GDP – Gross Domestic Product
GEF – Global Environment Facility
GFSG – Green Finance Study Group
GIZ - Die Deutsche Gesellschaft für Internationale Zusammenarbeit
G20 – Group of Twenty
ICA – The Infrastructure Consortium for Africa
IFC – International Finance Corporation
IWMI – International Water Management Institute
IWRM – Integrated Water Resources Management
JMSC – Joint Management Study Committee
L-BWT – Lesotho-Botswana Water Transfer
LHWP – Lesotho-Highlands Water Project
MCDA – Multi-criteria Decision Analysis
NPV – Net Present Value
ORASECOM – Orange-Senqu River Basin Commission
PES – Payments for ecosystem services
PPP – Public-private partnership
RDM – Robust Decision Making
RIF – Regional Infrastructure Foresight
RO – Real Options
RQ – Research question
SADC – Southern African Development Community
TCTA – Trans-Caledon Tunnel Authority
WRPM – Water Resources Planning Model
WYRM – Water Yield Resources Model

1 Introduction

Strategic investments in water infrastructure in southern Africa are required to increase climate resilience, provide reliable access to clean water, and increase material and non-material wellbeing (Quinn *et al.* 2017; Hanjra *et al.* 2009). Countries in the Southern African Development Community (SADC) are experiencing major challenges providing equitable and sustainable water access in the region, which contributes to entrenched poverty and places limits on socio-economic growth (Hanjra *et al.* 2009; Grey and Sadoff 2007). The ecology of some river basins is also under threat due to both natural and anthropogenic forces that reduce the quality and quantity of the water and its ability to provide ecosystem services (Orange-Senqu River Basin Commission (ORASECOM) 2014c). Socio-economic and demographic trends in the region are uncertain and depend on migration patterns, commodity prices, and a wide range of other factors (African Development Bank 2012). In addition to these challenges, the southern African region is characterised by intensifying climatic variability and regional water scarcity (Jury 2013; Kusangaya *et al.* 2014). Annual precipitation may decrease by up to 20 percent in 2080 and temperatures are expected to rise, both of which directly affect hydrological responses (Conway *et al.* 2015). Though indicative of a problematic trend, regional projections mask the significant spatial and temporal distribution of water availability across the tropical and arid zones. Regions with abundant water sources such as the Mountain Kingdom of Lesotho, and those with significant demand, such as the Gauteng region of South Africa and southern Botswana, are often mismatched in time and space, demanding bulk storage and conveyance of fresh water (ORASECOM 2014b). In addition, approximately 70 percent of the region's fresh water is situated in transboundary river basins making governance of water resources challenging and political (Lebel *et al.* 2005), such as the Orange-Senqu River Basin shared by Namibia, Botswana, South Africa, and Lesotho (South African Institute for International Affairs 2016).

In the face of these challenges, decision makers in the water sector are tasked with taking efficient and effective action, while also considering the deep uncertainties introduced by climate change and socio-economic transitions (Bhave *et al.* 2016; Hallegatte *et al.* 2012; Wardekker *et al.* 2010). Issues associated with these persistent and wicked problems are exacerbated by the high expense and impact of water infrastructure decisions (Lienert *et al.* 2013) and long infrastructure lifetimes (J. Hall *et al.* 2012), which present the risk that unintentionally poor decisions result in locked-in solutions that are ineffective or maladaptive (Gersonius *et al.* 2013). For example, previous water management efforts to deal with water supply challenges in southern Africa have led to the development of highly complex, engineered water systems that may not be built to manage the expected spatial and temporal variability of water availability due to climate change (Meissner 2015). In addition, water is a fundamental part of livelihoods, economies, and the environment, so many water infrastructure solutions serve multiple stated and unstated functions with a range of impacts (Casadevall 2016). These multiple functions can be described as multifunctionality, defined simply as the multiple social, ecological and economic functions or benefits of an intervention like a piece of infrastructure. A lack of consideration of multifunctionality can result in lost opportunities to realise more benefits for more entities (Ahern 2013) and may introduce compounding risk as multiple sectors suffer if water supply is disrupted.

A growing number of scientists and practitioners are addressing these challenges by advocating governance paradigms and decision-making processes that absorb greater uncertainty and multifunctionality guided by the resilience of socio-ecological systems. This form of resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.* 2004). The theory of adaptive governance evolved from the need for a resilience-based governance paradigm and describes a suite of implicit characteristics of governance contexts that better deal with uncertainty and change (Chaffin *et al.* 2014). In addition, a new paradigm of explicit tools is being adopted to better consider the uncertainty and multiple functions of water infrastructure, including participatory methods, forms of experimentation, and adaptive planning tools (Hallegatte *et al.* 2012; Arkesteijn *et al.* 2015; Stapelberg 2010; Lempert and Groves 2010; Swanson *et al.* 2010). However, the existing, conventional paradigm still relies on the ability to predict and plan for a future based on historical trends and to optimise solutions based on engineering and scientific rationality (Lienert *et al.* 2015; Salet *et al.* 2013). This paradigm also views water infrastructure solutions within a water silo, drawing clear boundaries around water use as the primary function of infrastructure without considering multifunctionality (Butterworth and Soussan 2001). Decades of practice under a conventional engineering paradigm do not easily accommodate innovation, and the water sector in southern Africa exhibits a bias toward the expert knowledge and governance centralisation that is characteristic of this paradigm (Knüppe 2011).

The complexity and urgency of the issues of the southern African region present both practical and scientific challenges for water infrastructure decision making. The practical challenge is the need to operationalise the emerging paradigm of decision making to better deal with pervasive uncertainty and leverage the multiple purposes of infrastructure (Stakhiv 2011; Kalra *et al.* 2014; Scholten *et al.* 2015). This requires a better understanding of how these methods are adopted in real-world decision problems and the associated challenges and opportunities. The scientific challenge is the need to expand the current understanding of how decision contexts deal with uncertainty and multifunctionality in real-world decisions. This requires supplementing the numerous studies addressing the *implicit* adaptive governance characteristics of different case contexts (e.g. Herrfahrdt-Pähle 2013; Green *et al.* 2013), with investigations of how decision methods that *explicitly* address uncertainty and multifunctionality are operationalised in real-world case contexts that inevitably utilise a range of methods from both the conventional and emerging paradigms of decision making. Addressing this scientific challenge requires a more synthesized and integrated approach than currently exists in the literature that addresses various conceptualisations of uncertainty and definitions of multifunctionality (e.g. Van Asselt and Rotmans 2002; Stirling 2006; Van Huylenbroeck *et al.* 2007), addresses individual uncertainties like climate change in water decisions (e.g. Gersonius *et al.* 2013), and innovates or tests individual decision-making tools or methods designed to deal with uncertainty or multifunctionality (e.g. J. Hall *et al.* 2012; Haasnoot *et al.* 2013; Kiker *et al.* 2005). Such literature does not appear to take a holistic view to understand how these elements intersect, overlap, and collide with one another in practice.

In addition to the movement toward integrating uncertainty and multifunctionality into decisions, the financial sector plays an important role in bringing critical resources to water infrastructure projects. However, a funding gap is inhibiting the development of water infrastructure projects in southern Africa (Briceño-Garmendia. *et al.* 2008; Quinn *et al.* 2017; Tandi and Earle 2015). This funding gap persists for a number of reasons: the past decade has placed constraints on the ability of governments to access traditional forms of debt finance (World Economic Forum 2013), access to alternative sources and structures of finance depends on a host of context-specific factors (Biensan 2017), and there are persisting challenges connecting strategic project pipelines with appropriate sources of funding (Infrastructure Consortium for Africa (ICA) 2017). Governments, investors, and other actors in the financial sector are working to close this gap, including efforts to cater to unique risk contexts (Caltz and Fourie 2010), blend finance and develop mechanisms to access new sources of revenue (Corfee-Morlot *et al.* 2012), and assess the sustainability value of investments to satisfy a broader range of environmental, social and governance criteria from investors and emerging green finance mechanisms (Clapp *et al.* 2016). These efforts place financial actors in a unique position of influence in defining and enabling sustainable development pathways, recognized in international efforts to transform the financial system to support sustainable development (e.g. Zadek and Robins 2016).

Despite the emerging sustainability lens of some financial actors, the fundamental criteria of the sector continue to be project bankability and risk-adjusted financial return (Morel and Bordier 2012). In addition, discourses that take a complexity-based or systems approach to water infrastructure have yet to pervade the financial sector in literature, save a few isolated examples (e.g. Cremades *et al.* 2018). This results in a bias to projects that are only easily understood under a traditional engineering paradigm and a tendency to consider project risks and functions that are more easily related to financial metrics (Corfee-morlot *et al.* 2012; Merk *et al.* 2012). The apparent dissonance between the paradigms of water infrastructure decision making and project finance comes in combination with the significant power of the financial sector and a rapidly changing risk environment due to climate change. This presents a major practical challenge; namely, how to reconcile these differences in a manner that allows the financial sector to continue operating under its own internal norms, but also enables decisions that promote resilience of water systems and their surrounding contexts. It also presents the scientific challenge of characterising and leveraging opportunities that exist in the dynamic intersection between two disparate fields of study.

The described challenges could apply to any region, project, or institution in southern Africa or elsewhere. Grounding the research in a project-level case study presents opportunities to generate immediately relevant findings alongside experts connected directly to a contemporary decision process and to provide evidence for general recommendations to the broader decision making and financial arenas. The Orange-Senqu River Basin in southern Africa, pictured in figure 1-1 below, is an excellent example of a region with high stakes, complex water management, permeated with significant uncertainties and multifunctionality. The river originates in the highlands of Lesotho and travels through South Africa before draining into the Atlantic Ocean through Namibia and Botswana. The basin is also characterised by severe spatial differences in water availability; the highlands of Lesotho have been dubbed the "water tower of southern Africa", while the western arid regions in Namibia and Botswana face extreme and worsening water scarcity (ORASECOM 2011b). Regional demands for water are expected to change based on development trajectories throughout the basin, and climate projections reveal significant but uncertain impacts (ORASECOM 2011b). In addition, issues of inequity and basic access to water still pervade the sub-Saharan African region (Dos Santos *et al.* 2017). Transboundary governance of water resources in the basin is led by the Orange-Senqu River Commission (ORASECOM) and has proven highly challenging: the river is regulated by 30 major dams with greater than 12 million m^3 of storage and many more smaller dams (Blumstein 2017), along with several large intra- and inter-basin transfer schemes (ORASECOM 2014b). The region also faces prevalent power differences between member countries (Turton and Funke 2008). Efforts to increase climate resilience and implement further infrastructure interventions in the basin are underway (ORASECOM 2014b), including the planned transfer of bulk water from the highlands of Lesotho to Botswana through South Africa, known as the Lesotho-Botswana Water Transfer (L-BWT) project (World Bank 2014; ORASECOM 2017). At the time of research, this project was in the pre-feasibility stage, providing an opportunity to embed the research in a timely decision-making process.

1.1 Research aim

The research moves from the critical assumption that uncertainty and multifunctionality are dealt with through a number of practices that promote the resilience of a water infrastructure system and its surrounding context. The overarching aim is to use the proposed Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin as a case study to examine how uncertainty and multifunctionality are conceptualised in decisions for water infrastructure and how these concepts are, or could be, considered in decision-making processes. In addition, as the water and financial sectors evolve and innovate under a different set of drivers, assumptions and objectives, it is important to consider how practices in the water sector that encourage resilience relate to efforts to finance water infrastructure. As such, the research also aims to examine how the financial sector can leverage conceptualisations and considerations of uncertainty and multifunctionality that promote the resilience of water infrastructure investments. These research aims will be realised by answering the following research questions (RQ):

> RQ1: *How are the concepts of uncertainty and multifunctionality currently conceptualised and considered in decision-making processes for the resilience of the Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin? How could these concepts be considered in decisions for the resilience of water infrastructure?*
>
> RQ2: *How might the financial sector leverage the findings of RQ1 to promote the resilience of water infrastructure investments?*

The research targets an audience of 1) academia in the fields of resilience of socio-ecological systems and project finance for water infrastructure, 2) governments and practitioners in southern Africa and similar contexts planning for and implementing water infrastructure, and 3) practitioners in the financial sector working to develop and finance projects or to transform the sector to support sustainable development.

1.2 Limitations and ethical considerations

The circumstantial limitations of the research include limited access to people and data. The current relevance of the L-BWT meant that governments were in negotiations for a path forward, introducing challenges securing interviews with government representatives. Similarly, the most recent desktop study for the L-BWT (Bigen Africa (PTY) Ltd. 2015) was not publicly available. The chosen scope focused on expert interviews, which left alternative worldviews and community-level perspectives out of consideration. In addition, the choice to focus on qualitative data analysis without supplementing with quantitative data affects the type of conclusions that could be drawn from the study. Other implications of the methodological choices are included in section 7.4. Ethical clearance from the Central European University was given and explicit permission for interview was received from all interviewees.

Figure 1-1 Map of the Orange-Senqu River Basin (ORASECOM 2014a)

2 Method

A worldview that embraces the complexity, unpredictability, and transdisciplinarity of the field of sustainability was adopted for the research, best addressed through the discipline of sustainability science. This discipline uses a problem-solving perspective to understand the complex interactions between social and ecological systems to lead to practical solutions (Salas-Zapata *et al.* 2017). Researchers embrace different forms of knowledge and research, while working on a dual agenda of knowledge generation and transformation through action (Wiek *et al.* 2012). This field uses the term socio-ecological systems (SES) to describe systems that are complex and integrated, in which humans are a part of nature (Berkes *et al.* 2000).

One of the main points of departure for the research was to use a transdisciplinary perspective rooted in sustainability science to bring together water governance and the financial sector. The research moved through a literature review, a conceptual framework, a preliminary document analysis, and semi-structured expert interviews in a project-based case study. The research design is briefly summarized in figure 2-1 below. Section 2.1 describes the epistemological and ontological basis for the research. Section 2.2 describes the rationale for the case-based research design. Sections 2.3 and 2.4 describe the structure of the document analysis and semi-structured expert interviews.

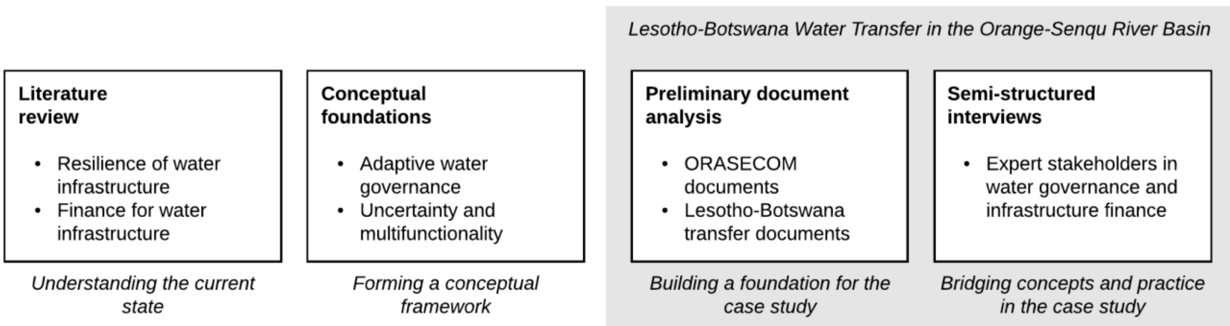

Figure 2-1 Stages of research design with grey box indicating the case study application

2.1 Research paradigm

The research was based on the ontology and epistemology of pragmatism, in which the researcher is external and believes that there are multiple positions on the nature of reality (i.e. reality is constructed). Under this perspective, the researcher typically chooses the view that is best achieved to answer the question at hand and accepts that both observable and phenomena and subjective meanings may provide acceptable knowledge depending on the research question (Wahyuni 2012). Though integrating different perspectives was viewed as favourable, the chosen research method tended toward expert knowledge and scientific paradigm. This introduced a risk that the results would be biased toward a more positivist or naïve realist paradigm in which there is an objective and independent position on the nature of reality and only observable, credible phenomena can provide credible facts and data (Wahyuni 2012; Saunders *et al.* 2009). To address this risk, a perspective on pluralism (i.e. whose perspective matters) was chosen. Van Asselt & Rotmans (2002) articulate four meta-perspectives on pluralism; the research adopted a 'science in perspective' perspective, which accepts that pluralism in science mirrors pluralism in society. Thus, the research attempted to include radical and unmeasurable uncertainties, provisions for diverse stakeholder participation, and socio-cultural perspectives (Van Asselt and Rotmans 2002). As the methods did not actively consider the socio-cultural perspective, it is briefly addressed in the final section of the analysis (section 6.4).

2.2 Case study

The defined research problem could have been applied to a range of geographic boundaries or stakeholders, but a case study research design was chosen to ground the research in everyday practice and to generate immediately actionable recommendations. Yin (1994) suggests three main conditions for determining the appropriateness of case study research. The first condition is the type of research question(s) being asked, with case studies as the preferred strategy for answering questions focused on "how" or "why" (Yin 1994). Because this study focused on asking *how* uncertainty and multifunctionality are conceptualised and considered in decision making for resilience, and *how* these elements might cross over into project finance, the first condition for case study research was met. The second condition is the level of control the researcher has over actual behavioral events, with case studies as the preferred strategy in situations in which the investigator has little control over the events (Yin 1994). Because this study situated the researcher as an observer of a broad system with a complex array of actors, the second condition for case study research was met. Lastly, the third condition is the focus on contemporary versus historical phenomena, with case studies as the preferred strategy in studies with a focus on contemporary phenomenon within a real-life context (Yin 1994). Because this study intended to address existing and evolving challenges in water governance and project finance in order to influence future decisions, the third condition for case study research was met.

The case study of the Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin was chosen for a number of reasons. Prior relationships to relevant stakeholders in the Orange-Senqu River Basin through the thesis supervisor helped secure access to interviewees and documents. At the time of study, the L-BWT project was at the pre-feasibility stage, providing opportunities to creatively discuss the decision process when project stakeholders were still open to generating new ideas. Lastly, the project (L-BWT) and the context (Orange-Senqu River Basin) exhibited characteristics of high uncertainty and complexity, multiple stakeholder involvement and multifunctionality, and significant pressure from climate impacts and other macro trends.

2.3 Preliminary document analysis

Document analysis involves a systematic review and evaluation of documents to find meaning, gain understanding, and develop practical knowledge, similar to other qualitative research methods (Corbin and Strauss 1993). The analysis is performed on text recorded without the intervention of a researcher (Bowen 2009). This technique was chosen because a large number of high-quality and closely relevant reports have been produced by institutions working in the Orange-Senqu River Basin region over the past decade. These reports address various aspects of water governance in the Orange-Senqu River Basin and specific aspects of the Lesotho-Botswana Water Transfer project. In this study, the primary purpose of the document analysis was to gain an understanding of the context to prepare for semi-structured interviews. The secondary purpose was to gain an understanding of context-specific and directly relevant perspectives in the river basin.

2.3.1 Data collection

Documents included in the analysis were chosen according to the following.

- A long list of documents was generated from the following.
    - Academic literature generated from the literature review and based on combinations of key words relevant to the case study (e.g. Lesotho-Botswana Water Transfer, Orange-Senqu River Basin, climate change, water infrastructure, uncertainty, benefits)
    - Documents provided by project stakeholders related to climate vulnerability and modelling in the Orange-Senqu River Basin.
    - Publicly available documentation in the online library from the Orange-Senqu River Basin Commission.
    - Project-specific documents (Lesotho-Botswana Water Transfer) from project stakeholders and through Google searches.
- The short list of documents for analysis was chosen based on a review of the abstracts, introductions, or executive summaries of each, considering:
    - Relevant content for application of the conceptual framework
    - Overlapping content (e.g. interim reports under a work package were not analysed if a final summary report was available)
    - Dates of publication (i.e. only the most up-to-date information)

2.3.2 Data analysis

The chosen documents were analysed according the major themes in the conceptual framework, using a simple procedure for coding qualitative data (Miles *et al.* 2013). Such a procedure involved choosing major categories and sub-categories, combing and labelling documents under each of these categories, and consolidating and analysing the results. This document analysis addressed similar topics to the semi-structured interviews, so findings from this document analysis were fed into the themes identified during the analysis of the semi-structured interviews.

2.4 Semi-structured interviews

Semi-structured interviews were the main source of primary data for the research design. In semi-structured interviews, the interviewer asks pre-defined, open-ended questions for 30 minutes to over an hour (Jamshed 2014) and they are best used in situations where concepts and their relationships are relatively well understood (Ayres 2008). This was the case for the first research question, but the second research question demanded a more unstructured approach to generate creative solutions tailored to interviewee's expertise.

2.4.1 Data collection

Interviewees were chosen according to a snowball sampling technique. The names of interviewees for the first round of interviews were identified through online communications with a collaborator in Pretoria, South Africa. For the duration of the field research in South Africa, the researcher was based in the offices of Pegasys Consulting Ltd. in Pretoria, allowing easy access to other consultants for interview. Interviews with project consultants were supplemented with interviews with stakeholders in various influential institutions in the Orange-Senqu River Basin. Desired interviewees had some elements of the following expertise:

- *People with insights about decision making for large-scale water infrastructure projects in southern Africa:* including experience with 1) governance and institutional structures, 2) sources and methods for gathering different types of knowledge (e.g. environmental flows, climate/hydrological models, traditional knowledge, water demand, reconciliation studies, social impacts, etc.) and integrating them into decision structures (e.g. cost-benefit analysis, multi-criteria analysis, etc.), and/or 3) stakeholder engagement and participatory methods.
- *People with knowledge of the financial sector to provide tools and concepts that bridge water decision making with water project investment and green/climate finance:* including those who knew about risk, enabling investment environments, financial structuring, risk mitigation, and green finance.

This approach resulted in 14 interviews involving 16 stakeholders from the following institutions:

- Climate Resilient Infrastructure Development Facility (CRIDF): 5 interviewees
- Pegasys Consulting Ltd.: 1 interviewee
- Trans Caledon Tunnel Authority (TCTA): 3 interviewees
- International Water Management Institute (IWMI): 4 interviewees
- Independent expert: 1 interviewee
- 2 unnamed institutions: 2 interviewees

Interviews were conducted using an interview guide. The section for RQ1 was informed by the conceptual foundations (section 3). The section for RQ2 demanded an exploratory approach. Scenario planning is increasingly recognised as an effective method to prepare for change (Reed *et al.* 2013; Varum and Melo 2010). Scenarios allow for discussion about, and preparation for, alternative futures or to envision desired futures and plan accordingly using backcasting (Carlsson-Kanyama *et al.* 2008). Scenarios serve a variety of functions, including political decision-making support, facilitation of public learning, and research support (Reed *et al.* 2013). Two scenarios were constructed to facilitate the process of bridging water governance with finance. These scenarios were based on elements of the case context and the utopias described regarding uncertainty in integrated modelling by Van Asselt & Rotmans (2002). As the scenarios proved too complicated for practical use, segments were used as prompts. The interviewee guide is included as appendix 1.

2.4.2 Data analysis

The data was analysed according to a classic qualitative data analysis approach (Miles *et al.* 2013). Interviews were recorded, transcribed and initially coded based on the conceptual framework. Once a set of broad themes emerged, interviews were combed a second time to avoid missing pertinent information on these major themes. Findings from the preliminary document analysis were then fed into these major themes. This process of reconciling the preliminary document analysis with the semi-structured interviews revealed that several documents that were analysed did not fit within the relevant scope. This led to a significant portion of this information being discarded.

3 Conceptual foundations

This section describes the conceptual foundations for the research. The main functions were 1) to rationalise the assumption that uncertainty and multifunctionality connect to the resilience of socio-ecological systems, 2) to justify the selection of themes for analysis, and 3) to provide a framework that relates uncertainty and multifunctionality to decision making and finance for resilience.

3.1 Conceptualising uncertainty

The work of Stirling (2006), *Precaution, foresight, and sustainability: reflection and reflexivity in the governance of technology* was used to define a typology of uncertainty. The typology presented by Stirling was chosen because it is informed by principles that reflect a deeper consideration of the subjective, worldview-based assumptions behind different understandings of uncertainty, allowing for a more robust analysis. Stirling bases his work on the principles of reflexivity and reflectiveness. Reflexivity is the recognition of the social contingency or subjective framing on which a governance regime is based (Stirling 2006). A reflexive process explicitly addresses various uncertainties informed by divergent worldviews, options, and contexts (Störmer and Truffer 2009). Reflectiveness is the degree to which a decision process considers the full range of choices available and the probabilities of all bias and error associated with each choice (Stirling 2006). Together, reflexivity and reflectiveness reveal multiple valid futures, multiple possibilities and solutions, and multiple layers of uncertainty and bias in decision making. The typology of uncertainty used for this analysis is depicted in figure 3-1 below. Stirling categorizes types of uncertainty based on "knowledge about likelihoods" and "knowledge about possibilities", reflecting important dimensions of both reflexivity and reflectiveness. "Knowledge about likelihoods" describes situations in which probabilities, errors, and bias in estimations of uncertainty are known and quantifiable. "Knowledge about possibilities" indicates a high level of consensus on how best to generate, select, describe, delineate, prioritise, or interpret the framing of each option.

Risk is defined by an adequate level of knowledge about likelihoods and possibilities, while *uncertainty* is defined by problems with the level of knowledge about likelihoods. For example, *risk* indicates confidence that the full range of possibilities is considered (knowledge about possibilities) and that the probabilities and errors associated with estimating risk are known (knowledge about likelihoods). In contrast, *uncertainty* maintains that some likelihoods cannot be known or quantified. *Ambiguity* is defined by an adequate level of knowledge about the likelihoods, but it maintains problematic consensus-building on how best to generate, select, describe, delineate, prioritise, or interpret the meaning or framing of the possibilities. If neither dimension has adequate levels of knowledge, decisions are made in a state of *ignorance*. These terms are *italicised* when referring to a quadrant in the theoretical framework.

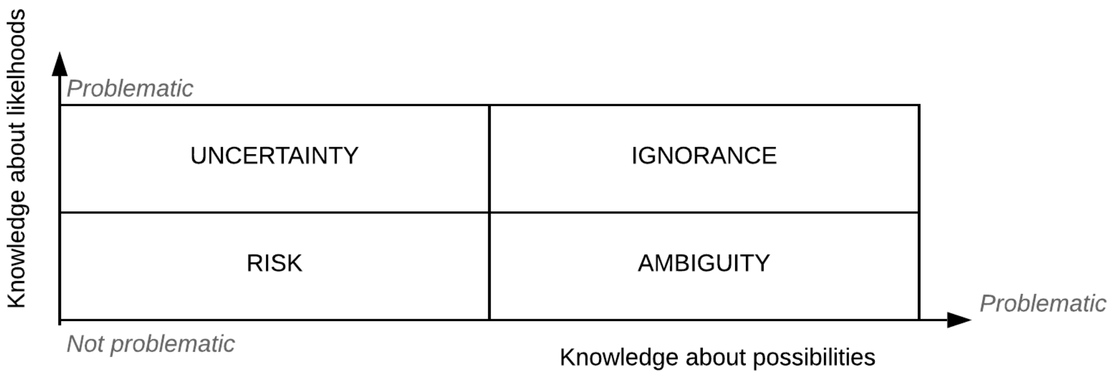

Figure 3-1 Theoretical framework for types of modes of uncertainty addressed with various decision-making methods (Based on: Stirling, 2006)

3.2 Conceptualising multifunctionality

There are several existing definitions of multifunctionality in literature for various sectors, which describe multifunctionality as a planning principle that considers the multiple benefits or functions of an intervention or ecosystem (e.g. Hansen and Pauleit 2014). Such definitions often break these benefits or functions into categories of society, economy, and environment. The research chose to define multifunctionality as a principle and a planning paradigm in which multiple economic, social and ecological functions are explicitly considered or leveraged, rather than simply occurring by chance (Kambites and Owen 2006). Multifunctionality of this nature seeks to combine multiple functions to use space more effectively (Ahern 2011). It is also recognised that multifunctionality may not be homogeneously located in time, space and interest to various stakeholders.

3.3 Connecting resilience, uncertainty and multifunctionality

A fundamental assumption guiding the research was that uncertainty and multifunctionality can be understood and considered in decision making in a manner that contributes to a more resilient water infrastructure system. As previously stated, resilience is defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.* 2004). Resilience theory accepts that change will manifest unexpectedly as surprise or uncertainty given the dynamics and interdependencies of complex systems (Folke 2006), leading to challenges predicting and planning for the future. Literature describes the interrelated concepts of resilience, adaptability and transformation (Folke *et al.* 2010). A socio-ecological system with high adaptability is able to reorganise within desired states or to maintain its current trajectory as a response to disturbance and changing conditions. In contrast, transformation is the ability of a system to cross thresholds and advance into new development trajectories (Walker *et al.* 2004). Transformation occurs in overlapping phases of 1) preparing a system for change, 2) navigating a transition to whatever the alternative system will be, and 3) institutionalizing and implementing the alternative system (Olsson *et al.* 2006).

Such conceptualisations of resilience point to the different types of uncertainty that exist to varying degrees in water infrastructure decision-making contexts, and the risk that a lack of consideration of these uncertainties may result in solutions that are brittle to uncertain futures or maladaptive (Gersonius *et al.* 2013). In the Orange-Senqu River Basin, a decision-making paradigm that better copes with uncertainty may contribute to adaptability by promoting solutions that are appropriate for a range of uncertain future conditions. For example, the possibility of unprecedented and difficult-to-predict population growth may require the water system to reorganise its ecological, social and institutional context to continue to deliver water services despite this pressure. The concept of multifunctionality is less obviously connected to the resilience of large-scale infrastructure like the Lesotho-Botswana Water Transfer in literature, as multifunctionality is most often used in association with ecosystems and natural infrastructure (e.g. Geoff 2010). However, actively leveraging the multiple functions of a piece of infrastructure recognises the interdependencies between the direct use of water and the resulting cascade of benefits and risks to ecology, economy and society. Thus, the multifunctionality lens contributes to resilience and adaptability by connecting solutions to the biophysical scale (Chaffin *et al.* 2014), focusing on ecosystem services (Anthony *et al.* 2017), and promoting a flexible and integrated knowledge lens (Herrfahrdt-Pähle 2013; Karpouzoglou *et al.* 2016). While uncertainty and multifunctionality highlight the biophysical realities and the drive toward resilience through adaptability, the role of transformation is apparent in efforts to transition from the conventional to emerging paradigms of decision making and finance.

