BEYOND DOWNSCALING

A Bottom-up Approach to Climate Adaptation for Water Resources Management

AGWA Alliance for Global Water Adaptation alliance4water.org
WORLD BANK GROUP Water
WATER PARTNERSHIP PROGRAM
CONSERVATION INTERNATIONAL
US Army Corps of Engineers
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Moving beyond downscaling

"In grappling with long-term climate change, it is natural to turn to climate modeling for guidance … The models, which are essential for elucidating the global climate system, have been informative in some applications related to agriculture or water development over large regions. But for many planning and design applications, especially when applied to smaller areas, to precipitation, and to extreme events, models often give too wide a dispersion of readings to provide useful guidance. A review of the application of these models…found that they are often used as a backdrop for urging the adoption of 'no-regret' actions, and rarely for quantitative decision-making on options."

Adapting to Climate Change: Assessing the World Bank Group Experience. Independent Evaluation Group (IEG)-World Bank/IFC/MIGA. Washington, DC, 2012. Overview, pp xxii-xxiii

ACRONYMS

AGWA - Alliance for Global Water Adaptation

BCA - Benefit-cost analysis

CF - Change factor

CIDA - Climate Informed Decision Analysis

CRiSTAL - Community-based Risk Screening Tool - Adaptation and Livelihoods

DSS - Decision Support System

GCM - Global Climate Model or General Circulation Model

GHG - Greenhouse gases

GWP - Global Water Partnership

IEG - World Bank's Independent Evaluation Group

IGDT - Information-gap decision theory

IISD - International Institute for Sustainable Development

Intergovernmental Panel on Climate Change

IWRM - Integrated Water Resources Management

ODI - Overseas Development Institute

OR - Operations Research

RCM - Regional Climate Model

RDM - Robust decision-making

TTL - World Bank's Task Team Leader

UNDP - United Nations Development Program

USACE - United States Army Corps of Engineers

WPP - World Bank's Water Partnership Program

FOREWORD

Most developing countries around the world will need to invest heavily in infrastructure in order to meet the needs of their people and of their economy more broadly. Estimates of the global financing gap to meet sector demands for water supply and sanitation vary, but are on the magnitude of $100 billion a year (McMahon, Rodriguez, and Berg 2012). The challenge facing developing countries is therefore how to get the most benefit from their limited investment budget—which requires careful planning, and infrastructure that is designed for the long term.

A water resources plan will include infrastructure, but will also have many components of a more institutional and dynamic nature. Infrastructure will last a long time, and there is only a limited amount of flexibility once it has been built. The task of the water resources planner is to optimize the risk vs. cost trade-off under basic hydrologic, socioeconomic, and environmental assumptions. Decisions on water-related activities and projects have always faced many uncertainties, to which those caused by climate change are now added. Climate change adaptation is seen as adjusting to evolving conditions, potentially far in the future. Some tools are needed and may be useful for non-climate pressures; some may be better for adjusting to current climate conditions; and others for adjusting to climate change.

Complex global circulation models (GCMs) have been developed to project future climate conditions under various greenhouse gas (GHG) emission scenarios. The results are only applicable at the continental scale, as their resolution is very coarse, and have to be further processed to obtain information useful for decision-making. Researchers have developed methodologies that follow a similar process: create an ensemble of climate outputs from several GCMs, downscale the GCM outputs, bias-correct the outputs based on climate observations in the area of interest, and use them as input for a calibrated hydrologic model to assess climate change impacts on a given endpoint for guidance in practical project and program planning and analysis. These methods, although useful for setting a global and regional long-term context, have proven of little practical use for site-specific water resources management and water infrastructure project design decisions at a local level, as reported in 2012 by the World Bank's Independent Evaluation Group (IEG). Moreover, sometimes time and resources are disproportionately assigned to application of these so-called top-down methods in detriment of analyses of other non-climate related, uncertainties that might prove more important in the short and medium terms.

While searching for solutions to this dilemma, it was found that similar concerns also existed in other water resources organizations—including universities, government agencies, and private entities, such as those represented in the Alliance for Global Water Adaptation (AGWA), of which the World Bank is a founding and active member. Thus, benefiting from the knowledge base of AGWA's member organizations and with the participation of world renowned experts, an internal-external workshop was organized by the World Bank Water Partnership Program (WPP)/AGWA in November 2011. As a result, an AGWA technical working group was formed to explore a number of alternative methods for risk-based decision-making and adaptation of vulnerable water systems, considering the effect of uncertain information. The focus was on the so-called bottom-up approaches. The development of practical guidelines for practitioners, project coordinators and, in the case of the Bank, Task Team Leaders (TTLs), was deemed necessary.

As a member of this working group, the World Bank/WPP continued on this path and with the participation of renowned external and Bank experts organized a session (Special Session 3) at the HydroPredict2012 international conference held in Vienna, Austria, in September 2012, and a Learning Session at the Bank SDN Forum 2013 in March of this year. As discussed in the HydroPredict2012 conference, practitioners involved in managing flood risk, or developing infrastructure for water supply or hydropower, seemed particularly uncomfortable with the uncertainty of climate predictions. As one HydroPredict2012 participant pointed out, "in the discussion following Special Session 3, suggestions that perhaps the GCM outputs should supplement and inform the predictions from hydrologic models rather than drive the hydrologic models, seemed to garner support from many participants."

As a result of these discussions and consultations, a set of guidelines and bottom-up approaches for including climate uncertainty in water resources planning and project design were identified by the Bank for its own purposes and by AGWA. The basic principles supporting these guidelines have evolved into the framework presented in the last chapter of this book. They have also formed the basis for the World Bank/WPP initiative to develop a practical, risk-based bottom-up decision-making-aide instrument (called the "decision tree"). This work is in progress and we expect its results to provide an alternative approach contributing to improvement in the quality and effectiveness of water resources management planning and project design under climate variability and change uncertainty, which can be operationally used by practitioners and TTLs in World Bank projects at site-specific locations.

William Rex
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INTRODUCTION

An AGWA-supported approach to sustainable water management

This section introduces an adaptation approach supported by AGWA and addresses the following questions:

- *Who should read this book?*
- *Is there a genuine need for an alternative approach to resilient water resources management?*
- *What's in the rest of the book?*

Media

Video i.1 - Hydrologic engineering perspective on adaptation approaches

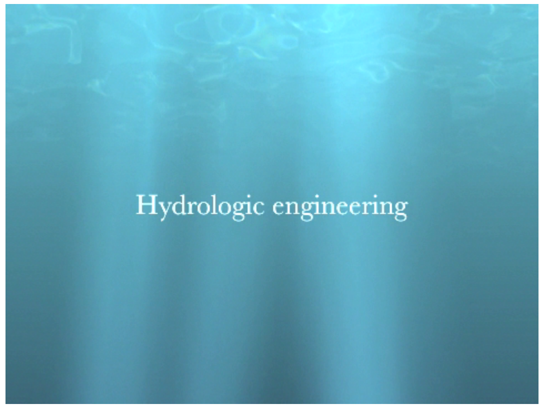
Video i.2 - An introduction to AGWA and the practice of climate adaptation

Who should read this book?

This book focuses on how we achieve water sustainability over long timescales—decades, even centuries from now. These timescales are important and relevant to our decisions about planning, infrastructure, and institutions today. Many of the methods we use to manage water, directly or indirectly, commit us to future decision pathways and restrict us from making other, alternative decisions.

This book is designed for individuals who are exploring the best means of incorporating climate adaptation perspectives into their water resources management work, particularly if they are interested in mainstreaming that work in the context of other drivers that affect water supply and demand such as urbanization, demographic change, ecological shifts, and economic cycles. It is designed for individuals who are asking questions such as: How do we estimate climate change impacts? Do the problems of climate adaptation pose new challenges for water managers that require new decision-making methods, or will existing, traditional techniques be sufficient? Can we make sound operating rules for addressing uncertainty about future hydrological conditions (Video i.1)?

Video i.1 Hydrologic engineering perspective on adaptation approaches



Dr. Luis García (The World Bank) refers to hydrologic engineering in the context of adaptation approaches supported by AGWA.

In many cases, these individuals work in technical disciplines or are engaged in active resource management—engineers, planners, economists, conservationists, finance specialists, academics, and scientific and analytical staff. However, the challenges of climate change for water resources are important at many organizational levels. The technical implications will be meaningless without a broad understanding of climate issues by high-level decision-makers, policymakers, and professional communicators, as these are the individuals who consume the reports produced by technical staff, as well as interact with, set the strategy for, and manage this technical staff.

Is there a genuine need for an alternative approach to resilient water resources management?

The mainstream approach to water resources management used in most countries for well over a century assumes that the statistical properties of past water history remained unchanged over time and did not follow any trends. This is an assumption widely referred to in the scientific and engineering literature as "stationarity," which is often interpreted to mean that the past is a good predictor for the future. This assumption is understood to be a simplifying, practical approach to working with water data and—at best—an approximation of the real world.

The water cycle—that is, the cycling of water molecules from ocean evaporation to precipitation, surface and groundwater flows, and return to the ocean—has proven to be both extremely sensitive to climate shifts and very difficult to predict. Climate prediction is particularly difficult and uncertain over the long timescales of a decade or more, to which many water management decisions commit us. The manifestation of climate change in the water cycle is complex. For instance, precipitation may shift in form (rain, snow, fog, sleet, and so on), intensity (hard, light), seasonality (e.g., the timing of monsoons), frequency and magnitude of extreme events (floods, droughts, tropical cyclones), and the degree of inter-annual variability.

Because of this complexity, most recent approaches to climate-adaptive water management have been based on qualitative assessments (e.g., "this region will become dryer")—characterized as "no-regrets" or "low-regret" actions (i.e., actions that do not conflict with a wide range of future scenarios)—or based on quantitative outputs from climate model projections (e.g., derived from GCMs, applied in a top-down framework to define climate impacts based on a narrow range of climate variables). Approaches based on climate models attempt to provide quantitative projections of future climate states; however, climate models were not developed for climate adaptation purposes and are associated with levels of uncertainty that—used in isolation or without careful qualification—are unacceptable as standalone sources of information for most water resources management applications. This is particularly true of management applications requiring high-confidence quantitative estimates of future states.

What's in the rest of the book?

Across the first four chapters, this book describes the challenges of including climate change in water management decision-making and provides an overview of current practices in the adaptation field. After considering the pros and cons of these practices, the book concludes with a framework for an adaptation approach supported by AGWA. The first chapter provides an overview of climate change, highlighting important concepts for water resources managers. A selection of mechanisms for sustainable water development and ways to mainstream adaptation into these mechanisms are described in Chapter 2. Chapters 3 and 4 describe tools, methodologies, and frameworks available to water managers for climate risk assessment and climate risk management, respectively. Chapter 3 hones in on the bottom-up risk assessment approaches supported by AGWA, i.e., those approaches that begin by assessing system vulnerabilities to variations in climate and only consider GCMs in later assessment stages. Chapter 4 focuses on tools for identifying robust management actions once climate risks have been assessed in relation to other challenges water managers face. Lastly, the information provided in this book is synthesized in Chapter 5 by framing a theoretical approach supported by AGWA to include adaptation in water resources management, planning, and investment (Video i.2). Ongoing and future projects seek to operationalize this framework through case study applications of the adaptation approach supported by AGWA.

