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Margot Hill

Climate Change and Water Governance

Adaptive Capacity in Chile and Switzerland

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Foreword

The contents of this volume of *Advances in Global Change Research* represent several years of research conducted by Dr. Margot Hill, focusing on adaptive capacity and water governance in two widely-separated regions of the globe, namely the Swiss Alps and the Chilean Andes. While there are clearly different institutional frameworks in the two countries in terms of the water policies that are implemented, there are close similarities in both regions in terms of the response of hydrology and water resources to a changing climate. These include shifting precipitation patterns, highly variable winter snow packs, and receding glaciers, ultimately resulting in changing seasonality and amounts of runoff that will subtly modify water availability and water use.

As climate change is likely to amplify already observable trends in surface runoff, the question is posed as to whether adaptive capacity in the regions studied is sufficiently robust to respond to a situation which has never been experienced to date. Indeed, because of the presence of snow and ice in the Alps and the Andes, the runoff from the melting cryosphere has up till now largely buffered the negative impacts of hot, dry seasons on water availability. For example, during the 2003 heat wave in Western Europe, rivers such as the Rhine or the Rhone saw large increases in discharge as a result of enhanced glacier melt. However, as long-term global warming will inevitably accelerate glacier melt and shorten the winter snow season, there is a very likely risk of seeing a major change of paradigm by the middle of this century, in particular very low flows from spring to autumn that will be in sharp contrast to the peak flows that occur in today's climate during these very same seasons. Because up till today there is no precedent for the situations projected to occur in coming decades, there has been little thought dedicated to the manner in which water-dependent economic sectors (e.g., hydro-power, agriculture, or tourism) may respond to significant water shortfalls at certain critical times of the year.

It is thus in the context of complex and interlinked environmental and socio-economic issues that Margot Hill has focused her attention. By looking specifically at adaptive capacity and exploring possible avenues for new water governance, she has assessed the robustness of current water policies in the contrasting case-study regions and, whether in a changing environmental context, existing water policies

will be sufficient to cope with the large changes in water resources that are expected over the course of the twenty-first century. The thought-provoking narrative, upheld by very clear tables, graphics, and an abundant literature, suggests that technology and changes to infrastructure will not in themselves resolve all future problems that a changing climate will impose upon hydrological resources. Nor will these totally resolve the problems faced by a number of key economic sectors that depend directly or indirectly upon water in the right amounts and at the right times of the year for their revenue. Margot Hill emphasises that there is instead a genuine need for "developing a stronger focus and understanding of institutional adaptation and adaptability".

The innovative ideas outlined in this volume come at a timely moment for national and supra-national authorities, in particular the European Commission which is monitoring the Water Framework Directive and will need to progressively adapt its texts to incorporate the changes that are now becoming apparent. The contents of the book will certainly provide some essential guidance for the decision-making process that will need to be initiated fairly rapidly if we are to avoid disruptions to many key economic sectors where water is an essential element for their business, and the potential and sterile rivalries between sectors that will inevitably arise if no forward-planning is envisaged.

Professor and Head of the Institute of Environmental Sciences Martin Beniston
University of Geneva, Switzerland

I met Margot Hill in 2010 at World Water Week in Stockholm, as I scrambled for a seat in a seminar on climate adaptation and water governance. She was presenting a comparison of the institutional, ecological, hydrological, and legal challenges of two snowpack-mediated regions in Chile and Switzerland. Her talk was as exciting and thoughtful as it was sobering about the shifting landscape that we all face as a result of accelerating climate change. When she proceeded from the podium to the chair next to me, much animated discussion followed. She convincingly articulated that climate change adaptation was not a "science" or "policy" problem but an institutional issue, exposing weaknesses in our governance and operating rules. She remains in a small, if growing, coterie of insightful observers and this volume distils much of her experience from Chile and Switzerland.

