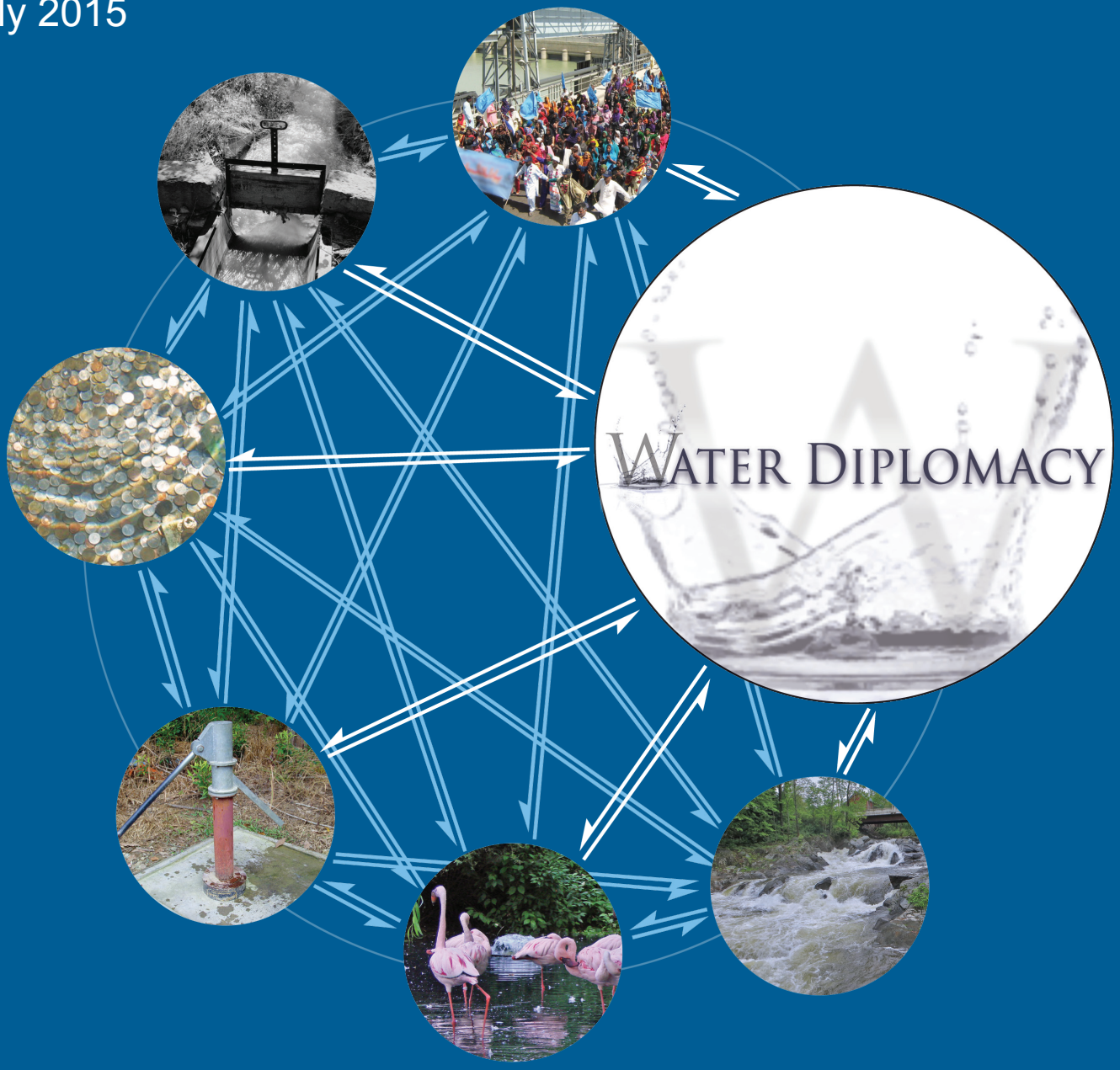
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Water Diplomacy

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Water Diplomacy: A Negotiated Approach to Manage Complex Water Problems

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Abstract: Many water management decisions have evolved from addressing simple problems, such as accessing water near its source, to complex problems of managing and allocating water in the face of multiple and competing demands in the natural, societal and political domains. The Water Diplomacy Framework (WDF) is emerging as an alternative to traditional techno- or values-focused approaches to water management. The WDF is an approach that diagnoses water problems, identifies intervention points, and proposes sustainable resolutions that incorporate diverse viewpoints and uncertainty as well as changing and competing demands. As such, WDF rests upon diverse forms of contextual inquiry of and intervention in complex water problems, with negotiation functioning as the fulcrum of diagnosis and intervention. Several case studies from this volume are used to highlight the utility of this framework for understanding and managing complexity, uncertainty and contingency when addressing complex water problems. We invite the reflective water community to identify and analyze water case studies - from different places, settings, and scales - that will contribute to our collective effort of developing actionable approaches to manage complex water problems in our AquaPedia database.