Our hope is that this book will spark a sophisticated dialogue about how to make systematic, credible, and quantitative decisions about sustainable water management that can be used by a wide variety of audiences. We also hope that individuals engaged in the planning, management, design, finance, economics, evaluation, and operations of water resources—directly or indirectly—will find this publication helpful.

Video i.2 Introduction to AGWA and the practice of climate adaptation

For more information, please visit the AGWA site (http://alliance4water.org)

John H. Matthews, Coordinator, AGWA

Diego Rodriguez, The World Bank

CHAPTER 1

Understanding climate change

Chapter 1 provides an overview of climate change and its impacts on water resources management by addressing the following questions:

- *What is climate and how is it changing?*
- *What does hydrologic non-stationarity mean for technical water resources management?*
- *What does sustainability mean in the context of a non-stationary climate?*

Media

Video 1.1 - History of climatic changes on earth

Video 1.2 - Climate variability and extremes

What is climate and how is it changing?

The earth's climate has changed in the past and will continue to change into the future. "Climate" refers to how the atmosphere behaves over relatively long time periods (decades to thousands of years), as opposed to "weather," which describes atmospheric conditions over short periods of time (hourly to annually). In the last 700,000 years, glacial periods have occurred about every 100,000 years, and the earth has experienced both colder and warmer periods than today (Video 1.1). The historical record of changes reveals that our climate is highly sensitive to relatively small changes in heat retention and atmospheric circulation, such as those caused by shifts in human- and natural-source greenhouse gas (GHG) concentrations, e.g., carbon dioxide and methane.

Video 1.1 History of climatic changes on earth

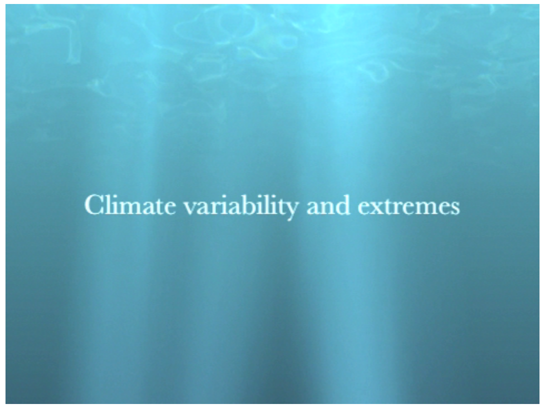
Dr. Eugene Stakhiv (US Army Corps of Engineers) discusses climatic changes that occurred historically on earth, using a case study from the Great Lakes Region, US-Canada border.

If climate change is in itself not new, then what is novel about the current changes the earth is undergoing? In recent years, we've increasingly come to realize that the pace of modern climatic changes has been accelerated by human actions. Each subsequent report by the United Nation's Intergovernmental Panel on Climate Change (IPCC) recognizes a stronger link between observed warming over the last 50 years and human-source GHG concentrations. Recent IPCC communication (Stocker, Dahe, and Plattner 2013) states that human influence on the climate system is clear and that it has been the dominant driver of shifts in the global climate system since 1950. Over the past 150 years, GHG levels have increased by 40 percent, mainly from the burning of fossil fuels (US Department of Commerce 2013).

Climate models and recent observations indicate both changes in *mean* climate as well as increases in climate *variability* (e.g.,Dai, Trenberth, and Karl 1998; Hulme, Osborn, and Johns 1998; Lettenmaier et al. 1999; Lins and Slack 2005; Jones et al. 1998). Mean climate refers to broad generalizations about regional climate, such as the total annual precipitation and the mean annual temperature. Variability includes intra-annual variability—seasonal patterns and shifts—and inter-annual variability, the degree to which one year can be characterized as climatologically similar to other years.

Water resources will likely be the principal medium by which these climate change impacts are felt and mitigated (UN Water, 2010). Indications of hydrologic change renew attention for the assumption of "non-stationarity" and call into question whether the statistics of the historical record are an accurate and useful descriptor for the future. For most water managers, the main concern lies with changes in variability and extremes (Video 1.2). A warmer climate could increase the risk of floods and droughts of greater magnitude, duration, and frequency with respect to recent observations (IPCC 2007). In most regions, changes in extremes are occurring more rapidly than changes in long-term, average patterns of drying or wetting. Observations since the 1950s show changes in the hydrologic extremes in all critical variable dimensions: intensity, frequency, spatial extent, duration, timing, and probability distribution functions (IPCC 2012).

Video 1.2 Climate variability and extremes



Dr. Juan Valdéz (University of Arizona) and Dr. Kenneth Strzepek (University of Colorado) discuss the importance of climate variability and extremes for water resources management and how these may change in the future.

Unfortunately, projections regarding climate extremes remain highly uncertain, vary by region, and may be overshadowed by natural variability, at least in the short term. According to IPCC (2012),

> *Projected changes in climate extremes under different emissions scenarios generally do not strongly diverge in the coming two to three decades, but these signals are relatively small compared to natural climate variability over this time frame. Even the sign of projected changes (i.e., trends towards greater or lesser precipitation) in some climate extremes over this time frame is uncertain. For projected changes by the end of the 21st century, either model uncertainty or uncertainties associated with emissions scenarios used becomes dominant, depending on the extreme.*

Given the uncertainties in projected climate, it is important to consider climate in the context of other trends affecting a water system's performance, particularly in the shorter term, such as shifts in demography, land use, economic patterns, and urbanization.

What does hydrologic non-stationarity mean for technical water resources management?

The implications of non-stationarity have received much attention since the publication of a critique of climate change–neutral approaches to water management by Milly and colleagues (2008). The probability distributions of stationary hydrologic processes do not change with time, i.e., the mean and the variance are constant in the long term. However, even stationary variables may show regular natural variability and periodic oscillations (Kundzewicz 2011). In contrast, the statistical properties of non-stationary processes vary over time. For instance, droughts may become more (or less) severe or frequent, or the mean timing of seasonal monsoons may advance (or retreat).

Stationarity has generally been interpreted as the rule that the past is a guide to the future, which has shaped most water resources planning, operations, and management in the modern era. While it has long been known that the assumption of stationarity is not correct, it was believed to be a reasonable, simplifying approximation until recently. The assumption that streamflow was a stationary process facilitated the generation of plausible "future" sequences of stochastic inputs. If non-stationarity is viewed as a deterministic component of a time series, then no conceptual difficulty is introduced in dealing with non-stationary inputs (Matalas 2012). Furthermore, several approaches have been proposed in the literature to address non-stationarity, as reported by Salas et al. (2012), including stochastic approaches to simulate, for example, monthly and yearly hydrologic processes such as streamflows (e.g., for drought studies and designing reservoirs).

Matalas (2012) also stressed the need to qualify the "assertion that the past was stationary, that the present is not stationary, and that the future will never be stationary." According to Matalas (2012), since at least 1938 it has been known that time series are composed of deterministic and stochastic components, evolving to the present view that these components include a trend, fluctuations about the trend, seasonal movement, and irregular or random movement. Time series are not simply stationary or non-stationary; they may be stationary in some components and non-stationary in others.

While there has been much discussion and even attribution of non-stationarity solely to the effects of climate change, climate change is only one of the possible causes of non-stationarity. According to Salas et al. (2012):

> *Over the past three decades, hydrologists and water resources specialists have been concerned with the issue of non-stationarity arising from several factors. First is the effect of human intervention on the landscape that may cause changes in the precipitation–runoff relationships at various temporal and spatial scales, such as deforestation and urbanization. Second is the occurrence of natural events such as volcanic explosions or forest fires that may cause changes in the composition of the air, thenonst soil surface, and geomorphology. Third is the low-frequency component of oceanic–atmospheric phenomena that may have significant effects on the variability of hydrological processes such as annual runoff, peak flows, and droughts. Fourth is global warming, which may cause changes to oceanic and atmospheric processes, thereby affecting the hydrological cycle at various temporal and spatial scales.*

Although it is essential that water managers recognize the hydrologic non-stationarity associated with climate change, this must be considered in the context of other sources of non-stationarity and the specific decision context.

What does sustainability mean in the context of a non-stationary climate?

The implications of a non-stationary climate for decision-makers are both significant and subtle. If we have overestimated our ability to reliably and predictably plan for the future, then we face a serious crisis in how we make water management decisions for energy, water supply and sanitation, natural resource management, navigation and transportation, and the myriad other uses to which we put water. We are in effect making long-term decisions based on short-term information and potentially limiting our options and economies for the future. In some cases, we may need to make such potentially regrettable decisions. However, this text is meant to show that there are pathways that can avoid or reduce those regrets.

Perhaps the most difficult implication of non-stationarity is what sustainability itself means. In most cases, water managers and decision-makers have viewed "sustainable" water resources management as a fixed target, as if there were a single optimal balance point for allocation, water infrastructure design, governance, and operations. By recognizing that the water cycle can undergo significant shifts over relatively short timescales, we have to transition to a view of "sustainabilities," with multiple and evolving ("unfixed") targets. For instance, the Murray-Darling basin in Australia and the lower Colorado River basin in North America may be seeing long-term declines in precipitation patterns. Are these decadal droughts or part of a relatively permanent shift in climate? In response, should resilience mean "bouncing back" following extreme events, or maintaining systemic integrity as environmental and economic conditions undergo major transformations?

As investors, our ability to see the future is limited, so our challenge now may be closer to the latter model: avoiding decisions that commit us to too much or too little—or too soon or too late. In effect, sustainable water management is a *pathway* of decisions, some of which may reverse or contradict previous decisions.

However, water managers and decision-makers are not simply investors: they are also resource managers of aquatic ecosystems and the broader eco-hydrological landscape. "Sustainability" presents significant difficulties here as well, since all species and even areas such as groundwater recharge zones respond dynamically and in complex, often unpredictable ways, to shifts in climate (Matthews and Wickel 2009).

Ultimately, a sustainable vision of water resources management must encompass both ecological and engineering perspectives of non-stationary change (Matthews et al. 2011). While this topic has not been widely addressed by the conservation or water management communities, climate change may provide an opening to conjoin these perspectives into a more coherent whole—which will be covered more extensively in another publication.

CHAPTER 2

Mainstreaming adaptation into water resources management

Chapter 2 discusses how adaptation can be mainstreamed into water resources management through existing sustainable management mechanisms, including those that address:

- *Uncertainty and confidence in planning information,*
- *Investment under uncertainty,*
- *Integrated water resources management (IWRM),* and
- *Natural and environmental flow regimes.*

Media

Video 2.1 - Uncertainty, confidence, and consequences in water resources management

Video 2.2 - IWRM under climate change

Video 2.3 - Environmental flows under climate change

Uncertainty and confidence in planning information

Water resources engineers and decision-makers have long dealt with uncertainty and variability. Standard engineering practices account for uncertainties through risk management techniques; design redundancy; and adding safety factors to deal with the unknowns (e.g., by adding a levee “freeboard” onto a “standard project flood” to accommodate the uncertainties associated with historic climate variability). However, water managers face greater magnitudes of future uncertainty than historically experienced. Climate change projections are highly uncertain—in fact, the unknowns about climate change dynamics go beyond our understanding of classical risk and uncertainty analysis. This requires new perspectives on risk and uncertainty analysis (Video 2.1). As stated by Kundzewicz (2011), “We know increasingly well that we do not know enough.”