When we met, I had just returned from the Tibetan plateau, where traditional herders reported what Margot here refers to as "transformations" of their grasslands, soil, and wetlands and rivers. Over the span of about a decade, the plateau grasslands were becoming something unrecognisable to families that had lived there for millennia. As an ecologist, the rate of change was occurring on a scale that I had never seen outside of regions of intense industrial development such as Eastern Europe or coastal China. Similar rates of climate-induced ecological change are occurring elsewhere–the Andes, the cloud forests of Central America, the Himalayas and their flanks, many coral-rich marine zones, and of course the latitude and boreal zones. Given such dramatic ecological shifts, the social, political, and cultural systems of the plateau were stressed beyond the experience of many generations.

Most of us are headed to the same unfamiliar place. Hydrology is destiny on some level, and the water cycle has proven to be exquisitely sensitive to climate. Moreover, current impacts are not simply shifts in the frequency or severity of extreme events. These impacts are essentially geological-scale leaps, occurring in less than a single human lifetime. They are largely unidirectional and irreversible, and they are hard to predict with confidence.

What Margot's talk confirmed for me was that one of the most crucial components for how well we deal with transformative ecological change is to take back resource management decisions from the kingdom of the engineers and economists. We need to understand that while individuals (and often technical specialists) make most of the *direct* decisions about managing water resources, these individuals also reflect broader intra- and inter-institutional arrangements. Individuals are the faces of governance, but they are also expressions of larger forces. And by extension, resilience comes from adjusting the operating rules for whole governance systems to promote many of the qualities enumerated here.

Can we cope with unknown and hard to predict climate conditions? I have a great deal of faith in humans from our long evolutionary and ecological history, but that history also provides many concerning examples. What I take away now from Margot's insights in this volume is that our future security will emerge from our ability to realize that resilience is a shared, governed quality that reflects learning, memory, imagination, and creative anticipation. She is right in particular to focus our attention on the centrality of both water and institutional, regulatory, and legal frameworks to our social and ecological well-being. And she redefines this landscape of decision making in a useful, exciting manner.

We can expect transformation. Can we prepare by engineering flexibility?

Director, Freshwater Climate Change
Conservation International

John H. Matthews

Preface

Despite gridlock in the supra-national climate governance regime and continuing uncertainty in climate modelling outputs, regional climate impacts are being observed with quickening pace from the Alps to the Andes. The stresses on linked social and ecological systems (SES) from shifting precipitation patterns, glacial retreat and associated changes in run-off regimes are exacerbating a number of underlying governance and management challenges that suggest present water governance regimes may not be robust or resilient enough to cope. While SESs have long adapted to climate influences, the speed and magnitude of change in future climatic and hydrological conditions pose serious challenges, and are increasingly recognised as potentially lying beyond human experience and the coping ranges of social and natural systems.

This book is for all those interested in the growing theoretical and management challenges surrounding climate change adaptation, adaptive capacity and resilience in the governance of linked social-ecological systems. This book looks beyond the technology, modelling, engineering and infrastructure so often associated with water resources management and climate change adaptation, to the decision making environment within which these water and adaptation decisions are made.

Climate change will not only impact on the function and operation of existing water infrastructure, but also the institutions (government agencies, ministries, river basin authorities and user group associations) that manage valuable water resources and water courses. The focus on governance looks to the broader sets of rules, norms and policy frameworks, within which institutions operate. Not only will institutions and water governance frameworks need to respond and shape adaptation responses (through the legislation, operations, policies, decisions) but they will also need to become more adaptable to better manage increasing uncertainty and change as climate change impacts become increasingly prevalent.

In order to achieve this, it is vital to go beyond the technical and hard infrastructural solutions for climate change adaptation that have so far been the corner stone of climate change adaptation. It is vital to better understand the adaptive processes that allow the regimes that govern water resources to respond to new shocks and changes

in the hydrological system, in order to build more resilient water governance systems that can bend, but not break, in the face of new and unexpected challenges. This increasing focus on adaptation has signalled a shift to focus on the need for more flexible and adaptive processes in water governance regimes, to manage uncertainty. Over the past decade, the concept of adaptive capacity, its identification and characterisation, has received increasing attention, but primarily through work relating to other related fields, such as adaptive governance and adaptive management approaches.