Keywords: *complexity, contingency, uncertainty, emergence, AquaPedia*

Today we face an incredibly complex array of interconnected water issues that cross multiple boundaries: Is water a property or a human right? How do we prioritize between economic utility and environmental sustainability? Do fish have more rights to water than irrigated grain? Can we reconcile competing cultural and religious values associated with water? How much water do people actually need? Many of the questions raised above share two key defining characteristics: (a) competing values, interests and information to frame the problem; and (b) differing views - of how to resolve a problem - are related more to uncertainty and ambiguity of perception than accuracy of scientific information. In the public policy world, problems with these attributes are called wicked or complex problems (Rittel and Weber 1973; Islam et al. 2010).

Over-utilization of easily available water resources is creating constraints on our planet. We can debate the nature and implications of those constraints and how they are manifested across water, energy, food, climate change, and nano-, bio-, and info- sectors; but these constraints are creating an uncertain water future. Water, as a limited resource, lends itself to conflicts over how it should be allocated, managed and prioritized for use. While scientific formulation and engineering solutions are needed to address to find technical solutions to some of these complex water problems; effective synthesis of societal and political solutions have not been an integral part of long-term and adaptive resolutions of many of these complex water problems. Water security concerns combined with uncertainty associated with water availability and access create contentious arguments over water allocation for human needs, agriculture, development and ecosystems.

Our challenge is how to translate solutions that emerge from science and technology into the messy context of the economy and politics. In this edited volume, we hope to address this challenge by seeking linkages across domains and scales that will

allow us to understand the nature and scope of the complexity that defines the management of water resources. These linkages involve the competition, interconnections, and feedback among variables, processes, actors and institutions.

In this paper, we show how water management has evolved from addressing simple to complex problems. Many of our contemporary and emerging water problems are complex. We need to define what makes a class of water problems complex and how to resolve competing and often conflicting needs inherent to these complex water problems. We hope to show that the Water Diplomacy Framework (WDF) is emerging as an alternative to traditional techno- or values-focused approaches to water management problems. The WDF diagnoses water problems, identifies intervention points, and presents sustainable solutions that are concurrently sensitive to diverse viewpoints and uncertainty as well as changing and competing needs of the stakeholders (Islam and Susskind 2012). The WDF actively seeks value-creation opportunities by blending science, policy, and politics in innovative and contextually appropriate ways.

This overview sets the stage with an informal discussion of the evolution of water management problems and provides an overview of the Water Diplomacy Framework before providing examples for how complexity, uncertainty, and contingency are addressed with specific examples from the papers included in this issue.

Water Management: A Historical Look and an Alternate Perspective

In ancient societies, water management was hyper-local. As settlements grew into cities, new water sources and water storage were needed; canals and cisterns were developed, expanding the scale of water management to regional scales. Industrialization led to a surge in urban populations and a need to address water on a larger scale - to ensure supply of water by introducing national scale policies and institutions. These policies and institutions have led to modern water infrastructure and provided the quantity, quality and reliability of water supply that many enjoy today. Yet, there is a global recognition that this sectoral water management approach is fragmented and needs to be integrated across usages, sectors, scales, and institutions. However, as the complexity of meeting competing needs across multiple sectors and the claims to water by multiple stakeholders - including the needs of ecosystems - grow, this conventional approach has reached its limits for many reasons. Therefore, multi-level management of water resource problems - that is adaptable to an uncertain and changing future - is needed.

We can examine the historical evolution of water management problems using the simple-complicated-complex lens to understand how different types of water problems require different management strategies (Table 1). The first water management problems were simple and solved at the community and household levels by bringing water from the source to the place of use via simple diversions or shallow wells. Water could be directly collected and put to immediate use. As society grew and water needs changed, the challenge of providing water management became complicated. In Boston, this began in the mid-19th century when small reservoirs within the cities could no longer support the water needs of the growing population and a reservoir/canal system was built to transfer water from 30 km away to the city (MWRA 2014).

Table 1. Different types of problems require fundamentally different responses.

Problem Type	Definition
Simple	Cause-effect relationships are well-understood; best management practices are effective.
Complicated	Cause-effect relationships are not straightforward; range of possible solutions are possible for a given management intervention; analysis and intervention requires experts with contextual knowledge.
Complex	Cause-effect relationships are ambiguous; uncertainty, nonlinearity and feedback are inherent; emergent properties dominate system behavior and response.

Supplying the water to the growing city became more complicated as additional reservoirs were connected via canals. Finally, in the early 20th century, the large Quabbin reservoir was built outside of Boston's watershed to meet Boston's regional water needs. Building the Quabbin reservoir transformed the complicated engineering challenge to a complex water problem as four towns were selected to be eliminated and inundated to create the reservoir. How do we reconcile the rights of people from those four towns with the competing development agenda for Boston to grow? This is not a scientific question with a precise and predictable answer. Resolution of this class of complex water problems with conflicting needs requires a different framework. The Water Diplomacy Framework is a step in that direction.