Video 2.1 Uncertainty, confidence, and consequences in water resources management

Dr. Guillermo Mendoza (US Army Corps of Engineers) discusses the relationship between confidence and consequence and how these may shape decisions regarding adaptation approaches.

There is currently no consensus on how best to approach the planning and hydrologic design of water resources projects under climate uncertainty. Unlike uncertainties of the past, climate uncertainties cannot be estimated with the current state of climate modeling. While some standard hydrological practices, based on assumptions of a stationary climate and variability, can be extended to accommodate aspects of climate uncertainty, new issues and approaches must be considered (Stakhiv 2010). Some of these are discussed below.

Investment under uncertainty

Climate change poses significant challenges for investments in the water sector, particularly due to the long lifespan and large upfront costs associated with many water projects. While water practitioners have long contended with variability and uncertainty in hydrology, the circumstances surrounding climate change and the inability to derive probabilities of future scenarios require a major shift in thinking, planning, and designing water investments of the future (Qaddumi et al. 2009). At the same time, adaptation to climate change must continue to build on conventional interventions while also addressing immediate challenges and needs, such as disaster management, ecological restoration, and poverty alleviation. Investment decisions must place the climate change dimension in the context of other factors, such as population growth, land management, and economic markets, which in some cases may be far more significant and critical than that of climate change in some parts of the world (Qaddumi et al. 2009).

The discount rate used in economic models to assess adaptation costs and benefits plays a key role in determining the trade-offs between the benefits and costs of actions taken now versus actions taken later. Put simply, discount rates help determine how much people are willing to pay today for benefits accrued in the future. Due to the long life-span of water infrastructure (typically 30-50 years, although in some cases it may reach 100-200 years), applying the 12 percent discount rate generally used by multi-lateral development banks makes it difficult to justify spending much money on climate adaptation today. Thus, some economists, notably Nicolas Stern in the *Stern Review* (2007), advocate the use of significantly lower discount rates when assessing climate policy, or discount rates that decline throughout project lifespans (Groom et al. 2005; Gollier, Koundouri, and Pantelidis 2008). The choice of the discount rate can strongly influence the perceived economic value of a project. This choice remains controversial and no consensus exists on what discount rate to use when assessing climate policies or adaptation projects.

The dominant effect of the discount rate on future water system benefits and costs can be partially mitigated by reducing the economic lifetime of current projects. One way of this is by adaptive management, which adds the flexibility to upgrade current, less expensive investments in the future. Upgrades occur only if new information confirms the need for the extra investment and reduces the factors of safety required. "Real options theory" is an example of a systematic procedure for incorporating flexibility into project designs, further discussed in Chapter 4. A second option for low-impact adaptation is the adjustment of water system operating rules developed for existing and planned water infrastructure, especially relevant to reservoirs (e.g. Ghosh et al. 2010, Raje and Mujumdar 2010).

Integrated Water Resources Management (IWRM) under climate change

IWRM provides a useful framework for integrating climate adaptation into water resources management. The goal of IWRM is the sustainable management and development of water resources, taking into account social, economic, and environmental interests. It recognizes the interdependence of many different competing interest groups and considers the effects of each use on the others when making water allocations and management decisions (GWP 2009). As a framework, IWRM can directly assist communities in coping with climate change and climate variability, especially since good management of systems allows the right incentives to be passed on to water users (Cap Net 2009, Video 2.2). Although IWRM is not a new idea, many questions re-

Video 2.2 Integrated water resources management (IWRM) under climate change

Dr. Torkil Jønck Clausen (DHI Water Policy), one of the most influential people in the Global Water Partnership's embracement of the IWRM concept, discusses IWRM in relation to climate adaptation.

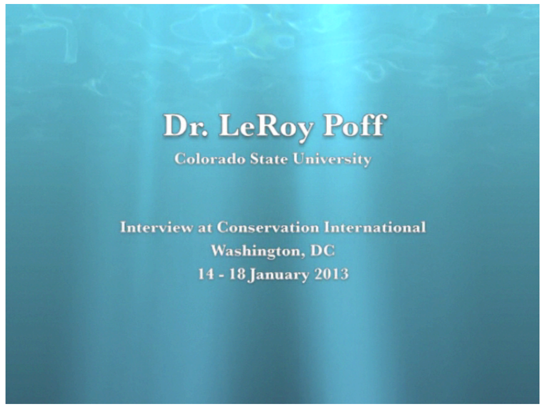
main regarding IWRM implementation and success in practice.

Natural and environmental flow regimes: Towards a management model of eco-engineering

For freshwater ecosystems, climate change is expected to have its most profound effects through changes in the historical natural flow regime (Le Quesne et al. 2010). The flow regime is a primary determinant of freshwater ecosystem structure and processes—the so-called “master variable” (Poff et al. 1997). Changes in the volume and timing of freshwater flows are already a leading driver of global declines in freshwater biodiversity from abstractions and infrastructure; the impacts of climate change are accelerating this pressure. Ongoing changes in precipitation and evapotranspiration regimes are altering many aspects of water quality and quantity, while some of the most important long-term ecological impacts now come from impacts on water timing (Le Quesne et al. 2010).

The World Bank report *Flowing Forward* points out the existence of opportunities to undertake assessments of vulnerability to climate change in a range of planning activities and operations. *Flowing Forward* acknowledges the considerable uncertainty about ecosystem impacts of climate change. In view of this, it recommends risk-based sensitivity and vulnerability assessments for freshwater ecosystems, rather than impact assessments (Le Quesne et al. 2010), similar to the bottom-up approaches described in the following chapter. In Video 2.3, Dr. LeRoy Poff discusses natural and environmental flows in relation to climate and climate change.

Video 2.3 Environmental flows under climate change



Dr. LeRoy Poff (Colorado State University) discusses how climate shapes flow regimes; how both may change in the future; and what we can do to maintain freshwater ecological integrity.

One of the biggest challenges for natural resource managers of freshwater ecosystems is how we define success and set management targets. Historically, these targets have been set based on a past reference state, which was presumably a healthier or more intact system. Even the definition of environmental allocations globally has been based on historical conditions in most cases. However, while the human drivers of the current period of climate change are “new” and unprecedented, climate change itself is not new for ecosystems and species. Paleoecological studies show dramatic shifts, transformations, and reassembling of ecosystems and ecological processes. Thus, a management system based solely on a past reference state may be ineffective, even counterproductive, during periods of rapid climate shifts. Can we manage ecosystems in a way that allows them to maintain integrity and auto-adapt as much as possible?

Traditionally, freshwater ecosystem management decisions have been *after* and *in response to* water infrastructure and management decisions. As suggested in Chapter 1, however, we may be able to use shifts in risk assessment as an opportunity to better integrate these perspectives through “eco-engineering” systems that include more flexible environmental allocations—which can better balance operational, user, and environmental allocations—and that link dynamic ecological and engineering performance markers.

CHAPTER 3

Key tools supporting climate risk assessment

Chapter 3 provides an overview of the available tools, frameworks, and methodologies to support climate change risk assessment in the water sector, by addressing the questions:

- *What are climate risk assessment tools?*
- *Screening tools: how relevant is climate change to my project?*
- *Data tools: what data is available and how could it be used?*
- *Impact assessment tools: how do top-down and bottom-up climate impact assessments differ?*

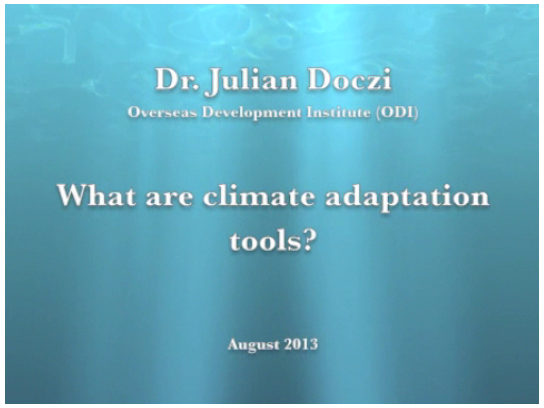
Media

Table 3.1 - Classification of adaptation tools
Video 3.1 - What are climate adaptation tools?
Video 3.2 - Intended use of models
Video 3.3 - Climate uncertainty
Video 3.4 - Top-down versus bottom-up
Figure 3.1 - The cascade of uncertainty
Figure 3.2 - Top-down versus bottom-up

What are climate risk assessment tools?

The Overseas Development Institute (ODI) has identified over 100 climate change adaptation tools relevant to the water sector, defining these tools as “documents, computer programs or websites that clearly and thoroughly operationalize a set of principles or practices that could build the resilience of water services to current climate variability or future climate impacts, preferably in an engaging and user-friendly manner” (Doczi 2013) (Video 3.1). These tools can be classified by function into three major types: process guidance tools, data and information tools, and knowledge sharing tools. Also, tools can be classified by target users and sector, such as tools for general climate adaptation, best management practices, or specifically for water sector climate adaptation (Table 3.1).

Video 3.1 What are climate adaptation tools?



Dr. Julian Doczi (Overseas Development Institute, ODI) discusses climate risk management tools for the water sector.

Considering the wide range and variety of available climate adaptation tools, choosing the most appropriate tool(s) requires identification of the users’ specific adaptation needs and concerns at the outset. Using the wrong tools may lead to inappropriate adaptation actions, which could actually increase system vulnerability to climate change, termed maladaptations. Some important considerations in tool selection include:

- What problem is the tool intended to address?
- Is a tool needed at all?
- What relevance does it hold for the particular context, language, users, region?
- What type of tool(s) is(are) needed?
- How complex is the tool? (What is the local capacity to use the tool? Will training be needed?)
- What is the price?
- Is user support available? (Is the tool kept up-to-date?)

This chapter focuses on tools that support climate risk assessment, namely, climate screening tools, data tools, and risk assessment frameworks. There is a natural progression to questions regarding how to assess climate risk and start the adaptation process. Whereas traditional approaches began by asking how the climate conditions in the future would differ from the past, we propose a more strategic starting point for climate change adaptation: an exploration of the vulnerabilities of the water system to changes in historic climate conditions. Once the conditions to which the water system is vulnerable have been identified, questions on the likelihood of those conditions arising can be addressed in a more efficient, targeted manner. Methods for progressing through these questions are referred to as climate risk assessment tools. Beyond simply identifying climate-related risks, climate risk assessment tools place

Table 3.1 Classification of climate adaptation tools based on function (Doczi 2013).

<table>
<tr><th>Type 1 Tools
Comprehensive Process Guidance</th><th>Type 2 Tools
Data & Information</th><th>Type 3 Tools
Knowledge Sharing</th></tr>
<tr><td>Communication tools</td><td>Climate information primers</td><td rowspan="6">Web-based platforms, offering access to:
– Relevant news
– Scientific, policy, and project documents
– Personal observations and experiences
– Professional networks
– Type 1 Process guidance tools
– Type 2 Data & information tools</td></tr>
<tr><td>Screening Tools</td><td rowspan="2">Primary climate info:
– current temperature and rainfall data, maps, etc.
– projections (GCMs, downscaling tools)

Secondary impact models, maps

Vulnerability info
– Poverty, livelihood, socio-economic data</td></tr>
<tr><td>Assessment Tools</td></tr>
<tr><td>Implementation Tools</td><td></td></tr>
<tr><td>Monitoring & Evaluation Tools</td><td></td></tr>
</table>

climate-related vulnerabilities in the context of all other vulnerabilities facing a project.