Despite the increasing amount of attention more recently paid to adaptive capacity and adaptive processes, the understanding of how adaptive capacity to respond to climate change may be developed within water governance regimes is still in its relative nascence. Moreover, even with the advances in the conceptualisation of adaptive capacity, there still are considerable gaps in understanding the role of different governance regimes in building adaptive capacity and challenges in mobilising proactive and reactive capacity at different scales as well as the mechanisms that allow transformation to more sustainable water resources management. To date there still has been relatively little empirical verification of indicators of adaptive capacity at local and regional levels, as well as across different scales.

This book aims to contribute to the conceptualisation and operationalisation of adaptive capacity, as well as proffering new case studies to the empirical body of evidence on adaptation and adaptive capacity. It attempts to bridge the conceptual gap by contributing a more nuanced conceptualisation and operationalisation of adaptive capacity, through better understanding how the governance context and mechanisms within those frameworks contribute to an enabling environment for adaptive capacity. It also seeks to better understand the challenges in generating adaptive capacity across temporal and spatial scales by drawing heavily on resilience based approaches.

Evidence in this book highlights the challenge of balancing out proactive and reactive responses, as well as responses to multiple forms of stress at different magnitudes of physical change and scales of governance to ensure that responses to one kind of risk do not undermine the capacity to address others. Recently, there has been a growing recognition of the challenges in ensuring that short term adaptation actions do not undermine long term social-ecological resilience, by limiting the adaptive capacity to cope with shocks at different magnitudes of change.

Adaptation and long term adaptability are not therefore one and the same thing, and this needs to be better understood in the process of developing adaptation and broader environmental policy, plans and projects that address the impacts of climate change. The framework developed in this book is therefore intended to improve the assessment of different forms of adaptation outcome in the context of transformation to more adaptive water governance frameworks for coping with climate change impacts. Closer attention is now needed to better identify and understand the nature of the trade-offs between adaptation policies, plans and adaptability across multi-scale contexts.

The two case studies presented in this book come from the highly contrasting cases of Chile and Switzerland, namely the Rhône Basin in the Canton Valais,

Switzerland, and the Aconcagua Basin in Valparaiso, Chile. Despite their many differences, both regions do represent mountain watersheds, nivo-glacial regimes, in which observed impacts of climate change on glacial melt and elevation of the snow line have been documented.

Conclusions drawn from these two geographies do encompass broader implications for other regions. Both countries have repercussions outside their national boundaries for broader water, economic and political issues. To date, most academic and practitioner studies on Chile have focussed either on issues concerning the water market (for which there is broad international interest, in terms of reports by the World Bank and the Global Water Partnership) or physical impacts of climate change. This book bridges those questions and looks at the implications of climate change for the broader governance context, and the adaptability of that context to the impacts of climate change.

Understanding the adaptability of the Chilean case is particularly relevant in the broader context of Latin American. The style of water governance in Chile has long been held as a potential model by international institutions such as the World Bank for other Latin American countries seeking to reform their own water governance frameworks. Closer inspection of the Chilean water governance context in relation to its adaptive capacity to climate change is warranted not only for water managers and policy makers in the country itself, but also for many of the international experts who often cite Chile as one potential model of water governance for other countries (often, but not limited to Latin America).

The case of Chile also has important repercussions for global economic issues, considering its important role as an exporter of water intensive/polluting commodities to the global marketplace (copper, avocado, table fruit, vegetables, and wine). Chile can also potentially serve as a "canary in the coal mine", for a context that is more advanced in terms of global change impacts and closer to tipping points (reduced glacier melt contribution etc.) in the physical system. On the other hand, the case of Switzerland, as the water tower of Europe, has high relevance for the neighbouring European countries that its headwaters eventually flow into. The adaptability of the governance context and the impacts of climate change in the headwaters of the Alps are of high interest and relevance to those countries further downstream.

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Finally, I would like to thank my family for their encouragement and support from near and far. I thank my husband Stuart, for boundless support, reassurance and constant interest in my work, which cannot have always been as easy as he made it look.