3.4 Adaptive governance and categories of decision making

Existing applications of adaptive governance theory tend to analyse case study contexts for *implicit* governance characteristics that better deal with uncertainty and complexity. In contrast, the RQs investigate a case context for *explicit* decision methods and tools that actively deal with these elements. As such, the research did not evaluate the governance context in the Orange-Senqu River Basin for evidence of adaptive governance characteristics, but rather used the theory of adaptive governance to situate the research within the broader resilience discourse and define categories for analysis.

Governance is defined as the processes and structures used by people and societies to share power and make decisions, or the process of resolving trade-offs to provide a direction for sustainability (Folke *et al.* 2005; Lebel *et al.* 2006). Adaptive governance emerged from literature in resilience theory and can be defined as the "dynamic link between social and ecological landscapes that recognizes the complexity of ecological systems, inherent uncertainty, and unknown feedbacks stemming from social actions taken to manage ecological resources" (Chaffin *et al.* 2014). Adaptive governance attempts to recognize the inherent uncertainty in governance regimes built under a broad set of sustainability objectives, embracing the view that "whatever form a transition to sustainability might take, it implies finding the institutional frameworks to stimulate the kinds of innovation that solve rather than augment our environmental challenges" (Steffen *et al.* 2011). Table 3-1 summarises the key themes resulting from a brief review of the literature.

Table 3-1 Overarching themes based on literature review of adaptive governance theory (categories highlighted in grey make up the chosen themes for analysis)

Theme		Adaptive management paradigm
1. Structures for diversity and redundancy	1.1 Decision-making authority	Polycentric organisational authorities and mixed hierarchies, redundancy (Anthony *et al.* 2017; Folke *et al.* 2005; Chaffin *et al.* 2014; Pahl-Wostl 2009; Olsson *et al.* 2006)
	1.2 Collaboration	Networks and partnerships as a collective search for responsibility sharing, including state and non-state actors (Anthony *et al.* 2017; Folke *et al.* 2005; Pahl-Wostl 2009; Gunderson and Light 2006; Karpouzoglou *et al.* 2016)
	1.3 Scale and fit	Governance scale(s) matched to government system capacity, ecological/bioregional scale, and smallest appropriate level for function (i.e., subsidiarity) (Anthony *et al.* 2017; Chaffin *et al.* 2014; Olsson *et al.* 2006);
2. Knowledge integration, participation, and legitimacy	2.1 Knowledge systems and information	Preference for integration of scientific and indigenous/traditional/local knowledge, flow of knowledge between scales (Folke *et al.* 2005; Karpouzoglou *et al.* 2016; Pahl-Wostl 2009);
		Using best-available, real-time, actionable data (e.g. climate change); rapid but rigorous data; tightened loops between science and action (Ripley and Jaccard 2016)
		Integrated and flexible knowledge lens with a focus on ecosystem function and processes (Anthony *et al.* 2017; Herrfahrdt-Pahle 2013)
	2.2 Uncertainty and risk	Uncertainty conceptualized at multiple levels of risk, ambiguity and uncertainty, not all quantifiable (Stirling 2006; Folke *et al.* 2005); Uncertainty accepted and quantified if possible; remaining uncertainty explicitly recognized in governance methods like scenario planning (Varum and Melo 2010)
	2.3 Participation	Participation as a tool for knowledge generation, deliberation and legitimacy; strong commitment to equity (Anthony *et al.* 2017; Folke *et al.* 2005; Pahl-Wostl 2009; Karpouzoglou *et al.* 2016)
3. Methods for flexibility, experimentation and learning	3.1 Institutional adaptive capacity	High institutional adaptive capacity (3rd loop learning) (Pahl-Wostl 2009; Folke *et al.* 2005; Karpouzoglou *et al.* 2016)
	3.2 Experimentation	Policy and management as experiments (learning by doing), with continuous monitoring and iteration (Anthony *et al.* 2017; Folke *et al.* 2005; Pahl-Wostl 2009; Karpouzoglou, Dewulf, and Clark 2016)
4. Navigating a transition	4.1 Leadership functions	The ability to span different scales of governance, orchestrate networks, integrate and communicate understanding, and reconcile different problem domains (Olsson *et al.* 2006)
	4.2 Leadership entities	Epistemic and shadow networks that bring forward novel ideas, constructing incentives (Olsson *et al.* 2006)

The themes highlighted in grey in table 3-1 above were simplified and reorganised to form two categories analysis in table 3-2 below. These elements were chosen based on direct applicability to the research questions and the type of information available through documents and interviews. The main elements of row 2.1 on knowledge systems and information and 2.2 on uncertainty and risk from table 3-1 were combined into a theme simply called "knowledge systems". Similarly, the main elements of row 1.2 on collaboration and 2.3 on participation were combined into a theme called "stakeholder participation". As such, qualitative data collection about RQ1 (i.e. how uncertainty and multifunctionality are conceptualised and considered in decision-making processes) focused on the knowledge systems and stakeholder participation within those decision-making processes.

Table 3-2 Simplified categories for analysis based on adaptive governance theory

	Category	Definition	Adaptive governance
1	**Knowledge systems** *Sections 2.1, 2.2 from Table 3-1*	Sources and types of information, flow of knowledge and information between actors and scales, the primary lens of information processes	Integration of scientific and traditional knowledge; flow of knowledge between scales; using best available data with tight data-action cycles; focus on ecosystem function and processes; explicit tools and techniques for managing uncertainty and risk
2	**Stakeholder participation** *Sections 1.2, 2.3 from Table 3-1*	Roles, relationships, and responsibility sharing between actors to achieve objectives	Participation as a tool for knowledge generation, deliberation and legitimacy; strong commitment to equity; focus on networks and partnerships

3.5 Conceptual framework

The following conceptual framework depicts the main concepts applied to the case study context of the Lesotho-Botswana Water Transfer in the Orange-Senqu River Basin. RQ1 is addressed by applying the conceptualisations of uncertainty (section 3.1) and multifunctionality (section 3.2) that connect to resilience (section 3.3), and by examining the knowledge systems and stakeholder participation in the case study context according to the conventional and emerging decision-making paradigms from literature (section 4.1 of literature review). RQ2 is answered by the results of RQ1 to finance in a creative dialogue with interviewees.

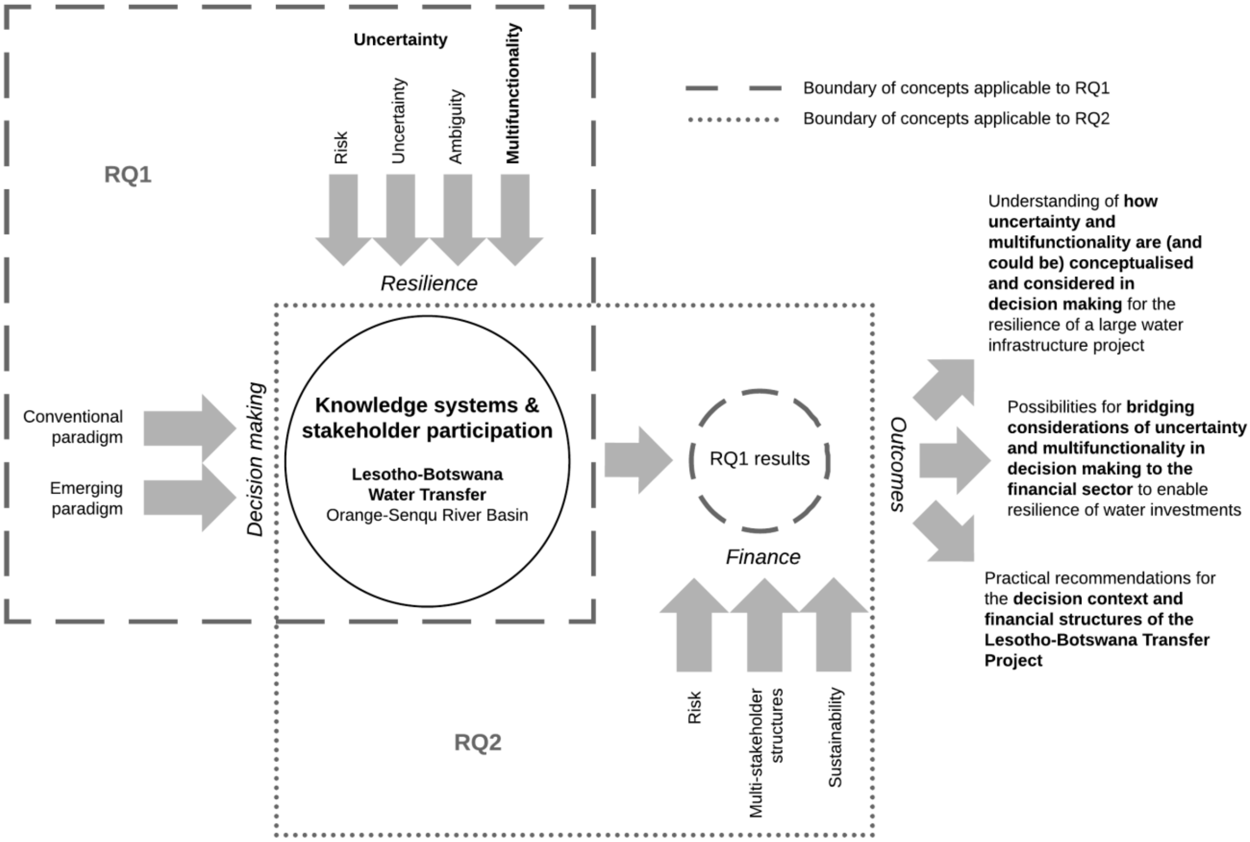

Figure 3-2 Conceptual and analytical framework

The intended outcomes of the process of applying the conceptual framework are indicated on the right of figure 3-2. These include 1) a better understanding of how uncertainty and multifunctionality are (and could be) conceptualised and considered in decision making for resilience of a large water infrastructure project, 2) possibilities for bridging considerations of uncertainty and multifunctionality in decision making to the financial sector to enable resilience of water investments, and 3) practical recommendations for the decision context and financial structures of the Lesotho-Botswana Water Transfer project.

4 Literature review

The literature review relates to two primary fields, water governance and finance, which operate in different academic paradigms and communicate in different languages. The first section addresses literature addressing resilience, uncertainty and multifunctionality in water infrastructure decision making. The exploratory nature of RQ2 demanded a broad review of finance literature, focusing on the water infrastructure gap in southern Africa, financial transformations for sustainable development, and investment decision making under deep uncertainty and for multifunctionality. This is followed by an introduction to the case study (section 5), including the water situation in the SADC, the Orange-Senqu River Basin, and the proposed Lesotho-Botswana Water Transfer project. Figure 4-1 depicts the flow of this literature review.

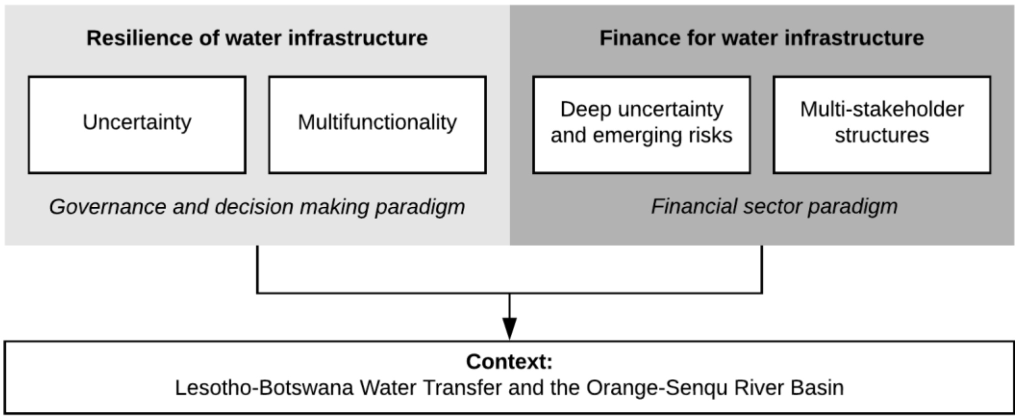

Figure 4-1 Literature review structure

4.1 Resilience of water infrastructure

Socio-ecological resilience is defined as the ability of a system to withstand or absorb disturbances and stressors so that the system stays within the same regime, essentially keeping its functions and structures (Holling 1973; Walker *et al.* 2004; Gunderson and Holling 2001). There is clear demand for water infrastructure to provide multiple benefits, particularly in emerging and developing economies experiencing the pressures and uncertainties of demographic shifts, poverty and climate change (Briceño-Garmendia *et al.* 2008). However, understanding the contribution of water infrastructure to the resilience of the surrounding socio-ecological system is a complex task (e.g. Tilt *et al.* 2009). Decision making that addresses the uncertainty and multiple functions of infrastructure can play a critical role in the addressing the resilience of water infrastructure systems (see section 3.3). The literature on water infrastructure decision making reveals various understandings of uncertainty and multifunctionality, which are considered in decision making through various methods. It also reveals distinction between the conventional engineering paradigm in contrast to an emerging, adaptive paradigm. These paradigms are termed "conventional" and "emerging" throughout the review.

4.1.1 Uncertainty

The review of literature on water infrastructure decision making under uncertainty brought out contrasting decision-making paradigms and a range of methods under each. The focus on uncertainty resulted in a focus on literature that favoured the emerging paradigm in contrast to the conventional.

4.1.1.1 Conceptualisations of uncertainty

In the context of water infrastructure decisions, uncertainty and risk can be characterised in a number of ways. Some simply define uncertainty as a situation in which incomplete knowledge exists about a project (Piyatrapoomi *et al.* 2004). Others define risk as "uncertainty management" (Piyatrapoomi *et al.* 2004) or as the probabilistic uncertainty that exists in the randomness of major flood and drought events and the sensitivity analyses performed alongside hydrological or climate models (Hallegatte *et al.* 2012; Piyatrapoomi *et al.* 2004). These uncertainties propagate when uncertainties in single variables generate uncertainties on probability functions or outcomes built upon them (Gersonius *et al.* 2013; Kalra *et al.* 2014). Deep uncertainty describes situations characterized by multiple potential futures without quantifiable probabilities that are informed by divergent worldviews (Bhave *et al.* 2016; Kalra *et al.* 2014; Lienert *et al.* 2015). Some define this deep uncertainty as a lack of consensus or knowledge of (1) the appropriate model to describe interactions in a complex system, (2) the probability distributions that represent the uncertainty of model parameters, and/or (3) how to prioritize or value alternative outcomes or desirable futures (Lempert 2003). For example, the uncertainty of socio-economic futures and climate science cascades to the water sector through the downscaling of regional-scale climate models to basin-level hydrological flows (Hallegatte *et al.* 2012; Lienert *et al.* 2015).

4.1.1.2 Conventional paradigm of decisions under uncertainty

The conventional paradigm of water infrastructure decision making that has traditionally dominated the water sector is a centralized, civil engineering paradigm (Störmer and Truffer 2009; Lienert *et al.* 2015; Lebel, Garden, and Imamura 2005) based on the goal of technical and economic optimisation and scientific rationality leading to a singular optimal strategy (Stakhiv 2011; Salet *et al.* 2013; Arkesteijn *et al.* 2015; Stapelberg 2010). This conventional paradigm focuses on minimizing risk assuming a stationary risk environment (Ranger *et al.* 2013) and using safety margins to account for unknowns (Kalra *et al.* 2014; Stakhiv 2011). This paradigm has continued to dominate decision making in recent decades (Störmer and Truffer 2009). These methods combined with the long life-span of water infrastructure have built a system characterised by path dependencies, self-reinforcing lock in (Wardekker *et al.* 2010), and a perpetuating dominant socio-technical regime (Störmer and Truffer 2009; Arkesteijn *et al.* 2015). Decision processes under the conventional paradigm are sometimes described as "agree-on-assumptions" processes, in which assumptions about present and future conditions are collectively defined and infrastructure alternatives are analyzed against those conditions.

Since the 1980s, the lens of scientific rationality is increasingly viewed as inadequate under conditions of increasing uncertainty and complexity (Lienert *et al.* 2013; Salet *et al.* 2013). Some claim that assumptions-based methods lead to 'brittle' solutions, meaning they may be ineffective or maladaptive if any assumptions break down (Kalra *et al.* 2014). The deep uncertainties of socio-economic forecasts, techniques for localizing global climate models, and projected hydrological flows is pushing the water sector to consider decision methods that embrace structural complexity (e.g. Williams 1999) to avoid brittle solutions (Hallegatte *et al.* 2012; Wardekker *et al.* 2010; Bhave *et al.* 2016).

4.1.1.3 Emerging paradigm of decisions under uncertainty

These challenges and the growing influence of resilience theory has led to a new generation of decision making from theories in transition management (Rotmans and Loorbach 2009) and adaptive management (Holling 1978). The emerging paradigm builds water infrastructure solutions and strategies from a foundation of uncertainty and complexity (Hallegatte *et al.* 2012; Arkesteijn *et al.* 2015; Stapelberg 2010; Lempert and Groves 2010) and several authors use the term robustness to describe a desired state of solutions (e.g. McDaniels *et al.* 2008). Robustness "trad[es] some optimal performance for less sensitivity to broken assumptions, performing relatively well compared to the alternatives over a wide set of plausible futures" (J. Hall *et al.* 2012). These solutions contrast with agree-on-assumptions processes by using a principle of "agree-on-decisions". Such decisions absorb several possible futures and objectives, without requiring consensus over which conditions are most likely and which objectives are most important (Kalra *et al.* 2014), requiring a suite of methods including scenario planning (J. Hall *et al.* 2012; Lempert and Groves 2010). Though promising, these methods have not permeated decision making at a global scale (Bhave *et al.* 2016), due to institutional barriers, competing development priorities, resource and capacity constraints, transaction costs, and limited applicability to surprise events (Allen and Gunderson 2011; Berkes *et al.* 2000; Bhave *et al.* 2016; Hallegatte *et al.* 2012).

4.1.1.4 Examples of decision making methods

Water infrastructure decisions under the conventional paradigm define a set of future context conditions, choose a set of objectives, and employ a variety of methods to devise a plan that achieves those objectives according to the assumed future context. Even those that consider climate change often choose a specified "most likely" core scenario and optimise a plan to that scenario as an adaptive strategy, including planning under the paradigm of Integrated Water Resources Management (IWRM) (Gersonius *et al.* 2013; Gourbesville 2008). Traditional risk analysis identifies project risks and ranks them according to the likelihood of the risk event and the severity of the impact (Ascough *et al.* 2008; Piyatrapoomi *et al.* 2004). Decisions made based on assessments of cost-benefit analysis (CBA) compare alternatives to determine the overall benefit-cost ratio to society (Piyatrapoomi *et al.* 2004), and though methods exist to consider a wider range of ecological and social externalities, they are not integrated into routine practice due to practical challenges monetizing and discounting those externalities into the future (Hallegatte *et al.* 2012; Stakhiv 2011). Multi-criteria decision analysis (MCDA) considers a more multidimensional decision criteria in a weighted decision index (Lienert *et al.* 2015) but still strives for optimality. Under this paradigm, uncertainty tends to be quantified with probability or sensitivity methods or ignored.

Planning processes under the emerging paradigm reflect principles of adaptivity and flexibility. Manocha and Babovic (2018) provide a summary of underlying methodological approaches that support this emerging paradigm, including scenario planning, assumption-based planning, exploratory modelling analysis, and info-gap decision theory. Scenario planning appears to be one of the most common methods (Varum and Melo 2010; Dong *et al.* 2013), using known future elements in combination with participatory processes to construct possible alternative futures and understand the complexity that may lead to surprises. The literature also describes a long list of established planning methods (Manocha and Babovic 2018). Examples of regional-scale planning processes based on these methodologies and tools include Regional Infrastructure Foresight (RIF) and Dynamic Adaptive Policy Pathways (DAPP). RIF is derived from transition management theory and attempts to address multiple worldviews, interdependencies, and adaptivity into a 9-month, multi-stakeholder regional infrastructure planning process (Störmer and Truffer 2009). DAPP situates infrastructure planning within a broader context of a long-term future and includes collaborate scenario development, visioning exercises, and formulation of desired pathways and contingency plans (Haasnoot *et al.* 2013; Lawrence and Haasnoot 2017). Specific analytical tools applied to individual projects or pieces of infrastructure also appear useful, including Robust Decision Making (RDM) that tests solutions against a wide range of possible futures (J. Hall *et al.* 2012; Bhave *et al.* 2016; Kalra *et al.* 2014; McDaniels *et al.* 2008). Climate-informed decision analysis, similar to decision scaling (Brown 2011), connects top-down climate models with bottom-up vulnerability analyses by identifying which climate changes are expected to affect the project, determining the likelihood of those sets, and facilitating decision options that are robust to various plausible futures (Hallegatte *et al.* 2012). Climate modellers are also seeking ways to deal with uncertainties of downscaling global climate models to regional scales (Hallegatte *et al.* 2012; Lienert *et al.* 2015), such as the use of multi-model ensembles (Tebaldi and Knutti 2007).

Table 4-1 Summary of literature review on uncertainty in water infrastructure decision making

	Conventional	**Emerging**
(Some) common characteristics	Rational, technocratic, deterministic, technocratic, static plans, confident probabilistic outcomes, predict-then-act, "agree on assumptions"	Deep uncertainty, experimentation, adaptive solutions and plans, multiple goals, multiple outcomes, multiple scenarios, "agree on decisions"
Managing uncertainty	Identify, calculate and communicate uncertainty	Build decisions from uncertainty
Examples of analytical methods	CBA, MCDA risk analysis, sensitivity and probability-based analyses	RDM, info-gap methods, climate-informed decision analysis, real options analysis
Examples of infrastructure planning methods	Risk and probability-based infrastructure planning	Regional infrastructure foresight, dynamic adaptive policy pathways

Though some authors attempt to adapt methods under the conventional paradigm to emerging challenges (e.g. Alves *et al.* 2018), the literature under the emerging paradigm tends to be critical of the conventional paradigm, potentially overlooking opportunities to integrate methods from multiple paradigms. The literature does not articulate which methods are appropriate for different scales or objectives, and cases from the emerging paradigm in developing countries are underrepresented. This section of the literature review is summarised in table 4-1.

4.1.2 Multifunctionality

Water infrastructure is traditionally viewed as having the primary function of supplying, treating, or conveying water to specific end users; a more holistic lens reveals its multiple functions. Multifunctionality as a concept used in infrastructure planning means that multiple economic, social, and ecological functions are explicitly considered, rather than occurring by chance. These multiple functions are meant to provide benefits like human health and social cohesion, while also providing for intact ecological systems (Hansen and Pauleit 2014; Kambites and Owen 2006; Pauleit *et al.* 2011). By combining and intertwining these functions, planning processes utilise space more efficiently (Ahern 2011) and benefits may be allocated more effectively to different stakeholders over time. Co-benefits is a term used to describe a similar concept as multifunctionality in the literature (e.g. Alves *et al.* 2018).

The concept of multifunctionality originated in the agricultural sector as a way to describe its contribution to wealth in rural landscapes by providing ecological services, water management, rural development, and food security (Van Huylenbroeck *et al.* 2007; Fraiture *et al.* 2010). From the 1990s onward, the European Union adopted multifunctionality as a cornerstone of its European Model of Agriculture in response to pressures from international bodies to reduce price support for agricultural commodities, leading to a view that agriculture provides a fundamental contribution to rural quality of life and livelihoods (Renting *et al.* 2009). From this strong conceptual foundation, the concept of multifunctionality has more recently moved to the field of green infrastructure planning (Tiwary *et al.* 2016), with planners borrowing from the field of ecosystem services to operationalise the concept (Hansen and Pauleit 2014). For example, a performance index approach was developed to plan for the multiple benefits of urban streetscapes (Tiwary *et al.* 2016) and a method for identifying spatial synergies and trade-offs between multiple functions was developed for applications in city planning (Madureira and

Andresen 2014). These efforts have met challenges categorizing and allocating benefits and services, due to the multi-scalar character of green infrastructure (Demuzere *et al.* 2014).

Most literature for green infrastructure focuses in the urban context, but some authors point to the landscape dynamics of nature conservation, agriculture, and residential development in a complex group of actors in rural areas (Dijst *et al.* 2005). Function-analysis and economic valuation has been used as a tool to assess the socio-economic benefits and ecological services of landscapes (Groot 2006). This process simplifies ecological complexity to a list of ecosystem functions, which provide a range of goods and services. These goods and services are then valued, and conflicts between scale levels and stakeholders are assessed; an example of the findings from such a process is that natural and semi-natural landscapes are often more economically beneficial than converted landscapes (Groot 2006). The concept of multifunctionality has also been used to merge residential development and nature conservation, the landscape dynamics of agricultural abandonment, and the complex relationships between spatial planning, changing land use, and urban sprawl (Dijst *et al.* 2005).

Multifunctionality has more recently moved to the water sector. Emerging urban water management efforts aim to align urban development and basin-wide water resources goals (Bahri 2012), using multifunctionality to reduce the impacts of urban developments on the total water cycle (e.g. Mitchell 2006). Others point to the need for integration across sectors to provide for sanitation, irrigation, energy, and environmental services (Gourbesville 2008). Some literature urges for a longer-term perspective that leverages synergies between agricultural production and multiple ecosystem services (Fraiture *et al.* 2010). More recently, climate change and demographic uncertainties are motivating research on multifunctionality for grey and green infrastructure for flood risk. Alves *et al.* suggest a method for selecting green and grey urban flood solutions that uses MCDA for flood reduction, cost minimization, and co-benefit enhancement (Alves *et al.* 2018). Taking these dynamics a step further, a multi-agent framework was tested in Chile to consider indirect complexities by connecting the impacts of informal rental markets and technology change on water use efficiency and household income (Berger *et al.* 2007). A more directly relevant case in Senegal examined multifunctionality in the context of a large dam, where the centralised rice irrigation projects that were used to justify the investment failed. The case examined the potential benefits of an alternative strategy investment in multifunctional irrigated agro-forestry (Venema *et al.* 1997).

In the water sector the concept of benefit sharing complements the concept of multifunctionality. Rather than managing multiple beneficiaries through water quantity allocation, benefit sharing promotes the distribution and allocation of benefits (Phillips *et al.* 2006). Several authors argue that benefit sharing opens up opportunities for a positive sum solution (Biswas 1999), avoiding difficult negotiations (Sadoff and Grey 2005). Other authors argue that in practice delinking negotiation of rights and benefits in practice is difficult and often impossible (Dombrowsky 2009). The literature placing multifunctionality in the water sector focuses on identifying and leveraging multiple functions to make better decisions. It appears less developed than that for agriculture and green infrastructure, perhaps because of the sectoral silos that dominate conventional water sector planning. There appear to be few applications to large-scale, high-impact infrastructure projects, despite the complexity and distributed nature of the impacts and benefits upstream and downstream.

4.2 Finance for water infrastructure

This section provides a brief description of the current financial sector transformation and a review of literature that connects uncertainty to finance, addresses investment decision making under deep uncertainty and emerging risks, and describes the structuring of multi-stakeholder agreements when operationalising the multifunctionality of large-scale water infrastructure.

4.2.1 Financial sector transformation

Closing the water infrastructure gap is one factor among many that is pushing the financial sector toward a broader sustainability transformation. The literature converges on the need to transform to a system that better supports the 2030 Agenda for Sustainable Development and the measures under the Paris Agreement (Kerste *et al.* 2011; Wang *et al.* 2017). Specific actions include market-based initiatives to integrate social and environmental risks and opportunities in businesses approaches, national-level efforts to implement climate adaptation or mitigation policies or achieve development goals, and international initiatives under the Group of Twenty (G20), the Financial Stability Board, and the United Nations (World Bank and UNEP 2017). The United Nations Environment Program Inquiry into the Design of a Sustainable Financial System is attempting to push the dialogue to a united movement to transformative change. The report titled *Financing sustainable development: Moving from momentum to transformation in a time of turmoil* (Zadek and Robins 2016) outlines the actions required to "place sustainable development at the heart of the financial system".

4.2.2 The water infrastructure gap

Commitments to water infrastructure in the southern African region were $1.9 billion in 2016 with South Africa receiving an estimated $528 million (ICA 2017); however, the water infrastructure gap persists estimated at $11 billion (Tandi and Earle 2015; Briceño-Garmendia, Smits, and Foster 2008). It is also estimated that the overall cost of climate adaptation in Africa will range from $20 to 30 billion per year for the next two decades (Duru and Nyong 2016). Several sources blame the infrastructure deficit on a lack of capacity to build a pipeline of feasible and financially attractive projects (ICA 2017; Collier 2014) within a strategic, forward-looking framework (Gutman *et al.* 2015). In addition to the long lifetimes, multifunctionality, high expense, and exposure to climate risk previously described, water infrastructure has distinct, financially-relevant characteristics including irreversibility, design for a single function despite its multifunctionality, high capital requirements and elements of a monopoly (Collier 2014; Caltz and Fourie 2010). Other sources blame a lack of available financing for the gap. The financial crisis of 2008 placed constraints on bank lending, traditional risk mitigation tools are proving unsuitable in new contexts (World Economic Forum 2013), and many African governments do not have access to resource pools like pension funds and capital markets (Biensan 2017). These are exacerbated by ongoing issues of weak transparency, accountability and corruption in the infrastructure sector (Rose-Ackerman and Palifka 2016).

4.2.2.1 The role of green finance

In 2008, the World Bank Group put forward the Strategic Framework for Development and Climate Change (Coston *et al.* 2014), describing a clear set of actions required to mitigate or manage the challenges of introduced with climate change. In 2016, the Heads of State at the G20 Hangzhou Summit recognized the need to "scale up green finance" (G20 Green Finance Study Group 2017b). The G20 Green Finance Study Group (GFSG) defines green finance as "financing of investments that provide environmental benefits in the broader context of environmentally sustainable development" (G20 GFSG 2017b). Green finance mechanisms are intended to address climate change mitigation and adaptation and the challenges of infrastructure projects accessing finance, including the water sector (Morel and Bordier 2012).