The two broad methods for assessing the effects of climate change on water resources use data tools differently and begin the impact and vulnerability assessment from different directions. Traditional methods to assess climate risk and vulnerability take a top-down approach, by downscaling a necessarily limited selection of individual projections from GCMs to identify snapshots of potential climate impacts. The water system's vulnerability to those particular scenarios is then assessed by forcing hydrological and water systems models with each scenario's climate information. Bottom-up approaches reverse this assessment process by first identifying system vulnerabilities to a very wide range of future climates (beyond that projected by GCMs) and then determining the plausibility of particular climate impacts using the best available and most credible climate information.

This chapter begins by building the conceptual and scientific basis for bottom-up approaches, and then describes methods for bottom-up climate change risk assessment, using a method called decision scaling as an example. Once climate-related vulnerabilities have been quantified, many other questions related to adaptation can be addressed, such as: "What to do?" "When to start action?" "How fast to proceed?" "How to incorporate updating mechanisms?" and "What are the costs of action, compared to the costs of inaction?" Kundzewicz (2011). Tools for answering these questions can be categorized as climate risk management tools, discussed in Chapter 4.

Screening tools: how relevant is climate change to my project?

A subset of climate risk assessment tools is *climate screening tools*. Comprehensive climate risk assessment is potentially expensive and laborious. Screening tools classify water systems and water projects according to broad categories of climate sensitivity. For example, in the short term (<20 years out), natural, internal climate variability is likely to dominate uncertainties in the climate parameters of relevance to water resources system planning (Deser et al. 2012, Lownsbery 2014). Thus, water projects with economic lifetimes of less than 20 years are not likely to be sensitive to climatic changes in that timeframe. In order to efficiently use financial, computational, and human resources, it is important that climate risk assessment tools allocate effort in a way that is consistent with the potential sensitivity to climate risk.

Screening tools are important for project managers in the early stages of project development and climate risk assessment. Climate change is not relevant to all water resource management work, and other factors may play a larger role in prescribing and designing management actions. Screening tools allow for a quick assessment of the sensitivity of a system or project to climate change. For example, tools such as The Nature Conservancy's Climate Wizard are helpful for quickly identifying possible broad trends in temperature and precipitation relevant to the location of the planned water project. Similarly, The World Bank's Climate Change Knowledge Portal, and Climate and Disaster Risk Screening Tools (available January 2015) can identify potential changes in climate conditions that may affect projects and communities, while also allowing consideration of climate change relative to other types of risk. The United Nation's Development Programme's (UNDP's) Adaptation Learning Mechanism offers geographically-targeted resources for climate change adaptation, including overviews of current adaptation practices and needs. The International Institute for Sustainable Development's (IISD) Community-based Risk Screening Tool (CRiSTAL), among others, involves community members, planners, and managers in the process of determining the relevance of climate change to a specific project.

In cases in which the screening process indicates that climate sensitivity poses a significant threat to project performance, further assessment of climate risks is warranted. The following sections describe the data and information tools available for such an assessment.

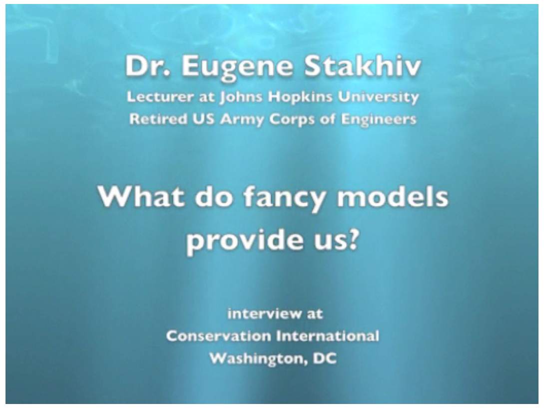
Data tools: what data is available and how could it be used?

Data tools provide the information necessary for climate risk assessment. These include historical water system performance, hydrological statistics based on the historical record, paleodata, stakeholder experience, and projections of future changes in hydrology, demographics, economics, technology, and land use. Traditionally, too much emphasis has been placed on the application of climate models, the generation of emissions scenarios, and the translation of those scenarios to long-range projections of climate patterns. While these models and scenarios provide insight into the scale and character of epistemic climate uncertainty, climate projections continue to underperform in terms of the information needed by water resources engineers, operators, and managers for effective adaptation (Brown and Wilby 2012; Mendoza and Gilroy 2012).

Global Circulation Models (GCMs)

GCMs have emerged as the standard tool for projecting future climate conditions. However, the use of GCMs for assessing the implications of climate change for water resources needs to be carefully considered in the context of the decision at hand since climate models were not designed for adaptation planning (Video 3.2). Regional Circulation Models (RCMs) are narrower in spatial focus and believed to capture some dynamics better, though this has recently been called into question (Kerr 2013). Further, the computational burden and resource requirements associated with RCM may overshadow the value they added (Kerr 2013). Both GCMs and RCMs attempt to represent climate dynamics and how the global climate system may respond to changes in external forcings, particularly elevated GHG concentrations. Therefore, they may be useful in national- and regional-scale vulnerability assessments (IEG 2012). However, there is growing consensus that climate models are ill-equipped to support robust water resource management decisions (e.g., see the AGWA white paper Caveat Adaptor).

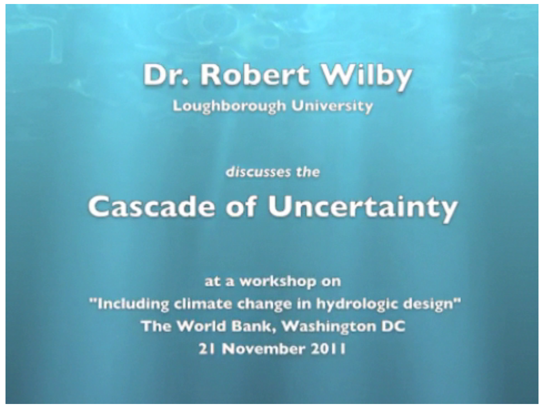
Video 3.2 Intended use of models



Dr. Eugene Stakhiv (US Army Corps of Engineers) provides a perspective on the use of "fancy models" and Dr. Robert Wilby (Loughborough University) discuss the value and limits of GCMs.

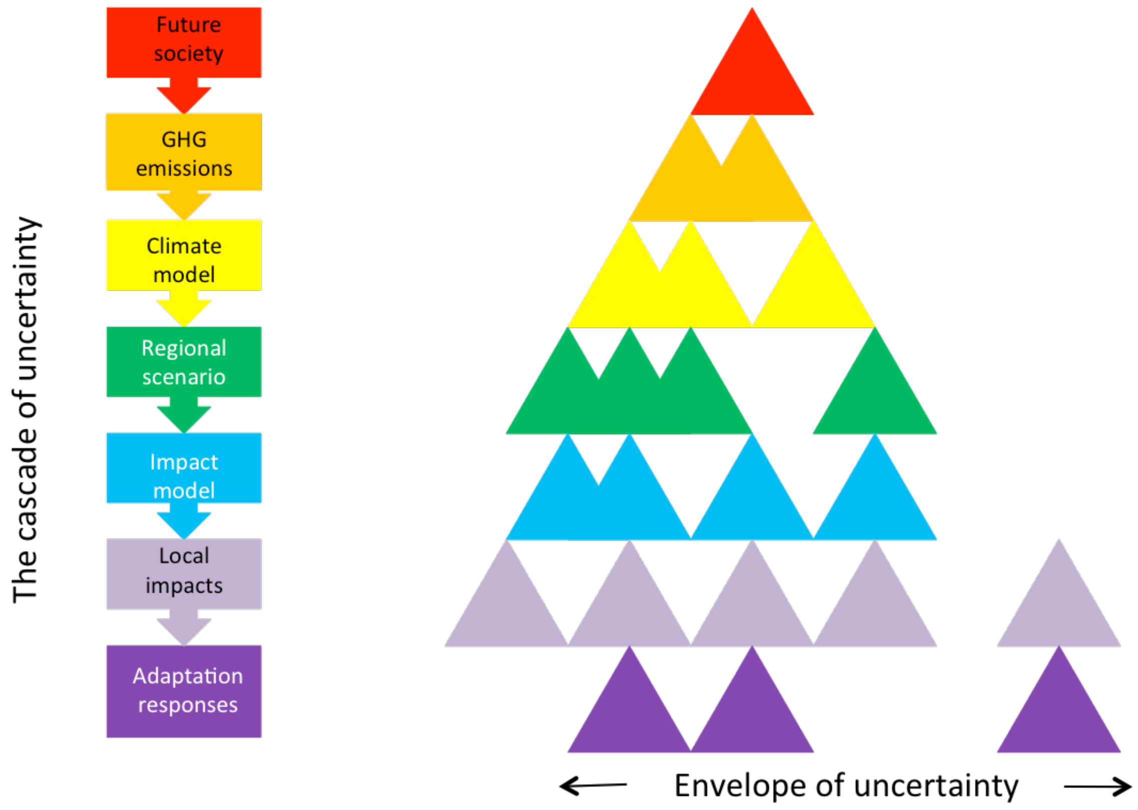
The problems in using GCMs to model the likelihood of future hydrologic events stem from the cascade of uncertainty propagated through climate projections and downscaling processes (Wilby and Dessai 2010) (Video 3.3 and Figure 3.1). Foremost, future GHG emissions are uncertain since they depend on hard-to-predict future human behavior. Second, GCMs contain uncertainties in model parameters and structure (Stainforth et al.

Video 3.3 Climate uncertainty



Dr. Robert Wilby (Loughborough University) discusses the cascade of uncertainty that occurs during downscaling along with distinguishing between the different sources of uncertainty.

Figure 3.1 The cascade of climate change uncertainty (adopted from Wilby and Dessai 2010).



2007). Third, natural climate variability adds uncertainty to projections, since it continues to be unpredictable at lead times longer than a few seasons. Finally, there is uncertainty in the underlying science, since all the complex interactions of the Earth system are not well understood. Even a consensus between a broad set of models and scenarios is no guarantee that the future will in fact mirror projected outcomes.

More specifically, climate projections provide limited and often biased explorations of the effects of natural climate variability, especially precipitation variability (Rocheta et al. 2014), with amplified carry-over effects for runoff estimates (Fekete et al. 2004). Water resource managers are primarily concerned with planning and design at the local and regional scale, yet precipitation (and to a lesser extent temperature) output from GCMs is only considered spatially credible at coarse resolution grid cells (100s of km) and temporally credible at a monthly time step.

Perhaps the most critical weakness of climate projections is that they are less reliable in regard to the variables that are most important for water resources projects, such as hydrologic extremes (e.g., flood and drought). Those extreme events are located at the tails of distributions of climate variables and percentage-wise will change more rapidly than the mean in a changing climate (Dai et al. 1998). As a final complication, imperfect hydrologic models may take GCM climate parameters as input, translating climate variables into water resources variables, and adding another level of uncertainty to the cascade.

Scientists employ several techniques to try to overcome some of the limitations inherent in GCMs. The Coupled Model Inter-comparison Project (CMIP) establishes standard experimental protocols for studying GCM output, enabling scientists to analyze GCMs in a systematic fashion. Further, CMIP supports model diagnosis, validation, intercomparison, documentation, and data access. The IPCC's most recent (Fifth) Assessment Report uses the CMIP Phase

5 (CMIP5) framework for coordinated climate change experiments.