Contents

Abbreviations

AIWM	Adaptive and integrated water resources management
AM	Adaptive management
ADB	African Development Bank
AVDE	Association Valaisanne des Distributeurs d'Eau
BAFU	Bundesamt für Umwelt (Federal Office for the Environment)
BFE	Bundesamt für Energie (Federal Office for Energy)
CCIAV	Climate Change Impacts, Adaptation and Vulnerability literature
CERISE	Cellule scientifique de crise (Scientific cell for crises)
CNE	Comisión Nacional del Energía (National Commission for Energy)
CNR	Comisión Nacional del Riego (National Commission for Irrigation)
CONAMA	Comisión Nacional del Medio Ambiente (National Commission for Environment – now MMA)
COP15	15th Conference of the Parties
CODELCO	Corporación Nacional del Cobre de Chile (National Copper Corporation of Chile)
COREPIL	Commission Régional de Pilotage
CPR	Common Property Resource Regime
CRA	Confederacion de Regantes de Aconcagua
EOS	Energie Ouest Suisse
EU	European Union
FP7 ACQWA	Framework Project 7 'Assessing Climate change impacts on water Quantity and Water quality in vulnerable mountain regions
DETEC	Department of the Environment, Transport, Energy and Communications
DFID	Department for International Development (UK)
DFSB	Dienstelle für Strass- und Flussbau (Administration for Road and River Building)
DGA	Direcion General de Aguas (General Directorate of Water)
DOH	Direcion de Obras Hidrologicas (Directorate of Hydraulic Works)

DWL – Valais	Dienstelle für Wald und Landschaft (Office for Forests and Landscape)
EAWAG	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz (Federal Institution for Water Provision, Sanitation and Protection)
EIA	Environmental Impact Assessment
ENSO	El Nino Southern Oscillation
EPFL	Ecole Polytechnique Fédéral Lausanne
EWZ	Elektrizitätswerk Zermatt (Electricity Utility Zermatt)
FOEN	Federal Office for the Environment
GCM	Global Climate Model
GWP	Global Water Partnership
GWP-TEC	Global Water Partnership – Technical Committee
HEID	Institut de Hautes Etudes Internationales et du Développement (Graduate Institute of International and Development Studies)
IISD	International Institute of Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
ICWE	International Conference on Water and the Environment
IWRM	Integrated Water Resources Management
IUCN	International Union for the Conservation of Nature
JdV	Junta de Vigilancia
KEV	Kostendeckende Einspeisevergütung (Cost covering Compensation)
MIDEPLAN	Ministerio de Planificación (Ministry of Planning)
MINERVE	Modélisation des Intempéries de Nature Extrême, des Retenues Valaisannes et de leurs Effets (Modelling of Extreme Events, Valais Resevoirs and their Effects)
MLG	Multi-level governance
MMA	Ministerio del Medio Ambiente (Ministry of Environment)
MOP	Ministerio de Obras Publicas (Ministry of Public Works)
NeWater	New Approaches to Adaptive Water Management under Uncertainty
NGO	Non-governmental organisation
OcCC	Organe Consultatif sur les Changements Climatiques (Consultative Body on Climate Change)
OECD	Organisation of Economic Co-operation and Development
PDO	Pacific Decadal Oscillation
SAEFL	Swiss Agency for Environment, Forests and Landscape
SEA	Strategic Environmental Assessment
SES	Social Ecological System
SIB	Services Industriels de Bagnes (Industrial Services of Bagnes)
SRES	Special Report on Emission Scenarios
SSIGE	Société Suisse de l'Industrie du Gaz et d'Eau (Swiss Society of Gas and Water Industry)
TRC	Third Rhône Correction

UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nation Economic Commission for Europe
UN-ECLAC	United Nation Economic Commission for Latin America and Caribbean
UNFCCC	United Nations Framework Convention on Climate Change
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UVEK	Eidgenössischen Departement für Umwelt, Verkehr, Energie und Kommunikation (Federal Department for Environment, Transport, Energy and Communication)
WA21	Wasser Agenda 21
WB	World Bank
WCC-3	World Climate Change Conference in Geneva
WEF	World Economic Forum
WWC	World Water Council
WWF	World Wildlife Fund