4.2.3 Investments under deep uncertainty and emerging forms of risk

This section of literature situates investment decision making as a subset of the broader decision-making space described in section 4.1. This focus is warranted as the capital budgets of African governments generally fall short of actual needs (Briceño-Garmendia *et al.* 2008), and the literature suggests that a shift is required to promote robust and flexible investment decisions. Such decisions can be supported by the range of planning methodologies (e.g. scenario planning), still but require financially-relevant metrics (e.g. robustness) and tools (e.g. real options) to influence investment decisions.

4.2.3.1.1 Investment decision metrics

Conventional investment decisions are based on least-cost approaches and optimal solutions (Gersonius *et al.* 2013; Hallegatte *et al.* 2012). Such approaches view aggregate costs and benefits as the ultimate basis for decisions (Huskova *et al.* 2016), with decisions made without full knowledge of the long-term implications (Cohon and Marks 1975). Investment decisions that consider climate change impacts are often based on a most-likely climate scenario that informs "singular optimal adaptive strategy" (Gersonius *et al.* 2013). However, truly optimal decisions are elusive due to the presence of market uncertainties (Slovik 2009), now exacerbated with deep climate and socio-economic uncertainties (Hallegatte *et al.* 2012) and the trade-offs between environmental, engineering and financial performance metrics (Huskova *et al.* 2016). These challenges have led to some convergence on "robustness" as a preferred metric, testing investment options for an ability to achieve objectives over a range of future scenarios (Huskova *et al.* 2016). A subset of this literature reflects efforts to increase the "flexibility" of infrastructure investments (e.g. Grayburn 2012; Gersonius *et al.* 2013).

4.2.3.1.2 Investment decision tools

Similar decision-making methods for addressing uncertainty and multifunctionality in section 4.1 apply to investment decisions. An investment-specific lens highlights robust approaches such as "no-regret" strategies, "reversible and flexible" strategies, "safety-margin" strategies, and strategies that reduce decision-making time horizons (Hallegatte *et al.* 2012). In addition, flexible investments include the agency provided to infrastructure managers or government to change course after the infrastructure investment is undertaken and the flexibility of delaying the investment until a later time (Grayburn 2012). Traditional Net Present Value (NPV) or Internal Rate of Return approaches to assessing economic and financial options are biased against flexibility as they assume that investments are "now-or-never" with no opportunity to react to new information (Yeo and Qiu 2003). Real Options (RO) analysis complements NPV for conditions when 1) the investment is at least partly irreversible, 2) there is a significant element of uncertainty associated with the underlying asset and the amount of time before a decision is required, 3) there must be available investment opportunities that provide management with the freedom to respond to new information, and the 4) investment should be relatively marginal (Grayburn 2012).

The choice to sequence investments provides another dimension of flexibility (Grayburn 2012). This includes the possibility to build one piece of infrastructure in phases, or to build multiple pieces of infrastructure in phases that take advantage of growing certainty or economies of scale. In addition to the flexibility provided by the choice to sequence in itself, each possible investment sequence may provide a varying level of flexibility that can be quantified (Manocha and Babovic 2018). Tools have been developed to assess this flexibility, which may also help participatory scenario planning processes to choose which among multiple planned development pathways may be preferred. However, executing this flexibility requires a mature process of institutional learning in which each phase of the infrastructure investment informs decision making for subsequent phases (Pahl-Wostl 2008).

4.2.3.2 Emerging forms of risk and water infrastructure

Local contexts and infrastructure projects are subject to a variety of risks that investors expect to identify, quantify and manage (Gutman *et al.* 2015; ICA 2017). This section of literature addresses 1) corporate investment and supply chain risk, and 2) the process of mitigating and distributing risk in multi-party agreements like public-private partnerships (PPPs). The financial sector is grappling with how to address deep uncertainty in financial language and risk tools.

4.2.3.2.1 Assessing risk

Various sources categorize risk differently, though typologies often include project development risk, construction risk, operating risk, credit risk, political risk, and liquidity risk (Green Climate Fund 2015; Mbeng Mezui and Hundal 2013; Gutman *et al.* 2015; Oji 2015; Biensan 2017; Collier 2014). Other sources differentiate sector risk, such as market demand or technology risk, and project risks associated with the circumstances of a project that affects the benefits the project may achieve. Many sources show that the magnitude of these risks diminishes through the phases of the project cycle (Heath and Read 2014). Risks such as climate change impacts, resource scarcity, environmental pollution, and social issues such as voluntary resettlement, are often identified for their role in exposing financial institutions to reputational, liability or credit risk. In addition to efforts from banking regulators and other institutions (International Finance Corporation (IFC) 2014), the G20 GFSG is addressing Environmental Risk Assessment (ERA) as a cross-cutting issue that supports its strategic objectives. Their findings show that more widespread adoption of ERA requires broadening the scope of risk, linking these assessments across scales, promoting coherence in scenarios analyses, integrating ERA into core processes, and moving from a prudential to a systemic view of environmental risk (G20 Green Finance Study Group 2017a; IFC 2014).

4.2.3.2.2 Water infrastructure risk

Most research about water infrastructure risk has emerged to facilitate risk allocation in PPPs, and studies that identify, categorize and rank these risks are numerous (Xu *et al.* 2011; Cheung and Chan 2011; Ameyaw and Chan 2013). However, many of the risks were obtained from samples limited by geography or project type (Chen and Messner 2005; Ameyaw and Chan 2015b). The most relevant study ranking risk categories in PPP water supply projects in developing countries listed financial risk as the most significant, followed by legal and socio-political (Ameyaw and Chan 2015a). Another study ranked the top ten risks as poor contract design, water pricing and tariff review uncertainty, political interference, public resistance to PPPs, construction time and cost overrun, non-payment of bills, lack of PPP experience, financing risk, faulty demand forecasting, high operational costs, and conflict between partners (Ameyaw and Chan 2015b). This literature misses a more integrated, long-term view of environmental and social risk.

4.2.3.2.3 Climate change risk

Climate risk is often categorized into physical and transition risks (Berg *et al.* 2018; G20 Green Finance Study Group 2017a; Clapp *et al.* 2017). Physical risks result from increased extreme weather such as floods, droughts, storms, and high winds. Transition risks are those associated with the policies, liabilities and technologies that connect to a transition to a low carbon economy (Clapp *et al.* 2017). These risks can be connected to financial impacts, such as production and operation distributions for utilities, physical damage to assets, rising insurance costs, and changes in demand for products and services (Berg *et al.* 2018). Analytical tools, like the Drought Testing Tool from GIZ (i.e. Die Deutsche Gesellschaft für Internationale Zusammenarbeit) and the Natural Capital Financial Alliance, help investors identify and manage physical risk (Clapp *et al.* 2017). The literature also promotes scenarios analysis to map out transition risks of climate change and their financial implications; scenarios for physical risk are only relevant in the long-term view as climate impacts in the next 10 to 20 years are more dependent on historical greenhouse gas emissions (Berg *et al.* 2018). Other sources promote the use of scenarios alongside a method for specifying the shades of climate risk, which considers the probability of a physical event, the vulnerability of the context to the hazard, and the exposure of the entity (Clapp *et al.* 2017).

The insurance sector can be a messenger of the costs of climate change, as accessibility to insurance at desired costs is very sensitive to changes in the underlying risk environment, such as those introduced with socio-economic development and climate change (Association of British Insurers 2005). The insurance sector is innovating to deal with the variability and surprise of climate change. For example, resilience bonds link insurance to resilience projects in order to monetize avoided losses from extreme events (e.g. reduced flood insurance costs and claims) through a rebate mechanism. The "resilience rebate" provides a source of reliable funding that insurance policyholders can invest in projects that proactively reduce risk (re:focus 2017). In addition, a recent article by Cremades *et al.* (2018) urges the insurance sector to use the adaptive cycle (Fath *et al.* 2015), a framework that describes the dynamism of ecological systems, to reduce climate insurance costs and secure future insurability in the face of increasing frequency of extreme hydrological events (Cremades *et al.* 2018). Recent studies on green-labelled investments show that these assets and projects may introduce "environmentally related credit risk" due to their exposure to climate change risks that may affect the bottom line (Clapp *et al.* 2016; Ehlers and Packer 2016; Corfee-Morlot *et al.* 2012).

4.2.4 Multi-stakeholder structures and multifunctionality

The financial elements of multifunctionality include a broad set of project functions and beneficiaries, leading to the diverse set of users that offtake water from the system. In addition, the dominant discourse indicates that a mixture of public and private sector funders and financiers for water infrastructure is required (Briscoe 1999). Offtake agreements between the government or water supplier and a commercial water user are often negotiated before project construction to secure a market for a portion of the water by contractually binding the user to off-take a volume of water at a negotiated price for a period of time. Literature addressing agreements with multiple beneficiaries is difficult to separate out from broader discourse, so a select few sources were chosen that provide a summary relevant to the southern African context.

Public and private sector entities in South Africa dominate large-scale infrastructure finance in the Orange-Senqu River Basin (Turton and Funke 2008). Traditionally, the national government took full responsibility for planning, installing and financing infrastructure (D. Hall *et al.* 2005), setting the end price of water at a marginal level or lower. More recently there has been growing involvement of non-public entities (D. Hall *et al.* 2005), though current water sector legislation prevents full privatisation of the water sector. A recent study identified the primary models for financing water infrastructure in South Africa; the conventional model uses on-budget funding from the National Revenue Fund or through grants (Ruiters and Matji 2015). For projects implemented by the Department of Water and Sanitation (DWS), special purpose vehicles like the Trans-Caledon Tunnel Authority (TCTA) have been set up to facilitate agreements between the DWS and offtakers, raise loans for ring-fenced projects based on committed revenue streams from these agreements, and project manage the implementation (Busari and Ndlovu 2012; TCTA 2016). Alternatives to these models include fundraising on financial markets, PPPs, or through other financial institutions (Ruiters and Matji 2015).

Despite the recognition that the business case may improve if water projects are conceptualised to serve a range of purposes (Tandi and Earle 2015), several challenges inhibit these processes in Africa. The mixed performance of partnerships between the public and private sectors and public-sector capacity challenges have led to slow implementation and caution about their effectiveness from financiers and governments. In addition, potential future water users may be excluded from financial models and project design in circumstances where there is uncertainty over when and if they will commit to offtaking water (Tandi and Earle 2015). The process of developing multifunctional business cases for infrastructure projects that apply across scales and sectors is a difficult coordination exercise and many utilities in Africa face major challenges with bill non-payment, perpetuated by a lack of incentive for utilities to address these issues (Szabó and Ujhelyi 2015). In some cases, the solution has been to ring-fence an infrastructure project and raise money based on the strength of the revenue streams realised through the tariff payment system. This approach allows projects that benefit water users who can pay for water to be funded off the budgets of government, allowing government to maintain ownership of infrastructure and prioritise allocate of its fiscus to social users who cannot afford to pay tariffs (Department of Water Affairs (DWA) South Africa 1997). There is some concern that this approach may limit some locales to adjust their spending to reflect needs across sectors and that government guarantees may have consequences on the public financial system (Tandi and Earle 2015), though the details of this claim are unclear.

5 Case context: The Lesotho-Botswana Water Transfer in the Orange-Senqu River Basin

The context for this case study is the proposed Lesotho-Botswana Water Transfer project in the Orange Senqu River Basin. This section provides an overview of the regional economic community, the river basin, and the infrastructure project, including biophysical, transboundary governance, socio-economic, and financial characteristics.

5.1.1 The Southern African Development Community

The SADC includes fifteen member countries, encompassing the region from the northernmost humid region of the Democratic Republic of Congo to the southern tip of South Africa. The region has rural and urban populations of approximately 181 and 101 million people respectively, with significant expected population growth (SADC 2016b). Individual countries in the SADC have dramatically different natural resource and development profiles (SADC 2016b), and in 2013 South Africa held 55.5 percent of the regional gross domestic product (GDP) (South African Institute for International Affairs 2016). The SADC is characterised by extreme temporal and spatial differences in availability of water resources. Annual rainfall varies from approximately 4000 mm in the north to less than 50 mm in the southwest along the Namibian coastline (Boroto 2004), with most of the region receiving less than the global average of 860 mm per year (Turton 2008). The Intertropical Convergence Zone runs across the northern part of the SADC and pushes moist, warm air southward in the summer, causing much of the summer precipitation. Any disturbance to this process can cause significant changes to rainfall patterns, making southern Africa particularly vulnerable to climate change (Entholzner and Reeve 2016).

The level of natural resource development also varies considerably, including water storage capacity, quality of infrastructure, and ability to convey water to locations of growth and economic development (Schreiner and Baleta 2015). The region has 15 major transboundary rivers (Ashton and Turton 2009) and 20 major transboundary aquifers (Christelis *et al.* 2013). In addition, some of the region's most developed countries face the most water stress, including Botswana, Namibia, South Africa, and Zimbabwe. Spatial differences in water availability within each country are also a concern, as major growth centres are often distant from water sources (World Bank 2014). Several regional water management efforts have been established including the Revised SADC Protocol on Shared Watercourse Systems (SADC 2000), the Regional Water Policy (SADC 2005) and its supporting Regional Water Strategy (SADC 2006), and Regional Strategic Action Plans (SADC 2016a). The SADC Regional Infrastructure Development Master Plan guides development of transboundary water infrastructure (SADC 2012).

5.1.2 The Orange-Senqu River Basin

The Orange-Senqu River Basin originates in the Lesotho Highlands and travels over 2300 km along a geographically variable path from the water-rich mountains in Lesotho, the arid regions of Karoo and Richtersveld in South Africa, and the deserts in Namibia (African Water Facility 2016; World Bank 2014). A brief summary of some key elements is described in table 5-1 below.

Table 5-1 Water resource supply and demand by country of the Orange-Senqu River Basin (ORASECOM 2014b)

Country	Proportion of basin area (%)	Estimated contribution to runoff (%)	Proportion (%) of basin population	Consumptive water use in 2014 (Mm^3) (%)
Botswana	12.7	0.3	0.3	0.008
Lesotho	3.2	41.5	15.4	0.749
Namibia	24.8	5.2	2.6	2.953
South Africa	59.3	53.0	81.7	96.291

5.1.2.1 Biophysical context

The Orange-Senqu River Basin covers a catchment area of 1 million km^2, of which 64.2% is in South Africa, 24.5% is in Namibia, 7.9% is in Botswana, and 3.4% is in Lesotho (ORASECOM 2008, 2014c). The Orange-Senqu covers nearly half of South Africa, all of Lesotho, and drains almost all of the southern part of Namibia. Precipitation decreases dramatically from the east to west of the catchment, with Lesotho contributing 40 percent of the total runoff (World Bank 2016b) and the arid, lower ephemeral reaches of the river contributing very little surface runoff to the main river (ORASECOM 2013a). Figure 1-1 in the Introduction shows a map of the Orange-Senqu River Basin demarcated by a red line.

Botswana, Namibia and South Africa have already experienced regional water scarcity to varying degrees. This is exacerbated by climate change impacts that are expected to increase temperatures and climate variability and decrease precipitation in the arid portion of the basin, leading to an increase in frequency of severe droughts (ORASECOM 2011b). A recent Transboundary Diagnostic Analysis identified severe environmental problems in the basin, including deteriorating water quality, increased sediment loading, degrading land and ecosystem services, and changing hydrological regimes. Unsustainable agricultural and mining land management have created compounding impacts in the region (ORASECOM 2014b).

5.1.2.2 Socio-economic context

The Orange-Senqu is among the top three most important river basins in Africa, contributing over 10 percent of the GDP of sub-Saharan Africa (World Bank 2016b) and supporting the livelihoods of 14 million people within the basin system (ORASECOM 2014b). The significant and fluctuating demand for water resources combined with variable water availability make it one of Africa's most disputed water sources (Turton and Funke 2008). The flow is regulated by 30 major dams with greater than 12 million m^3 of storage and many more smaller dams (Blumstein 2017), with reservoirs depicted in figure 5-1 above. South Africa dominates water consumption in the basin at 96 percent by volume in 2014 (table 5-1) (ORASECOM 2014b), with agricultural irrigation and strategic industries in the Vaal region comprising the most significant share (ORASECOM 2014a). Estimates of the mean runoff and abstractions from 2005 show that of the 11,500 Mm^3 annual runoff, abstractions equal 5,730 Mm^3, with 780 Mm^3 transferred directly from the Lesotho Highlands to South Africa through the Lesotho Highlands Water Project (LHWP). Groundwater infiltration and evaporation are expected to remove an additional 3,000

Mm^3, leaving 3,000 Mm^3 for exploitation. However, 1,000 Mm^3 of this is required for ecosystem functions, leaving only 2,000 Mm^3 available for sustainable use (World Bank 2014).

Figure 5-1 Map of the reservoirs in the Orange-Senqu River Basin (ORASECOM 2013b)

5.1.2.2.1 Lesotho

With a poverty rate of 56.3 percent and an income per capita of US$851, Lesotho is one of the least developed countries in the SADC (World Bank 2016a). The country currently uses very little of its own high-quality water resources for agriculture, though this is expected to change with increasing development. Instead, Lesotho is dubbed the "regional water tower" of southern Africa, as it transfers enough water to supply for over 12 million people in the Gauteng region of South Africa through the LHWP (Rousselot 2015). It is difficult to estimate the value of Lesotho's domestic water use to various sectors in its economy but estimates of direct revenues from royalties and tariffs after construction of Phase 1 of the LHWP were $US 20 to 30 million per year, or approximately 5 percent of the national GDP (Lesotho Highlands Development Authority 2017).

5.1.2.2.2 South Africa

South Africa dominates water use in the river basin through a complex water management system. For example, the Vaal and Orange Rivers are linked via basin transfer schemes and contribute 26 percent of the GDP through agriculture, energy production, manufacturing and mining (African Water Facility 2016). The Gauteng region receives its water supply from Lesotho via the LHWP, which contributes the largest portion of its economic development. South Africa also relies on the basin for hydropower and thermal power plant cooling, and an inter-basin transfer moves water resources from the Orange-Senqu to the Eastern Cape (ORASECOM 2014b). Such complexity has led to concentration of a significant share of the basin's water management competency in South Africa (Turton and Funke 2008).

5.1.2.2.3 Botswana

Botswana has a track record of economic growth and good governance, with its poverty rate declining by 30 percent since independence in 1966 and access to basic services improving dramatically (Statistics Botswana 2018). Botswana successfully implemented its National Water Master Plan (Setlhogile and Harvey 2004) and a 2006 review of its policies led to efforts in improving efficiency of water allocations, technological developments, and strategic infrastructure developments. Since then, its water losses, non-revenue water, and other metrics are at levels better than most other similar African utilities (Republic of Botswana 2016). However, the severity of current and future climate impacts and water scarcity combined with a high dependency on transboundary or international water sources, places Botswana in a vulnerable position. The North-South Carrier lies outside of the Orange-Senqu River Basin and was one of the first of several planned strategic investments to improve water security for Botswana. The pipeline moves water for 360 km from the Shashe River in the north to Gaborone, with Phase 1 completed in 2000 and Phase 2 completed in 2012 (Water Research Commission 2010). A proposed extension for would bring more water from the Zambezi River further north, shown in red.

5.1.2.3 Transboundary governance

The Orange-Senqu River Commission (ORASECOM) was established in 2000 to manage transboundary water resources in the Orange-Senqu River Basin. It was the first commission ratified after the SADC Protocol on Shared Watercourse Systems, which promotes the establishment of shared water system institutions and agreements (ORASECOM 2014b). ORASECOM is mandated to promote the beneficial development of the basin for socio-economic wellbeing and environmental safeguarding (ORASECOM n.d.). Though the states have the main responsibility to develop and manage water resources within their territory (ORASECOM 2014b), the goals of ORASECOM are to develop a comprehensive perspective of the basin, study the present and planned uses of water resources, determine the requirements for monitoring the flow and managing floods, and enhance socio-economic cooperation through solidarity. ORASECOM has established a basin-wide IWRM Plan that guides joint resource development and infrastructure planning under principles of equitable utilization, carefully planned measures, integrated management, avoiding significant harm, and preparing for emergency situations (ORASECOM 2011c). The structures of ORASECOM are complemented by several preceding bilateral agreements (ORASECOM 2014b) and Namibia and South Africa are also party to the United Nations Convention on the Law of the Non-navigational Uses of International Watercourses (McCaffrey 1998).

5.1.3 Lesotho-Botswana Water Transfer

The ORASECOM IWRM Plan provided the foundation for shared water management in the basin and identified the need for joint, mutually beneficial project implementation (ORASECOM 2014b, 2017b). Extreme and growing water scarcity, broad disparity in spatial distribution, and dependency on internationally shared water sources has led Botswana to seek out alternative solutions for a more water-secure future. Most of the water available in Botswana is located in the northwest, far from large and increasing water demands around the capital city of Gaborone in the southeast of the country (ORASECOM 2017). A hard-hitting drought in 2015 and 2016 further prompted urgent action (ORASECOM 2017). Botswana also has a dependency ratio of 80 percent, meaning that 80 percent of its total renewable water resources have origins outside of its borders (ORASECOM 2017). Climate change scenarios show that its already low and unreliable rainfall, flat topography, and low surface runoff may decrease significantly in the coming decades (ORASECOM 2011b).

As a response, the governments of Lesotho, Botswana and South Africa initiated a high-level study to evaluate possible water resource development and transfer options from the Lesotho Highlands to Botswana under the oversight of the ORASECOM. In March of 2013 the countries of Lesotho, Botswana and South Africa signed a Memorandum of Understanding to facilitate this process, reaffirming commitments to the SADC Revised Protocol on Shared Watercourses and the principles included in the Agreement on the Establishment of the ORASECOM (ORASECOM 2017). The World Bank led the 'Lesotho Highlands Botswana Water Transfer Desktop Study' (Bigen Africa (PTY) Ltd. 2015) that looked at the viability of options, assessing social, legal, environmental, financial, and engineering information (World Bank 2014). Though this study was not publicly available at the time of research, it led to the selection of a technical option for further study, which was a new dam on the Makhaleng River in the lowlands of Lesotho with a piped conveyance system to Botswana that would eventually pump at a capacity of 150 million cubic-metres annually (ORASECOM 2017). At the time of research, the intended outcomes of the L-BWT appeared to be to secure Lesotho's role as the "water tower of southern Africa", to initiate a longer-term strategy for strategic water security and integration in the region, and to benefit the estimated 600,000 people in southern Botswana with improved water supply. In addition, the approximately one million citizens of Lesotho were intended to receive benefits from investments in water infrastructure from the secured revenues, and 400,000 people in South Africa were intended to gain water access along the supply route (World Bank 2014). Detailed studies regarding water supply and demand were not yet completed at the time of research.

5.1.3.1 Future plans

In late 2017, the three governments announced they would move forward with a 24-month feasibility study for the L-BWT and mandated that ORASECOM facilitate this process alongside the development of a basin-wide infrastructure investment plan (ORASECOM 2017). A multi-disciplinary task team with representatives from all governments was established to consolidate information into advice for higher levels of decision making in ORASECOM and their representative governments. At the time of research, the guiding document for this work was the 'Terms of Reference for the Selection of Consultants for the Orange-Senqu River Basin: Climate Resilient IWRM Investment Plan and Lesotho – Botswana Water Transfer Project' (ORASECOM 2017). Because the ORASECOM IWRM Plan was developed without provisions for the L-BWT (ORASECOM 2014b), these new Terms of Reference (ToRs) account for future efforts to update plans and develop further thematic and strategic studies. Component I of the ToRs includes basin-wide efforts to update the core development and climate change impact scenario that informed the original ORASECOM IWRM Plan, to prepare a basin-wide investment plan with a list of prioritized projects, to optimise the IWRM plan core scenario according economic criteria, to develop a financing strategy for the IWRM plan, and to assess the instructional arrangements and structures that surround the IWRM plan and the L-BWT project. Component II includes plans to operationalise the IWRM plan by preparing a road map and action plan. Component III lays out plans for pre-feasibility studies for the L-BWT, including validation of water requirements, assessing options for siting the dam along the Makhaleng River, and conducting technical pre-feasibility for the dam and the conveyance system including an environmental and social impact assessment. Component IV provides for feasibility studies for the L-BWT including pre-feasibility studies for the dam and its linkages to the water conveyance system and preliminary design of the selected options with cost estimates (ORASECOM 2017). At the time of research, this information was available under the call for consultants.

6 Results and analysis

The four sections of the results and analysis are as follows. First, interviews were analysed for conceptualisations of resilience, uncertainty and multifunctionality, including commentary on the typology of uncertainty (figure 3-1). Second, interviews and documents were analysed for knowledge systems and participation that contribute to *understanding* uncertainty and multifunctionality and *integrating* them into decision making. This section includes commentary on which findings reflect the conventional versus emerging decision-making paradigms (table 4-1). Third, interviews were analysed for major themes bridging these elements of decision-making to the financial sector. A final section explores the influence socio-cultural on decision making to put the research into context.

6.1 Concepts in practice

The concepts of resilience, uncertainty and multifunctionality are defined differently in different fields of practice and from different perspectives. Interviewees characterised the concepts in multiple ways.

6.1.1 Resilience

Though the research is informed by a definition of resilience from the field of socio-ecological systems, interviewees communicated various characterisations of the term. Climate resilience was referred to as "resilience that can be provided by water infrastructure", situating infrastructure projects in a vulnerability context. Such resilience was firmly differentiated from the resilience of water infrastructure, which was dismissed as "climate proofing". One interviewee suggested that the relative abundance of water in Lesotho compared to the scarcity in Botswana was an opportunity to "build resilience". In contrast, some interviewees hesitated to provide definitive understandings of resilience and to assert a direct relationship between the L-BWT and resilience. One interviewee stated "there are a lot of uncertainties around is this the right thing to do, and what [we] mean by resilience". Another said, "we argue that because we have done the project it will provide resilience, but the question [is], is it the right project to provide resilience or is there another way of doing it"? Another interviewee criticized the climate resilience space, asserting that, "people in organisations love to jump on projects thinking this is going to make us resilient and transform lives, while [to] build resilience you need to build adaptive capacity, which is the ability to deal with uncertainty and change". In discussing the role of resilience in water utilities, an interviewee stated that, "when you think about resilience, you think about climate change and the ability to manage it, the ability to manage current climate variability, the ability to manage changes in demand for your services, the ability to just stay afloat. Those are different aspects and [it is important to me to say] which of those is more important to put more energy into." These responses reveal slightly different understandings of resilience, but they commonly characterise resilience as a desired state for a piece of infrastructure and its contribution to the broader system.

6.1.2 Uncertainty

Though uncertainty was not addressed widely in documentation, when prompted interviewees brought forward a host of uncertainties including the unknowns inherent at early project stages, uncertainties that can be quantified as risk, and ambiguities that are understood as a deep uncertainty. Interview prompts focused on identifying critical uncertainties, or uncertainties that were viewed as both high in uncertainty and high in importance. Major themes of uncertainty emerged including climate, water supply, water demand, political economy, and typical unknown project characteristics. These uncertainties are visualised in figure 6-1 below.

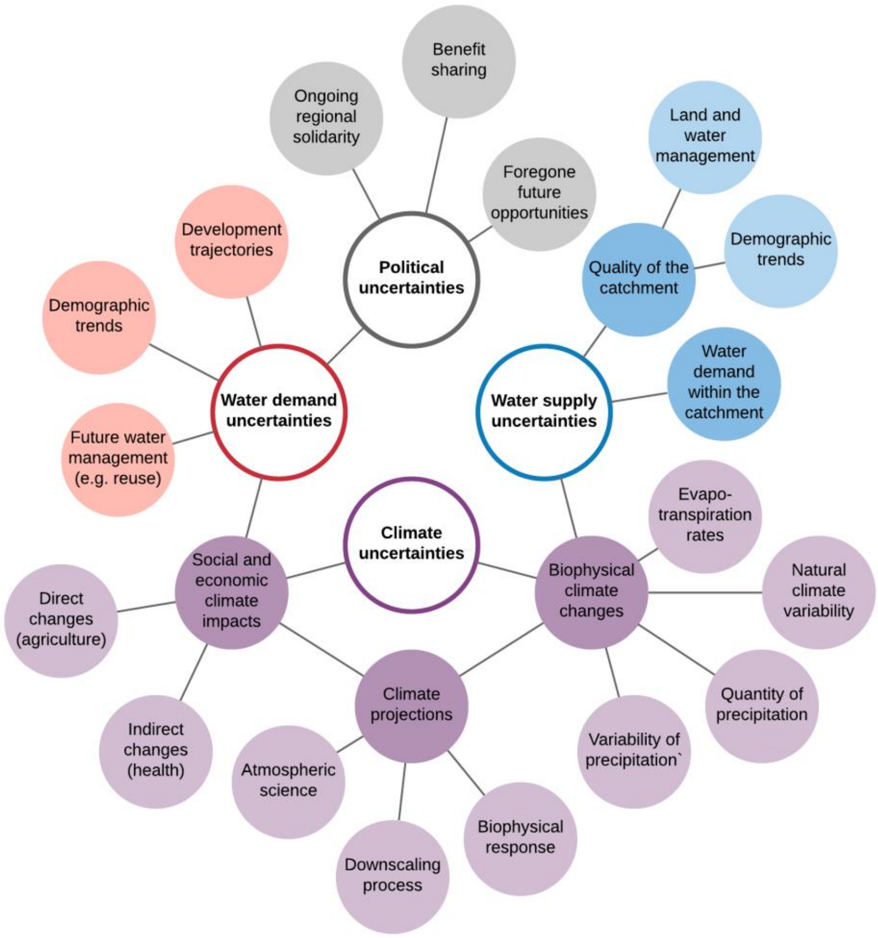

Figure 6-1 Mind map of critical uncertainties voiced by interviewees in the Lesotho-Botswana Water Transfer project

6.1.2.1 Climate

Climate uncertainty was a major topic discussed by nearly all interviewees. This included uncertainty with "the climate science itself" including the radiative forcing of gases, time lags, and how much carbon dioxide is absorbed. Interviewees highlighted uncertainty in the biophysical system response at multiple scales and the impacts of that response on socio-economic development. Interviewees also identified uncertainties exposed through the downscaling of global climate models to the regional scale; efforts to downscale models of future climate scenarios in the Orange-Senqu River Basin converged on the arid regions of the west becoming drier but showed a potential increase or decrease of rainfall in the highlands of Lesotho (World Bank 2016b). This climate uncertainty is considered deep uncertainty in the literature, or as *ambiguity* or *ignorance* in the conceptual framework.