To overcome the limitations of GCM resolution, scientists apply downscaling methods to construct climate information at the higher resolutions needed for water resources management. For example, a new archive of downscaled CMIP5 climate projections is being developed at a spatial resolution of approximately 800 meters for the coterminous United States (Thrasher et al. 2013). While applying downscaling techniques can produce higher-resolution regional and local projections, they will not correct for large-scale errors in GCMs (Barsugli et al. 2009, Olsen and Gilroy 2012). New generations of GCMs, RCMs, and downscaling techniques all have the potential to better characterize uncertainty; however, these new models and techniques will by no means eliminate uncertainty, and instead may even increase uncertainty in future climate projections (Roe and Baker 2007; Knutti and Sedláček 2013).

While GCM-based climate change projections may indicate a range of possible challenges for water systems, they do not typically reduce the uncertainty of future climate relevant for water systems planning; climate projections are in fact unlikely to describe the limits of the range of possible climatic changes. As a result, climate model-based projections may have difficulty providing managers or decision-makers with the climate-related information they require (Kundzewicz and Stakhiv 2010). Nor are they able to provide probabilistic representations of the uncertainty itself (Hall 2007). Because risk is a function of both probability and impact (Dessai and Hulme 2004), the inability of climate projections to probabilistically represent uncertainty is a substantial obstruction to assessing and mitigating climate-related risks to proposed water projects if used in a conventional "predict-then-act" framework. Impact model structures and parameters also contribute significant uncertainty to the overall cascade (e.g., Dobler et al. 2012; Wilby and Harris 2006). In practice, therefore, there are insufficient resources to explore exhaustively all components in the uncertainty cascade so the inferred uncertainty range is almost certainly an underestimate of the true range.

Historical record and weather generators

If GCM output is unreliable, how can projections of future climate be generated? One way is to perturb the historical climate record in a manner that is consistent with the best current understanding of climate change effects on the statistical properties of the historical climate signal (e.g., mean, low-frequency variability, duration, autocorrelation, etc.).

Weather generators are computer algorithms capable of producing long series of synthetic daily weather data. The parameters of the model are conditioned on existing meteorological records to ensure that the characteristics of historic weather emerge in the daily stochastic process. Weather generators are a common tool for extending meteorological records (Richardson 1985), supplementing weather data in a region of data scarcity (Hutchinson 1995), disaggregating seasonal hydroclimatic forecasts (Wilks 2002), and downscaling coarse, long-term climate projections to fine-resolution, daily weather for impact studies (Kilsby et al. 2007, Wilks 1992). A major benefit afforded by most weather generators is their utility in performing climate sensitivity analyses (Wilks and Wilby 1999). Several studies have used weather generators to systematically test the climate sensitivity of impact models, particularly in the agricultural sector (e.g., Confalonieri 2012, Dubrovsky et al. 2000). These sensitivity studies systematically change parameters in the model to produce new sequences of weather variables (e.g., precipitation) that exhibit a wide range of change in their characteristics (e.g., average amount, frequency, intensity, duration). The permutations created by the weather generator are not dependent on any climate projections, allowing for a wide range of possible future climates to be generated while avoiding biases propagated from the projections. However, the particular permutations generated can be informed by available projections to ensure that they more than encompass the range of GCM projections.

Paleodata

While the use of paleodata has traditionally received little attention in risk estimation, paleodata are becoming more important to inform expectations for future climate scenarios. Paleodata allow for the use of very extended data sets (multi-decadal to multi-centennial), to understand the risks to which the water system could be exposed. These are based on observations from the history of a given location and not on contentious projections of what "unprecedented" conditions might arise in the future. This is important, particularly if the period of modern engineering practice has coincided with a relatively benign epoch (as in the western United States). Adapting to past low-frequency variations in water resources presents significant challenges even before considering the additional risks posed by anthropogenic forcing.

Risks associated with a non-stationary climate have been presented as deviations from observations of the past 100 years or so of record; however, natural climate cycles resulting in extreme flood and drought that repeat on periods greater than a single century are likely to provide much better information regarding the risks faced in the economic lifetime of long-lived water infrastructure such as dams.

Unfortunately, paleodata are often only available for specific variables and at coarse temporal resolution (annual or decadal). Improvements in the development and processing of paleodata hold potential to greatly improve our understanding of natural climate variability, and the longer-term risks facing our water systems.

Local expertise

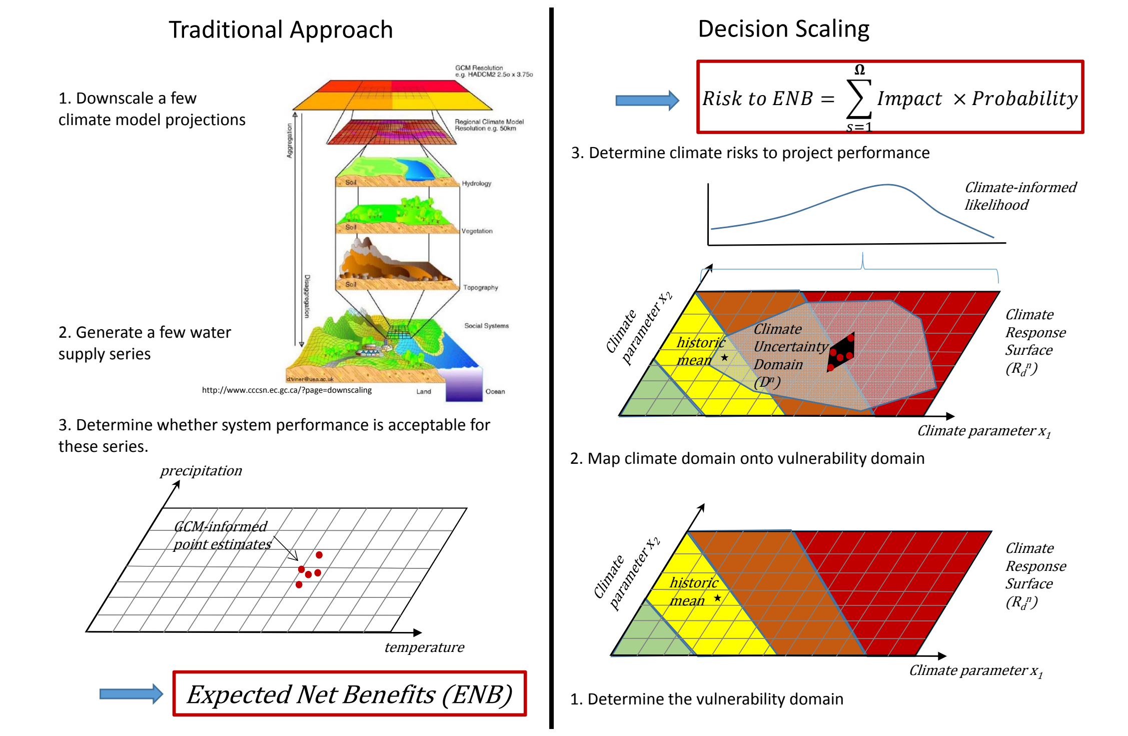
Along with recorded data from hydrometeorological stations, much information can be garnered from the experiences of local people regarding the occurrence and impacts of historical weather patterns and extreme events. Farmers, for example, have strong institutional memory regarding floods, droughts, precipitation patterns, seasonal transitions, and planting and harvesting times. Those living near water bodies tend to retain stories regarding floods or surges and to observe gradual changes in water levels. Local newspapers are often good sources of information on noteworthy historical climate events. These observations and anecdotal information are a very valuable supplement to the hydrometeorological record.

Impact assessment tools: How do top-down and bottom-up climate impact assessments differ?

Top-down climate assessments

Figure 3.2 and Video 3.4 compare the traditional top-down approach for climate change risk assessment with decision scaling, which is a particular example of a bottom-up approach. Top-down approaches begin by downscaling a few climate model predictions (from low-resolution GCM) and run the downscaled climate projections through various models to develop expectations for changes in hydrology, vegetation, social systems, etc. Those few selected scenarios (shown as GCM-informed point estimates on the 3rd level of the traditional analysis in Figure 3.2) are then evaluated for their effect on the expected net benefits of the project under evaluation.

Figure 3.2 Top-down versus bottom-up risk assessment



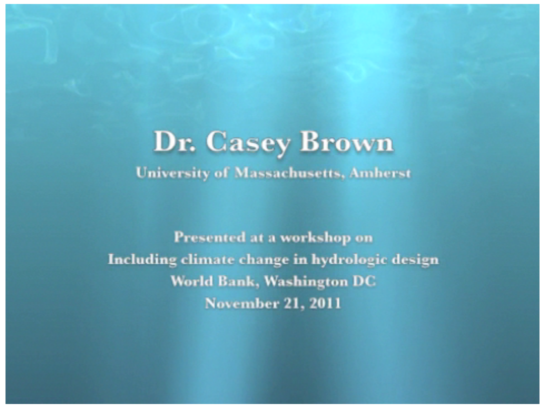
A top-down framework can help quantify the relative contribution of different components to overall uncertainty for extremes such as low flows (e.g., Wilby and Harris, 2006). Moreover, very high resolution RCMs are now being used to investigate the sensitivity of extreme precipitation to temperature forcing (e.g., Kendon et al., 2014). In other words, climate models and downscaling methods can be usefully deployed to enhance understanding of the physical processes or critical thresholds that drive hydrological extremes.

Limitations of top-down assessments

Top-down climate assessments rely heavily on GCM outputs for describing local and regional climate impacts.

Most top-down approaches begin with a small selection of future scenarios from GCM output, which themselves, even if taking all GCM output, represent only a subset of all possible climate futures. As a result, top-down methods do not sample from the full range of climate futures. And, as described earlier, the process of downscaling GCMs results in a cascade of uncertainty. Further, all models have similar resolution and must parameterize the same processes (Tebaldi and Knutti 2007). Uncertainties that are related to the underlying science will be the same in different models.

Video 3.4 Top-down versus bottom up climate assessment



Dr. Casey Brown (University of Massachusetts-Amherst) compares traditional top-down approaches with the bottom-up Decision Scaling approach.

While top-down climate change analyses present a wide range of possible mean future climate conditions, the models do not adequately describe the range of potential future conditions more generally (Stainforth et al. 2007b). In addition, top-down analyses provide limited insight into the changes in climate drivers (such as monsoon patterns and atmospheric rivers), and climate extremes (Olsen and Gilroy 2012). As a result, deriving probability distributions from an ensemble of GCMs is problematic, making it impossible to predict which future is most likely. Given the essential role of likelihood concepts in risk assessment (where risk is a function of impact and probability of that impact), top-down methods tend not to provide the insights needed for water resources system planning.

Bottom-up climate assessments: Decision scaling and other methods

In contrast to top-down approaches, bottom-up climate assessments begin in the vulnerability domain. They take important system characteristics and local capacities into account before the sensitivity and robustness of possible adaptation options are tested against climate projections, such as GCM outputs. Bottom-up approaches account for particular intrinsic system characteristics such as exposure, sensitivity, and adaptive capacity as important elements for describing risk (Bouwer 2013). This is in contrast to top-down approaches that use GCM downscaling to “predict, then act” in response to a narrow range of climate variables (Weaver et al. 2013).