Water Diplomacy Framework

The WDF begins by asking "Know Why" before prescribing "Know How" (Figure 1). In other words, the WDF makes a distinction among values, interests, and tools and suggests ways of thinking about these issues before prescribing a solution. Values are the deeply held beliefs that shape how people view the world. These values include economic, political, cultural, religious, and ethical considerations. For example, religious values shape stakeholders' perspectives on water such as regarding a water source (such as the Ganges) as sacred; values can prioritize a desire to preserve a way of life that relies on access to a water source and its ecological productivity; or even lead to viewing access to water as a basic human right. Interests on the other hand are the reasons and objectives that underlie positions that develop to secure or advance the values held by stakeholders. In the context of negotiation - interests are the "why" behind the "what" sought by a stakeholder (e.g., Fisher et al. 1991). An example of an interest common to water negotiations is the desire to support a robust agricultural sector; this will require a discussion of tradeoff among competing uses of water for multiple sectors. Finally, Tools are the techniques and processes that can be used to answer specific questions in support of understanding the range of outcomes that are possible from a policy, management, or infrastructure based intervention. Tools such as optimization, cost-benefit analyses, and scenario analysis can aid decision making for complex problems, but cannot provide sustainable solutions.

It follows that beginning from a "know-why" perspective allows the examination of how values and interests shape the definition of a water problem, which in turn influences how tools are employed to explore pathways for resolutions (Figure 1). For example, for a complex problem similar to the construction of the Quabbin reservoir and elimination of four cities, the WDF begins by involving relevant stakeholders to discuss and agree on what values and interests need to be recognized and how to arrive at a set of tools to resolve their competing and conflicting needs.

For centuries we have taken nature apart and analyzed its components in ever-increasing detail (de Weck et al 2011; Miller and Page 2007). Now we realize that this process of "reductionism" provides limited insight. We recognize that a system is more than the sum of its parts and that "systems engineering" only works well when systems are

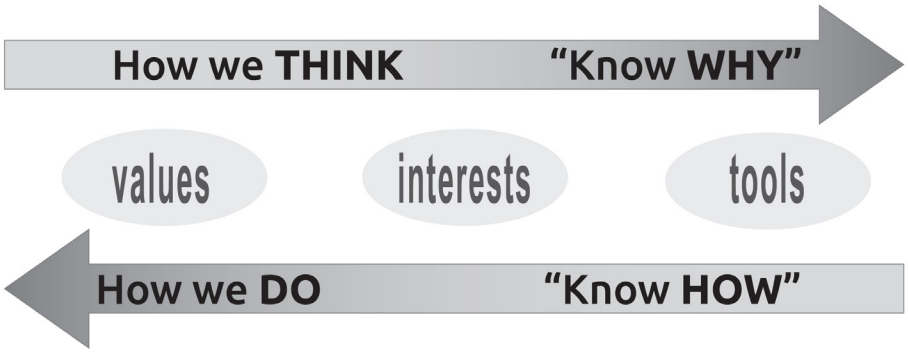


Figure 1. *Know Why vs. Know How* - a distinction between roles of values, interests and tools in the processes of understanding (*how we think*) and determining appropriate action (*how we do*).

bounded and cause-effect dynamics are known (de Weck et al 2011). For open and purposeful systems like water resources management, where system boundaries are ill-defined and cause-effect relationships are ambiguous, an indiscriminate use of the systems engineering approach can provide little insight (Kauffmann 1993; Barabasi 2003; Miller and Page 2007). A key difference - between addressing predictable systems (simple and complicated) and complex systems - lies in our differential capacity of understanding and managing them. We can understand and optimize simple and complicated systems by taking them apart and analyzing the details; however, we cannot understand and manage complex systems by applying a reductionist strategy. A failure to appreciate this difference could cause us to apply exactly the wrong approach to the right water problem or the right approach to the wrong problem. In general, continued efforts to refine existing tools like cost-benefit analysis and optimization algorithms to address complex problems have not worked when systems are complex (e.g., Ackoff 1979; Bennis et al. 2010; Stiglitz et al. 2010). While best practices can be used to address simple problems (such as the design of a household's water system) and systems engineering can be used for complicated problems (such as meeting domestic water demand within a water distribution system for a city), these tools are not suited for complex problems. We need a different approach to address complex water management problems.

Complex problems are ill-defined, ambiguous, and often associated with strong moral, political and professional values and issues. For complex water problems, certainty of solutions and degree of consensus varies widely. In fact, there is often little consensus about what the problem is, let alone how to resolve it. Furthermore, complex problems are constantly changing because of interactions among the natural, societal and political forces involved. Addressing these problems requires a differentiation between systems thinking and systems engineering. Systems thinking remains useful for systems containing feedback loops, uncertainty and poorly understood relationships between and among parts and the whole; however, systems engineering requires a clear understanding of the system, its boundaries, its interactions at those boundaries (inputs/outputs), and the ways in which perturbing parts of the system will change outcomes and flows.