6.1.2.2 Water supply

The uncertainty of climate change on future hydrology appeared to be exacerbated by natural hydrological variability, resulting in a "selective distribution of (water) scarcity" and "fluctuation across years and across seasons". One interviewee stated that "… even those who have not lived that long can already see the seasons changing. The absolute quantities of rainfall have not changed much, but the time at which it comes is becoming very problematic". This wide range of hydrological and climate futures appears to be a challenge for infrastructure planning. One interviewee said, "we kind of know where we're starting from, we may have very little idea of where we want to end. Do we end in the middle of a possible set of scenarios, do we end at the top, or do we end at the bottom?". This reflects an uncertainty of *uncertainty* verging on *ignorance.*

Long term water supply from the lowlands of Lesotho also depends on the quality of the catchment and changing domestic water demand. In essence, "how is the land and water management going to affect the long-term sustainability and operability of the supply side of the scheme?". Several interviewees were concerned that the current low population density and clear water quality may not be guaranteed in the future, while others expressed concern over the long-term impacts of the ongoing ecosystem degradation due to overstocking of livestock. These concerns are reflected in literature that projects a loss of wetland storage and aquifer recharge, increased sedimentation, and several other issues (ORASECOM 2014c). This uncertainty be a *risk* to be mitigated or managed through targeted preservation efforts, though the influence of uncertain demographic trends introduces *ambiguity* and *ignorance.*

6.1.2.3 Water demand

The long-term demand for water in Botswana and along the pipeline in South Africa was also identified as an uncertainty. The dual effect of climate change on both supply and demand means that, as one interviewee stated, "you need more and you've got less" and interviewees mentioned increasing agricultural and domestic demand due to increasing evapotranspiration rates. Other interviewees were concerned about the indirect effects of climate change demand, such as pressure on the health care system due to changing disease vectors or fundamental shifts in agriculture. Some interviewees wondered what effect events like the Cape Town crisis might have on future demand along the pipeline in south Africa, stating "they might be fine now, some of these cities where the pipe will pass through, but can that demand be factored in looking at an extreme drought?". Efforts from within the water sector like demand-side management, water reuse initiatives, or efforts to improve rural water access, were also expected to impact the demand in southern Botswana, though the baseline quality of these services is already relatively high (DWA Botswana 2017).

Uncertainties with socio-economic development in Botswana and South Africa were also identified as affecting water demand for the project. One interviewee provided a demonstrative example in the mining sector; forecasting water demand in industrial mining zones to the 40 or 50-year time horizons of water infrastructure planning is highly uncertain, as the commodity prices that enable mining operations are dependent on a range of complex factors far outside the water sector in South Africa. Interviewees also expressed concern that trends of urbanisation and informal settlement would have an effect on the long-term spatial distribution of demand. Other interviewees suspected there may be unintended consequences of the L-BWT infrastructure itself, including social responses such as migration to or from different water sources. Though some of these uncertainties may simply be *uncertainties*, the more indirect forms of uncertainty can be conceptualised as *ambiguity* or *ignorance*.

6.1.2.4 Political economy

The challenges of transboundary cooperation were discussed in nearly every interview, summed up by one interviewee with, "how you get those parties to work together in a way that is mutually beneficial to all of them so the project goes ahead and is not delayed is a significant uncertainty". A few stakeholders emphasised the importance of solidarity, stating "for South Africa this will always be a solidarity project… that is an important piece… now it depends with other policy makers whether they will maintain that solidarity for Botswana". The political economy perspective was emphasised by most interviewees because of the importance of South Africa's involvement for project success, while others pointed to the balance of power in decision making, asking "who has power and therefore who counts in these sorts of decisions". One interviewee pointed out the ambiguity associated with the pure unknown, such as whether a decision might compromise a country down the line. This pure unknown has been addressed in literature as the inherent risk of transboundary cooperation (e.g. Subramanian *et al.* 2014). Other uncertainties addressing foregone future opportunities and the questions of power and equity exist in the domain of *ambiguity* and *ignorance*.

6.1.2.5 Project characteristics and alternatives

Interviewees identified a wide range of unknowns that are typical at early project stages, such as technical and financial feasibility, environmental and social impacts, and legal and institutional options. Upcoming studies were meant to address these uncertainties (e.g. ORASECOM 2017), and "as you move through the design process, you will make a series of assumptions which will deal with some uncertainty". These reflect simple *risks* or *uncertainties* and were left out of figure 6-1 and the subsequent analysis. Interviewees also identified uncertainty regarding whether the L-BWT was the best alternative for addressing regional water scarcity. In other words, "it's a classic case of, is this the optimum solution?". One interviewee suggested that "people were stuck within this water transfer idea" implying that other alternatives may have been available, while another stated that "it has always been clear it would be a transfer". The only concrete alternative mentioned was a transfer scheme from the Zambezi River. These comments may have come from a lack of awareness of alternatives assessments conducted by others, but they may also elude to the *ambiguity* or *ignorance* of complex water decision-making spaces. This uncertainty was not included in figure 6-1 and was not addressed explicitly in the analysis, as it is an overarching theme that connects to all other uncertainties.

6.1.3 Multifunctionality

Interviewees were asked explicitly to articulate the multifunctionality associated with the L-BWT and documents were scanned for considerations of multifunctionality. A unique element emerged from the interviews, which is that the aggregate benefits of the L-BWT may differ at varying scales, or "the nature of regional projects is that they are probably very rarely the most important project for a country, but they are the most important project for a region". Table 6-1 shows the major themes, distinguished by a transboundary and country perspective.

Table 6-1 The multifunctionality of the Lesotho-Botswana Water Transfer project as articulated as "benefits" by interviewees

Scale		**Function**
Transboundary scale		• Mitigate regional water scarcity • Establish political trust and solidarity
Country scale	South Africa	• Additional water supply • Economic and social development • Mini-hydropower
	Botswana	• Secure fresh water supply • Economic and social development
	Lesotho	• Revenues (water and energy) • Hydropower • Domestic and agricultural water supply • Economic and social development • Catchment management

The transboundary scale reveals the macro-level opportunities to address regional water scarcity in the basin. The neighbouring countries identify the catchment in Lesotho as "attractive for addressing basin-wide or other parts of the basin issues of water access or water security". The worsening water scarcity in the western part of the basin, the lack of alternative water supply, and the strength of ORASECOM, appeared to make consideration of large, transboundary solutions like the L-BWT possible. At this level, political stability due to increasing interdependence were explicitly identified as desired outcomes of the project with statements such as "on a transboundary level, the successful implementation of projects like this builds a massive amount of trust".

From a country perspective, the drivers for multifunctionality were summarised as "if the Lesotho-Botswana transfer is going to work, it's got to meet local water needs in Lesotho – water supply, livelihoods, agriculture. It's got to meet the water needs in Botswana, which are predominantly, given the cost of the water, going to be industrial and high-end water users. And it's got to meet some needs in South Africa… It could involve mini hydro, local power grids, mines". Early-stage project documents define project benefits of water supply to 600,000 beneficiaries in Botswana, water revenues contributing to investments in Lesotho's water infrastructure for its 1,000,000 citizens, and water supply to 400,000 beneficiaries in South Africa (World Bank 2014). Interviewees hoped access to secure water supply could enable economic and social development for beneficiaries in South Africa and Botswana, and that the project could include benefits to local electricity grids in South Africa with mini-hydropower projects. Revenues in Lesotho could also enable economic and social development, and interviewees identified a range of other beneficiaries in the upstream catchment through hydropower and local water supply for irrigation and livelihoods.

Multifunctionality in literature often focuses on a landscape perspective rather than a project-specific perspective, situating agriculture or green infrastructure as an enabler of multiple ecosystem services and socio-economic functions (Hansen and Pauleit 2014). However, the rangelands in Lesotho provide benefits to people through livestock grazing, flow attenuation and reducing the sediment load in water (ORASECOM 2014d) and the downstream estuary in Namibia is a designated Ramsar site and contributes to a range of ecosystem services (ORASECOM 2014b). Applying the concept to a large piece of infrastructure like the L-BWT did not bring forward such considerations, which may be an important gap as the L-BWT may introduce new risks to the rich landscape of ecosystem services in the basin. Though such elements may be important for fully conceptualising multifunctionality as defined in literature, only those identified by interviewees were included in the analysis.

6.1.4 Summary of understandings of uncertainty and multifunctionality

In summary, interviewees described uncertain climate futures, the dynamics of water supply, ambiguous future development trajectories, and political risks covering all four quadrants of Stirling's framework (i.e. *risk, uncertainty, ambiguity* and *ignorance*). This included the full range from simple project unknowns that would become clearer at later project stages to radical uncertainties described as "possible foregone future opportunities" or "unknown unknowns". The depth and breadth of these descriptions of uncertainty may indicate that a lack of consideration of uncertainty in decisions is unlikely to stem from a lack of awareness, but rather from other factors that limit the capacity of decision makers to effectively deal with them.

Conceptualisations of multifunctionality brought out a range of economic, social and ecological functions, and interviewees expressed a desire to understand which benefits could be leveraged in which contexts. Some interviewees began to peel back multiple layers of project benefits, describing the economic or social development that a project function might enable. Interviewees often implied that these multiple functions were critical for the L-BWT, driven by the need to leverage benefits in each country to secure political buy-in. However, interviewees did not consider a full range of ecosystem services or the temporal distribution of benefits, which are critical to the concept in the literature.

6.2 Considering and integrating uncertainty and multifunctionality in decisions for the Lesotho-Botswana Water Transfer project

The first research question asked "*how are the concepts of uncertainty and multifunctionality currently conceptualised and considered in decision-making processes for the resilience of the Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin? How could these concepts be considered in decisions for the resilience of water infrastructure?"* The dual processes of first *understanding* uncertainty and multifunctionality and then *integrating* them into broader decision-making process emerged as two important themes, visualised in figure 6-2. On the left uncertainty and multifunctionality are shown as two concepts without detailed characterisation. The process of *understanding* uncertainty and multifunctionality allows for differentiation between various elements of the uncertainty and a more detailed understanding of each element. The process of *integration* brings these elements into the broader decision-making process alongside other factors.

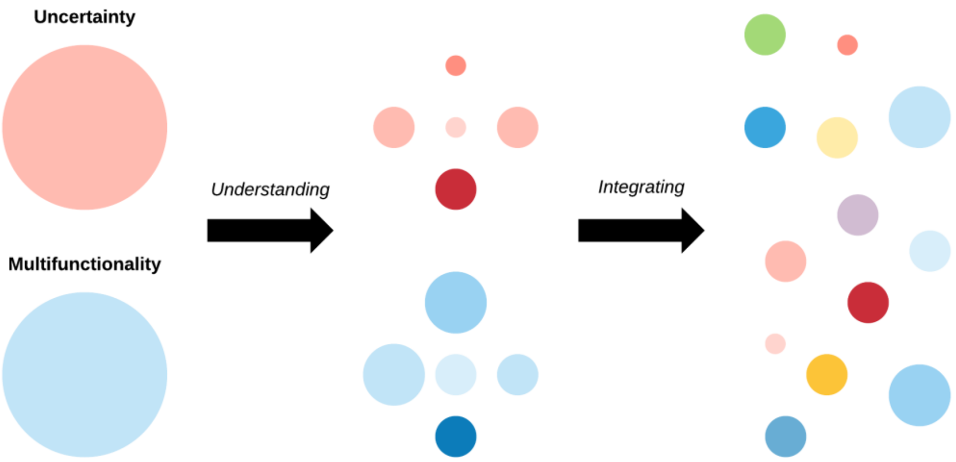

Figure 6-2 A visualisation of the breakdown of two overarching themes of the analysis of uncertainty and multifunctionality; namely, the processes of 1) understanding and 2) integrating

6.2.1 Understanding uncertainty and multifunctionality

Documents and interviews were analysed for knowledge systems and stakeholder participation that contribute to *understanding* the uncertainty and multifunctionality identified by interviewees. This included three processes: 1) compiling evidence that addresses each of the uncertainties into major themes, 2) separating findings according to 'current practice' (completed studies and methods in use), 'future planned' (upcoming studies and processes), and 'future possible' (potential methods identified by interviewees or in literature), and 3) analysing findings according to the conventional and emerging decision-making paradigms in literature. To provide more clarity, processes for understanding uncertainty and multifunctionality were separated into two sections as follows.

6.2.1.1 Understanding uncertainty

Knowledge systems and stakeholder participation that contribute to *understanding* water supply and demand uncertainty, climate uncertainty and political uncertainty are summarised in figure 6-3 below. Elements are plotted according to the time scale (y-axis) and decision-making paradigm (x-axis).

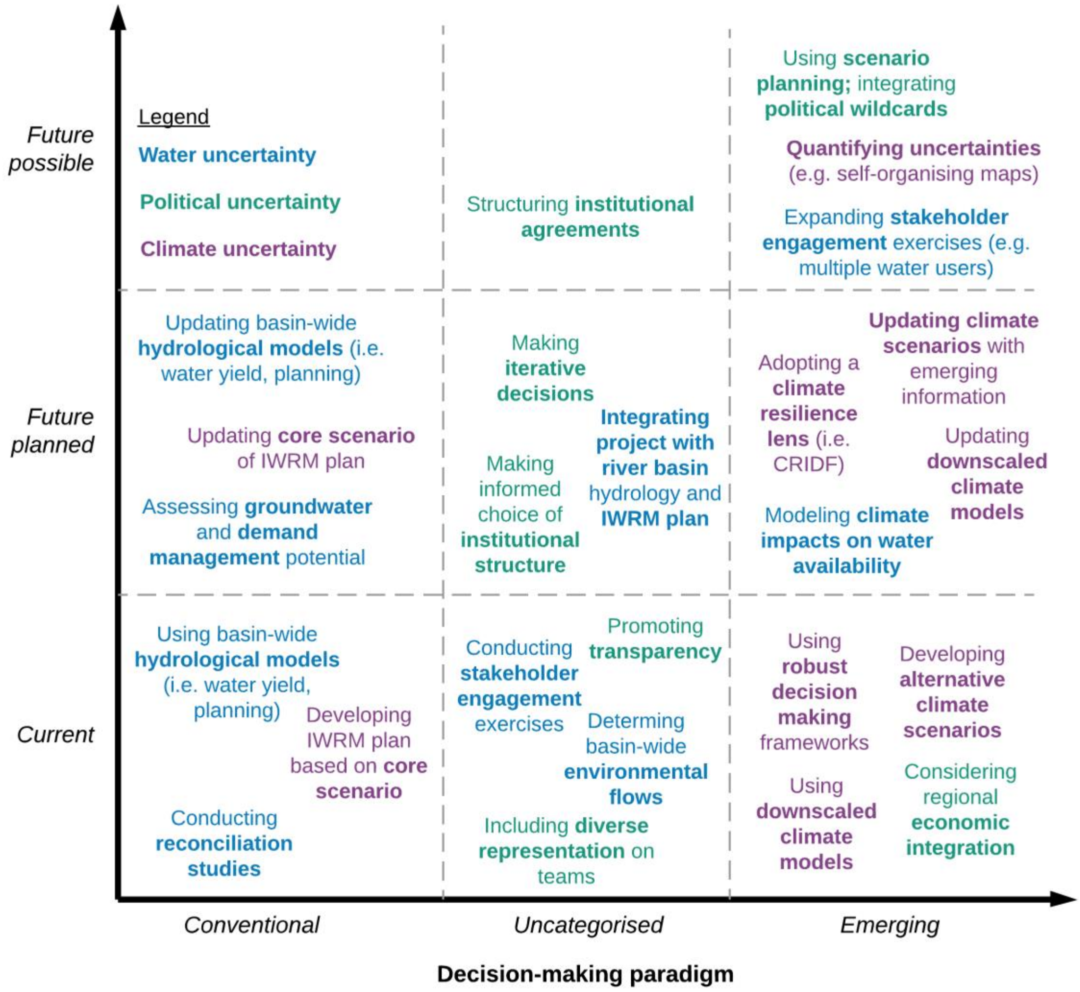

Figure 6-3 Knowledge systems and stakeholder participation for understanding climate, water supply and demand, and political uncertainty in the L-BWT

6.2.1.1.1 Understanding climate uncertainties

Elements that contribute to *understanding* climate uncertainty are depicted in purple text in figure 6-3 and evidence gathered from the analysis is summarised in table 6-2 below. It is clear that most methods for understanding climate uncertainties exist in the emerging paradigm to address *ambiguity*.

Table 6-2 Results from the analysis of knowledge systems and stakeholder participation in the L-BWT for understanding climate uncertainties

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Current	• Climate modeling and scenario analysis are the most common methods; "we are hoping that the modelling or the climate science has also improved or evolved so it might give us a better perception" (interview) • Climate models have been combined with a RDM framework in the Lesotho Water Security and Climate Change Assessment (World Bank 2016b) • The ORASECOM IWRM Plan used downscaled climate models (e.g. ORASECOM 2011a, 2011b), but a range of assumptions were required to select a most-likely core scenario (interview)
Future planned	• Further climate modelling exercises "might be launched in the coming months on Lesotho or on the whole basin" • ORASECOM IWRM Plan core scenario to be updated based on new climate and development information (ORASECOM 2017) • Planned involvement of the Climate Resilient Infrastructure Development Facility expected to bring a pro-poor, climate resilience lens (interview)
Future possible	• Interviewees suggested better quantification and communication of climate uncertainties, mirroring literature (e.g. Hallegatte *et al.* 2012) • Interviewees also suggested the use of statistical methods like self-organising maps, which clusters model types to better understand the uncertainties in the assumptions behind them (e.g. (Climate Resilient Infrastructure Development Facility 2017), reflecting multi-model ensembles in literature (Tebaldi and Knutti 2007) • Literature suggests further ways of defining and quantifying such uncertainties introduced by the socio-economic factors considered in integrated climate modelling (Gillingham *et al.* 2018)

6.2.1.1.2 Understanding water supply and demand uncertainties

Elements that contribute to *understanding* water supply and demand uncertainty are depicted in blue text in figure 6-3 and summarised in table 6-3 below. The complexity of the hydrology of the river basin appears to be understood using hydrological models, existing primarily within a conventional engineering paradigm that deals with *risk* or *uncertainty*. Such efforts may ignore compounding uncertainty; for example, the projections from climate change models may be used as inputs to hydrological models, and the outputs of hydrological models may be used as inputs to climate impact models.

Table 6-3 Results from the analysis of knowledge systems and stakeholder participation in the L-BWT for understanding water supply and demand uncertainties

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Current	• ORASECOM IWRM Plan used a Water Yield Resources Model (WYRM), which models the hydrological yield of the river basin system and its sub-systems (ORASECOM 2014e) • The WYRM was an input to the Water Resources Planning Model (WRPM), which models system operations and reconciles availability with demand (ORASECOM 2014e); WYRM and WRPM quantify uncertainty using established stochastic and probabilistic methods • Reconciliation studies conducted in the South African part of the basin to reconcile current use and future requirements with water availability through system operations or new infrastructure (e.g. DWA South Africa 2012) • South Africa hosts stakeholder engagement platforms semi-annually during seasonal transitions to reduce uncertainty over water supply and demand (interview) • Basin-wide environmental flow studies were prepared for IWRM Plan (ORASECOM 2013a) • A complex engineered system was deemed necessary for "one of the most complex systems in the world"
Future planned	• ORASECOM IWRM Plan expected to be updated every 5 years (ORASECOM 2014b); e.g. including provisions for the L-BWT • Basin-wide hydrological models and reconciliation studies to be developed to inform the upcoming basin-wide investment plan (ORASECOM 2017) including a review and update of water requirements, updates to the WYRM and WRPM, and provisions for the L-BWT • Assessments to be done for potential groundwater utilisation or water conservation or demand management efforts to inform the basin-wide investment plan (ORASECOM 2017) • Pre-feasibility and feasibility studies for the L-BWT plan to clarify water availability, demands, and changes to hydrology from climate change (ORASECOM 2017)
Future possible	• A more rigorous stakeholder engagement exercise may provide a better understanding of the identified water supply and demand uncertainties (interview)

6.2.1.1.3 Understanding political uncertainties

Elements that contribute to *understanding* political uncertainty are depicted in blue text in figure 6-3 and summarized in table 6-4. The prevalence of this uncertainty was unexpected and proved challenging to analyse with the conceptual framework.

Table 6-4 Results from the analysis of knowledge systems and stakeholder participation in the L-BWT for understanding political uncertainties

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Current	• SADC Protocol and ORASECOM agreement promote transparency (SADC 2000; ORASECOM 2009b) • Diverse representation on task teams and stakeholder platforms, including government departments outside of the water sector, ORASECOM representatives and external experts, helps bring out potential political risk (interview) • Transboundary dialogue that considers the dynamics of economic integration through the South African Customs Union exposes political uncertainties and opportunities (interview)
Future planned	• Iterative decision stages over the phases of the L-BWT expected to clarify political uncertainties and allow for critical decisions to wait for more certainty (interview) • Preparation of basin-wide investment plan to include assessments of existing policies, institutional arrangements and structures and a study of institutional and financial structural options available for the L-BWT (ORASECOM 2017)
Future possible	• The process for structuring agreements may better characterise or reduce various types of uncertainties and risks for various parties (interview) • Literature suggests ways of integrating political uncertainty into scenario planning using participatory science and policy processes, including defining shared socio-economic pathways that specify assumptions about political conditions and relate these to climate projections (Kriegler *et al.* 2012; O'Neill *et al.* 2014) • Further efforts to incorporate political uncertainty could be to introduce political wildcards into scenario plans to see how a development trajectory may respond

6.2.1.2 Understanding multifunctionality

The analysis of data addressing *understanding* multifunctionality is summarised in figure 6-4 below. Evidence showed that multifunctionality in the case study context is understood through a combination of basin-wide efforts alongside processes conducted specifically for the L-BWT project.

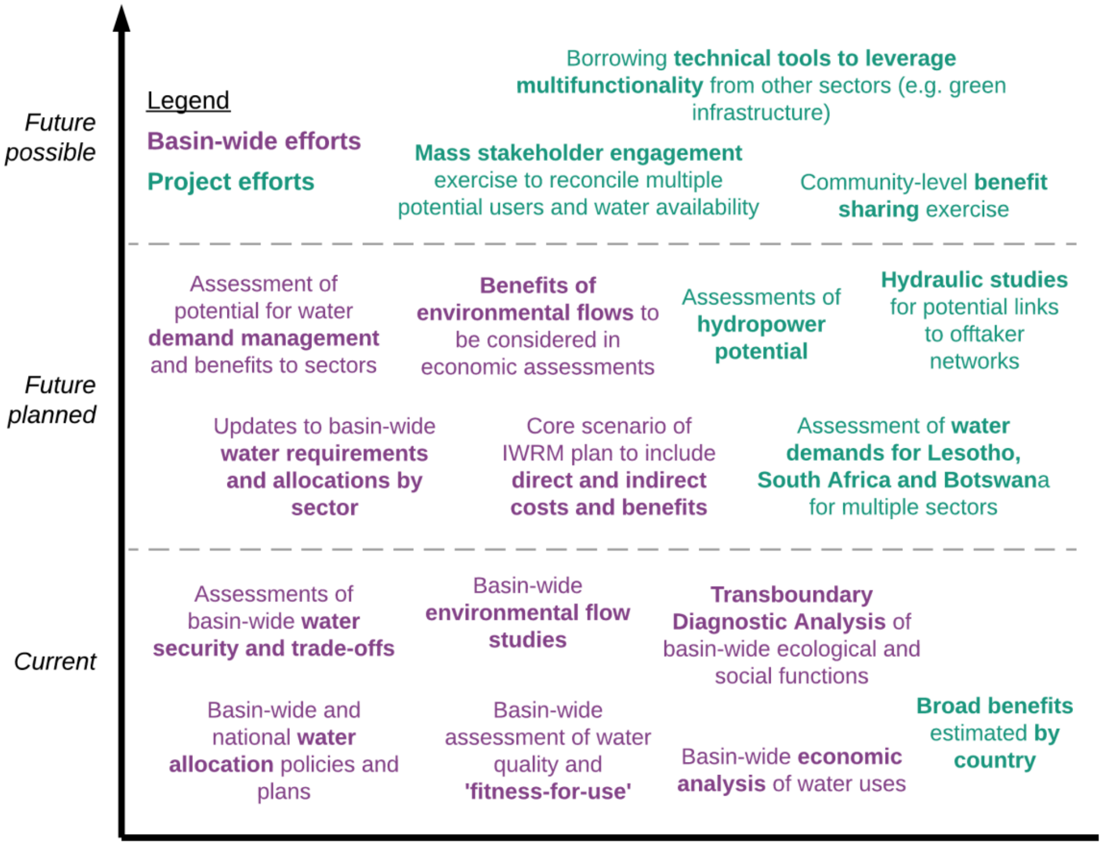

Figure 6-4 Knowledge systems and stakeholder participation for understanding multifunctionality in the L-BWT

Multifunctionality from a transboundary perspective was derived from the biophysical requirements to address regional water scarcity and the political requirement for trust and solidarity-building in the region. At a project-level, the political need to ensure that each of the three countries involved would receive shared benefits appeared to be a driver for investigating the potential multifunctionality of the project. Interviewees and the literature suggested several ways to further incorporate a multifunctionality lens in the project. Table 6-5 summarises this part of the analysis.

Table 6-5 Results from the analysis of knowledge systems and stakeholder participation in the L-BWT for understanding multifunctionality

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Current	*Basin-wide (transboundary)* • National water plans provide for water allocation and prioritisation of water for different uses (ORASECOM 2014b) • Water security assessments incorporate a better understanding of potential trade-offs between various water functions (World Bank 2016b)

	• Basin-wide 'fitness-for-use' assessment that looks at the water quality of different sections of the basin for a variety of uses (ORASECOM 2009a) • Transboundary Diagnostic Analysis points out the functions of water for ecology and society of various aspects of the river (ORASECOM 2014c) • Basin-wide environmental flow assessments (ORASECOM, 2013) and economic analysis of water use (ORASECOM 2014a) done in preparation for the ORASECOM IWRM Plan *Project (L-BWT)* • At the pre-feasibility stage of the L-BWT, broad benefits to each country were estimated (World Bank 2014), though literature considers a broader scope of benefits to human health, social cohesion and ecological systems (e.g. Hansen and Pauleit 2014) • Interviewee experience suggests multifunctionality is often deprioritised "… in my experience whatever the decision makers and the powerful are interested in gets priority. The rest… is screened against negative impact… rather than thinking about 'here are the multiple benefits of this piece of infrastructure', often it translates into 'oh, it is going to provide use for livelihoods'. But that is never really the driver, it is often just dressing"
Future planned	*Basin-wide (transboundary)* • Planned efforts in preparation of the ORASECOM basin-wide investment plan include reviewing and updating water requirements by sector and using assessments and interviews to investigate the potential benefits of water demand management (ORASECOM 2017) • Updates to the IWRM core scenario are meant to include both direct and indirect costs and benefits of water functionality (ORASECOM 2017) • Economic assessments will consider functionality of environmental flows (ORASECOM 2017) *Project (L-BWT)* • Pre-feasibility and feasibility studies are meant to assess water requirements for irrigation in Lesotho, estimate water requirements for urban areas, rural communities, mines and other major industries in South Africa along the pipe route, and assess for mining water demand in Botswana (ORASECOM 2017) • Further studies to investigate hydraulics, potential linkages with existing water networks, and hydropower generation potential (ORASECOM 2017)
Future possible	*Project (L-BWT)* • A mass stakeholder engagement exercise is required to gain a collection of views from interested and impacted groups (interview) • Benefit sharing exercises (mirrored in literature, (Turton 2008)) could be conducted in a participatory manner by independent entities at a community-level to understand which stakeholders benefit and disbenefit (interview) • Literature suggests other independent benefit sharing exercises (Phillips *et al.* 2006), better integration between sectors (Gourbesville 2008) and tools like MCDA (Alves *et al.* 2018) • Tools, or elements of tools, from the literature for planning for multifunctionality in green infrastructure or flood infrastructure (e.g. Schindler *et al.* 2014; Pauleit *et al.* 2011) could be utilised for the L-BWT

6.2.1.3 Summary of understanding uncertainty and multifunctionality

In summary, the analysis showed that uncertainties are understood through a range of knowledge systems and stakeholder participation from both the conventional and emerging decision paradigm. Efforts to understand water supply and demand uncertainty were biased toward the conventional paradigm, while efforts to understand climate uncertainty were situated in the emerging paradigm. Future plans in the basin may provide a better understanding, but most planned elements reaffirm the current paradigms. Together, the literature and interviewees generated a host of possibilities to better understand climate and water supply and demand uncertainties. Political uncertainties were a major topic but proved difficult to analyse with the conceptual framework, though interviewees identified several future options. Similarly, multifunctionality appeared to be understood using conventional approaches to quantify and allocate direct water use. Current and planned practices may provide a clearer picture, though this would require synthesizing disparate pieces of information. Interviewees identified several stakeholder engagement mechanisms that may enable further understanding, and the literature suggests that understanding the role of ecosystem services would be required to utilise the tools for understanding multifunctionality from other sectors (e.g. green infrastructure).

6.2.2 Integrating uncertainties and multifunctionality

Integrating uncertainty and multifunctionality into decision making is complex and may include processes that streamline the concepts into conventional decision processes alongside those that more dramatically shift the entire decision process into the emerging paradigm. The analysis of methods for *integrating* uncertainty and multifunctionality is summarised in figure 6-5 below based on emergent themes including scenario planning, stakeholder engagement, system integration and others.