Part I
Addressing Water Governance Challenges in the Anthropocene

Chapter 1
Addressing Water Governance Challenges in the Anthropocene

Abstract Water governance, negotiation between actors and institutions for the effective implementation of acceptable water allocation and regulation, faces a plethora of challenges over the coming decades. The challenges arising from population growth, development, climate variability as well as climate change impacts. Concurrently, a crisis of governance has been recognised as one of the major issues facing global water resources over the past decades. The duality of essential role water governance plays in responding to these challenges and the recognised limitations and failures of governance regimes to adequately manage legacy issues predicates the value of closer investigation of both water governance challenges and solutions in the context of climate change and uncertainty. This chapter provides an introduction to the developments in both the challenges to and solutions from water governance over the past few decades.

Keyword Water governance challenges • Climate change uncertainty • Hydroclimatic pressures • Water governance solutions • Adaptive and integrative water management

1.1 Climate Change and Uncertainty: The Great Acceleration

The crisis of governance in the challenges facing global water resources is now well recognised (Gleick 2009; UNESCO 2006; WEF 2009). Governance reflects the negotiation between society and government for effectively implementing socially acceptable allocation and regulation by mediating behaviour through values, social norms and laws (Rogers and Hall 2003). Water governance therefore encompasses the laws, regulations, property rights, institutions, policies and actions, which manage and negotiate water resources as well as networks of influence, such as international market forces, the private sector and civil society (UNDP 1997). Population growth, development, and diminishing water supply from current climate variability

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are already stressing the availability of high-quality water resources. Water governance is essential to managing variability in water supply and delivery (due to seasonality and local variability), in part through the construction and management of regulating infrastructure, but also through the rules (permits, ownership rights, laws, regulations) that administer valuable water resources.

Even if greenhouse gas emissions cease tomorrow, the inertia of the climate system is committed to a likely increase in global temperatures of at least 2°C by the end of the century (IPCC 2007). The associated shifts in climatological patterns will require us all, but water managers in particular, to adapt in a timely and effective manner. The physical and environmental changes pose significant challenges to water infrastructure and management systems, despite the fact that water stakeholders have long dealt with changes and stresses relating to climate variability. The projected speed and magnitude of anthropogenic climate change is set to exacerbate underlying variation and stresses, rendering future situations less manageable (IISD 2006) unless our current institutional arrangements can become adaptive to the realities of future environmental situations.

The release of the fourth assessment report by the Intergovernmental Panel on Climate Change (2007) could have been seen as a tipping point for an increasing awareness of the linkage between climate change and related resource management issues, including water management. Significant progress was made, yet the subsequent years have seen a number of setbacks to significant traction being made by the scientific community on a number of resource related issues. Climate and water cannot be separated as independent issues, especially as water is the primary medium through which climate impacts will be experienced, through changes in local hydrological patterns (Parry et al. 2007). The significance of the water, energy, food nexus is so fundamental to economic development globally, that the intensification of hydrological cycle will impact on both rich and poor, whether through too much water, or too little. Moreover, mountainous areas, commonly considered 'Water Towers' of the world are at the forefront of these warming patterns (Häberli and Beniston 1998). Climate impacts on glacier retreat, precipitation patterns (seasonality and snow line) and associated changes in run off regimes are already observed in Alpine and Andean regions, and model projections suggest a continuation if not heightening of current trends (Viviroli et al. 2011).

In 2002, a Nature paper (Crutzen 2002) suggested that the advent of a new geological period was upon us, one defined by the fact that human actions were playing a dominant role in shaping biospheric processes. This period was called the 'anthropocene', and has fundamentally challenged our perception of human interaction with bio-physical processes. Humans can no longer view themselves as an observer of bio-physical or bio-chemical processes, but instead have become a major contributor and actor in them. This has significant consequences for how human actors should view their part in the 'management' of bio-spherical process and natural resources. Moreover, it prescribes a shift in how actors evaluate and design the management processes to cope in a less stable climatological period, and the increasing need to be aware of the planetary boundaries that we are rapidly approaching (Rockström et al. 2009). The Nature article on planetary boundaries suggested that

the regulatory capacities of the earth maintained a safe operating space of natural environmental change within which humanity could thrive and develop (Rockström et al. 2009). It goes on to define a set of interlinked biophysical thresholds, or planetary boundaries, which if crossed, could lead to irreversible and abrupt environmental change with disastrous consequences for human development. These planetary boundaries are: climate change; rate of biodiversity loss; interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading.