A complex adaptive systems (CAS) approach is more appropriate for managing complex water problems than a typical systems engineering approach (de Weck et al 2011; Miller and Page 2007). CASs are characterized by non-linearity and interdependency, in which small changes can create large impacts. Complex behaviors from these systems can emerge from simple rules applied locally within a CAS. Managing a CAS requires co-production of knowledge because co-evolution is inherent in the system through the process of emergent possibilities.

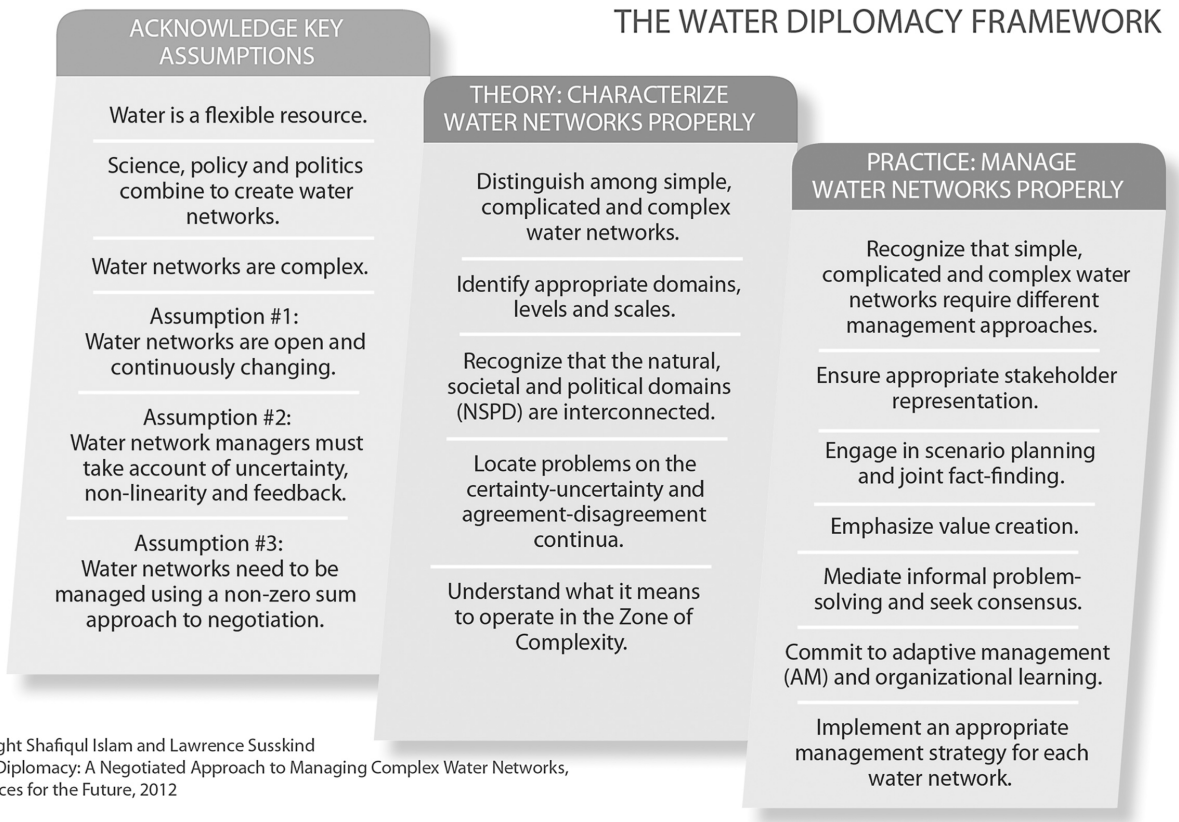
A watershed is a common unit of analysis for assessing inputs and outflow for a water resource and traditional water management - for example, integrated water resource management (IWRM) - advocates for basin level resource characterization and management (Agarwal et al 2000). However, a watershed may not always be aligned with "problem-shed" and "policy-shed" for effective and efficient management for a given water problem (Islam and Susskind 2013). Cohen and Davidson (2011) argue that there are at least five recognized challenges associated with the watershed approach to water resource management: the difficulties of boundary choice, accountability, public participation, and asymmetries with "problem-sheds" and "policy-sheds".

Complex water problems cross multiple domains (natural, societal, political) at different scales (space, time, jurisdictional, institutional), and aspects of these problems occur at different levels within each scale (e.g., short or long term duration, extent across a city, within an organizational hierarchy). The interactions between domains or scales at various levels contribute to the complexity of a water system and preclude solutions that were applicable for simple and complicated systems.

Water Diplomacy's related initiatives are rooted in ideas of complexity theory as well as mutual gains approaches to arriving at a negotiated resolution in the midst of competing and conflicting water needs. A key goal of the Water Diplomacy initiatives has been to refine and test a framework to facilitate the production and use of "actionable knowledge" for the characterization and management of complex water problems.