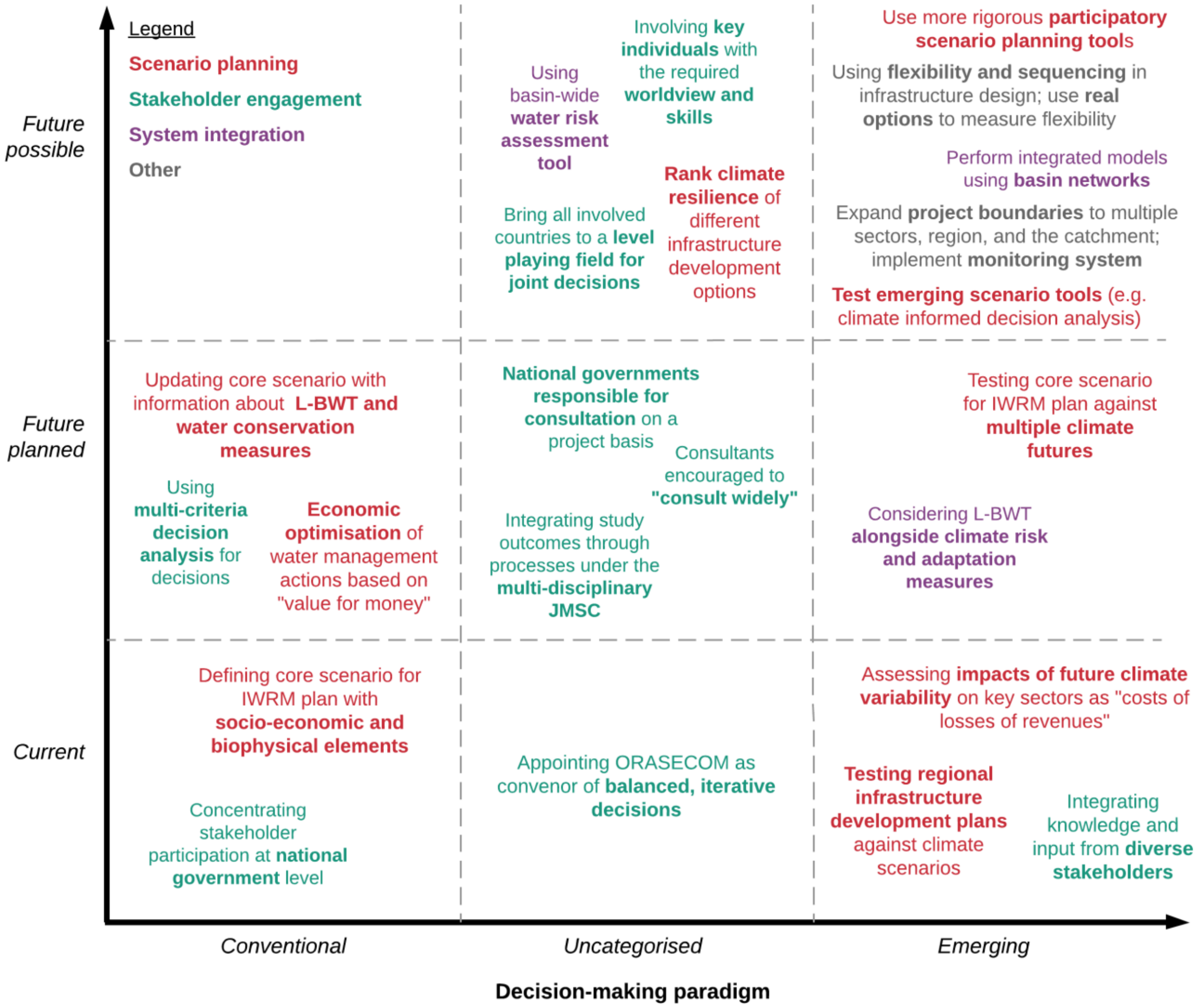

Figure 6-5 Knowledge systems and stakeholder participation that integrate uncertainty and multifunctionality in decisions in the Lesotho-Botswana Water Transfer

6.2.2.1 Scenario planning

Interviewees most often discussed the use of scenarios as a favourable method for dealing with uncertainty, with relevant text in red in figure 6-5 above. Table 6-6 summarises this part of the analysis.

Table 6-6 Analysis of scenario planning for integrating uncertainty and multifunctionality in the L-BWT

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Current	• Historical and future climate scenarios in Lesotho were analysed according to the impacts of variability and change on key sectors using a "costs of losses of revenues" approach (World Bank 2014) • The ORASECOM IWRM Plan defines multiple development scenarios according to a most-likely core scenario based on socio-economic and biophysical elements (ORASECOM 2014b)

	• The SADC Regional Infrastructure Development Master Plan considers a range of climate scenarios tested against a subset of infrastructure (SADC 2012) • The assumptions required to focus on a singular, climate dimension of uncertainty (e.g. the RDM framework (J. Hall *et al.* 2012) used to assess water security in Lesotho, or to choose a most likely scenario for planning infrastructure (e.g. the ORASECOM IWRM Plan) may ignore the *ambiguities*
Future planned	• Plans for the development of ORASECOM's basin-wide investment plan includes provisions for scenario planning (ORASECOM 2017) • Updates to the core planning scenario in the ORASECOM IWRM Plan to include new projects (such as the L-BWT) and the potential for groundwater and water conservation (ORASECOM 2017) • Efforts to develop the investment plan also includes an economic optimisation process to prioritise actions based on "value for money", and the chosen "optimal" development scenario would be tested against a range of climate futures using a probabilistic approach or through sensitivity analysis (ORASECOM 2017)
Future possible	• Interviewees identified opportunities for more rigorous and participatory scenario planning approaches, such as the Climate Resilient Development Pathways (CRDP) approach developed and tested in the Okavango River Basin (Climate Resilient Infrastructure Development Facility 2017) • Interviewees suggested simple processes of ranking development options against different future scenarios based on simplified metrics • Other tools from literature could be used, including climate-informed decision analysis or planning tools like DAPP or RIF framework (Haasnoot *et al.* 2013; Störmer and Truffer 2009) • Rigorous scenario exercises may expose tensions that stakeholders do not want to engage with in early stages, though this may not be a reason to avoid the processes altogether (interview)

6.2.2.2 Stakeholder engagement

Interviewees also discussed stakeholder engagement as an important aspect of *integration* of uncertainty and multifunctionality in decision making, with relevant text in red in figure 6-5 above. Table 6-7 summarises this part of the analysis.

Table 6-7 Analysis of stakeholder engagement for integrating uncertainty and multifunctionality in the L-BWT

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Current	• ORASECOM as the transboundary project convenor or facilitator allows for a better balance of power (interview) and for facilitating decisions iteratively by consensus (interview) • Early-stage discussions focused on government-to-government and expert-level interactions (interview); no clarity on provisions for the transfer of knowledge from stakeholders at local to higher scales, which does not reflect the level of collaboration and collective visioning in literature (e.g. Lawrence and Haasnoot 2017)

	• Diversity of representations on task teams (e.g. JMSC) meant to encourage a multi-disciplinary and integrated perspective
Future planned	• National governments are responsible for consultation within their own countries on transboundary projects according to their own protocol (interview) • There did not appear to be concrete plans outside of encouragement of consultants engaged in project preparation to "consult widely" (ORASECOM 2017) • The JMSC is meant to provide a multi-disciplinary, integrated perspective to consolidate advice for the ORASECOM Council (interview) • Discussion within the JMSC meant to facilitate the ranking of options using MCDA (ORASECOM 2017)
Future possible	• Several emerging methods for scenario analysis or other engagement exercises (e.g. ranking of development options) identified as potential opportunities to engage stakeholders (interview); (not labelled on diagram) • Stakeholder engagement can be used to reduce risk and better target critical risk issues at an adequate level of specificity (interview); (not labelled on diagram) • Stakeholder engagement is required to bring all three countries to a level playing field for joint decisions including planning time horizons, definitions of costs and benefits, capacities for data collection and analysis, and local skills (interview) • Recruiting and defining the roles of key individuals may be important; "where I've seen those types of issues [i.e. dealing with uncertainty] managed successfully it comes down to individuals and how they choose to engage with each other and with stakeholders involved with the process… I think there are ways of working and ways of seeing the world … that pull these various bits together and bring people together to get things to happen" (interview)

6.2.2.3 System integration, flexibility, and expanding project boundaries

Interviewees also suggested possible methods that are designed to provide a systems perspective that may support *integration* of uncertainty and multifunctionality, with relevant text in purple in figure 6-5 above. Several interviewees also identified possibilities to embed flexibility into decisions or expand project boundaries, depicted in grey in figure 6-5 above. Table 6-8 summarises this part of the analysis.

Table 6-8 Analysis of possibilities for system integration, flexibility and expanding project boundaries for integrating uncertainty and multifunctionality in the L-BWT

	Knowledge systems and stakeholder participation in the Lesotho-Botswana Water Transfer
Future possible ***System integration***	• Basin networks borrowed from the insurance sector may provide opportunities to expose the complexities; "I think basin networks are the way to go…You can model absolutely everything… if it relates then it can fit in. [For example], by building the L-BWT, it is going to remove water from the Lowlands scheme, therefore the for the scheme will go up. Which means the risks to downstream people below the dam go up because there is more water being taken out so there's less downstream… once you've

	got the whole basin network set up, you can take some water out of the lowlands scheme and it just updates for all of the other things. It's very advanced." (interview) • Integrated water risk assessments borrowed from corporation may also be useful (interview)
Future possible ***Flexibility***	• Suggestions to plan phased, flexible infrastructure and to establish a rigorous monitoring system may provide for adaptivity (e.g. dam designed in phases, with subsequent increases to the dam height only necessary under specific climate futures) (interview) • Opportunities to leverage multiple layers of flexibility; "there is flexibility in decid[ing] which projects you're going to build and how you're going to build each of these projects" (interview) • RO Analysis can help consider flexibility in investment decisions (an emerging form of cost-benefit analysis that includes consideration of delaying an investment or sequencing decisions to take advantage of increasing certainty) (Kalra *et al.* 2014)
Future possible ***Project boundaries***	• Connecting catchment management efforts to opportunities to reduce the impacts of future climate variability (interview) • Looking at the multiple sectors and systems to consider how other efforts in the basin may offset demand for piped water in the future (e.g. treating polluted water in the Gauteng region for local use may have an impact on long-term demand from the L-BWT) (interview) • Ecosystem services management can better define and leverage multifunctionality (Tiwary *et al.* 2016), though this can be challenging as ecosystem services often manifest for stakeholders outside of the spatial/temporal boundaries of a project; dynamics of stakeholder's demands for ecosystem services are just as complex and important as the dynamics of the ecosystem services themselves • Embedding infrastructure projects within a regional plan (e.g. Regional Infrastructure Foresight (Störmer and Truffer 2009)) integrates a project in the broader context; (not on diagram)

6.2.2.4 Summary of analysis of integrating uncertainty and multifunctionality in decisions

In summary, exploring current and future processes of *integration* revealed a range of mechanisms that embed uncertainty and multifunctionality into the complexity of water infrastructure decisions. These mechanisms fell under themes including scenario planning, stakeholder engagement, integrating systems using tools or diverse stakeholder platforms, designing flexible infrastructure systems, expanding project boundaries, and establishing monitoring systems to track the trajectory of uncertain variables against assumptions. It is clear that processes that contribute to *integrating* these concepts in real-world decisions reflect degrees of both the conventional and emerging decision paradigms.

The results also revealed that elements classified under the emerging paradigm were often pulled back into the conventional due to how they were used. For example, modelling exercises that estimate future quality and quantity of hydrological flows may be required to engineer complex water systems, so scenarios may be a critical way to integrate uncertainty. However, the assumptions behind the choice of a core planning scenario in the ORASECOM Basin-Wide IWRM Plan (ORASECOM 2014b) or hopes that climate models would "give us a better perception" may indicate a tendency toward the conventional predict-plan-act paradigm. Similarly, the case did not fully utilise the collective visioning and transformative potential of scenario planning in literature (e.g. Amer *et al.* 2013; Mahmoud *et al.* 2009), in favour of expert-led scenario approaches based on one dimension of uncertainty (i.e. climate) like Robust Decision-Making (World Bank 2016b; J. Hall *et al.* 2012). In addition, information gathered from emerging methods may feed into optimisation processes from the conventional paradigm, which may negate their potential to inform better decisions. Though stakeholders identified many *ambiguities*, it may not be fully acknowledged in the decision context.

It appears that some elements of multifunctionality were *integrated* in decision making, but innovative methods for doing so were largely absent from the case study. Multifunctionality in literature extends to economic, social and ecological functions to various stakeholder groups over time and space, while the multifunctionality in the case study focused on the most obvious beneficiaries via direct water use.

6.3 Bridging uncertainty and multifunctionality to finance in the Lesotho-Botswana Water Transfer project

The second research question sought to bridge the findings of RQ1 to the domain of project finance. Interviewees were asked to reflect upon creative possibilities, prompted by scenarios (see Appendix I), with responses generating four themes depicted in figure 6-6 below.

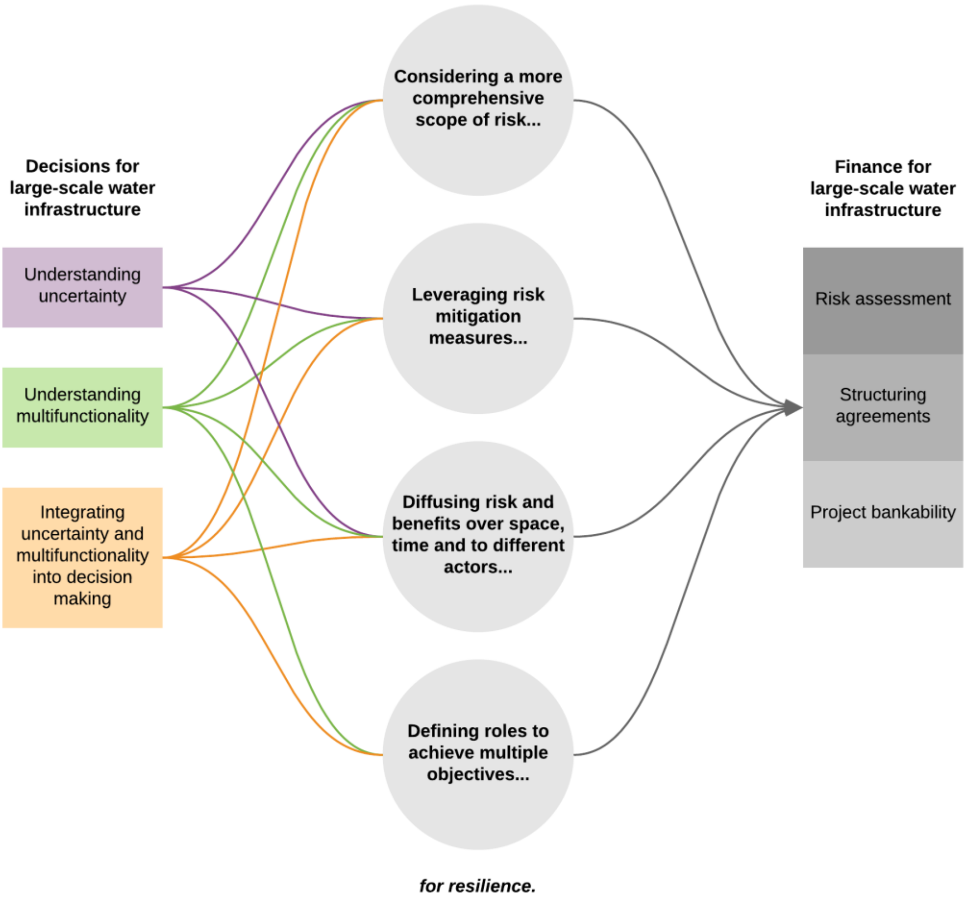

Figure 6-6 Bridging concepts from elements of understanding and integrating uncertainty and multifunctionality in decisions for the L-BWT to finance

The categories for analysis of RQ1 are shown on the left side of the figure, including *understanding* uncertainty (section 6.2.1.1), *understanding* multifunctionality (section 6.2.1.2), and *integrating* uncertainty and multifunctionality in decision making (section 6.2.2). The large circles in the centre of the diagram show the four emergent bridging concepts to finance. Each of these four themes link to the project finance perspective, including risk assessment, project bankability, and structuring agreements. Risk assessment and project bankability were emphasised in the literature (Morel and Bordier 2012; G20 Green Finance Study Group 2017b) and structuring agreements became a topic of importance in interviews.

6.3.1 Considering a more comprehensive scope of risk

The language of risk appears to be a key element bridging uncertainty and multifunctionality for resilience from decision making to project finance. This bridge appears to prompt consideration of a more comprehensive scope of risk factors, including future changes to known risk factors (i.e. climate). Though not directly articulated by interviewees, this process may lead to better project outcomes as financiers shift to supporting projects that are more resilient to a wider range of risks. This shift in financier expectations for risk management may push project implementers and governments to better consider these risks in planning processes, leading to a pipeline of more resilient projects.

Interviewees emphasised that a quantifiable impact on cash flow and project bankability over a defined period of time is a critical criterion for inclusion in contemporary risk assessments. Thus, the process of understanding and synthesizing a comprehensive range of project characteristics into quantitative financial terms becomes a central process. According to interviewees, one must know "what is the probability of [the event] happening, and if there is a financial cost to the event can the project manage it or handle it". Interviewees identified several challenges in factoring the whole range of risks associated with uncertainty and multifunctionality into the financial model. As one interviewee put it "financiers look at pretty much all of the risks, not that they tend to understand them". One interviewee articulated the challenge as "trying to get the financiers to extend the boundary of their thinking and risk". Interviewees drew from several examples and climate risk was a demonstrative one; growing competencies in decision making for quantifying climate uncertainties or understanding the implications on infrastructure plans, such as using Robust Decision-Making frameworks (Hallegatte *et al.* 2012), may move the sector closer to quantifying these aspects and translating them into financial terms. The case is similar for the hydrological models and stakeholder engagement exercises that expose the impacts of changing water demands on project revenue (ORASECOM 2014e). Measurable impacts of political risk on water supply and demand may also be enabling, such as the impacts on cash flow if a large water user leaves an offtake agreement. Lastly, integration of uncertainty and multifunctionality into basin-wide network models or through integrated risk assessments may help financiers relate risks to one another synthesize them into a practical outcome. Such possibilities are not a silver bullet; challenges exist at each of the analytic steps required to quantify financial risk.

The ability to quantify and value risk appears to be one of many conditions that determine whether elements are absorbed into a project risk profile. Interviewees indicated that in order for risks to be included they must have an impact within the payback period of the financier, which may be in range of 10 to 15 years, up to multiple decades. In addition, the risk must have a scale impact large enough to affect the risk profile of the entire project when discounted to present terms. One interviewee mentioned that these challenges are exacerbated by unpredictability in the way communities and governments mitigate or adapt to risks as they manifest in the future. Interviewees also mentioned that considering increasingly complex risks is likely to increase transactions costs.

6.3.2 Leveraging risk mitigation measures

A better understanding and quantification of risk may incentivize governments and financiers to support resilience-based risk mitigation measures associated with a project. Interviewees stated that some kind of catchment management consideration "needs to be integrated into the project because of the likelihood of greater intensity of rainfall and greater sediment erosion". One interviewee summarized the potential driver for considering such project elements in the financial model: "any environmental risk of potential siltation that would affect the capacity of the dam would definitely have to be considered… If actions around catchment conservation are going to keep those risks at bay then you would definitely consider them." Though alternative infrastructure design may mitigate some of these risks, governments and financiers may also consider other catchment conservation and the associated cost implications within the financial model. It appears that a better understanding of the risks associated with climate uncertainty and catchment degradation (i.e. an element of multifunctionality) may help the financial sector understand the value of the scale impacts of these risks, and therefore enable them to calculate the financial value of catchment preservation efforts. This may, in turn, encourage investment in enabling programmes as "the scope of risk decreases because of the activities on the positive side [of risk]". Evidence for such efforts may be gathered using methods that link future climate scenarios and socio-economic development trajectories in Lesotho, such as a basin network model or scenario planning methods.

Despite this potential, interviewees cautioned that the average financier would not naturally link ecological and land management practices to the risk profile. Though this may change with capacity building, financiers may also lack the incentive to do so. Interviewees expected that the impact of catchment management efforts may be small relative to the overall project risk profile, particularly when considered over the 10 to 15-year time horizon of a typical financier, though this assumption was not supported with evidence. Such a challenge may be exacerbated by the large uncertainties associated with long-term trends in the catchment and the adaptive response of governments and communities to impacts as they manifest. These mismatched time scales and difficult-to-measure impacts means that the positive impact of catchment preservation would need to "come through very strongly on the operational side of things… in the data that we use to understand what's happening on an operational level" to be included in the financial model. This highlights the importance of monitoring as a tool for building evidence to inform both planning and financing, but one interviewee cautioned that higher transaction costs associated with implementing these efforts may be an additional disincentive. Such observations point to the need to weigh the costs of ignorance (i.e. not investing in monitoring and the costs of potential unknowns and surprise) against the cost of reducing ignorance (i.e. the cost of implementing monitoring programmes).

The direct link between the livelihoods of cattle farmers and the degradation of the catchment prompted several interviewees to reflect on the importance of benefit sharing or payment for ecosystem services (PES) schemes as part of the L-BWT). Such schemes were viewed as a secondary priority to decision makers, stating "if those benefits were not realized or realisable it wouldn't stop the project from going ahead". Another stated that, "… you should be looking for opportunities [for a PES-type scheme] … and you should be taking into account the benefits they could have… but you should not be dependent on it working".

6.3.3 Diffusing risk and benefits over space, time, and to different actors

Connecting an understanding of uncertainties and multifunctionality to the financial sector may allow for project structures and agreements that consider a more granular diffusion of risk and benefits. This diffusion of risk may allow for a water system that is better able to recover from the impacts of uncertainties as they manifest. Interviewees familiar with the operations of South Africa's water infrastructure implementing agency, the Trans-Caledon Tunnel Authority (TCTA), provided a demonstrative example. The TCTA is responsible for raising finance, implementing infrastructure and facilitating agreements between a range of offtakers and government for DWS projects (TCTA 2016). The Minister of Water & Sanitation in concurrence with the Minister of Finance grants the TCTA borrowing powers and directs the TCTA to fund and implement projects on behalf of the DWS. Back-to back agreements are signed between DWS and TCTA and between DWS and the off-takers, which commit the off-takers to pay for water at a specified tariff level for a certain number of years to recoup the cost. The loans that the TCTA raises to pay for infrastructure projects are then paid back through tariffs from these off-takers. In a simple water transfer project, these agreements may involve a handful of water users, including mines, large municipalities, or state power agencies like the Electricity Supply Commission (ESKOM). Several interviewees confirmed that up-front commitments to offtake from a project directly reduces the volatility of the cash flows of the project, reducing risk and improving bankability.

A project like the L-BWT, which at the time of research intended to supply water to various types of offtakers along the pipeline in South Africa to an end-point in Botswana, faced the complex challenge of structuring agreements with a large number of entities with very different characteristics. Considerations of multifunctionality may directly inform this process. According to one interviewee, “the analysis of different beneficiaries along the way, which is essentially distributing beneficiaries, is a make-or-break in this project”. This was confirmed repeatedly by several interviewees, as these agreements impact the end cost of water, and therefore the risk profile and bankability of the project. An overarching principle articulated by several interviewees is that “the larger your user-base the larger your risk spread”; in essence, there is value in diffusing or distributing sources of risk to multiple entities. Another stated that “in extremely broad terms you have a revenue driver and a cost driver, and if you are beefing up your revenue drivers you are automatically reducing the risk and making the project more resilient”. Another interviewee drew parallels to the energy sector, which tries to get its energy from as many sources as possible when exposed to uncertainty and risk. These statements imply that greater diversity leads to greater resilience, a connection that is well-established in literature (e.g. Norberg *et al.* 2008; Walker *et al.* 2004). While the diffusion of risk appeared to be important, one interviewee mentioned that “at the same time you don’t want that many offtakers… you do want solid offtakers. If you have an offtaker that’s not so solid then they mustn’t comprise the majority”.

This quote emphasises that diffusing risk to multiple end users is not the only opportunity afforded by a better understanding of uncertainty and multifunctionality; a more granular characterisation of the individual characteristics of each end user may allow for dilution of higher-risk offtakers in order to bring a more diverse set of water users into the project. Interviewees drew from several comparative examples. High-functioning municipalities like RAND Water, state power companies like ESKOM or large commercial farmers may be able to commit to multi-decade agreements with relatively low risk, while a more dysfunctional municipality or a small mining operation on a 3 to 5-year planning cycle may struggle to make and uphold long-term commitments. Scenario planning or integrated modelling tools that combine socio-economic trajectories and climate futures with water supply and demand may help with this process by bringing out such "mismatched time scales" and "different stages of development". However, interviewees were quick to point out that these riskier offtakers were not to be completely avoided. Rather, the proportion of riskier offtakers can be diluted with a higher number of less risky users. Though such arrangements reflect common practice in the financial sector, they come with a set of unique challenges. In addition to improving the profile for commercial offtakers, one interviewee hoped that improved characterisation of project risk may improve government's confidence in the project and encourage support for social beneficiaries that cannot afford water tariffs.

In addition to diffusing risk to multiple users, several interviewees suggested that better knowledge of uncertainty might encourage solutions that spread risk into the future by designing infrastructure that is flexible and phased out over time. The most cited example was the building of a dam with foundations that allow for increasing the size of the dam at a later date when decision makers are more certain that the extra capacity is required, but the underlying principle of flexibility and its associated costs and benefits may be applied to many project types. Interviewees identified several potential financial implications: the initial capital burden would likely be lower, the cost of capital could be spread over a long period of time, and the income gained from earlier project phases may help pay for later enhancements. Though the overall costs may be greater if the need for later upgrades is required, the project may achieve savings if the future upgrades are deemed unnecessary. One interviewee reflected that projects involving this type of temporal flexibility could provide opportunities to innovative different types of financial models.

6.3.4 Defining roles to achieve multiple objectives

An overarching emergent theme is that questions of project finance bring out the highly dissonant primary objectives of different stakeholders, placing boundaries around innovation.

These objectives include the emphasis on project bankability for the implementing agency, on risk-adjusted financial return for a financier, on the end-cost of water for the off-taker, and on long-term water security and service delivery for governments. Interviewees repeatedly reaffirmed that these objectives significantly impact the priorities of stakeholders involved in structuring financial agreements. In addition, there appears to be a "bit of a conflict of interest in terms of the time horizons"; the 10 to 15-year time horizons of a typical financier, compared to the 3 to 5-year planning horizons of a mining operation and the multi-decade planning efforts of governments, appear to place clear limits on what aspects of uncertainty and multifunctionality might bridge into project finance.

These boundaries emphasise the need for government and transboundary organisations like ORASECOM to take on and advocate the macro-scale, long-term perspective. Interviewees voiced concern that the process of translating non-financial risks into financial terms may deprioritise significant social impacts with disproportionately small financial impacts. Similarly, challenges quantifying and financially valuing impacts may cause the financial sector to ignore some impacts. These factors demand a check-and-balance from government. For example, in discussing the challenges of including catchment preservation upstream of a project in a financial model, one interviewee emphasised that even if the financial sector does not consider them, "from a government perspective that impact [of catchment degradation] is real – it will happen in the future and it will be big". Similarly, another perspective was that, "the financiers are looking at financial impacts, but the impacts [may be] on individual communities… The impacts may be well understood, but if it's only impacting one thousand people we (the financial sector) might actually ignore it". Another example was found in climate change; the lengthy time horizons and uncertainties of climate change impacts may leave considerations of climate change solely with government. One interviewee stated, "a lot of financiers do not think about climate change too much yet… they may decide that if they are getting their money back in 5, 10, or 15 years time it may not make a huge difference… as long as they can get their money back within 10-15 years… This may be unfair, but perhaps they don't actually care whether the [project] is a white elephant in 15 years time… the government would". In addition to the use of government guarantees that place the burden of project risk back on government, such practices place government as the ultimate risk taker. This appears to be a common practice in infrastructure finance; however, if these risks manifest and become significant they may have an impact on public finance (e.g. sovereign debt and credit ratings), which may in turn affect financial sector development and international capital inflows (Kim and Wu 2008).

In discussing the understanding and diffusion of risk to different offtakers, interviewees also emphasised the role of government. One interviewee encouraged a macro-economic perspective of the mining sector and its impacts to reduce uncertainty of water demand. This interviewee claimed the water sector should consider the effect of the global trend of electric cars, its effect on South African platinum mines and their resulting water use. Another understood that mining companies are often reluctant to commit to long-term off-take agreements due to their short-term planning cycles, stating that government needs to step in and understand that "if there is a lot of mining activity in a certain area that requires water, we do not know which individual mines will still be operating there in 20 years' time… we do know there will be some mines operating there in all likelihood… and there will be a revenue generation coming from taxes… so they (the government) need to be able to step in and say the mines cannot take a 20-year view on this, but we can take a 20-year view on this." Such a long-term governmental view on mining is not only relevant to the water sector; for example, decommissioning and closure planning are part of many countries' regulatory systems (Gonzales 2017). In addition, the complex challenge of setting up offtake agreements with many entities was cited as a challenge by many stakeholders. While some governments prefer to take a "demand-responsible approach" by securing committed off-takers to repay the loan before building the infrastructure, several interviewees stated that it is the role of government to assume additional risk to allow the project to move forward. In one interviewee's words, "I don't think you'll always have that luxury as government, to say first I will pass on the risk and then I will put up the infrastructure… like roads, rail, hospitals. You don't have people signing up for breaking a leg before you build a hospital. You need that service, you need that infrastructure, and in the future people will start to use it."

Despite the focus on government, interviewees also suggested several opportunities to leverage different perspectives outside of government to make better decisions. For example, two interviewees suggested bringing a financial perspective into the project task teams under ORASECOM earlier in the decision process to help mainstream finance into planning and vice versa. Another suggested that the private sector perspective would be useful, even if the private sector is not directly involved in the project; "the private sector wants returns and they need transparency, checks and balances… If this project can stand up and bring in private sector money it allows you, even if you do not use them, to understand some of the dynamics better… It is a more rigorous approach than the traditional government approach". In addition, some interviewees emphasised that bringing in project facilities and financiers with different agendas can help the project move forward in a balanced way, such as the Climate Resilient Infrastructure Development Facility with its pro-poor, climate resilient lens or the African Water Facility with a focus on regional projects that promote peace and transparency. It is important to note that although such conversations were framed under a resilience perspective, the precautionary principle also provides useful framing for risky or uncertain government action, requiring preventative action in conditions of uncertainty, shifting the burden of proof to those conducting activities, exploring a wide range of alternatives, and increasing public participation in decisions (Kriebel *et al.* 2001).