The 15th Conference of the Parties meeting (COP15) in Copenhagen was seen as a major disappointment for the global change science research community on many fronts. The water community was one of many that came out of Copenhagen severely disenchanted, since all references to water were dropped entirely from the final text on adaptation, which represented a widening of the gap between the climate and water contingents when many had hoped a connection would be further fused.[1] COP15 showed that many were still not making the link between the climate and water agendas, or even the wider environmental issues at stake. It also raises the issue that many governance regimes focus on separate aspects of the social or ecological systems (e.g. climate, or forests, freshwater fisheries, marine fisheries, or even less coherently across sector specific legislation or different institutional combinations at ministerial level). However, there is an increasing focus from the global change community on the need for human society and the governance systems that moderate our actions and decisions to operate within multiple inter-connected earth systems. Since the climate negotiations centred purely on the climate system, those involved in carving out the climate regime fell short in recognising the need for human society to operate within the other earth systems (Rockström et al. 2009).

The link between tipping points in these planetary boundaries has been reflected in theories of environmental resource management and governance, as well as in the water disciplines, but has not yet been widely adopted by those outside of the research and scientific community (Rockstrom et al. 2009). The retreat of mountain glaciers is one of the indications that certain sub systems of the earth are moving out of their relatively stable Holocene state, and into the anthropocene (Crutzen 2002; Rockström et al. 2009). Global freshwater consumption has moved from a pre-industrial value of 415 km^3 per year to 2,600 km^3 per year, which while it may fall under its proposed planetary boundary, is tightly coupled with other boundaries in the system. Our ability to stay within the climate boundary may depend on stopping the transgression of the freshwater boundary and vice versa, since all of them are conceived as 'bio-physical preconditions for human development…and well-being' (Rockström et al. 2009, p 474).

[1] Co-operative Programme on Water and Climate (CPWC); Netherlands Commission for Environmental Assessment (MER); Institute for Environmental Studies (IVM); Netherlands Environmental Assessment Agency (PBL).

Additionally, it should be noted that uncertainty does not stem only from the increasing risks and hazards for a potentially warmer world, but also from the very nature of the knowledge system used to map out climate impacts. Despite significant advances in climate change science and modelling techniques, the uncertainty associated with such projections (rather than predictions) at either global or regional levels is likely to continue for the foreseeable future (Carter et al. 2007). Yet, decisions about how to adapt the governance and management of complex water resource systems to climate change impacts cannot just wait until climate model projections are more precise.[2] While models can project a range of futures or alternative scenarios of change, the complex nature of the bio-spherical processes that drive water hydrological patterns means that in the conceivable future short and long term management decisions about future water quality, security and availability will still be subject to a large range of uncertainty in both projected and unanticipated changes.

Social systems have tended to have rules or tools to cope with normal ranges of uncertainties, or moderate deviations from the norm (what Mathews et al. (2011) term 'predictable certainty'), such as wet years followed by dry years on an inter-annual or decadal timescale (Smit and Wandel 2006; Yohe and Tol 2002). For example, from a governance perspective, prioritisation rules may kick in when indicators suggest a dry year is underway. From a management perspective, reservoir storage could tie over water provision during dry years, or flood management strategies such as dykes and early warning systems might protect against high precipitation events (Herrfahrdt-Pähle 2010; Huntjens et al. 2010; Smit and Wandel 2006). However, climate change embodies a more unpredictable and indeterminate form of uncertainty (Matthews et al. 2011) or irreversible changes in state (reduced run off contribution from glacier and snow melt, shifts in seasonality, increasingly consecutive dry years) that may lie outside or beyond the boundaries of past and present coping ranges of water management and governance regimes[3] (Smit and Wandel 2006; Yohe and Tol 2002).