Decision scaling (also referred to as Climate Informed Decision Analysis or CIDA) is a bottom-up approach to integrate the best current methods for climate risk assessment and robust decision analysis with simple procedures for risk management. It is also a robustness-based approach to water system planning making use of a stress test for the identification of system vulnerabilities, and simple, direct techniques for the iterative reduction of system vulnerabilities through targeted design modifications. The decision scaling methodology has been presented in a number of publications (e.g., Brown 2010a, Brown et al. 2011, Brown et al. 2012).

The decision scaling stress test consists of three major steps, as shown in Figure 3.2. First, the vulnerabilities of the system to changes in climate are evaluated throughout a large climate space using a “weather generator.” Weather generators are developed for the region of interest to produce numerous stochastic time series that preserve the variability, seasonal, and spatial correlations of the historical record. This may be done either by resampling directly from the historical record, or by generating new time series based on the perturbations of the statistical characteristics of the historical record. The parameters are systematically changed to produce new sequences of weather variables such as precipitation, which exhibit a wide range of change in their characteristics (e.g., annual average, frequency, intensity, duration). Trends can be added to the precipitation and temperature of the numerous stochastic time series to simulate climate change on a range informed by the available downscaled GCMs. Using the stochastic time series, the hydrologic and water resources system model is then run repeatedly over the entire period for many future climates for each of the water system plans considered. The performance of each proposed plan is evaluated over a range of future climate states and the results are presented on a climate response map. Examples of system performance evaluations could include cost-benefit ratio, total net benefits, the relative likelihood of maintaining a state of no regret for each design, and violations of performance thresholds. An example method for conducting the stress test is provided in Steinschneider and Brown (2013).

In the second step, as various sources of climate information can be applied without rerunning the modeling analysis, decision scaling can make use of all sources of climate information, such as a frequency analysis of GCM output, historical data, stochastically-generated climate simulations, paleodata, and the expert judgment of scientists and stakeholders.

In the third step, collectively, all of these sources of climate information can then inform the likelihoods of different types of climate change. When climate information is deemed fairly reliable and projections are consistent, this allows for model-based probabilistic estimates of risk and risk-weighted decision-making. If, on the other hand, projections based on the various sources are contradictory, not relevant, or not credible, the process enables the identification of climate sensitivities and provides a framework for addressing potential hazards through robustness approaches.

Decision scaling supports the use of bottom-up approaches for defining decision-making pathways. The first step here is a stakeholder consultation for identification and characterization of historical system performance and vulnerabilities to change. While standard decision analysis requires well-characterized uncertainties, decision scaling was developed to handle poorly characterized uncertainties and make the best use of available information. A further advantage of the bottom-up approaches is that non-climatic stressors of the system are readily accommodated. This enables a more holistic approach to risk screening, thereby avoiding what some have termed "climate exceptionalism."

Crucially, decision scaling determines whether the time- and effort-intensive process of downscaling is likely to be beneficial. The resulting climate response function provides insight into the expected performance of the system in an uncertain future. The procedure does not include an explicit framework for risk management, as will be discussed in Chapter 4, but the methodology does contribute many of the informational elements required for a decision tool to be effective.

Bottom-up approaches similar to decision scaling

Other examples of bottom-up approaches to climate risk assessment are the scenario-neutral approach (Prudhomme et al. 2010), the information-gap decision theory (IGDT, Ben-Haim 2006), and risk-informed decision-making (Olsen and Gilroy 2012). These approaches focus on the decision at hand and then scale climate information based on what is needed to best inform that decision. This allows water managers or planners to ask specific questions about the relevance of climate change to a project or decision.

Prudhomme et al. (2010) favor a procedure very similar to the climate stress test used in decision scaling. The authors use a "change factor" (CF) to apply an absolute percentage change to temperature and precipitation in line with that suggested by the GCMs, and then use a harmonic function to model the seasonal pattern of precipitation and temperature. By performing repeated simulations using a hydrologic model to observe flood peaks across scenarios, the procedure generates valuable information (risk analysis) on the critical climate conditions at which a water system fails.

IGDT characterizes the uncertainty of system performance as a group of nested sets. The method requires the user to identify a best estimate of each unknown parameter from which to start the uncertainty analysis. Next, each of the input parameters is bounded in an interval, the range of which is meant to encompass most of the uncertainty particular to that parameter. Whereas in the stress tests developed within decision scaling and scenario-neutral modeling a single increment of uncertainty is explored—the total range of average annual temperature and precipitation over which the performance of a water project is evaluated—IGDT explores the range of performance within subsets of the total uncertainty space, which are referred to as "horizons." Careful attention must be given to the selection of the best estimate of the uncertain parameter, and the horizon of uncertainty explored should be chosen large enough to encompass all reasonable parameter realizations. In this way, decision scaling represents an improvement on the IGDT approach by starting from a logical point (climate normal) and then using projections to inform the probabilities of the space that can be derived.

Limitations of bottom-up assessments

The bottom-up approach relies on top-down information to inform the likelihoods of future climate conditions; this is essential. The scientific understanding of physical climate mechanisms (and specifically, response to changes in forcing) informs the experiments performed using bottom-up techniques. Without these inputs from the physical climate modeling community, the bottom-up approach would lack a basis for selecting the range over which to test the vulnerability of the system. The vulnerability exploration would be imprecise and unbounded, and of limited decision-making value.

Concluding remarks on bottom-up approaches

For most risk-assessment applications in water resources management, bottom-up approaches are more relevant than top-down approaches since climate impacts are difficult to untangle or correlate with hydrologic changes (Matthews and Wickel 2009, Parmesan et al. 2011). However, both top-down and bottom-up approaches can potentially provide complementary information (Le Quesne et al. 2010). The selection of an approach, alone or in combination, should be guided by the level of specificity and confidence necessary: local scales, operations decisions, and the maintenance or stress testing of water infrastructure have different governance and decision-making needs compared to national or global priority-setting exercises to allocate limited capacity or funds (Wilby and Dessai 2010, Brown 2010b).

CHAPTER 4

Identifying robust adaptation strategies

Chapter 4 reviews some of the most prominent approaches to identify and evaluate robust adaptation strategies for water projects, including:

- *No-regret / low-regret,*
- *Precautionary principle/ safety margins,*
- *Sensitivity analysis,*
- *Benefit-cost analysis,*
- *Stochastic optimization,*
- *Adaptive management,*
- *Real options, and*
- *Robust decision-making.*

Media

Video 4.1 - Low-regret climate adaptation

Video 4.2 - Adaptive institutions

An overview of approaches to evaluate and include adaptation in water projects

How do we move from the diagnosis and assessment of potential climate impacts to planning, design, and action? Given uncertainties in the magnitude and direction of climate change, project planners are ill-equipped to assess the trade-offs of adaptation options to reduce the effects of climate change on water resources systems relative to alternative actions intended to address changes in other variables such as population, technology, and demand (the magnitudes and directions of which are also uncertain). Project planners are consequently unable to incorporate climate information into a broader assessment of a project's probability of success, and to make intelligent modifications to the project design to reduce its vulnerabilities to failure. Project planners faced with these challenges should not expect climate science to develop a single, clearly defined, "most likely" future.

Under these conditions, robust adaptation is the most effective approach. Robust adaptation strategies prioritize the ability of projects to perform well over a wide range of climate and non-climate uncertainties rather than attempting to define a single set of targets. Robust adaptation strategies can take many forms and be classified as "no-regret," reversible and flexible, incorporating safety margins, employing "soft" solutions, or reducing decision timeframes (Hallegatte 2009). Wilby and Keenan (2012) further distinguish between activities related to creating an enabling environment for adaptation and the implementation of activities to manage future flood risk. Developing and applying a robust adaptation strategy requires an enabling environment, supported by activities such as routine monitoring, flood forecasting, data exchange, institutional reform, bridging organizations, contingency planning for disasters, and insurance and legal incentives to reduce vulnerability. These enabling activities are "low-regret" in that they yield benefits regardless of the climate scenario. On the other hand, reducing vulnerability to plausible future climates may require implementing activities that go beyond low-regret enabling activities, including climate safety factors for new build, upgrading the resistance and resilience of existing infrastructure, modifying operating rules, development control, flood forecasting, temporary and permanent retreat from hazardous areas, and periodic review and adaptive management. While implementing activities have high potential for vulnerability reductions, they are generally more expensive, less flexible, and less reversible than enabling activities, opening the window to regrets in the event that the future climate differs from that for which the adaptation was developed (Wilby and Keenan 2012).

As previously implied, robustness typically increases project cost, and it's economically and physically impossibly to design a project that can perform under the full range of uncertainties. In view of this, vulnerability thresholds are commonly established for robustness to many, but not all, possible climate futures. There is further concern that interventions intended to increase adaptation in one sector might inadvertently increase total system vulnerability by, for example, increasing carbon emissions or transferring risks from one group to another (Barnett and O'Neill 2010), reinforcing the need to develop holistic adaptation strategies.

Approaches developed to identify a most efficient path through a subset of the available adaptation actions/activities have to this point mostly been founded on modifications to traditional decision-making models. Risk- and robustness–based approaches to decision-making under uncertainty trade off initial investment costs with benefits returned and potentially future costs avoided over the lifetime of the project. Recently, a number of suggestions have been made for developing and implementing robust designs and policies that accommodate uncertain, non-stationary information (Salas et al. 2012). In this chapter we provide snapshots of the most prominent approaches for the identification of robust adaptation strategies. The usefulness of each approach depends on the individual situation, and in many cases a combination of approaches may prove advantageous.

The essential approach of decision scaling uses iterative application of the climate stress test to systematic, targeted modifications of the preliminary design or existing system in order to identify configurations that are more robust than others to the potential future climate domain. When the complexities of the application demand it, the risk-assessment aspects of decision scaling work in concert with a combination of risk management tools described here to create a holistic climate risk assessment and management approach.

No-regret / low-regret

In the absence of accurate climate prediction models, the "no-regret" or (perhaps more aptly named "low-regret") approach gives priority to actions that are prudent regardless of future climate conditions (Video 4.1). For example, it is always good to save water (hence prospect for water demand management) and improve water use efficiency in agriculture ("more crop from a drop"). Low-regret adaptation decisions perform reasonably well compared to the alternatives over a wide range of future climate states and typically have positive net benefits over the entire range of anticipated future climate states (Field et al. 2012). In contrast to the low-regret approach, a decision based on a small number of possible climate futures may lead to maladaptation if the actual future doesn't match the limited number of scenarios considered.

The "soft path" to climate adaptation often features prominently in low-regret decision-making (e.g. Gleick 2003, Pearce 2004). The soft path may include non-structural measures such as water conservation, demand management (e.g., water pricing), floodplain zoning, disaster relief and emergency preparedness (e.g., flood forecasting, warning, and evacuation plans), flood and drought insurance, optimization of existing systems (e.g., reservoir operation rules), water-efficient cropping patterns and indigenous agriculture, watershed management and protection of water quality, adjustments in river transportation standards, enhancement of water storage and other aquifer augmentation, and low-impact utilization of run-of-the-river hydropower. Reservoir reoperation, in particular, has been shown to be a cost-effective adaptation strategy (e.g., Watts et al. 2011; Vonk et al. 2014), with the understanding that the opportunities, constraints, and goals for dam reoperation are region- and site-specific, and strongly influenced by the main operating purpose(s) of the dam (e.g., flood mitigation, production of hydropower, water supply) (Richter and Thomas 2007).