Bridging Theory and Practice: Managing Complexity and Uncertainty

The Water Diplomacy Framework (Figure 2) is emerging as an alternative to the conventional ways of addressing boundary-crossing water management problems (Islam and Susskind 2012). The WDF challenges conventional thinking about water management in three important ways: (1) it assumes water is a flexible not a fixed resource; (2) science, policy and politics combine to create water networks; and (3) water networks are complex and need to be treated as open-ended and unpredictable rather than closed and predictable systems. The three key assumptions embedded in the WDF have important consequences for how water disputes should be approached. In Figure 2, we present the WDF, including the theoretical basis of the framework and a guideline on how to apply the framework in practice. Our effort to theorize about water systems has been vast, but the set of tools and techniques available to pursue and implement these theories in practice has often led to a science that is "smart but not wise." This is because we do not have the tools and techniques to integrate our "scientific learning" with the "contextual reality" of water problems that are filled with uncertainty, ambiguity, nonlinearity and feedback. Yet, solutions to most real world water problems demand integration of such contextual realities with scientific knowledge. The promise of policy science to provide useful prescriptive advice, and its failure to do so, has led to the recognition of the need to bridge the divide between "theory and practice," or between "know-why" and "know-how." The most significant insight that policy science has generated from its inability to effectively integrate theory and practice is an understanding that the problems that must be addressed in a public policy context are not like the problems for which the tools of systems engineering or optimization were designed. This realization is often conveyed in terms of the "messiness" or "wicked" nature of the problems that arise when science, policy, and politics are intertwined with uncertainty, ambiguity, nonlinearity, and feedback



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Water Diplomacy: A Negotiated Approach to Managing Complex Water Networks, Resources for the Future, 2012

Figure 2. The Water Diplomacy Framework.

loops (e.g., Rittel and Webber 1973; Bar-Yam 2004; Milly et al. 2008; Orlove and Caton 2010).

The problem identification phase - simple, complicated and complex - sets the stage to describe and bound the range of certainty or consensus and defines the types of effective and efficient approaches to address a problem (Figure 3). Simple problems are amenable to optimization because they involve easily identified and neatly bounded elements of water management systems that respond in predictable ways and pose challenges about which there is almost complete agreement with regard to means and ends. Complicated water management problems involve water systems that operate in somewhat unpredictable ways or those in which the means and ends of action are contested. Complex water management problems lie in the zone between certainty and uncertainty and between agreement and disagreement; managing problems in this zone of complexity requires reliance on network theory and the theory of multiparty negotiation.

In our assessment, water management problems such as allocating supplies among contending interest groups or deciding whether to deploy a new technology that might "expand" water supplies, but at the same time could jeopardize water quality, fit into the complex category. Approaches to address many complex water management problems lie somewhere between certainty and uncertainty, defining the "zone of complexity." The dynamics in this zone is neither entirely certain nor uncertain. Agreement about means and ends is far from clear, but within reach if the right procedures are followed. Complexity Theory - drawing on assumptions about nonlinearity, emergence, interaction, feedback, mutation and adaptation - can be used to identify the parameters of management problems that fall into this zone of complexity. Problem solving in this zone is distinct from what works in simple and complicated settings. Below, we discuss features of several papers from this volume regarding different ways WDF has been applied in practice.

The ideas of Water Diplomacy are emerging as an alternative framework because conventional approaches appear to be not flexible and adaptable enough to address complex problems with multiple sources of conflicts involving values, interests, risks, and uncertainty. Through synthesis of student perspectives from the Water Diplomacy program at Tufts, Read and Garcia (2015) offer a case study illustrating the benefits and challenges of the interdisciplinary graduate education in addressing complex water issues with competing and conflicting needs. While students in the Water Diplomacy program come from very different backgrounds and apply different research methods, they share a common perspective shaped by four principles: the importance of both values and science in addressing complex water problems; the need to recognize the importance and limitations of disciplinary lenses; a