Climate change is therefore seen as exacerbating these broader challenges affecting water governance, acting as an overarching pressure that causes these underlying stresses on water institutions to become even more pronounced as impacts intensify (Lettenmaier et al. 2008). Since climate change is a systemic threat that will have significant interactions with other drivers of change (as discussed above), it will require fundamental shifts in how water governance regimes operate, and how they interact and coordinate across local, regional, national, and trans-boundary scales. More specifically, increasing uncertainty of future conditions, or 'non stationarity'

[2] Also refer to http://www.newater.info/index.php?pid=1045

[3] *Adaptive capacity has been analyzed in various ways, including via thresholds and "coping ranges", defined by the conditions that a system can deal with, accommodate, adapt to, and recover from (de Loe and Kreutzwiser 2000; Jones 2001; Smit et al. 2000; Smit and Pilifosova 2001, 2003). Most communities and sectors can cope with (or adapt to) normal climatic conditions and moderate deviations from the norm, but exposures involving extreme events that may lie outside the coping range, or may exceed the adaptive capacity of the community.* (Smit and Wandel 2006, p 287).

(Kiang et al. 2011; Milly et al. 2008) and possible bifurcations ("thresholds") in the climate system implies that water governance cannot approach the future based on the assumption that it will replicate the relatively stable conditions of the past. The resulting implication is that a shift is required in how we plan and manage water resources, which respects non stationary conditions and embraces (rather than seeks to remove) increased levels of uncertainty, transforming how water governance relates to ecosystems and communities over climate-relevant timescales.

Climate change impacts on hydrological resources and patterns will affect water governance and management primarily through alterations in the timing of hydrological patterns (seasonality), quantity of water resources (floods and droughts) and quality (suitability for consumption or use) (Matthews and Le Quesne 2009; Cook et al. 2011). Impacts include alterations in seasonality, a rise in the frequency or intensity of extreme hydrological events (increased drought and flood recurrence and duration), higher variability of precipitation patterns, increased hurricane intensity, changing trends in snow pack, and generally accelerating rates of glacier melt leading to changes in run-off (first increasing then decreasing) (IPCC 2007). These changes imply both a shift in the alteration (shifts in timing and averages) and intensification (increasing number and severity of extreme events) of the hydrological cycle. Changing seasonality, water temperatures and alterations in precipitation patterns affect water quality, in terms of dissolved oxygen levels, concentration of pollutants, as well as levels of toxic algae and sedimentation impacting aquatic species (Matthews and Le Quesne 2009) and infrastructure such as dams.

Therefore, governance processes that were designed in a context of 'stationarity' may not be equipped to address accelerated changes to the hydrological cycle and more unpredictable uncertainties in relation to future climate. Water rights, regulatory and policy contexts that do not take into account the ecological requirements for maintaining healthy, productive and protective waterways threaten to undermine the resilience of the socio-ecological system, at a time when it is needed most (i.e. as climate impacts mount). Likewise rights, plans, policies and regulation that do not acknowledge inherent uncertainties by allowing for revision if the bio-physical parameters, upon which they are based, change, are likely to become increasingly ineffective in managing the rivalries and negative impacts arising from climate change. Legislation and rules set now or in the past may impact decisions on investment and management paths for the next 10, 20 or 30 years, over which time these impacts will intensify. Simply scaling up past solutions to environmental challenges to tackle climate related issues may not be adequate to manage future challenges, because rules may not have taken unpredictable uncertainty into account, or solutions have been focussed primarily on enabling technical 'hard' adaptations that do not address the social reality in which they must be implemented, or because the timelines for re-assessment and the integration of new knowledge do not match increasing speeds of change.

However, water governance, and the institutions it effects, do not just experience climate change, but play a crucial role in developing an enabling environment for successful adaptation (Tompkins and Adger 2004), to anticipate and respond to a changing climate. Governance regimes define the context within which adaptation