Video 4.1 Adaptation challenges and low-regrets

Dr. Zbigniew Kundzewicz (Potsdam Institute for Climate Impact Research (PIK)) describes adaptation challenges and a low-regret approach to climate adaptation.

However, a soft path by itself would not be sufficient for the needs of most of the developing world. When combinations of hard infrastructure, soft-path practices, and institutional adjustment are required for robust adaptation, more advanced tools for trading off benefits and costs may be needed. Examples highlighted here include benefit-cost analysis (BCA) under uncertainty, stochastic optimization, adaptive management, real options analysis, and robust decision-making (RDM).

Precautionary principle / safety margins

A simple and effective strategy for decision-making under uncertainty is to be conservative. Uncertainty associated with estimation errors and acknowledged faults in the stationarity assumption were historically addressed using the "precautionary principle" and safety margins. For example, planners oversized dams and added extra height or freeboard to levees above the size analytically deemed necessary (Stakhiv 2010). Of course, the magnitude of the safety margin is affected by many factors, including the cost of additional capacity, the consequences of system failure, the economic lifetime of the project, the flexibility of the design, and the likelihood that better forecasts of future conditions will become available in time to add additional capacity at a later stage.

In many cases, the projected future hydrologic and socioeconomic conditions challenge the theory that design conservatism and safety margins can adequately address future uncertainties. The magnitude of future uncertainties affecting water resources management is far greater than the uncertainty assumed in the past (Hall and Murphy 2012; Wilby and Dessai 2010). Also, due to budget constraints and growing demands for water, energy, and environmental protection, many water and economic budgets no longer have room to allow for operational and economic inefficiencies associated with the historical conservative approach to designing water resources systems (Frederick et al. 1997).

Sensitivity analysis

Sensitivity analysis is a method for assessing the effect of uncertainty on system performance, which considers the possible costs of making alternative choices to some "optimal" decision. According to Loucks and van Beek (2005), "A sensitivity analysis attempts to determine the change in model output values that results from modest changes in model input values. A sensitivity analysis thus measures the change in the model output in a localized region of the space of inputs." A sensitivity analysis, however, is not the same as a thorough analysis of the uncertainties potentially affecting system performance (together with their probability of occurrence), and it does not address the question of what decision should be made when the future is unknown or unknowable (Loucks et al. 1981). Furthermore, as argued by Lempert et al. (2006), the attachment of sensitivity analysis to traditional decision analysis techniques is an adequate measure for risk exploration only when the optimum strategy is relatively insensitive to key assumptions. When it is not, sensitivity analysis techniques can lead to strategies vulnerable to surprises that might have been countered had available information been used differently (Lempert et al. 2002).

Benefit-cost analysis (BCA) under uncertainty

Traditionally, BCA has often been used in water resources development to choose among alternative projects. BCA under uncertainty generally requires estimates of possible future states as well as the probability of those states occurring. This information can then be used to calculate the expected net present value of future benefits and costs of competing projects. Subsequently, an optimal solution can be found that maximizes economic benefit or some other performance criterion (Olsen and Gilroy 2012). Operations Research (OR), developed during World War II, has provided the tools for modern decision analysis of this type (Hillier and Lieberman 2005).

Historically, probability distributions for future hydrologic states have been estimated statistically based on the observed record and the assumption that the statistical properties of hydrologic variables in the future will be statistically similar to the observed record. However, as discussed in Chapter 1, this stationarity assumption is no longer appropriate (Milly et al. 2008). Further, as mentioned in Chapter 2, no consensus exists regarding the appropriate discount rate used to assess future costs and benefits under climate change. As a result, depending on the project, BCA may be extremely dependent on parameters for which there is either no scientific agreement (probabilities of future hydrologic states) or no consensus (discount rate).

BCA can be useful in water management decision-making, particularly in situations in which uncertainty is quantifiable or limited. However, conducting a BCA under the deep uncertainty of climate change and other drivers poses considerable challenges. When representing the uncertainty associated with climate change indices (e.g., temperature and precipitation) with Gaussian or other asymptotically diminishing probability distribution functions, the BCA under uncertainty method is extremely sensitive to tails of the distribution functions (Weitzman 2009). In situations of deep uncertainty, therefore, BCA is best used as a screening tool (Hallegatte et al. 2012).

Stochastic optimization

While approaches aimed at producing a narrow conception of optimality ("one future") have traditionally been at odds with approaches aiming at robustness ("many futures"), stochastic optimization is a technique in which multiple future scenarios are weighted probabilistically. The "best" design performs reasonably well across the range of considered futures. In all likelihood, a stochastically optimized solution is not the best-performing design for any single future. Stochastic optimization offers a straightforward, first-order approximation of hedging against unfeasibility, and is thus a step toward robustness. For summaries of stochastic optimization techniques that apply probabilistic uncertainty paradigms to water systems decision-making, see Revelle and colleagues (2004), Loucks and van Beek (2005), and Sen and Higle (1999). Multi-objective robust optimization extends stochastic optimization to explicitly make it more robust to challenging scenarios (Ray et al. 2014).

Adaptive management

Adaptive management "promotes flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood" (NRC 2004). It is a structured, iterative process that requires adaptive system components, including institutions (Video 4.2), infrastructure, policy and regulations, etc. In the context of climate change, documentation and monitoring of each step and all outcomes advances the scientific understanding of climate change and informs adjustments in policy or operations as part of an iterative learning process. Adaptive management is a continuous process of adjustment that attempts to deal with the increasingly rapid changes in our climate, societies, economies, and technologies. It increases the ability of decision-makers to formulate timely responses to new information. Adaptive institutions are essential to adaptive management.

Video 4.2 Adaptive institutions

Dr. Margot Hill Clarvis (University of Geneva) discusses what it means to be an adaptive institution.

As noted by Stakhiv (2011), the water resources management sector has developed a variety of strategies to deal with periods of high demand and low water availability. They consist of longer-term infrastructure "adaptation" to stationary climate signals and shorter-term "adaptive management" measures that center mostly on flexible operations, forecasting, and innovative uses of existing delivery and supply infrastructure to meet unexpected demands and match changing extremes. There are five ways that water managers have of adapting to climate variability and change, and different water management strategies employ various combinations of all the categories listed below:

- Planning new investments or capacity expansion (reservoirs, irrigation systems, levees, water supply, wastewater treatment).
- Operation, monitoring, and regulation of existing systems to accommodate new uses or conditions (ecology, climate change, population growth).
- Maintenance and major rehabilitation of existing systems (dams, barrages, irrigation systems, canals, pumps).
- Modifications in processes and demands (water conservation, pricing, regulation, legislation) for existing systems and water users.
- Introduction of new, more efficient technologies (desalination, drip irrigation, wastewater reuse, recycling) (Stakhiv 2011).

Real options

Real options analysis is an established probabilistic decision process by which adaptability can be explicitly incorporated into project designs in an effort to avoid potential regrets associated with either over-investment or under-investment in adaptation measures. Real options encourages staged decision-making through which more expensive and more highly-irreversible decisions are reserved until more information is available on which to base those decisions. The philosophical underpinning of real options has roots in the work of Dewey (1927), who promoted policies with continual learning and adaptation in response to experience over time, as well as Rosenhead (1989), who defined flexibility and keeping options open as an indicator for evaluating the robustness of strategies under uncertainty. The mechanism for real options is founded on the analysis of financial decision-making (Arrow and Fisher 1974, Henry 1974, Myers 1984, Copeland and Antikarov 2001). A real options analysis can be integrated into a stochastic optimization strategy.

A strong water system management plan combines elements of adaptability, flexibility, diversification, and robustness. Real options analysis is applicable when uncertainty is more "dynamic" than "deep" (i.e., the quality of our knowledge should improve over time) and the project involves potentially irreversible decisions, such as major infrastructure investments. Some adaptation strategies will be more flexible than others in the future. The expected value of each option—its degree of flexibility—can be calculated and compared. The objective in this formulation is still to maximize net present value, but the adaptability of design options is explicitly considered. The government of the United Kingdom, for example, requires that climate change adaptation analyses account for "the value of flexibility in the structure of the activity" (HMT DEFRA 2009).

Examples of real options for water supply include investments in pumps to draw upon dead storage, pipelines to connect to storage at another impoundment, or infrastructure to tap groundwater resources. Demand-oriented real options for water supply are also possible, such as investments in household metering and a strong public outreach campaign that could be implemented at some cost to help enforce future conservation efforts (Steinschneider and Brown 2012). Real option water transfers provide a mechanism by which water supply can be augmented without the need for large-scale infrastructure expansion. A number of studies have demonstrated how financial instruments such as leases, option contracts, and water banks can facilitate the trade of water between low- and high-priority uses during a localized water shortage (see, for example, Brown and Carriquiry 2007, Characklis et al. 2006, Kirsch et al. 2009, Lund and Israel 1995, Palmer and Characklis 2009, Steinschneider and Brown 2012). Applications to water resources problems with a focus on the mitigation of flood damages have also become common (e.g., Gersonius et al. 2010, Gersonius et al. 2013, Hall and Harvey 2009, Haasnoot et al. 2013, HMT DEFRA 2009, Ingham et al. 2007, Merz et al. 2010, Woodward et al. 2011, Woodward et al. 2011).

Robust decision-making (RDM)

Robust decision-making (RDM) attempts to more strategically use deeply uncertain climate information to answer adaptation questions. RDM uses an iterative decision framework to identify strategies that perform reasonably well over a wide range of plausible future scenarios (Lempert et al. 2003; Lempert et al. 2006). RDM inverts traditional sensitivity analysis, seeking strategies whose good performance is insensitive to the most significant uncertainties. The process begins with scenario generation, based on the principles of scenario planning (Schwartz 1996) and informed by downscaled GCMs and stakeholder-derived information on expected local conditions. The scenario-generation process is designed to encompass a very wide range of possible futures. Typically, RDM uses *a priori* internally consistent scenarios and bases climate forecasts directly on time series of downscaled GCMs.

Once the climate scenarios have been developed, the next step in RDM is the identification of a proposed robust strategy, through an initial ranking or screening, along with the identification and characterization of one or more clusters of future states in which each of the strategies perform poorly. These clusters, unweighted by probabilities, are designed to be considered even if decision-makers find them unlikely or inconvenient. Faced with potential futures (or clusters of futures) in which a proposed strategy (or system) performs poorly, the RDM procedure makes modifications to the strategy (or system) that hedge against vulnerabilities. Finally, the trade-offs involved in the choice among the hedging options are explored.

Because RDM samples from all combinations of uncertain system parameters, it explores futures both more benign and more dire than the present. In a full RDM analysis, various aspects of candidate strategies would be successively altered and resubmitted to the RDM process until a suitably robust strategy was identified. A particular strength of RDM is its ability to model complex systems; its framework enables it to analyze very large numbers of scenarios in which any or all system and design parameters are altered in any number of configurations (RAND 2013).