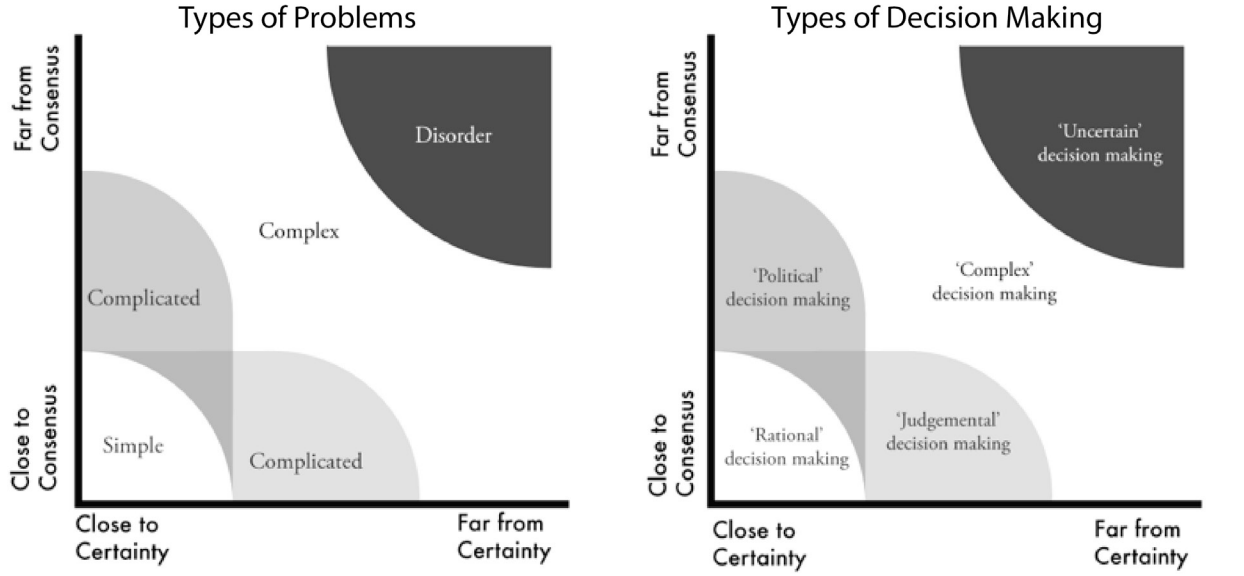


Figure 3. Degree of certainty and consensus: a lens to describe different types of decision making for different types of problems (Islam and Susskind 2012).

deep appreciation of understanding, characterizing and modeling water systems as complex adaptive systems; and an overarching goal of producing actionable knowledge with measurable outcomes despite inherent uncertainties.

Read and Kuhl (2015) discuss centrality of risk across a range of water problems and suggest that effective resolution of these problems necessitates interdisciplinary consideration of risk and risk management. They have highlighted the importance of risk-related challenges and management approaches for several water problems including water quality, water allocation agreements, climate adaptation planning, and infrastructure investments. From the articles reviewed, they have noted that understanding and managing risk did not feature in the discussion of key capacities for a water professional, or components of a water curriculum. This is a critical gap that needs to be addressed to prepare the next generation of water professionals.

Van Rees and Reed (2015) provide a case study from O'ahu, Hawaii in which water management focused on freshwater availability for municipal or irrigation use - at the expense of systems that rely on runoff or infiltration - such as aquifers, near-shore fisheries, coral reefs and wetlands. By neglecting systems that rely on runoff or infiltration (and stakeholders in these systems), problems that were viewed as ranging from simple to complicated - maximizing the availability of freshwater through technological means for growing urban development - grew to complex issues with poor quality runoff impacting near-shore ecosystems and increased flood risk due in part to land development-related wetland loss. They argue that a "zero-sum" perspective treating ecological water needs as constraints to management and overly simplistic and phenomenological data may not properly describe system behavior to design and implement effective intervention strategies. They provide an intuitive method for integrating ecological factors into the WDF by treating ecosystems, focal species, and other ecological phenomena of interest as "surrogate stakeholders" as part of the negotiations approach of the WDF. This increases opportunities for discovering mutual-gains solutions to water management conflicts involving ecological factors and encourages a hypothesis-based, deductive approach to research on the ecology of water management. By differentiating between the "positions" and "interests" of ecological stakeholder surrogates, water decision-makers can make greater use of the potential added value of ecosystem services in water management and avoid costly misunderstandings of the behavior of ecological systems affected by management.

Opportunities to examine and address water problems using the WDF continue to expand as we face increasing recognition that we must identify and address sources of uncertainty in complex water problems through negotiated agreements or management policies. Agreements on water made 50 years ago - such as the Columbia Water Treaty discussed in Brady et al. (2015) or the Indus Waters Treaty discussed by Choudhury and Islam (2015) - could not anticipate emerging issues that are of importance today, such as climate change, changing water needs with population growth and agricultural expansion, or the true breadth of stakeholders and their interests. Consequently, new approaches are needed to address emerging complex water management challenges where values, interests, and position are intertwined. Once one starts "unpacking" a complex problem for possible solutions or remedial actions, the solution space becomes practically unbounded. Debates about what to do are not likely to end because there are no definitive solutions given the endless variability of problem definitions based on values, interests and perceptions. The only way to effectively address (not solve) complex problems is to design a decision-making process that can produce politically legitimate and tentative (rather than once-and-for-all or one-size-fits-all) prescriptions. This implies that concerns about water stress will give rise to normative debates (e.g., Water for whom? At what cost?). While science can help inform these debates, technical inputs will not solve them.

Choudhury and Islam (2015) focus on a particular class of complex water problem: allocation of transboundary water (TW). They argue that two universally emerging goals - sustainability and equity - provide the normative anchors to address the values and interests of the stakeholders involved in managing complex TW problems. The nature and resolution of TW issues need to be understood as complex and contingent because of dynamic and contextual changes occurring in the knowledge

and political communities as well as those that are inherent in the interaction among variables and processes operating within these two communities.