6.3.5 Role of green finance

Because of the excitement around the potential for green finance in the literature and in practice, interviewees were asked to reflect upon the potential role for green finance in the L-BWT project. Several interviewees converged on a critical view of green finance, asking "what's the difference between bonds and green bonds? Once you look at them are they really green?". Another claimed "it's another label for a similar type of funding", and another asked "the thing is, why green bond? Is it the flavour of the month? What does green bond bring to the market that we can't get through proper project management and funding?" Others saw green finance as a distraction, stating "it's a bit of a buzzword to me, it almost distracts a bit from the core, all finance should be sustainable" and "I think stuff like green finance and climate finance is a red herring. Good projects are good projects, and if they're financeable they're financeable", though literature (section 4.2) indicates that finance is not there yet. However, some interviewees were quick to point out a more nuanced perspective, stating "still, the general principle of applying a strong environmental lens to the investment is good".

When asked about the role of specific types of green finance, some opportunities emerged. Large-scale grant funding from the Global Environment Facility (GEF) and the Green Climate Fund (GCF) may be beneficial from a financial perspective because the funding comes into the project as a grant. Thus, GEF and GCF funding acts "kind of like a subsidy. It allows for the project to have a cost-reflective tariff that is much lower and much more affordable and people may be better able to pay for this water". Still, others more critical of these grant funding bodies said they are "… not fit-for-purpose, [are] massively bureaucratic, [and are] not asking the right questions". When considering the role of green bonds, interviewees saw potential to finance projects at the municipality level with pooled finance arrangements. In essence, green finance may provide opportunities for the project, but interviewees did now view access to green finance as critical to the success of the L-BWT.

6.4 Uncertainty and multifunctionality in context

As one interview summarised succinctly, "often we will talk about governance in this clinical way of processes and institutions, regulations and rules, when actually the real world is messy and far more complex". McDaniels and Gregory (1991) provide a framework for exploring cultural characteristics of decision making under uncertainty at the individual, organisational and governmental levels, visualised in figure 6-7. Though intended for cross-cultural analysis, the framework can also be used to examine the dynamics of decision making within cultures. The individual level refers to cultural influences on heuristics, patterns and norms in behavioural decisions and cognitive processes, including individual attitudes and responses to physical risks. The organisational level examines groups of individuals operating within bureaucratic structures, focusing on organisational behaviour and strategy. Lastly, the governmental level addresses collections of organisations acting within a political power structure (McDaniels and Gregory 1991). The following section describes the evidence gathered about these dynamics in the Orange-Senqu River Basin. Though not core to these research, these findings highlight the complexities that play a highly influential role in decision making. It is clear that more systematic methods and targeted data would be required for a more thorough analysis.

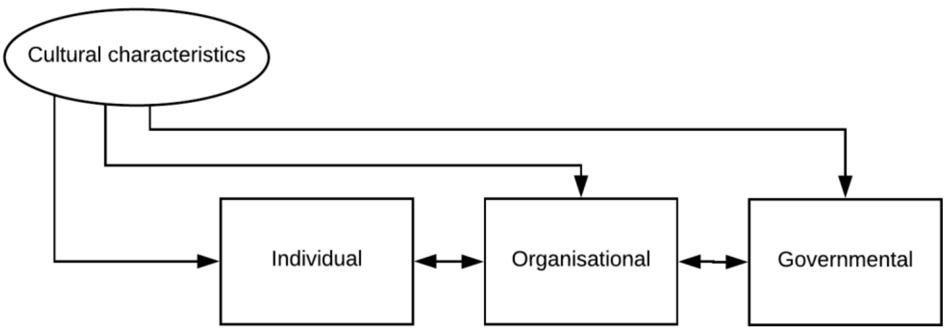

Figure 6-7 Framework for analysing cultural influences on decision making under uncertainty, Adapted from (McDaniels and Gregory 1991)

At an individual level, the reaction of citizens and politicians to extreme events and behaviour based on individual self interest emerged. At the time of research, the Cape Town water crisis was top-of-mind: "things like the drought in Cape Town are fantastic because they wake politicians up. But I've seen this so many times now - you go to a wet phase and politicians forget about it". One interviewee claimed "what you're seeing at the moment is ideas being floated by people, I think with vested interests…This actually does not make sense… We've got one of the most complex systems in the world… [it] makes no sense in the planning of how water is managed in southern Africa".

At an organisational level, several interviewees emphasised the importance of factors affecting if and how evidence gathered would be utilised in decisions. Elements may include the challenge of "bringing them [decision makers] up to speed and zooming into the [risks to the] level of specificity [required] to take forward and try to operationalise… it often zooms out to broader statements". Another challenge is "thinking about water outside of water, because most of what happens about water is thought about as a water issue, rather than an economic issue or a growth issue or a justice or equality issue". Tendency to maintain conventions was described as "the [organisation] doesn't think like that because it is not in their psyche". Similarly, stakeholders may wish to keep projects under a water silo to "claim victory" or to avoid "triggering downstream transboundary processes. Transboundary politics appeared to play an important role, with one interviewee asking "who is making decisions, based on what, and what mandate do they have from their governments?". One interviewee stated, "they can say yes we can hear what your numbers are saying, but politically this won't work".

Perhaps the most important element was the role of culture in the governmental bureaucracies of the region. "Some of the decisions are based on other elements of the traditions, the cultures, the practices of this part of the world, which are not necessarily documented in manuals and books or something that you may study at school. You may have interest to know that most of the population living in Lesotho, the bulk of this area up to the Vaal, all the way to Botswana speak nearly the same language. And politically you know the past history of Southern Africa. All of these elements tend to bring us together closer as countries than what may be documented in agreements and so on and so forth." One interviewee summed up these dynamics; "with the realisation we are in the same geographic space… and the agreements [under the SADC]… and the brotherliness of the people living in this region, then some of the so-called very difficult programmes and initiatives, they seem possible, let me say." Despite this solidarity, others described the challenges associated with the complex history of centralisation of power and management capacity in the water sector in South Africa.

7 Discussion

The research provides a unique contribution to science and practice by positioning research questions with a unique combination of concepts at the intersection of multiple fields of study in a timely and distinct case study. This discussion is separated into two major sections addressing each RQ.

7.1 RQ1: Understanding and integrating uncertainty and multifunctionality

The first research question asked "*how are the concepts of uncertainty and multifunctionality currently conceptualised and considered in decision-making processes for the resilience of the Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin? How could these concepts be considered in future decisions for the resilience of water infrastructure?*" The analysis revealed that uncertainty and multifunctionality are conceptualised as a wide range of risks and ambiguities, showing a depth and breadth of knowledge from interviewees. This makes a distinct contribution, as these nuanced conceptualisations indicate that any lack of consideration of these elements in decision making may not stem from lack of knowledge. In addition, a relatively shallow understanding of multifunctionality, which may be characteristic of large-scale, hard infrastructure projects (Venema *et al.* 1997), exposes the need for better understandings. The analysis also showed that uncertainty and multifunctionality are understood and integrated into decision making through a range of knowledge systems and participatory mechanisms from both the conventional and emerging decision paradigms. This provides a more comprehensive picture than is currently represented in literature, showing how disparate elements of research and practice that are innovating these methods come together in a real-world decision problem. This process exposed trade-offs and compromises that may characterise attempts to utilise methods for dealing with uncertainty from the emerging paradigm in decision contexts that are still dominated by the conventional paradigm. It also revealed that because a deeper definition of multifunctionality was not explicit and conscious in the decision context for the L-BWT, emerging methods from literature were not strategically utilised and multifunctionality was reduced to a question of direct water use. As such, this process generated a wide range of possibilities that can be adopted for better understanding and integrating both uncertainty and multifunctionality into future decisions for large-scale water infrastructure, under the category of 'future possible' (see tables in section 6.2). The analysis of socio-cultural elements that influence decision making (section 6.4) revealed that uncertainty and multifunctionality should not be considered in isolation from broader, yet highly influential, socio-cultural elements at the individual, organisational, and governmental levels.

Given these findings, the first research question holds legitimacy in its original intent, though the answer to the question may only be partially answered. However, it generated several main topics for further research, including the need for 1) a better understanding of the trade-offs between emerging and conventional methods that occurs in practice to better manage them, 2) a more detailed study into how the concept of multifunctionality can be leveraged for large-scale grey infrastructure in the water sector, and 3) a better diagnostic of which methods should be prioritised in complex decisions. Other areas of future research are explored further in section 7.5.

7.2 RQ2: Bridging uncertainty and multifunctionality from decision making to finance

The second research question of "*how might the financial sector leverage the findings of RQ1 to promote the resilience of water infrastructure investments?*" was meant to creatively bridge the findings of the first research question into finance. This section of the analysis was based solely on reflections from interviewees, who were pushed to respond to possible future scenarios and hypothetical situations to generate creative solutions. This process revealed opportunities 1) to consider a more comprehensive scope of risk, 2) to leverage risk mitigation measures, 3) to diffuse risks and benefits over space, time and to different actor groups, and 4) to define clear roles to achieve multiple objectives. In isolation, each of these four themes do not form a significant academic or practical contribution. The financial sector already utilises the concept of diffusing risk to multiple endpoints to decrease future volatility. Similarly, financial actors habitually look to mitigate risk with low-cost, high-impact measures when possible. However, under the framing of uncertainty and multifunctionality, each of these four concepts could be taken one step further in service of a broader goal of building socio-ecological resilience. It is also important to note that synergies exist between these opportunities, and they may need to be applied in sync to achieve the desired improvement in outcomes.

Each of the four themes may be extrapolated further than considered in the analysis (section 6.3) to more directly connect them to resilience. For example, under framings of uncertainty, multifunctionality and resilience, situations in which the financial sector "considers a more comprehensive scope of risk" may shift resources toward projects that are inherently more resilient and consider more benefits to a greater diversity of stakeholders. This in turn may impact the landscape of forces that currently dictate the priorities and trajectories of both project developers and the financial sector. For example, a more rigorous analysis of the financial implications of climate risk on infrastructure investments may push project developers and implementers to more actively mitigate climate risk in planning and project design. "Leveraging risk mitigation measures" draws more attention to efforts that promote resilience, such as catchment management efforts. Though it appears that these efforts face barriers to inclusion in financial discussions, greater attention to these efforts may help stakeholders build the evidence base and data required to attract financial support. These efforts require a better understanding of how much investment in risk mitigation can be accepted into a financial model and the metrics for determining how this is calculated. Similarly, a resilience framing on "diffusing risks and benefits over space and time" reveals opportunities to increase financial resilience by decreasing the volatility of cash flows to riskier revenue streams. It may also help bring a diverse range of beneficiaries into the project or highlight opportunities to design flexible infrastructure, which play a role in increasing the resilience of the broader social system. Lastly, the finding termed "defining roles to achieve multiple objectives" highlights that stakeholders involved in large water infrastructure decisions operate under disparate objectives, time horizons, and spatial scales. These differences may indicate that any degree of complacency from any stakeholder group may tip the scales toward the priorities and practices of others. This is not inherently negative, but a resilience perspective reveals the possibility that the divergent time horizons, objectives, and practices of different stakeholders may place government as the primary advocate for the resilience perspective.

Despite the future possibilities that surfaced through the findings of RQ2, comments regarding the peripheral role of green finance and the ongoing challenges in establishing a basic enabling financial environment in some contexts in southern Africa (e.g. Berensmann *et al.* 2015) put these findings into context. Capacity challenges and a host of other factors that introduce risk described in literature (section 4.2.3.2.1) place limits on the ability of stakeholders to adopt these findings and to keep pace with the financial sector transformation described in literature (section 4.2.1). It is also important to consider that the costs of adopting these opportunities need to be weighed against the cost of not adopting them, such as the cost of flexibility versus the cost of inflexibility, or the cost of ignorance to the nature of certain risks versus the cost of improving monitoring programmes. These costs bring back questions of the evidence base and the significant amounts of data, capacity and ongoing iteration are required to bring many of these opportunities to fruition. In the Orange-Senqu River Basin such mature systems may not be in place in all jurisdictions and data may be collected and managed by a number of different entities. Evidently, efforts to build a more robust financial system may need to happen concurrently with efforts to build a more robust knowledge and data transfer system.

Given these findings, the second research question holds legitimacy in its original intent, as this question was exploratory and meant to generate creative bridging concepts. It is unclear whether the same approach to another set of stakeholders in a similar decision problem would result in the same conclusions, but in the context of the L-BWT the question was answered. The research opened several topics for future research under each of the four main categories of findings including 1) an understanding of the systemic effect of integrating a more comprehensive scope of risk on the project finance landscape, 2) a characterisation of enablers and inhibitors for leveraging risk mitigation measures upstream or downstream of a project, 3) an understanding of the opportunities, challenges, and potential mechanisms for diffusing risk over time, space and to different actors, and 4) a better understanding of the consequences of the interactions between competing time scales and objectives of actors in the project finance landscape. Other areas of future research are explored in section 7.5.

7.3 The resilience assumption

The resilience of socio-ecological systems is a complex concept (Folke *et al.* 2010) and the transboundary context introduces further intricacies (Sapountzaki and Daskalakis 2016; Green *et al.* 2013). Though the primary assumption (i.e. that uncertainty and multifunctionality can be understood and considered in decision making in a manner that promotes the resilience of water infrastructure system) was established (section 3.3) and provided an important and effective foundation for the research, transboundary intricacies and some findings in the research demand that the concept of socio-ecological resilience is further explored in decision contexts like the L-BWT. For example, a simple exercise that defines the resilience *of what,* the resilience *to what*, and the resilience *for whom* (Cutter 2016) is difficult in the L-BWT context. Observations from interviews indicate that stakeholders at the transboundary scale may define resilience as resilience *of* the river basin *to* future pressures or surprise *for* water security in South Africa, Botswana, and Lesotho. From this lens, transboundary stakeholders may prioritise successful execution of the L-

BWT for its role in increasing political solidarity and trust, which may be an important part of building the resilience of river basin governance. Such transboundary resilience has been addressed in literature, and considers resilience as a dynamic trans-scalar and transboundary process that facilitates resource transfer, applying to contexts in which cities rely on water transfer from distant places among others (Sapountzaki and Daskalakis 2016). In contrast, another set of stakeholders may define resilience *of* a municipal water supply system *to* changes to the hydrological regime *for* constituents of the municipality. From this lens, the L-BWT may be assessed based on its potential to contribute to resilience from biophysical change. This type of resilience is also addressed in the literature, which describes the principles and managerial structures that enable resilient urban water systems (Johannessen and Wamsler 2017). In theory, resilience should integrate all perspectives, but operationalising the concept in transboundary decisions may require breaking them down further.

7.4 Methodological choices

The choices in methodology had a significant impact on the results. The use of documents and interviews as primary data provided a reasonable breadth of information, and the use of content analysis drew out complementary themes from the two sources. However, the method favoured expert viewpoints and the attempt to conduct the research from the ontology and epistemology of pragmatism deviated toward a more scientific, positivist paradigm. This was expected, but data collected from a wider range of stakeholders at the community level may have led to different findings. This became apparent in two interviews whose social lens highlighted the underrepresented voices.

The choice of a case study research design in a contemporary decision problem allowed for enthusiastic engagement from interviewees. The case study method also helped interviewees explore conceptual problems at a level of detail that might have been difficult otherwise. However, some aspects of the case study context were dissonant with the research aims. First, the L-BWT as a transboundary project led many discussions of politics, requiring adjustments to the analysis. This revealed a gap in the conceptual framework, as politicisation of financial decisions is commonplace in transboundary contexts (Newman 2009). Second, the sensitivity of concurrent political discussions led some interviews to hesitate to share detailed knowledge on emerging information. The most significant manifestation of this challenge is that no interviews were secured with government stakeholders and stakeholders did not share the most recent project study. Third, multifunctionality is most often used to highlight the wider range of benefits from green infrastructure in contrast to grey (Hansen and Pauleit 2014; Pauleit *et al.* 2011). Rigorous application of the concept to a large-scale piece of grey infrastructure like the L-BWT would require a broader scope of research. Similarly, the discourse about green finance and green bonds focuses on financing small-scale projects with characteristics that may not otherwise attract finance. For example, nature-based projects implemented at a municipal level may be marginal in financial terms, but may have significant ecological or social benefits that could be aggregated with other projects under a green bond (Shishlov *et al.* 2016; Lazurko and Venema 2017).

7.5 Additional areas for further investigation

The research generated issues for further investigation that were not core to the research questions.

7.5.1 RQ1: Transboundary peculiarities, scale, and integration

The application of RQ1 to a transboundary case brought out findings that may not have surfaced in a domestic case study. For example, joint transboundary projects like the L-BWT are often political, and early project buy-in appears sensitive to the perceived risks and benefits of each country. Although collective visioning and scenario exercises are increasingly accepted as effective ways to understand and handle uncertainty and complexity, interviewees indicated these approaches may need to be better situated alongside the objectives of political stakeholders.

Literature on resilience in transboundary water contexts systems exists (e.g. Green *et al.* 2013), but because RQ1 did not place the 'transboundary' characteristic at the forefront of analysis such literature did not address these complexities. This brings up research that asks *how can political motivations and sensitivities be usefully framed or managed within emerging methods for decisions under uncertainty such as scenario planning? How can we define the preconditions for enabling the constructive use of these methods?* Similarly, observations that a given transboundary project may be the most important project for a region, but not for each country, emphasises that consideration of scale may be critical to bring the concept of multifunctionality to new contexts. Future research may ask *how can multifunctionality be used to leverage projects to achieve multiple objectives at different scales (in transboundary contexts)?* Additionally, multifunctional infrastructure systems are also dynamic, meaning that factors affecting the ability of the system to deliver and the needs of beneficiaries are constantly changing. This leads to questions such as *how does the availability of multiple benefits and risks help negotiate and renegotiate the management of the system over time? How can scenarios help this negotiation?* Lastly, the socio-cultural elements addressed in the analysis highlight that the cooperation derived from executing large projects plays an important role in the resilience of water governance. This can be related to the social capital through questions such as, *what is the role of cooperation and social capital in managing multifunctionality as the surrounding context changes over time, and how is this capital built?*

The research also drew attention to the importance of scale. While a project case study was useful to frame the research, the boundary between the scale of the L-BWT and the Orange-Senqu River Basin was indistinct and any effort to draw a clear boundary between the two left out important information. It became necessary to oscillate freely between the two scales as required. Interestingly, this research challenge mirrored an observable challenge in practice. Namely, stakeholders were attempting to drive a project forward that seemed to be situated outside of the existing water management regime in southern Africa, or to be driven by political factors that preceded questions of technical feasibility and risk. The existing system appeared to be governed by established precedents and power dynamics from decades of water management in the basin. This dynamic was evident as interviewees from within the existing system appeared confused by the project. Managing these complexities may require a similarly oscillatory lens in practice; an isolated, project-specific lens may be required to push past power-related structural barriers or to advocate benefits to disparate stakeholders, but a river-basin lens may be required to embed the project in the regional biophysical and social characteristics. This dilemma prompts questions like *in which decision-making contexts is the biophysical scale beneficial and in which is it limiting? What are the most critical considerations for situating an isolated project within its biophysical and social context? What happens when you place these considerations within a dynamically changing spatio-temporal matrix?*

This analysis used a simple visualisation of *integration* (see figure 6-2) as the incorporation of uncertainty and multifunctionality within a combination of other factors in decisions. Further understanding *integration* might require prioritizing uncertainty and multifunctionality in relation to other concepts, aligning these concepts with the languages and processes of other disciplines, and mainstreaming conversations about these concepts into each decision phase and hierarchy. In essence, there may be important stages between introducing the concepts to a decision context and embedding them within all elements of a decision. Such considerations prompt many further research questions, such as *how can integration (of concepts such as uncertainty and multifunctionality) be usefully deconstructed and described in complex decisions? What is the relative significance of uncertainty and multifunctionality in complex decision problems and what is their relationship to other concepts? What elements of the decision context enable or constrain integration?*

7.5.2 RQ2: Financial sector transformation and the role of green finance

Save a recent study exploring issues of financial regulation from the lens of socio-ecological resilience (Dowell-Jones and Buckley 2017) and an article urging an adaptive cycle lens on climate insurance (Cremades *et al.* 2018), the financial sector appears distant from the field of socio-ecological resilience. Although the analytics and decision paradigms of the financial sector appear disconnected from biophysical and social impacts at local scales, its dynamics are made up of a landscape of forces that drive significant change in the development sector and can enable or inhibit local-level transformation (Weber 2014). In addition, the financial sector itself is undergoing transformative change: "financial institutions are operating in an unprecedented monetary- and fiscal-policy environment, and that environment may be with us for some time, as the underlying causes of slow growth are largely structural… faced with such large-scale sources of uncertainty, financial institutions will need to take a long-term view of sustainability to survive a wide range of economic and policy scenarios" (Ernst & Young 2016). Though this research generated bridging concepts, there may be more opportunities in further exploring the intersection of these two disparate paradigms, both in bringing the field of socio-ecological resilience to finance and in integrating the framings of transformation and change from the financial sector into the discourse of socio-ecological resilience.

Questions regarding the role of green finance in the context of the L-BWT did not generate ideas that are not already being discussed in other contexts. In fact, opinions of the role of green finance in the context of the L-BWT were different than that of innovation found in current literature about the Climate Bonds Standard (e.g. Climate Bonds Initiative 2017) or at the municipal government level in South Africa (City of Cape Town Media Office 2017). These entities advocate green finance as a way to set rigorous environmental standards on investments while channelling finance to uniquely beneficial development projects. Still, there may be opportunities to bring other elements of this research to green finance in ways that were not identified in interviews. For example, green finance mechanisms such as green bonds may enable large projects like L-BWT to leverage risk mitigation factors in the river basin, such as catchment management efforts, if they are designed in tangent with the hard infrastructure investments. Further addressing these ideas can occur within the scientific community, but they may also be further explored in diverse stakeholder groups.

8 Conclusion and recommendations

The Orange-Senqu River Basin provides critical resources to Lesotho, South Africa, Namibia and Botswana, but uncertain climate projections, multiple possible development futures, and a financing gap create challenges for water infrastructure decision making. At the time of research, the Lesotho-Botswana Water Transfer, a transboundary project facilitated by ORASECOM, was at pre-feasibility stage and exhibited characteristics of deep uncertainty, a multi-stakeholder decision environment, and pressures from climate impacts and other macro trends. The emergence of a resilience-based decision-making paradigm meant to deal with these challenges provides opportunities to make decisions that take into account this wide range of uncertain futures and to design solutions with social, ecological and economic multifunctionality. Such considerations can play an important role in increasing socio-ecological resilience. The first research question aimed to explore how uncertainty and multifunctionality are conceptualised and considered in decision making for the resilience of large-scale water infrastructure. Collecting and analysing data from documents and semi-structured interviews provided a rich platform for drawing conclusions and providing recommendations.

Although the basin has a history of water management under a conventional engineering paradigm, interviewees collectively conceptualised uncertainty as a range or risk, ambiguity and ignorance. In contrast, multifunctionality was conceptualised as a relatively surficial distribution of benefits, driven by the need to secure political commitments to the project. These understandings led to the use of a melange of methods from both the conventional and emerging paradigm for dealing with these concepts, resulting in trade-offs in how methods under the emerging paradigm were used and fed into decision making. In addition to discussing current and planned methods, creative responses from interviewees generated extensive possibilities for future ways to better consider uncertainty and multifunctionality in decisions. This process also generated several suggestions for further research, including examining trade-offs between conventional and emerging methods, studying how multifunctionality relates to large-scale grey infrastructure, prioritising which methods for understanding uncertainty and multifunctionality are suitable for which contexts, and several other more exploratory findings (section 7.5.1). This research question also led to more immediately actionable recommendations:

- **Recommendation 1.1:** All stakeholders should take advantage of untapped potential for better understanding and consideration of uncertainty and multifunctionality ('future possible' in the tables in section 6.2) in decision making. These actions can result in decisions that are more resilient to a range of difficult-to-predict context conditions. Fortunately, competencies exist in the basin, as many innovative ideas from interviewees mirrored the most recent literature.

- **Recommendation 1.2:** Stakeholders should set aside time early in the decision process to collectively define resilience and to decide how they will consider critical elements of uncertainty and multifunctionality. The potential adaptivity afforded by emerging methods like scenario planning may not be realised if the outcomes are fed into conventional decision processes that are not adjusted to utilise the findings or are not aligned to a well-defined goal (i.e. resilience). Practitioners implementing these methods must also find ways to balance their findings with other factors in the decision context and link them to relevant decision points.

- **Recommendation 1.3:** There is a need for scientists and practitioners to intentionally navigate the dynamics of scale. Regional water scarcity may lead to large, transboundary solutions, but resilient solutions are often developed at local level. Moving from project to basin-scale may help embed the infrastructure in the social and biophysical characteristics of the basin and take advantage of competencies from more stakeholders. Reaching to the local level may help clarify elements of multifunctionality and connect the project to local-level resilience (e.g. in relation to small-scale green infrastructure).

- **Recommendation 1.4:** Despite abundant research addressing adaptive governance characteristics and methods under the emerging paradigm, a research gap addressing how emerging decision-making paradigms integrate in real-world contexts remains. This gap demands further studies that innovate practical ways to navigate this complexity in the immediate future.

In addition to such decision-making challenges, growing efforts to address the powerful role of the financial sector in enabling or inhibiting sustainable development pathways demands an urgent look at the role of finance in addressing challenges like those faced in the Orange-Senqu River Basin. The second research questioned aimed to begin exploration into the intersection of the emerging decision paradigm with the financial sector. This was a creative and useful exercise, revealing opportunities for project finance to consider a more comprehensive scope of risk, to leverage risk mitigation measures, to diffuse risks and benefits over space, time and to a variety of stakeholders, and to define clear roles to achieve multiple objectives. While some of these findings may already be applied in contemporary finance processes, the focus on uncertainty and multifunctionality pushed these practices a step further in service of the broader goal of resilience. This exercise generated several topics for further research, including investigating the effect of integrating a broader scope of risk on the project finance landscape and identifying critical enabling conditions that would allow risk mitigation measures upstream or downstream of a project to be considered in a financial model. These are accompanied by a host of other potential research areas described in section 7.5.2. This research question also led to direct recommendations to practitioners:

- **Recommendation 2.1:** Stakeholders involved in project finance should consider how they can use emerging methods for understanding and integrating uncertainty in decisions to consider a more comprehensive scope of risk (e.g. climate change, water supply and demand) in financial decisions. This can help enable more resilient water infrastructure decisions and prepare financiers for future unknowns.
- **Recommendation 2.2:** Considering a broader scope of risk (recommendation 2.1), should prompt governments and financiers to support measures that mitigate risk and contribute to socio-ecological resilience (e.g. catchment preservation or water demand management). Such efforts may help deploy and finance innovative models like PES more effectively by connecting them to different resource pools and integrating them into a broader water management effort. However, a more robust risk framework requires concurrent efforts to develop stronger data and monitoring systems.

- **Recommendation 2.3:** Project finance can take advantage of practices that reflect the principle of increasing diversity for resilience to achieve multiple objectives. For example, efforts to include bringing diverse water users into projects to decrease cash flow volatility and integrating risky users with strong ones, can result in projects that are prepared for future uncertainties and allow government to more confidently commit water to social beneficiaries.

- **Recommendation 2.4:** It is critical that governments and transboundary organisations like ORASECOM continue to recognise their role as advocates for resilience, social benefit, and the long-term, macro perspective. The financial sector is governed by its own objectives and internal norms that may not tend toward these solutions.

Despite the potential in these recommendations, some entities in southern Africa are still working to institute a basic enabling environment for private finance. In the interim, financiers should ask how they can step outside of conventions to support the principles underlying these recommendations by taking advantage of competencies outside the financial sector, expanding boundaries to look at risks over new time horizons and scales, reconciling the incongruent objectives of stakeholders, and diffusing risk for the benefit of the financial sector and resilience.

Actors in the water sector in southern Africa and many similar contexts are working for transformative change to secure water resources under significant pressures. One interviewee said, "I feel like the problem is that there is an overabundance of certainty when there shouldn't be", while later stating that "part of the challenge of getting change to happen is that you have to sacrifice some of those uncertainties and present them as certainties". Though seemingly a contradiction, these statements together reflect the complexities of change in challenging environments. Though research that accepts and grapples with these challenges proved to be though-provoking and difficult, there appears to be great potential in further exploring concepts like uncertainty and multifunctionality in decision making, and in further navigating the junction between socio-ecological resilience and finance.

Bibliography

African Development Bank. 2012. Africa's demographic trends: Briefing notes for the AfDB's long term strategy. Briefing Note 4. URL: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/FINAL Briefing Note 4 Africas Demographic Trends.pdf.

African Water Facility. 2016. Orange-Senqu River Basin preparation of climate resilient water resources investment strategy & plan and multipurpose project: Project appraisal report. Abidjan. URL: https://www.africanwaterfacility.org/fileadmin/uploads/awf/Projects/PCRs/OSASECOM_-_Appraisal_Report___final.docx.

Ahern, J. 2011. From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*. Vol. 100. doi: 10.1016/j.landurbplan.2011.02.021.

———. 2013. Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology* 28 (6): 1203–12. doi:10.1007/s10980-012-9799-z.

Allen, C.R., and Gunderson, L.H. 2011. Pathology and failure in the design and implementation of adaptive management. *Journal of Environmental Management* 92 (5). Elsevier Ltd: 1379–84. doi:10.1016/j.jenvman.2010.10.063.

Alves, A., Gersonius, B., Sanchez, A., Vojinovic, Z., and Kapelan, Z. 2018. Multi-criteria approach for selection of green and grey infrastructure to reduce flood risk and increase co-benefits. *Water Resources Management* 32 (7): 2505-2522. doi:https://doi.org/10.1007/s11269-018-1943-3.

Amer, M., Daim, T.U., and Jetter, A. 2013. A review of scenario planning. *Futures* 46: 23–40. doi:10.1016/j.futures.2012.10.003.

Ameyaw, E.E., and Chan, A.P. 2015a. Risk ranking and analysis in PPP water supply infrastructure projects. *Facilities* 33 (7/8): 428–53. doi:10.1108/F-12-2013-0091.

Ameyaw, E.E., and Chan, A.P.C. 2013. Identifying public-private partnership (PPP) risks in managing water supply projects in ghana. *Journal of Facilities Management* 11 (2): 152–82. doi:10.1108/14725961311314651.