Using an approach similar to decision scaling, RDM characterizes uncertainty in the context of a particular decision. However, RDM applies equal probability to all considered climate futures and identifies adaptation strategies that perform well across as wide a range of those potential futures as possible. This type of approach thus makes it very difficult to weight extreme scenarios to which the adaptation strategy is vulnerable in proportion to the many less extreme scenarios to which it is robust. Importantly, RDM also includes iterative and adaptive decision strategies designed to evolve over time in response to new information.

CHAPTER 5

Moving beyond downscaling

Chapter 5 makes the case for moving beyond just downscaling GCMs for climate adaptation in the water sector. Instead, AGWA supports a bottom-up approach to adaptation, described subsequently through discussion of:

- *The impetus for a bottom-up approach to adaptation*,
- *A framework for an adaptation approach supported by AGWA*, and
- *Towards the AGWA Decision Support System (DSS)*

Media

Video 5.1 - A bottom-up adaptation approach supported by AGWA

The impetus for a bottom-up approach to adaptation

There is a tremendous need for practical guidance that supports water resources management under climate change. For applications relating to water management, the elusive "gold standard" for climate adaptation has been accurate, confident, and quantitative estimates of future climate states—ideally, decades from now, over the full operational lifetime of water infrastructure and long-term planning horizons. However, the data produced by downscaling GCM output are far from this standard and not appropriate for use as a starting point for water resources risk assessment. Consequently, improvements in data development and acquisition, particularly in developing countries, must be prioritized. Also, stakeholders must define performance metrics and performance thresholds. From its inception, AGWA has focused on this data problem, which is arguably the single most technically challenging issue surrounding climate adaptation.

Building upon previous recommendations to move beyond downscaling (Fowler and Wilby 2006), AGWA has adopted an approach to assist in the selection of appropriate strategies for robust water resources design and planning under uncertainty. This approach requires an evaluation of both the confidence in the available data and the potential consequences of climatic changes. Under high confidence and/or low-consequence situations, AGWA supports the use of traditional planning and design methods based on stationary, probabilistic concepts. However, traditional approaches for managing the uncertainties of future climate conditions have proven unsatisfactory and ineffective for quantitative engineering, long-term sustainable resource management, and many investment decisions. Under these low-confidence and high-consequence conditions, AGWA suggests shifting to a bottom-up, adaptive management strategy aimed at creating a more robust system given the relatively high uncertainty.

As a first product of the collective effort, AGWA is developing a Decision Support System (DSS) to guide water management planners, investment officers, and practitioners in combining existing tools, research, and data products into an evidence-based system to inform water management decision-making processes. The DSS is meant to provide a generalized methodology for (1) analyzing risk using "bottom-up" methodologies, (2) integrating ecological and engineering approaches to achieve resilient and robust water management, (3) using economic tools to enable and promote flexible decision pathways, as well as (4) governance mechanisms that represent broad allocation needs and enable consensus-based approaches. *Beyond Downscaling* particularly targets the first component, but attempts to touch on all of the topics.

A framework for an adaptation approach supported by AGWA

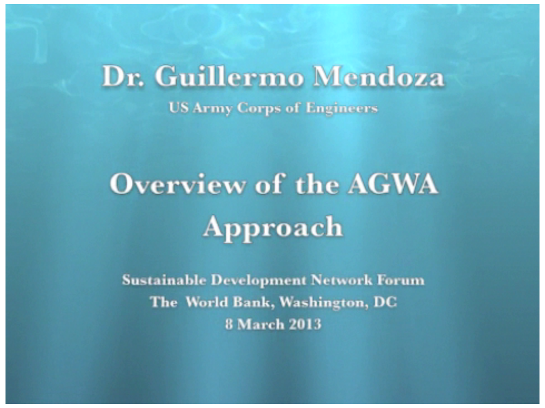
The adaptation approach supported by AGWA recognizes that robust, quantitative approaches and insights into climate adaptation have been accruing over the past decade, and that these insights span a wide range of disciplines: engineering, economics, hydrology and ecology, governance and law, climate science, and finance, among others. Each discipline's accrued knowledge however, has largely been developed in isolation and without clear reference to complementary or conflicting perspectives from other disciplines. This book represents great progress on the integration of engineering, economics, climate science, and hydrology. However, there is a great need for further integration into water resources management of ecology, governance and law, finance, and many other human factors, including urban/rural issues, manufacturing/agricultural water allocations and trade, transboundary water sharing (hydrohegemony), water-related aspects of poverty reduction, and social/religious/cultural links to and valuation of natural water resources. Further, climate analysts need to work more directly with decision-makers to co-explore and co-produce knowledge about climate risks and adaptation options.

AGWA believes that the convergence of disciplines, tools, and expertise represent the ascendance of a new paradigm for water management that integrates climate resilience with non-stationary water perspectives. Critical to this paradigm is the insight that current decision-making processes represent the weakest and most climate-vulnerable element in how we approach water management. Our decisions are not as credible, effective, or durable as we once believed they were. As a result, we can lock in ineffective investments for very long periods into the future if we are not robust to a wide range of potential shifts we may experience. As a result, decision-making processes around the adaptation approach supported by AGWA embody several strategies and assumptions, namely:

- Climate change is not relevant to all water resources management work, nor is climate change equally important to all problems when climate impacts will be relevant. The approach supported by AGWA recognizes the need to integrate climate adaptation into existing decision-making processes around water management rather than inventing completely new methodologies.
- Climate vulnerability assessments are widely understood to be a critical component to determine risks for water resources management under climate change, relative to other threats and opportunities. AGWA advocates bottom-up approaches to vulnerability assessment, which reflect inherent system limits and serve as an effective means of framing uncertainties about future climate projections rather than top-down methodologies, which rely heavily on climate models to frame vulnerability (Video 5.1). Stakeholders are a key gap—engaging and educating stakeholders can both help define systemic vulnerabilities and opportunities and serve as a platform for dialogue with a decision-scaling coach, fostering consensus and problem solving. This book attempts to begin enabling these methodologies for water management decisions. To

see case studies, watch Casey Brown (UMass Amherst) present a decision scaling study in the Great Lakes region and Kristen Gilroy (USACE) present an application of the approach supported by AGWA within the USACE's Shared Vision Planning methodology.

Video 5.1 A bottom-up adaptation approach supported by AGWA



Dr. Guillermo Mendoza (US Army Corps of Engineers) describes a bottom-up adaptation approach supported by AGWA.

- The use of explicit, systematic decision trees based on existing water resources management approaches, such as the approaches being developed by the US Army Corps of Engineers (USACE) and the World Bank ("Including Climate Uncertainty in Water Resources Planning and Project Design – Decision Tree Initiative"), will enable separate individuals to come to similar conclusions about vulnerabilities and effective adaptation responses for the same project, assuming they have access to the same initial datasets. In addition, these decision trees should help water managers and planners "track" the emergence of alternative futures over time and detect decision-making tipping points, which will enable long-term flexible management, operations, and implementation.
- Closely connected is the process of creating explicitly flexible decision pathways, so that the risk of making all-at-once stationary decisions is minimized. Critical here is the development of economic analytical methodologies that (a) estimate the costs of maintaining multiple options and flexibility, (b) evaluate the trade-offs between waiting for more certain information before implementation versus acting in the short term with less information (presumably requiring more robust and expensive solutions), and (c) design multiple decision-making pathways.
- The challenge of sustainability itself contains philosophical issues. Sustainable water resources management must merge perspectives on resilience and robustness from both engineering and ecological perspectives. Previously, these visions of resilience have been in tension and opposition, but bottom-up approaches can serve as a powerful framework for integration by making dynamic ecosystem integrity a performance marker for water sustainability.
- Finally, flexibility must be implemented and expressed through real-world governance mechanisms and institutional processes. Integrating into water resources management the use of flexible governance mechanisms that assume allocations can be adjusted in response to or anticipation of dynamic water conditions is essential to reducing the potential for conflict and crisis-induced decision-making.

Towards the AGWA Decision Support System (DSS)

The adaptation approach supported by AGWA is on its way to becoming a formal methodology called the AGWA Decision Support System (DSS). As an organization, AGWA seeks to harvest expert knowledge and place it in a format that can be used for systematic, consistent, repeatable applications for "bottom-up" risk assessment, integration of ecological and engineering resilience into water management, and economic analysis that promotes flexibility and robustness. The DSS will encompass the aforementioned strategies to provide water managers with a decision system that will help them select the appropriate techniques and tools for resilient water resources design and planning.

The content work streams for the AGWA DSS draw directly on the diversity of knowledge critical to making more resilient decisions. The work streams have been organized into four clusters, the first three of which were launched as a result of the World Bank / AGWA workshop (2011):

- Hydrology and climate science
- Economics and finance
- Engineering and ecology
- Governance

The AGWA DSS is intended as a resource center offering documents that describe how to implement the adaptation approach supported by AGWA and access to software tools for decision support, as well as a series of connected strategy and implementation guidance documents to support resource managers and technical staff, infrastructure designers and operators, and policy and planning staff across a wide range of sectors. As climate change risk assessments are now more commonly required as part of broader project evaluations, it is important that such evaluations be accomplished in the most efficient and direct manner possible. The bottom-up processes developed as part of the AGWA DSS are designed to be the most targeted and efficient tools available for climate change risk assessment and risk management. As the AGWA DSS grows, project planners will have access to the methodological frameworks, information, and community of practice to empower targeted and comprehensive risk management in proportion to the risks faced, resulting in robust, cost-effective project designs and management plans.

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ABOUT AGWA

The Alliance for Global Water Adaptation (AGWA) was founded in August 2010 as a network of institutions focused on how to develop effective, practical methods to incorporate the emerging best practices for climate adaptation. Our network spans a diverse array of multilateral institutions, governments, non-governmental bodies, and private sector. The AGWA steering committee includes a wide range of institutions and individuals: Casey Brown (University of Massachusetts), Christine Chan (a consultant based in Hong Kong), Joppe Cramwinckel (World Business Council for Sustainable Development), Paul Fleming (Seattle Public Utilities), Rebecca Tharme (The Nature Conservancy), Cees van de Guchte (Deltares), Karin Lexén (Stockholm International Water Institute), Robert Pietrowsky (U.S. Army Corps of Engineers Institute for Water Resources), and Diego Rodriguez (World Bank). AGWA is co-chaired by the World Bank and SIWI, and the secretariat is funded by SIWI and led by John H. Matthews.

Philosophically, AGWA has arisen as a result of dissatisfaction with the past decade of experimentation with top-down and no-regret approaches to climate adaptation. We acknowledge the need for a new paradigm for sustainable water resources management, and recognize that the challenge of climate adaptation requires the ability to bridge disciplinary, institutional, political, and sectoral boundaries, to harvest the best practices and approaches, and to connect them into a coherent paradigm. As a network, AGWA has come together to fill the decision-making gap by making contributions from multiple perspectives and disciplines, strengthening collaborations, reducing duplications and overlaps, and promoting coherence and effectiveness across institutions and sectors. Our fundamental goal is to provision tools, partnerships, and technical assistance to improve operational decision-making, governance, and analytical processes in water resources management, with a focus on the scales relevant to climate adaptation and climate change.

AGWA is especially interested in supporting resilient water management in the data-poor regions of the developing world.

How can I join AGWA?

AGWA welcomes new members. We have a flexible charter and governance system. To discuss membership, participation, and consultation, we ask that you contact us via the AGWA site: http://alliance4water.org.