Brady et al. (2015) contribute to understanding transboundary water agreements by analyzing the Columbia River Treaty renegotiation from the perspective of contract theory. They demonstrate the importance of the concept of contract completeness in identifying efficient contractual arrangements that can consider the tradeoffs of increased flexibility. The limited objectives of the first treaty - signed in 1961 - meant that it was possible to write a complete contract. Climate change and more complex stakeholder interests have moved any future agreement into the realm of incomplete contracts. Alternative types of incomplete contracts may be considered as potential future treaty arrangements. The approach suggested by Brady et al. (2015) has the potential to provide a more general framework for working through potential treaty designs for emerging wicked water problems.

On a similar note, Koebele (2015) suggests that to address complex water issues, collaborative governance of water resources is emerging as a widespread strategy that develops solutions that integrate diverse stakeholder needs and create consensus-driven solutions. She emphasizes that linking the outcomes of collaborative processes to improved water sustainability is difficult because of a multitude of scales and settings. Using data from 28 in-depth interviews with key participants involved in Colorado's statewide water plan, Koebele (2015) highlights not only what outputs and outcomes may be produced through a high-stakes collaborative process, but also what barriers exist to actualizing the outcomes desired by stakeholders. Gaining a better understanding of outputs, outcomes, and barriers from similar case studies related to collaborative water governance process can provide insight into improving future decision-making processes and stakeholder participation for a variety of complex water problems.

For instance, Abdelhady et al. (2015) describes the diverse stakeholders, issues and interests in the construction of the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile. While the historical political relationship between Ethiopia and Egypt impacts their discussions of use of the Nile water; the conversation about the GERD changes at different scales - the everyday politics occurring at the local scale of communities impacted by the project, the national scale within Ethiopia and at international and global scales through its impacts on the Nile system and transboundary use of Nile water (Abdelhady et al. 2015).

Aytur et al. (2015) proposes adaptive governance as a distinct framework that explicitly focuses on decentralized decision-making through social processes such as collaborative learning, networking, and promotion of cross-sectoral partnerships to enhance adaptive capacity. They explore an ongoing engagement process for climate change adaptation planning in Exeter, New Hampshire, and its alignment with key characteristics of adaptive governance. They demonstrate the importance of synchronizing modeling activities with a portfolio of engagement strategies to meet the needs of diverse stakeholders and emerging complex water problems.

Looking Forward

Issues related to water access, need, usage, and management are recognized as complex due to the crossing of multiple boundaries: political, social, and jurisdictional, as well as physical, ecological and biogeochemical. Sustainability and equity are emerging as two globally acceptable normative anchors to address values and interests of stakeholders involved in resolving complex water problems. These normative anchors provide overarching principles to guide water management strategies; however, given the contextual nature of complex water issues, neither can be pre-specified. They need to be debated and negotiated through an open participatory process, as they are contingent upon the issues and the stakeholders involved in a water conflict.

This volume provides multiple examples and perspectives on issues, challenges, and opportunities to develop a consistent framework to effectively diagnose and manage emerging complex water problems. The Water Diplomacy Framework is used as an example to demonstrate how values, interests, information, and tools need to be synthesized to address complex water problems. The WDF facilitates the process of resolving water conflicts involving multiple stakeholders with conflicting

or divergent interests and issues encompassing substantial scientific and political uncertainty by finding creative sustainable options that ensure mutual gains.

We invite the reflective water community to help us identify, characterize, and analyze water case studies - from different places, settings, and scales - and build an actionable theory of managing complex water problems guided by globally emerging normative anchors of sustainability and equity that is deeply informed by practice and complexity of local conditions.

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Water Diplomacy: Perspectives from a Group of Interdisciplinary Graduate Students

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Abstract: Water management challenges are multifaceted, often involving issues of water availability, quality, access and equity. It is increasingly recognized that professionals trained to work in traditional disciplinary roles are ill-equipped to address complex issues such as water that transcend both geographic and disciplinary boundaries. A growing number of interdisciplinary doctoral programs, including the Water Diplomacy Integrative Graduate Education and Research Traineeship (IGERT) at Tufts University, have formed to respond to demand for progress in this area. This paper presents a Water Diplomacy IGERT student perspective on the benefits and challenges of interdisciplinary water education. First, we find that articulating a set of shared principles helps to build a strong research community, which in turn shapes the research approach and perspectives of participating students. Second, we recommend students clearly state uncertainties and assumptions to tackle the challenge of working with multidimensional complex systems. Next, we advise that students collaborate with researchers and partner organizations to gain exposure to different approaches outside of their discipline, and to increase breadth of knowledge while maintaining sufficient depth. Finally, we recommend that students take an active role in program leadership to ensure balance between program and student development. These difficulties are not unique to water education, and therefore we hope this discussion can help inform future interdisciplinary education and research efforts.