Ameyaw, E.E., and Chan, A.P.C. 2015b. Evaluation and ranking of risk factors in public-private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach. *Expert Systems with Applications* 42 (12): 5102–16. doi:10.1016/j.eswa.2015.02.041.

Anthony, C., Arnold, T., Gosnell, H., Benson, M.H., and Craig, R.K. 2017. Cross-interdisciplinary insights into adaptive governance and resilience. *Ecology and Society* 22 (4): 14. doi:https://doi.org/10.5751/ES-09734-220414.

Arkesteijn, M., van Mierlo, B., and Leeuwis, C. 2015. The need for reflexive evaluation approaches in development cooperation. *Evaluation* 21 (1): 99–115. doi:10.1177/1356389014564719.

Ascough, J.C., Maier, H.R., Ravalico, J.K., and Strudley, M.W. 2008. Future research challenges for incorporation of uncertainty in environmental and ecological decision-making. *Ecological Modelling* 219 (3–4): 383–99. doi:10.1016/j.ecolmodel.2008.07.015.

Ashton, P., and Turton, A. 2009. Water and security in sub-saharan africa: emerging concepts and their implications for effective water resource management in the southern african region. In *Facing Global Environmental Change: Hexagon Series on Human and Environmental Security and Peace*, ed. H.G. Brauch, Ú.O. Spring, J. Grin, C. Mesjasz, P. Kameri-Mbote, N.C. Behera, B. Chourou, and H. Krummenacher, 661–74. Berlin, Heidelberg: Springer. doi:10.1007/978-3-540-68488-6_50.

Association of British Insurers. 2005. Financial risks of climate change: summary report. Climate Risk Management and Metroeconomica. URL: http://insurance.lbl.gov/documents/abi-climate.pdf

Ayres, L. 2008. *The SAGE encyclopedia of qualitative research methods*. Thousand Oaks: SAGE Publications, Inc. doi:10.4135/9781412963909.

Bahri, A. 2012. Integrated urban water management. Global Water Partnership Technical Committee. TEC Background Paper No. 16. doi:10.1080/09614520701469427.

Berensmann, K., Dafe, F., and Volz, U. 2015. Developing local currency bond markets for long-term development financing in sub-saharan africa. *Oxford Review of Economic Policy* 31 (3–4): 350–78. doi:10.1093/oxrep/grv032.

Berg, A., Clapp, C., Lannoo, E., and Peters, G. 2018. Climate scenarios demystified: a climate scenario guide for investors. Report from the Center for International Climate Research (CICERO). URL: https://www.cicero.oslo.no/en/publications/internal/2867.

Berger, T., Birner, R., Mccarthy, N., DíAz, J., and Wittmer, H. 2007. Capturing the complexity of water uses and water users within a multi-agent framework. *Water Resources Management* 21 (1): 129–48. doi:10.1007/s11269-006-9045-z.

Berkes, F., Colding, J., and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10 (5): 1251–62. doi:10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Berkes, F., Folke, C., and Colding, J. 2000. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge: Cambridge University Press.

Bhave, A.G., Conway, D., Dessai, S., and Stainforth, D.A. 2016. Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world. *Climate Risk Management* 14: 1–10. doi:10.1016/j.crm.2016.09.004.

Biensan, P. 2017. Africa focus: Unlocking international investment opportunities in Africa. Report from White & Case (August). URL: https://www.whitecase.com/publications/insight/africa-focus-2017.

Bigen Africa (PTY) Ltd. 2015. *Lesotho Highlands-Botswana water transfer desktop study*. World Bank. Not publicly available.

Biswas, A.K. 1999. Management of international waters: Opportunities and constraints. *International*

Journal of Water Resources Development 15 (4): 429–41. doi:10.1080/07900629948691.

Blumstein, S. 2017. Integrating water and climate diplomacy in the Orange-Senqu River Basin. Berlin: adelphi. URL: https://www.adelphi.de/en/publication/integrating-water-and-climate-diplomacy-orange-senqu-river.

Boroto, R.J. 2004. A collaborative effort towards implementing iwrm: A Southern African perspective. Paper presented at the *International Conference on IWRM*. 6-9 December 2004. Kyoto. URL: https://iwlearn.net/resolveuid/4a239dfc089bf6c9099d00bb914a4db0.

Bowen, G.A. 2009. Document analysis as a qualitative research method. *Qualitative Research Journal* 9 (2): 27–40. doi:http://dx.doi.org/10.3316/QRJ0902027.

Briceño-Garmendia, C., Smits, K., and Foster, V. 2008. Financing public infrastructure in sub-Saharan Africa: Patterns, issues, and options. *Africa Infrastructure Country Diagnostic*, no. 15. URL: http://www.eu-africa-infrastructure-tf.net/attachments/library/aicd-background-paper-15-fiscal-costs-summary-en.pdf.

Briscoe, J. 1999. The changing face of water infrastructure financing in developing countries. *International Journal of Water Resources Development* 15 (3): 301–8. doi:10.1080/07900629948826.

Brown, C. 2011. Decision-scaling for robust planning and policy under climate uncertainty. *World Resources Report Uncertainty Series*. URL: http://www.worldresourcesreport.org/files/wrr/papers/wrr_brown_uncertainty.pdf.

Busari, O., and Ndlovu, J. 2012. Leveraging water infrastructure for transformative socio-economic development in South Africa. *WIT Transactions on Ecology and the Environment* 162: 435–46. doi:10.2495/EID120381.

Butterworth, J., and Soussan, J. 2001. Water supply and sanitation & integrated water resources management: Why seek better integration? Water, Households & Rural Livelihoods. WHIRL Working Paper 2. *URL:* http://www.nri.org/projects/wss-iwrm/Reports/Working%7B_%7Dpapers/WHIRL%5Cnworking%5Cnpaper%5Cn2%7B_%7Dfinal.pdf.

Caltz, E., and Fourie, J. 2010. Infrastructure in South Africa: Who is to finance and who is to pay? *Development Southern Africa* 27 (2): 177–91. doi:10.1080/03768351003740449.

Carlsson-Kanyama, A., Dreborg, K.H., Moll, H.C., and Padovan, D. 2008. Participative backcasting: A tool for involving stakeholders in local sustainability planning. *Futures* 40 (1): 34–46. doi:https://doi.org/10.1016/j.futures.2007.06.001.

Casadevall, S.R. 2016. Improving the management of water multi-functionality through stakeholder involvement in decision-making processes. *Utilities Policy* 43. doi:10.1016/j.jup.2016.04.015.

Chaffin, B.C., Gosnell, H., and Cosens, B.A. 2014. A decade of adaptive governance scholarship : Synthesis and future directions. *Ecology and Society* 19 (3): 56. https://www.ecologyandsociety.org/vol19/iss3/art56/.

Chen, C., and Messner, J.I. 2005. An investigation of Chinese BOT projects in water supply: A comparative perspective. *Construction Management and Economics* 23 (9): 913–25.

doi:10.1080/01446190500184121.

Cheung, E. and Chan, A.P.C. 2011. Risk factors of public-private partnership projects in China: Comparison between the water, power, and transportation sectors. *Journal of Urban Planning and Development* 137 (4): 409–15. doi:10.1061/(ASCE)UP.1943-5444.0000086.

Christelis, G., Hunger, G., Mulele, O., Mangisi, N., Mannathoko, I., Wyk, E. Van, and Braune, E. 2013. Towards transboundary aquifer management in southern Africa. Siagua documents. URL: http://www.siagua.org/sites/default/files/documentos/documentos/sur_africa.pdf.

City of Cape Town Media Office. 2017. Green pays: City's R1 billion bond a resounding success in the market. Media article. URL: http://www.capetown.gov.za/media-and-news/Green pays City.

Clapp, C., Alfsen, K., Lund, H., and Pillay, K. 2016. Policy note 2016: Green bonds and environmental integrity : Insight from cicero second opinions. Oslo. URL: http://www.cicero.uio.no.

Clapp, C., Lund, H.F., Aamaas, B., and Lannoo, E. 2017. Shades of climate risk: Categorizing climate risk for investors. CICERO Report. URL: http://www.cicero.oslo.no/file/93/Shades of Climate Risk nyformatting (Sistetil web13 02 2016).pdf/download.

Climate Bonds Initiative. 2017. *Climate bonds standard, version 2.1*. URL: https://www.climatebonds.net/standards/standard_download.

Climate Resilient Infrastructure Development Facility. 2017. *Climate resilience development pathways: Final CRDP guidance*. Report. URL: http://cridf.net/RC/wp-content/uploads/2018/01/SP15-002-D09-Final-CRDP-Guidance.pdf.

Cohon, J.L., and Marks, D.H. 1975. A review and evaluation of multiobjective programing techniques. *Water Resources Research* 11 (2): 208–20. doi:10.1029/WR011i002p00208.

Collier, P. 2014. Attracting international private finance for African infrastructure. *Journal of African Trade* 1 (1): 37–44. doi:10.1016/j.joat.2014.09.002.

Conway, D., Van Garderen, E.A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., *et al.* 2015. Climate and southern Africa's water-energy-food nexus. *Nature Climate Change* 5 (9): 837–46. doi:10.1038/nclimate2735.

Corbin, J., and Strauss, A. 1993. *Basics of qualitative research - Techniques and procedures for developing grounded theory*. Thousand Oaks, California: Sage Publications.

Corfee-morlot, J., Marchal, V., Kauffmann, C., Kennedy, C., Stewart, F., Kaminker, C., and Ang, G. 2012. Towards a green investment policy framework: The case of low-carbon, climate-resilient infrastructure. *OECD Environment, Working Papers* June: 1-60. doi:http://dx.doi.org/10.1787/5k8zth7s6s6d-en OECD.

Coston, E., Odaro, E., Hartwick, E., and Jones, J. 2014. *Next season's green bond harvest: Innovations in green credit markets*. Working Paper from the Kellogg School of Management and the International Finance Corporation. URL: https://openknowledge.worldbank.org/handle/10986/26055.

Cremades, R., Surminski, S., Máñez Costa, M., Hudson, P., Shrivastava, P., and Gascoigne, J. 2018. Using the adaptive cycle in climate-risk insurance to design resilient futures. *Nature Climate Change* 8 (1): 4–7. doi:10.1038/s41558-017-0044-2.

Cutter, S. 2016. Resilience to what? Resilience for whom? *The Geographical Journal* 182 (2): 110–13. doi:10.1111/geoj.12174.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., and Orru, H. 2014. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management* 146: 107–15. doi:10.1016/j.jenvman.2014.07.025.

Department of Water Affairs Botswana. 2017. *Botswana water accounting report 2015/2016*. Republic of Botswana. Gaborone. URL: https://www.wavespartnership.org/sites/waves/files/kc/Botswana Water Accounting Report 2015_16.pdf.

Department of Water Affairs South Africa. 1997. White paper on water policy. Government of South Africa: Pretoria. URL: http://www.dwaf.gov.za/Documents/Policies/WP3.html.

Department of Water Affairs South Africa. 2012. *Development of reconciliation strategies for bulk water supply systems Orange River: Literature review report*. http://www.dwa.gov.za/Projects/Orange Recon/Docs/final/2 OrangeRecon Literature Review Report_ v2Fin.pdf.

Dijst, M., Elbersen, B., and Willis, K. 2005. The challenge of multi-functional land use in rural areas. *Journal of Environmental Planning and Management* 48 (1). doi:10.1080/0964056042000308120.

Dombrowsky, I. 2009. Revisiting the potential for benefit sharing in the management of trans-boundary rivers. *Water Policy* 11 (2): 125. URL: http://wp.iwaponline.com/content/11/2/125.abstract.

Dong, C., Schoups, G., and Van de Giesen, N. 2013. Scenario development for water resource planning and management: A review. *Technological Forecasting and Social Change* 80 (4): 749–61. doi:10.1016/j.techfore.2012.09.015.

Dos Santos, S., Adams, E.A., Neville, G., Wada, Y., de Sherbinin, A., Mullin Bernhardt, E., and Adamo, S.B. 2017. Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. *Science of The Total Environment* 607–608: 497–508. doi:https://doi.org/10.1016/j.scitotenv.2017.06.157.

Dowell-Jones, M., and Buckley, R. 2017. Reconceiving resilience: A new guiding principle for financial regulation? In *Northwestern Journal of International Law & Business*, 37:1–33. URL: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=121732320&lang=es&site=ehost-live.

Duru, U., and Nyong, A. 2016. Why Africa needs green bonds. Report from the African Development Bank. URL: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/AEB_Vol_7_Issue_2_Why_Africa_Needs_Green_Bonds.pdf.

Ehlers, T., and Packer, F. 2016. Green Bonds – certification , shades of green and environmental risks. Bank for International Settlements, contribution to the G20 Green Finance Study Group. URL: http://unepinquiry.org/wp-content/uploads/2016/09/12_Green_Bonds_Certification_Shades_of_Green_and_Environmental_Risks.pdf.

Entholzner, A., and Reeve, C. 2016. *Building climate resilience through virtual water and nexus thinking in the Southern African Development Community*. Springer.

Ernst & Young. 2016. Revolutionary change is transforming the financial services landscape. Financial Services Leadership Summit: Viewpoint. Tapestry Networks, Inc. URL: http://www.ey.com/gl/en/industries/financial-services/fso-insights-revolutionary-change-is-transforming-the-financial-services-landscape

Fath, B.D., Dean, C.A., and Katzmair, H. 2015. Navigating the adaptive cycle: An approach to managing the resilience of social systems. *Ecology and Society* 20 (2). doi:10.5751/ES-07467-200224.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16 (3): 253–67. doi:https://doi.org/10.1016/j.gloenvcha.2006.04.002.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chappin, T., and Rockström, J. 2010. Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society* 15 (4): 20–28. doi:10.5751/ES-03610-150420.

Folke, C., Hahn, T., Olsson, P., and Norberg, J. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environmental Resources* 30: 441–73. doi:10.1146/annurev.energy.30.050504.144511.

Fraiture, C. De, Molden, D., and Wichelns, D. 2010. Investing in water for food , ecosystems, and livelihoods: An overview of the comprehensive assessment of water management in agriculture. *Agricultural Water Management* 97: 495–501. doi:10.1016/j.agwat.2009.08.015.

G20 Green Finance Study Group (G20 GFSG). 2017a. *G20 green finance synthesis report*. Report to the Group of Twenty. URL: https://europa.eu/capacity4dev/climatefinance/blog/g20-green-finance-synthesis-report.

———. 2017b. *Enhancing environmental risk assessment in financial decision-making*. Report in support of the G20 Green Finance Study Group. URL: http://unepinquiry.org/wp-content/uploads/2017/07/Enhancing_Environmental_Risk_Assessment_in_Financial_Decision-making.pdf.

Geoff, W. 2010. Multifunctional "quality" and rural community resilience. *Transactions of the Institute of British Geographers* 35 (3): 364–81. doi:10.1111/j.1475-5661.2010.00391.x.

Gersonius, B., Ashley, R., Pathirana, A., and Zevenbergen, C. 2013. Climate change uncertainty: Building flexibility into water and flood risk infrastructure. *Climatic Change* 116 (2): 411–23. doi:10.1007/s10584-012-0494-5.

Gillingham, K., Nordhaus, W., Anthoff, D., Blanford, G., Bosetti, V., Christensen, P., McJeon, H., and Reilly, J. 2018. Modeling uncertainty in integrated assessment of climate change: A Multi-model comparison. Cowles Foundation Discussion Paper No. 2022. URL: https://cowles.yale.edu/sites/default/files/files/pub/d20/d2022.pdf.

Gonzales, A.B. 2017. Sustainable decommissioning and integrated closure planning of selected mine sites in the Bicol Region, Philippines. In *15th International Conference on Environmental Science and Technology*. 31 August to 2 September, 2017. Rhodes, Greece: Conference on Environmental Science and Technology. URL: https://cest.gnest.org/sites/default/files/presentation_file_list/cest2017_01078_oral_paper.pdf.

Gourbesville, P. 2008. Challenges for integrated water resources management. *Physics and Chemistry of the Earth* 33: 284–89. doi:10.1016/j.pce.2008.02.002.

Grayburn, J. 2012. *Real options and investment decision making*. Report for ofgem. London. URL: https://www.ofgem.gov.uk/sites/default/files/docs/2012/03/real_options_investment_decision_making.pdf.

Green Climate Fund. 2015. Consideration of funding proposals – addendum. Green Climate Fund Funding Proposal Summary for FP004 14 (November): 57. URL: http://www.greenclimate.fund/documents/20182/87610/GCF_B.11_04_ADD.05_REV.01_-_Funding_proposal_package_for_FP005.pdf/c38034c9-f86f-41b7-bc3a-11f052aba5e0?version=1.0.

Green, O.O., Cosens, B.A., and Garmestani, A.S. 2013. Resilience in transboundary water governance: The Okavango River Basin. *Ecology and Society* 18 (2). doi:10.5751/ES-05453-180223.

Grey, D., and Sadoff, C.W. 2007. Sink or swim? Water security for growth and development. *Water Policy* 9 (6): 545-571. doi:10.2166/wp.2007.021.

Groot, R. De. 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. *Landscape and Urban Planning* 75: 175–86. doi:10.1016/j.landurbplan.2005.02.016.

Gunderson, L., and Light, S.S. 2006. Adaptive management and adaptive governance in the everglades ecosystem. *Policy Science* 39: 323–34. doi:10.1007/s11077-006-9027-2.

Gutman, J., Sy, A., and Chattopadhyay, S. 2015. *Financing African infrastructure: Can the world deliver?* Report from Global Economy and Development, Brookings Institute. URL: https://www.brookings.edu/wp-content/uploads/2016/07/AGIFinancingAfricanInfrastructure_FinalWebv2.pdf.

Gunderson, L., and Holling, C.S. 2001. *Panarchy: Understanding transformations in human and natural systems*. Island Press. doi:10.1016/S0006-3207(03)00041-7.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., and ter Maat, J. 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change* 23 (2): 485–98. doi:10.1016/j.gloenvcha.2012.12.006.

Hall, D., Lobina, E., and Motte, R. de la. 2005. Public resistance to privatisation in water and energy. *Development in Practice* 15 (3–4): 286–301. doi:10.1080/09614520500076126.

Hall, J., Lempert, R.J., Keller, K., Hackbarth, A., Mijere, C., and Mcinerney, D.J. 2012. Robust climate policies under uncertainty: A comparison of robust decision making and info-gap methods. *Risk Analysis* 32 (10): 1657–72. doi:10.1111/j.1539-6924.2012.01802.x.

Hallegatte, S., Shah, A., Lempert, R., Brown, C., and Gill, S. 2012. Investment decision making under deep uncertainty: Application to climate change. World Bank Policy Research Working Paper, no. 6193: 41. doi:doi:10.1596/1813-9450-6193.

Hanjra, M.A., Ferede, T., and Gutta, D.G. 2009. Reducing poverty in sub-Saharan Africa through investments in water and other priorities. *Agricultural Water Management* 96 (7): 1062–70. doi:https://doi.org/10.1016/j.agwat.2009.03.001.

Hansen, R., and Pauleit, S. 2014. From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas. *Ambio* 43 (4): 516–29. doi:10.1007/s13280-014-0510-2.

Heath, A., and Read, M. 2014. Financial flows and infrastructure financing. Report from the Reserve Bank of Australia, Australian Government Productivity Commission, Lowy Institute for International Policy. URL: https://www.rba.gov.au/publications/confs/2014/pdf/conf-vol-2014.pdf.

Herrfahrdt-Pähle, E. 2013. Integrated and Adaptive Governance of Water Resources: The Case of South Africa. *Regional Environmental Change* 13 (3): 551–61. doi:10.1007/s10113-012-0322-5.

Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4 (1): 1–23. doi:10.1146/annurev.es.04.110173.000245.

Holling, C.S. 1978. Adaptive environmental assessment and management. *International Series on Applied Systems Analysis*, 402.

Huskova, I., Matrosov, E.S., Harou, J.J., Kasprzyk, J.R., and Lambert, C. 2016. Screening robust water infrastructure investments and their trade-offs under global change: A London example. *Global Environmental Change* 41: 216–27. doi:10.1016/j.gloenvcha.2016.10.007.

Infrastructure Consortium for Africa. 2017. *Infrastructure financing trends in Africa - 2016*. Report for the Infrastructure Consortium of Africa c/o African Development Bank. Abidjan, Cote d'Ivoire. URL: https://www.icafrica.org/fileadmin/documents/IFT_2016/Infrastructure_Financing_Trends_2016.pdf.

International Finance Corporation. 2014. *Moving forward with environmental and social risk management: Findings from IFC country baseline surveys*. Report for the International Finance Corporation. Washington, D.C. URL: https://www.ifc.org/wps/wcm/connect/3a1098804316ae1fb602fe384c61d9f7/ESRM-Report-Final.pdf?MOD=AJPERES.

Jamshed, S. 2014. Qualitative research method-interviewing and observation. *Journal of Basic and Clinical Pharmacy* 5 (4): 87–88. doi:10.4103/0976-0105.141942.

Johannessen, Å., and Wamsler, C. 2017. What does resilience mean for urban water services? *Ecology and Society* 22 (1). doi:10.5751/ES-08870-220101.

Jury, M. 2013. Climate trends in southern Africa. *South African Journal Of Science* 109 (1): 1–11. doi:10.1590/sajs.2013/980.

Kalra, N., Hallegatte, S., Lempert, R., Brown, C., Fozzard, A., Gill, S., and Shah, A. 2014. Agreeing on robust decisions new processes for decision making under deep uncertainty. *World Bank Policy Research Working Paper* No. 6906 (June). doi:doi:10.1596/1813-9450-6906.

Kambites, C., and Owen, S. 2006. Renewed prospects for green infrastructure planning in the UK. *Planning Practice & Research* 21 (4): 483–96. doi:10.1080/02697450601173413.

Karpouzoglou, T., Dewulf, A., and Clark, J. 2016. Advancing adaptive governance of social-ecological systems through theoretical multiplicity. *Environmental Science and Policy* 57 (March): 1–9. doi.org/10.1016/j.envsci.2015.11.011.

Kerste, M., Rosenboom, N., Sikken, B.J., and Weda, J. 2011. Financing sustainability: Triggering investments for the clean economy. European Political Strategy Centre Strategic Notes 25. European Commission. URL: https://ec.europa.eu/epsc/sites/epsc/files/strategic_note_issue_25.pdf.

Kiker, G. a, Bridges, T.S., Varghese, A., Seager, P.T.P., and Linkov, I. 2005. Application of multicriteria decision analysis in environmental decision making. *Integrated Environmental Assessment and Management* 1 (2): 95–108. doi:10.1897/IEAM_2004a-015.1.

Kim, S.-J., and Wu, E. 2008. Sovereign Credit Ratings, Capital flows and financial sector development in emerging markets. *Emerging Markets Review* 9 (1): 17–39. doi:https://doi.org/10.1016/j.ememar.2007.06.001.

Knüppe, K. 2011. The challenges facing sustainable and adaptive groundwater management in South Africa. *Water SA* 37 (January): 67-79. URL: http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1816-79502011000100010.

Kriebel, D., Tickner, J., Epstein, P., Lemons, J., Levins, R., Loechler, E.L., Quinn, M., Rudel, R., Schettler, T., and Stoto, M. 2001. The precautionary principle in environmental science. *Environmental Health Perspectives* 109 (9): 871–76. URL: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240435/.

Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H., and Wilbanks, T. 2012. the need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways. *Global Environmental Change* 22 (4): 807–22. doi:https://doi.org/10.1016/j.gloenvcha.2012.05.005.

Kusangaya, S., Warburton, M.L., Archer van Garderen, E., and Jewitt, G.P.W. 2014. Impacts of climate change on water resources in southern Africa: A review. *Physics and Chemistry of the Earth* 67–69: 47–54. doi:10.1016/j.pce.2013.09.014.

Lawrence, J., and Haasnoot, M. 2017. What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty. *Environmental Science and Policy* 68: 47–57. doi:10.1016/j.envsci.2016.12.003.

Lazurko, A., and Venema, H.D. 2017. Financing high performance climate adaptation in agriculture: Climate bonds for multi-functional water harvesting infrastructure on the Canadian prairies.

Sustainability 9 (7): 1237. doi:10.3390/su9071237.

Lebel, L., Anderies, J.M., Campbell, B., and Folke, C. 2006. Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society* 11 (1): 19. URL: https://digitalcommons.library.umaine.edu/sms_facpub/52/

Lebel, L., Garden, P., and Imamura, M. 2005. The politics of scale, position and place in the governance of water. *Ecology and Society* 10 (2): 18. URL: https://www.ecologyandsociety.org/vol10/iss2/art18/ES-2005-1543.pdf

Lempert, R.J. 2003. Shaping the next one hundred years: New methods for quantitative, long-term policy analysis. *Technological Forecasting and Social Change* 71 (3): 305-307. doi:10.1016/j.techfore.2003.09.006.

Lempert, R.J., and Groves, D.G. 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American West. *Technological Forecasting and Social Change* 77 (6): 960–74. doi:10.1016/j.techfore.2010.04.007.

Lesotho Highlands Development Authority. 2017. Briefing: Lesotho Highlands Water Project (LHWP). Presentation from the Lesotho Highlands Development Authority. doi:10.1017/CBO9781107415324.004.

Lienert, J., Schnetzer, F., and Ingold, K. 2013. Stakeholder analysis combined with social network analysis provides fine-grained insights into water infrastructure planning processes. *Journal of Environmental Management* 125: 134–48. doi:10.1016/j.jenvman.2013.03.052.

Lienert, J., Scholten, L., Egger, C., and Maurer, M. 2015. Structured decision-making for sustainable water infrastructure planning and four future scenarios. *EURO Journal on Decision Processes* 3 (1–2): 107–40. doi:10.1007/s40070-014-0030-0.

Madureira, H., and Andresen, T. 2014. Planning for multifunctional urban green infrastructures: Promises and challenges. *Urban Design International* 19 (1): 38–49. doi:10.1057/udi.2013.11.

Mahmoud, M., Liu, Y., Hartmann, H., Stewart, S., Wagener, T., Semmens, D., Stewart, R., *et al.* 2009. A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling and Software* 24 (7): 798–808. doi:10.1016/j.envsoft.2008.11.010.

Manocha, N., and Babovic, V. 2018. Sequencing infrastructure investments under deep uncertainty using real options analysis. *Water* 10 (2): 229. doi:10.3390/w10020229.

Mbeng Mezui, C.A., and Hundal, B. 2013. Structured finance: Conditions for infrastructure project bonds in African markets. Report for the African Development Bank and NEPAD Integration and Regional Trade Department. Tunis. URL: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Structured_Finance_-_Conditions_for_Infrastructure_Project_Bonds_in_African_Markets.pdf.

McCaffrey, S. 1998. The UN convention on the law of the non-navigational uses of international watercourses: Prospects and pitfalls. World Bank Technical Paper 49: 17–28. URL: https://www.unece.org/fileadmin/DAM/env/water/cwc/legal/UNConvention_McCaffrey.pdf.

McDaniels, T.L., Chang, S., Cole, D., Mikawoz, J., and Longstaff, H. 2008. Fostering resilience to extreme events within infrastructure systems: Characterizing decision contexts for mitigation and adaptation. *Global Environmental Change* 18 (2): 310–18. doi:10.1016/j.gloenvcha.2008.03.001.

McDaniels, T.L., and Gregory, R.S. 1991. A framework for structuring cross-cultural research in risk and decision making. *Journal of Cross-Cultural Psychology* 22 (1): 193–128.

Meissner, R. 2015. *interest groups, water politics and governance: The case of the Lesotho Highlands water project.* Springer International Publishing. doi:10.1007/978-3-319-21130-5_3.

Merk, O., Saussier, S., Staropoli, C., Slack, E., and Kim, J. 2012. Financing green urban infrastructure. OECD Regional Development Working Papers 10: 65. doi:10.1787/5k92p0c6j6r0-en.

Miles, M., Huberman, M., and Saldaña, J. 2013. *Qualitative data analysis: A methods sourcebook*. *Zeitschrift Fur Personalforschung*. Vol. 28.

Mitchell, V.G. 2006. Applying integrated urban water management concepts: A review of Australian experience. *Environmental Management* 37 (5): 589–605. doi:10.1007/s00267-004-0252-1.

Morel, R., and Bordier, C. 2012. Financing the transition to a green economy: Their word is their (green) bond? Climate Brief from the Institute for Climate Economics. No. 14. URL: http://www.cdcclimat.com/IMG/pdf/12-05_climate_brief_14_-_financing_the_transition_to_a_green_economy-_their_word_is_their_green_bond.pdf.

Newman, P. 2009. Markets, experts and depoliticizing decisions on major infrastructure. *Urban Research & Practice* 2 (2): 158–68. doi:10.1080/17535060902979063.

Norberg, J., Wilson, J., Walker, B., and Ostrom, E. 2008. Diversity and resilience of social-ecological systems. In *Complexity Theory for a Sustainable Future*, ed. J. Norberg and G. Cumming, 46–80. Columbia University Press.

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., and van Vuuren, D.P. 2014. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Climatic Change* 122 (3): 387–400. doi:10.1007/s10584-013-0905-2.

Oji, C.K. 2015. Bonds: A viable alternative for financing Africa's development. Diplomacy Programme, South African Institute of International Affairs. Occasional Paper 211 (March). URL: https://www.saiia.org.za/occasional-papers/769-bonds-a-viable-alternative-for-financing-africa-s-development/file.

Olsson, P., Gunderson, L.H., Carpenter, S.R., Ryan, P., Lebel, L., Folke, C., and Holling, C.S. 2006. Shooting the rapids: Navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society* 11 (1): 18. URL: http://www.ecologyandsociety.org/vol11/iss1/art18/.

Orange-Senqu River Basin Commission (ORASECOM). 2018. ORASECOM mandate, structures and functions. Website of the Orange-Senqu River Basin Commission. Accessed March 30. URL: www.orasecom.org/about/mandate.aspx.

———. 2008. Orange-Senqu River Basin: Preliminary transboundary diagnostic analysis. Main Report. Report for the Orange-Senqu River Basin Commission. URL: http://books.google.com/books?id=UBc9QwAACAAJ&dq=orange+senqu+river+basin&hl=&cd=1&source=gbs_api%5Cnpapers3://publication/uuid/00C18E3E-016C-4E59-B741-39294A304B83.

———. 2009a. Institutional analysis for ORASECOM. Report for the Orange-Senqu River Basin Commission. URL: http://www.orasecom.org/_system/writable/DMSStorage/661ORASECOM Institutional Analysis.pdf.

———. 2009b. A fitness for use assessment of the waters of the Orange-Senqu Basin. Report for the Orange-Senqu River Basin Commission. URL: http://www.orasecom.org/_system/writable/DMSStorage/661Fitness for Use Assessment.pdf.

———. 2011a. Projection of impacts under plausible scenarios and guidelines on climate change adaptation strategies. Report for the Orange-Senqu River Basin Commission. URL: http://www.orasecom.org/_system/writable/DMSStorage/1951Projection of Impacts and Guidelines on CC Adaptation Startegies-WP-WP4-009-2011.pdf.

———. 2011b. Support to Phase 2 of the ORASECOM basin-wide integrated water resources management plan: Overall project executive summary. Report for the Orange-Senqu River Basin Commission. URL: http://www.orasecom.org/_system/writable/DMSStorage/1951Overall Executive Summary_013_2011.pdf.

———. 2011c. GCC downscaling for the Orange-Senqu River Basin. Pretoria. Report for the Orange-Senqu River Basin Commission. URL: http://www.the-eis.com/data/literature/GCC Downscaling for the Orange-Senqu River Basin.pdf.

———. 2013a. Basin-wide environmental flow regime in the Orange-Senqu River Basin. Report for the Orange-Senqu River Basin Commission. Pretoria.

———. 2013b. The Orange – Senqu River Basin infrastructure catalogue report. Report for the Orange-Senqu River Basin Commission. Pretoria.

———. 2014a. Orange – Senqu River Basin transboundary diagnostic analysis. Report for the Orange-Senqu River Basin Commission. Pretoria. URL: http://wis.orasecom.org/transboundary-diagnostic-analysis-tda-of-the-orange-senqu-river/.

———. 2014b. Integrated water resources management plan for the Orange-Senqu River Basin. Pretoria. URL: http://wis.orasecom.org/content/study/GIZ/The IWRMP/Documents/019_2014_IWRM-Plan-Main-Report.pdf.

———. 2014c. Economic analysis of water based on water accounting for the Orange-Senqu River Basin. Report for the Orange-Senqu River Basin Commission. Pretoria.

———. 2014d. Rehabilitating rangelands for healthy headwaters. Pretoria. Report for the Orange-Senqu River Basin Commission. URL:

https://wedocs.unep.org/handle/20.500.11822/18255?show=full.

———. 2014e. Water resources modelling, baseline scenario, yield analysis, stochastic verification and validation. Report for the Orange-Senqu River Basin Commission. Gaborone.

———. 2017. Terms of reference: Selection of consultants for Orange-Senqu River Basin climate resilient IWRM investment plan and Lesotho to Botswana water transfer project. Pretoria: Orange-Senqu River Basin Commission, African Water Facility, and NEPAD Infrastructure Project Preparation Facility.

Pahl-Wostl, C. 2008. Adaptive and integrated water management: Coping with complexity and uncertainty. In *Requirements for Adaptive Water Management*, ed. C. Pahl-Wostl, P. Kabat, and J. Möltgen, 1–22. Berlin, Heidelberg: Springer. doi:10.1007/978-3-540-75941-6_1.

———. 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* 19: 354–65. doi:10.1016/j.gloenvcha.2009.06.001.

Pauleit, S., Liu, L., Ahern, J., and Kazmierczak, A. 2011. Multifunctional green infrastructure planning to promote ecological services in the city. In *Urban Ecology*. Oxford: Oxford University Press. doi:10.1093/acprof:oso/9780199563562.003.0033.

Phillips, D., Daoudy, M., McCaffrey, S., Ojendal, J., and Turton, A. 2006. Trans-boundary water cooperation as a tool for conflict prevention and for a broader benefit-sharing. Report for the Ministry of Foreign Affairs Sweden. Global Development Studies No. 4. URL: https://lwrg.files.wordpress.com/2014/12/phillips-et-al-benefit-sharing-smfa-2006.pdf

Piyatrapoomi, N., Kumar, A., and Setunge, S. 2004. Framework for investment decision-making under risk and uncertainty for infrastructure asset management. *Research in Transportation Economics* 8 (04): 199–214. doi:10.1016/S0739-8859(04)08010-2.

Quinn, A., Feeney, K., and Castro, H. 2017. *The economic benefits of investing in water infrastructure*. Knowledge Summary 24 for The PMNHC and the World Health Organisation. URL: http://www.who.int/pmnch/topics/part_publications/ks24_re_20130403_low.pdf?ua=1.

Ranger, N., Reeder, T., and Lowe, J. 2013. Addressing "deep" uncertainty over long-term climate in major infrastructure projects: Four innovations of the Thames Estuary 2100 project. *EURO Journal on Decision Processes* 1 (3–4): 233–62. doi:10.1007/s40070-013-0014-5.

re:focus. 2017. *A guide for public-sector resilience bond sponsorship*. Report from the Rebound Program. URL: http://www.refocuspartners.com/wp-content/uploads/pdf/RE.bound-Program-Report-September-2017.pdf.

Reed, M.S., Kenter, J., Bonn, A., Broad, K., Burt, T.P., Fazey, I.R., Fraser, E.D.G., *et al.* 2013. Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK Uplands. *Journal of Environmental Management* 128: 345–62. doi:10.1016/j.jenvman.2013.05.016.

Renting, H., Rossing, W.A.H., Groot, J.C.J., Van der Ploeg, J.D., Laurent, C., Perraud, D., Stobbelaar, D.J., and Van Ittersum, M.K. 2009. Exploring multifunctional agriculture: A Review of conceptual approaches and prospects for an integrative transitional framework.

Journal of Environmental Management 90: S112–23. doi:https://doi.org/10.1016/j.jenvman.2008.11.014.

Republic of Botswana. 2016. *Botswana water accounting report 2014/15*. Gaborone. URL: http://www.water.gov.bw/images/Reports/DWA_Website/Botswana Water Accounting Report 2014_15.pdf.

Ripley, M., and Jaccard, S. 2016. The science in adaptive management. From *The Lab: Market Systems Development for Decent Work*. URL: http://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/---ifp_seed/documents/briefingnote/wcms_537422.pdf.

Rose-Ackerman, S., and Palifka, B.J. 2016. *Corruption and government: Causes, consequences, and reform*. Cambridge: Cambridge University Press.

Rotmans, J., and Loorbach, D. 2009. Complexity and transition management. *Journal of Industrial Ecology* 13 (2): 184–96. doi:10.1111/j.1530-9290.2009.00116.x.

Rousselot, Y. 2015. Upstream Flows of Water: From the Lesotho Highlands to Metropolitan South Africa. *Journal of Alpine Research* 103 (3): 0–16. doi:10.4000/rga.3023.

Ruiters, C., and Matji, M.P. 2015. Water institutions and governance models for the funding, financing and management of water infrastructure in South Africa. *Water SA* 41 (5): 660–76. doi:10.4314/wsa.v41i5.09.

Southern African Development Community (SADC). 2000. Protocol on shared watercourses in the Southern African Development Community. From the *SADC Revised Protocl on Shared Watercourses*. Gaborone. URL: http://www.internationalwaterlaw.org/documents/regionaldocs/Revised-SADC-SharedWatercourse-Protocol-2000.pdf.

———. 2005. Regional water policy. gaborone. url: http://www.sadc.int/files/1913/5292/8376/Regional_Water_Policy.pdf.

———. 2006. Regional water strategy. Gaborone. URL: https://www.sadc.int/files/2513/5293/3539/Regional_Water_Strategy.pdf.

———. 2012. Regional infrastructure development master plan. Gaborone. URL: http://www.sadc.int/files/7513/5293/3530/Regional_Infrastructure_Development_Master_Plan_Executive_Summary.pdf.

———. 2016a. SADC regional vulnerability assessment and analysis (RVAA) synthesis report 2016. Gaborone. URL: https://reliefweb.int/sites/reliefweb.int/files/resources/SADC_RVAA-August-Final-Web.pdf.

———. 2016b. Regional strategic action plan on integrated water resources development and management phase IV. Gaborone: Southern African Development Community Secretariat. URL: https://www.sadc.int/files/9914/6823/9107/SADC_Water_4th_Regional_Strategic_Action_Plan_English_version.pdf.

Sadoff, C.W., and Grey, D. 2005. Cooperation on international rivers. *Water International* 30 (4): 420–

27. doi:10.1080/02508060508691886.

Salas-Zapata, W.A., Ríos-Osorio, L.A., and Cardona-Arias, J.A. 2017. Methodological characteristics of sustainability science: A systematic review. *Environment, Development and Sustainability* 19 (4): 1127–40. doi:10.1007/s10668-016-9801-z.

Salet, W., Bertolini, L., and Giezen, M. 2013. Complexity and uncertainty: Problem or asset in decision making of mega infrastructure projects? *International Journal of Urban and Regional Research* 37 (6): 1984–2000. doi:10.1111/j.1468-2427.2012.01133.x.

Sapountzaki, K., and Daskalakis, I. 2016. Transboundary Resilience: The case of social-hydrological systems facing water scarcity or drought. *Journal of Risk Research* 19 (7): 829–46. doi:10.1080/13669877.2015.1057202.

Saunders, M., Lewis, P., and Thornhill, A. 2009. *Understanding research philosophies and approaches*. *Research Methods for Business Students*. Vol. 4. Pearson Education.

Schindler, S., Sebesvari, Z., Damm, C., Euller, K., Pusch, M.T., Peter, K., Werner, Z., Christa, L., Henle, K., and Wrbka, T. 2014. Multifunctionality of floodplain landscapes: Relating management options to ecosystem services. *Landscape Ecology* 29: 229–44. doi:10.1007/s10980-014-9989-y.

Scholten, L., Schuwirth, N., Reichert, P., and Lienert, J. 2015. Tackling uncertainty in multi-criteria decision analysis: An application to water supply infrastructure planning. *European Journal of Operational Research* 242 (1): 243–60. doi:10.1016/j.ejor.2014.09.044.

Schreiner, B., and Baleta, H. 2015. Broadening the lens: A regional perspective on water, food and energy integration in SADC. *Aquatic Procedia* 5 (September 2014): 90–103. doi:10.1016/j.aqpro.2015.10.011.

Setlhogile, T., and Harvey, R. 2004. Water governance in Botswana. Policy Briefing 144: Governance of Africa's Resources Programme. Vol. 75. doi:10.2989/00306520409485465.

Shishlov, I., Morel, R., and Cochran, I. 2016. Beyond transparency: Unlocking the full potential of green bonds. Report from the Institute for Climate Economics. URL: https://www.i4ce.org/wp-core/wp-content/uploads/2016/06/I4CE_Green_Bonds_Summary.pdf.

Slovik, P. 2009. Market uncertainty and market instability. International Finance Corporation Bulletin 34 (3): 430–35. doi:10.1111/j.1536-7150.2009.00644.x.

South African Institute for International Affairs. 2016. *Current status of key economic indicators – Regional economic trends*. Report. URL: https://www.saiia.org.za/special-publications-series/615-sadc-business-barriers-current-status-of-key-economic-indicators-regional-economic-trends.

Stakhiv, E.Z. 2011. Pragmatic approaches for water management under climate change uncertainty. *Journal of the American Water Resources Association* 47 (6): 1183–96. doi:10.1111/j.1752-1688.2011.00589.x.

Stapelberg, R. 2010. Infrastructure systems interdependencies and risk informed decision making (RIDM): Impact scenario analysis of infrastructure risks induced by natural, technological and intentional hazards. *Systemics, Cybernetics and Informatics* 6 (5): 21–27. http://www.iiisci.org/journal/CV$/sci/pdfs/R105SQ.pdf.

Statistics Botswana. 2018. *Multi-topic household survey 2015/16: Poverty stats brief*. Report for the Government of the Republic of Botswana. URL: https://www.statsbots.org.bw/sites/default/files/BMTHS POVERTY STATS BRIEF 2018.pdf.

Steffen, W., Grinevald, J., Crutzen, P., and McNeill, J. 2011. The Anthropocene: Conceptual and historical perspectives. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369 (1938): 842–67. doi:10.1098/rsta.2010.0327.

Stirling, A. 2006. Precaution, foresight and sustainability: Reflection and reflexivity in the governance of science and technology. *Sustainability and Reflexive Governance* (January): 225–73. doi:10.4337/9781847200266.00020.

Störmer, E., and Truffer, B. 2009. Strategic decision making in infrastructure sectors : Participatory foresight and strategic planning for sustainable sanitation. *Geographica Helvetica* 64 (2): 73–80. doi:10.5194/gh-64-73-2009.

Subramanian, A., Brown, B., and Wolf, A.T. 2014. Understanding and overcoming risks to cooperation along transboundary rivers. *Water Policy* 16 (5): 824–43. doi:10.2166/wp.2014.010.

Swanson, D., Barg, S., Tyler, S., Venema, H., Tomar, S., Bhadwal, S., Nair, S., Roy, D., and Drexhage, J. 2010. Seven tools for creating adaptive policies. *Technological Forecasting and Social Change* 77 (6): 924–39. doi:10.1016/j.techfore.2010.04.005.

Szabó, A., and Ujhelyi, G. 2015. Reducing nonpayment for public utilities: Experimental evidence from South Africa. *Journal of Development Economics* 117: 20–31. doi:https://doi.org/10.1016/j.jdeveco.2015.06.002.

Tandi, N., and Earle, A. 2015. Financing water infrastructure in Africa: Financing water-related infrastructure development in Africa - What's Stopping Us? Paper 24. Stockholm International Water Institute. Working URL: http://www.siwi.org/wp-content/uploads/2015/11/ARC-Financing-water-infrastructure-in-Africa.pdf.

Tebaldi, C., and Knutti, R. 2007. The use of the multi-model ensemble in probabilistic climate projections. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 365 (1857): 2053–75. doi:10.1098/rsta.2007.2076.

Tilt, B., Braun, Y., and He, D. 2009. Social impacts of large dam projects: A Comparison of international case studies and implications for best practice. *Journal of Environmental Management* 90: S249–57. doi:https://doi.org/10.1016/j.jenvman.2008.07.030.

Tiwary, A., Williams, I.D., Heidrich, O., Namdeo, A., Bandaru, V., and Calfapietra, C. 2016. Development of multi-functional streetscape green infrastructure using a performance index approach. *Environmental Pollution* 208: 209–20. doi:10.1016/j.envpol.2015.09.003.

Trans-Caledon Tunnel Authority. 2016. Integrated annual report 2015-2016. Report for the Trans-Caledon Tunnel Authority. Pretoria. URL: http://pmg-assets.s3-website-eu-west-1.amazonaws.com/TCTA_IAR_20152016_Final.pdf.

Turton, A. 2008. A South African perspective on a possible benefit-sharing approach for transboundary waters in the SADC region. *Water Alternatives* 1 (2): 180–200.

Turton, A., and Funke, N. 2008. Hydro-hegemony in the context of the Orange River Basin. *Water Policy* 10 (S2): 51-69. URL: http://wp.iwaponline.com/content/10/S2/51.abstract.

Van Asselt, M., and Rotmans, J. 2002. Uncertainty in integrated assessment modelling: From positivism to pluralism. *Climate Change* 54: 75–105. doi:10.1023/A:1015783803445

Van Huylenbroeck, G., Vandermeulen, V., Mettepenningen, E., and Verspecht, A. 2007. Multifunctionality of agriculture: A review of definitions, evidence and instruments. *Living Reviews in Landscape Research* 1: 1–43. doi:10.12942/lrlr-2007-3.

Varum, C.A., and Melo, C. 2010. Directions in scenario planning literature: A review of the past decades. *Futures* 42 (4): 355–69. doi:10.1016/j.futures.2009.11.021.

Venema, H.D., Schiller, E.J., Adamowski, K., and Thizy, J.-M. 1997. A water resources planning response to climate change in the Senegal River Basin. *Journal of Environmental Management* 49 (1): 125–55. doi:10.1006/jema.1996.0120.

Wahyuni, D. 2012. The research design maze: Understanding paradigms, cases, methods and methodologies. *Journal of Applied Management Accounting Research* 10 (1): 69–80. doi:10.1675/1524-4695(2008)31.

Walker, B., Holling, C.S., Carpenter, S.R., and Kinzig, A. 2004. Resilience, adaptability and transformability in social – ecological systems. *Ecology and Society* 9 (2): 5. doi:10.1103/PhysRevLett.95.258101.

Wang, Y., Zadek, S., Liu, Q., Luo, T., Cong, H., Xu, Y., Xia, H., Chen, C., Pan, D., and Zhang, D. 2017. Establishing China's green financial system: Progress report 2017. Report to the United Nations Environment Programme Inquiry into the Design of a Sustainable Financial System. URL: http://unepinquiry.org/wp-content/uploads/2017/11/China_Green_Finance_Progress_Report_2017_Summary.pdf.

Wardekker, J.A., de Jong, A., Knoop, J.M., and van der Sluijs, J.P. 2010. Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change* 77 (6): 987–98. doi:10.1016/j.techfore.2009.11.005.

Water Research Commission. 2010. Feasibility design study on the utilization of the water resources of the Chobe/Zambezi River. Report from the Water Research Commission of Botswana. Gaborone. URL: http://www.water.gov.bw/images/Draft Prefeasibility_Feasibility Report.pdf.

Weber, O. 2014. The financial sector's impact on sustainable development. *Journal of Sustainable Finance & Investment* 4 (1): 1–8. doi:10.1080/20430795.2014.887345.

Wiek, A., Ness, B., Schweizer-Ries, P., Brand, F.S., and Farioli, F. 2012. From complex systems analysis to transformational change: A comparative appraisal of sustainability science projects. *Sustainability Science* 7: 5–24. doi:10.1007/s11625-011-0148-y.

Williams, T.M. 1999. The need for new paradigms for complex projects. *International Journal of Project*

Management 17 (5): 269–73. doi:https://doi.org/10.1016/S0263-7863(98)00047-7.

World Bank. 2014. *Project paper for small RETF grant from the multi-donor trust fund for cooperation in international waters in Africa*. Report to the Republic of Botswana Ministry of Minerals, Energy and Water Resources for a Lesotho Highlands-Botswana Water Transfer Study. URL: http://documents.worldbank.org/curated/en/910431468104642145/pdf/905840PJPR0P140pproved0002014008022.pdf.

———. 2016a. *Lesotho water security and climate change assessment*. Report from the World Bank. URL: https://openknowledge.worldbank.org/handle/10986/24905.

———. 2016b. Lesotho. *The World Bank data*. Accessed April 15, 2018. URL: https://data.worldbank.org/country/Lesotho.

World Bank and UNEP. 2017. *Roadmap for a sustainable financial system*. *World Bank*. Report to the United Nations Environment Programme Inquiry into the Design of a Sustainable Financial System. URL: http://www.monroban.org/public/documents/outils/uploaded/lts46ngv.pdf.

World Economic Forum. 2013. *Strategic infrastructure in Africa: A business approach to project acceleration*. Industry Agenda. Report prepared in collaboration with the Boston Consulting Group. URL: http://www3.weforum.org/docs/WEF_IU_StrategicInfrastructureAfrica_BusinessApproachProjectAcceleration_IndustryAgenda_2013.pdf.

Xu, Y., Yang, Y., Chan, A.P.C., Yeung, J.F.Y., and Cheng, H. 2011. Identification and allocation of risks associated with PPP water projects in China. *International Journal of Strategic Property Management* 15 (3): 275–94. doi:10.3846/1648715X.2011.617867.

Yeo, K.T., and Qiu, F. 2003. The value of management flexibility: A Real Option approach to investment evaluation. *International Journal of Project Management* 21 (4): 243–50. doi:https://doi.org/10.1016/S0263-7863(02)00025-X.

Yin, R.B. 1994. Case study research: Design and methods. *Applied Social Research Methods Series* 5. Thousand Oaks: SAGE Publications.

Zadek, S., and Robins, N. 2016. *Financing sustainable development. Moving from momentum to transformation in a time of turmoil*. Report to the United Nations Environment Programme Inquiry into the Design of a Sustainable Financial System. URL: https://www.un.org/pga/71/wp-content/uploads/sites/40/2017/02/Financing-Sustainable-Development-in-a-time-of-turmoil.pdf.

Appendix I

Interview guide

April 2018

RQ1: *How do elements of knowledge systems and information, stakeholder participation, and governance structure manage various types of uncertainty and multifunctionality in the context of the Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin?*

RQ2: *How can these elements be used creatively within project investment and green finance criteria to cope with future uncertainty and multifunctionality? What opportunities might this enable?*

1. **Introduction:** Set up the interview, sign consent forms, and ask warm up questions about role descriptions
2. **RQ1:** Water infrastructure decision making under uncertainty and multifunctionality: focus on experience with various knowledge systems, stakeholder participation, and governance structure
3. **RQ2:** Scenarios for bridging water governance with green finance: More creative exercise using scenarios to figure out how to bridge these findings to the financial sector, so that our financing mechanisms handle uncertainty and multifunctionality in a way that promotes resilience
4. **Closing**

Introduction

1. Introduce me
2. Introduce the structure of the interview, consent forms
3. What is your role in the southern Africa water infrastructure space? Where are you positioned within the decision-making space?
4. What is the primary lens you apply to your work? (i.e. managerial, engineering, social, etc.)
5. What is your involvement with financing water infrastructure projects?
6. What is your involvement with the Lesotho-Botswana Water Transfer project (or any transfer projects originating in the Lesotho Highlands)?

RQ1: Water infrastructure decision making under uncertainty and multifunctionality

How do elements of knowledge systems and information, stakeholder participation, and governance structure manage various types of uncertainty and multifunctionality in the context of the Lesotho-Botswana Water Transfer project in the Orange-Senqu River Basin?

1.1 Understanding the system:

7. ***Governance structure:*** Can you describe the typical institutions, government bodies, or other groups involved in making decisions about water infrastructure in the Orange-Senqu

basin? Feel free to focus on those most relevant to your work, or that you are most familiar with.

- Are there clear goals?
- Roles and responsibilities
- Relationships
- Flexibility and redundancy, handling risk?

8. ***Knowledge systems:*** Can you give an example of the interactions (i.e. collaboration, flow of knowledge, etc.) between these different groups in making decisions about water infrastructure?
    - Generation and flow of knowledge between groups
    - Scientific versus other types of knowledge
    - Understanding different scales, sectors and their interlinkages

9. ***Knowledge systems:*** What are some examples of the kind of information you use to make decisions regarding water infrastructure? Where do you obtain this data (qualitative or quantitative)?

10. ***Stakeholder participation:*** What are the primary mechanisms for stakeholder participation in the Orange-Senqu River Basin context (focusing primarily on interest in large water infrastructure decisions like L-BWT)? What is the role of this particular organisation in this process?

1.2 Uncertainty

11. ***Types of uncertainty and risk:*** Can you help me brainstorm a list of the types of uncertainty that you deal with in your work (related to water infrastructure decision making in this region)?
    - Inherent randomness of nature? (e.g. climate change, modelling hydrology)
    - Value diversity? (e.g. transboundary priorities, stakeholder worldviews)
    - Human behavioural variability? (social responses)
    - Social, economic and cultural dynamics (societal variability)? (e.g. water demand and development pathways)
    - Technological surprises?

12. ***Types of uncertainty:*** What parts of this uncertainty are quantifiable? Are there any uncertainties that you are not able to quantify? Would you describe any of these uncertainties as ambiguous?
    - "We roughly know" – inexactness
    - "We could have known" – lack of observations/measurements
    - "We know what we do not know" – practically immeasurable
    - "We don't know what we know" – conflicting evidence
    - "We don't know what we do not know" – reducible ignorance
    - "We will never know" – indeterminacy
    - "We cannot know" – irreducible ignorance

13. ***Managing uncertainty:*** In a typical scenario (e.g. deciding upon the details of a large-scale water transfer), what actions do you take to manage this uncertainty?
    - Decision making methods (e.g. CBA, RDM)?
    - Modelling?
    - Stakeholder participation?

14. ***Managing uncertainty***: Are there elements of [structure of governance, knowledge systems, stakeholder participation] that directly or indirectly contribute to managing uncertainty? How?
    - May need to split this question into multiple sections
    - May need to provide examples (e.g. participation → social risk; better knowledge flow → data certainty)

1.3 Multifunctionality

15. ***Types of multifunctionality:*** From your perspective, what are the functions or benefits that water obtained and supplied through the Lesotho-Botswana Water Transfer project provides? To society? To environment? To economy? Which stakeholders receive these function or benefits? And how do we know?
    - Many or few stakeholders?
    - Many or few represented social groups?

16. ***Types of multifunctionality:*** From your perspective, what are the functions or benefits that the Lesotho-Botswana Water Transfer project provides in general (beyond water)? To society? To environment? To economy? Which stakeholders receive these function or benefits?

17. ***Managing multifunctionality:*** In a typical scenario (e.g. deciding upon the details of a large-scale water transfer), do you consider these multiple functions/benefits in your decision making? How?
    - Water allocations, benefit sharing?
    - Payment schemes?
    - Participation forums?

18. ***Managing multifunctionality***: Are there elements of [structure of governance, knowledge systems, stakeholder participation] that directly or indirectly contribute to leveraging or managing multiple functions or benefits? How?

RQ2: Scenarios for bridging water governance with green finance

How can these elements be used creatively within project investment and green finance criteria to cope with future uncertainty and multifunctionality? What opportunities might this enable?

Framing:

- Simply using the case of a green bond to help structure the scenario exercise and narrow the scope – it is not meant to limit the conversation.
- The framework conditions may not be entirely comprehensive or realistic, but they are meant as a thought exercise.
- Try to tie in previously discussed elements, including the different governance structures, knowledge systems and forums for public participation.

Scenario 1: Egalitarian utopia

Worldview in the SADC
- Low economic growth
- Environment and society places strict limits on population growth and development
- Demand oriented water management
- Clean fresh water stock as potential supply
- High response to climate change

Lesotho-Botswana Water Transfer
- Water taxes to large users
- Sharing multiple benefits and functions with diffuse stakeholders in Lesotho, South Africa and Botswana
- Prioritising ecology and vulnerable populations in environmental flows and benefit allocation
- Heavy concurrent investment in demand-side management in Lesotho and Botswana
- Conservative estimates of available freshwater stock; valued as assets in government accounting
- Worst-case (drier) climate change scenarios expected and planned for (irrigation requirements, tradeoffs between transfers to South Africa and Lesotho)

Scenario 1: Individualist utopia

Worldview in the SADC
- High economic growth
- No limits on population growth and development
- Market oriented water management
- No limits on potential water supply
- Low response to climate change

Lesotho-Botswana Water Transfer
- Market price of water to all water users
- Sharing multiple benefits and functions with few, intensive stakeholders in Lesotho, South Africa and Botswana
- Prioritising benefits to high demand stakeholders (e.g. industrial farms, garment factories)
- Focus on investment in investment plan for augmenting supply of water in Lesotho and Botswana
- Moderate estimates of available freshwater stock
- Moderate climate change scenarios expected and planned for (minimal change to irrigation requirements, tradeoffs between transfers to South Africa and Lesotho unlikely

Figure A-1 Scenarios for interviews, based on (Van Asselt and Rotmans 2002)

<u>2.1 Scenario 1</u>

19. ***Bridging uncertainty and risk:*** *If these considerations for risk and uncertainty (worst-case climate scenarios, strict environmental limits, multiple stakeholders to manage, and others that fit into this worldview identified during the interviews) were known and actively considered during the design of a green bond, how might the investment vehicle be designed? What tools or techniques would you use to include them?*

a. What aspects (if any) of the governance structures, knowledge systems and information, and participation (that were discussed earlier, give examples) can be used to inform this financial structuring? What would need to happen to make these capacities useful?

20. ***Bridging uncertainty and risk:*** If these considerations for risk and uncertainty were *not* known in the design of a green bond, how might a standard use of proceeds or project bond respond to these conditions?
    - Revenues and backing
    - Risk assessment and allocation
    - Asset valuation
    - Others?

21. ***Bridging multifunctionality and finance:*** If these considerations for multifunctionality (water tax to large water users, benefit sharing amongst diffuse stakeholders, conservative estimates of water stock as assets, and others that fit into this worldview identified during the interviews) were known and actively considered in the design of the investment vehicle, how might the investment vehicle be designed? Risk? Revenues?
    a. What aspects (if any) of the governance structures, knowledge systems and information, and participation (that were discussed earlier, give examples) can be used to inform this financial structuring? What would need to happen to make these capacities useful?

22. ***Bridging multifunctionality and "green":*** If these considerations for multifunctionality (water tax to large water users, benefit sharing amongst diffuse stakeholders, conservative estimates of water stock as assets, and others that fit into this worldview identified during the interviews) were known and actively considered in the definitions of "green" for green bonds, how might the green bond portfolios be designed?

2.2 <u>Scenario 2</u>

- Go through the same process as for the first part, but this time, for uncertainty questions
    - Moderate climate change scenarios expected and planned for (minimal change to irrigation requirements, trade-offs between transfers unlikely)

<u>2.3 Bridging multifunctionality, "green" finance and multiple revenues (Scenario 2)</u>

23. Given the assumptions for the framework conditions, how might a standard use of proceeds green bond respond to or consider the multiple functions described in scenario 2?
    - "greenness" or "sustainability"
    - Use of proceeds, refinancing

24. If these multiple functions are known during the design of the investment vehicle, how might the investment vehicle be designed in order to actively leverage the multiple benefits described in scenario 2?

25. What aspects (if any) of the governance structures, knowledge systems and information, and participation (that were discussed earlier, give examples) can be used to inform this financial structuring? What would need to happen to make these capacities useful?

26. What opportunities would [answers to 21 and 22] enable?
    - Multiple revenue streams
    - Assessing co-benefits and 'sustainability' value

<u>Closing (for fun): Exploring a path forward</u>

27. How *could* the topics we have discussed associated with uncertainty and multifunctionality relate to the green label? In your view, what is the role of green finance and green bonds in building resilience?

28. What do you see as the highest potential mechanisms for building a financial sector that enables sustainable development?