Keywords: *interdisciplinary education, water resources, IGERT, student perspective*

In the last decade, water problems have emerged as one of the most significant global concerns for reasons including availability (McDonald et al. 2011, Vörösmarty et al. 2000), quality (Verhoeven et al. 2006), access (Dagdeviren and Robertson 2011), and natural hazards (Douben 2006). Meanwhile, the number of interdisciplinary graduate programs in universities around the U.S. has increased (Association for Integrative Studies 2014) and there is a growing consensus that interdisciplinary approaches are an essential component of the education required to prepare students to solve some of society's biggest problems (Gewin 2014; Derrick et al. 2011).

Several have written on the call for interdisciplinary approaches to specific water-related topics, to name a few: water quality (Haygarth et al. 2005), ecology (Wassen and Grootjans 1996), and public health (Rodriguez-Mozaz and Weinberg 2010). Perhaps as a response, the U.S. has seen an increase of such programs in the field of water, e.g., WaterSENSE at the University of California, Riverside (http://watersense.ucr.edu/), I-WATER at Colorado State University (http://i-water.colostate.edu/), and CCWAS at the University of California, Davis (http://ccwas.ucdavis.edu/). Since 1998 the U.S. National Science Foundation (NSF) has funded Integrative Graduate Education and Research Traineeship (IGERT) programs at universities around the country to provide collaborative interdisciplinary education and research opportunities to more than 4,000 doctoral students around an integrating theme (NSF 2014a).

These training programs, while relatively new, already show signs of success. A study following IGERT students through their studies and post-graduation found several key outcomes of the

NSF-IGERT program: (1) 75% of IGERT students incorporated at least two disciplines into their dissertation compared with 61% from non-IGERT students; (2) IGERT students finish their degrees on average a semester earlier than non-IGERTs, and (3) IGERT students value their training and 94% recommend the program to others with similar career goals (Carney and Neishi 2010). This positive feedback has encouraged more universities to develop formal interdisciplinary programs.

In 2011, Tufts University started an IGERT program on the theme of Water Diplomacy. Water Diplomacy is the theory and practice of implementing adaptive water management for complex water issues, developed by a group of researchers at Tufts, MIT, and Harvard. The Water Diplomacy (WD) approach diagnoses water problems, identifies intervention points, and proposes sustainable solutions that are sensitive to diverse viewpoints and values, ambiguity and uncertainty, as well as competing needs (Islam and Susskind 2012).

The WD IGERT aims to educate the next generation of water professionals as individuals who view water not as a fixed resource, but as a flexible resource that can be sustainably shared. The anticipated outcomes of this program are to create new avenues for resolving water conflicts by educating students to think across boundaries, integrate knowledge and action, and develop non-zero sum solutions. The main goal of this paper is to offer a case study illustrating the benefits and struggles of an interdisciplinary graduate education focused on water resources and solving water issues through synthesis of student perspectives from the WD IGERT program at Tufts.

Core Principles of Water Diplomacy

The identity of the WD program has evolved since its inception in 2011 as student cohorts have joined each year and shaped the student experience and program vision. Students in the WD IGERT come from a range of backgrounds including civil and environmental engineering, law and diplomacy, agriculture science, and biology; some students enter the program after years of professional experience while others enter directly after completing their undergraduate studies. Some, particularly engineering students, have worked on water issues for years while others come from intersecting fields but have not previously studied water issues directly. Given such a broad range of backgrounds, the student experience has varied significantly and as a group we have found that the common thread is not a set of skills, but rather a shared perspective. Through participation in WD courses such as Water Policy and Politics, the formation of research topics, and engagement in projects with peers, WD IGERT has shaped the perspective of participating students. This perspective can be summarized in four core principles that we feel are critical for solving complex water problems:

i. Science and values are both important in addressing water problems.
ii. Effective problem solving requires recognition of the strengths, limitations, and boundaries of disciplinary lenses.
iii. Water systems are complex adaptive systems.
iv. Researchers must strive to produce actionable knowledge despite inherent uncertainties.

These core principles are drawn from both our own research experience and a range of interdisciplinary scholarly articles summarized here. Resolving conflicts between multiple users of a water system requires not only an understanding of the facts but also the values of the stakeholders involved (Islam and Susskind 2012). While not all researchers are directly involved in stakeholder engagement, an understanding of the role of values in shaping feasible solutions enables researchers to appreciate the boundaries of their expertise. Water systems, similar to other complex adaptive systems, are characterized by emergent behavior, unpredictability, boundary-crossing and co-evolution (Islam and Susskind 2012). This complexity generates considerable uncertainties and challenges for researchers and practitioners aiming to produce actionable knowledge. Synthesizing data and knowledge from multiple disciplines can enhance our understanding of such systems (Sivapalan et al. 2011). However, decisions must proceed regardless of the resolution of substantial uncertainties (Lempert 2002). WD IGERT students recognize and clearly present

the uncertainties in their work to contribute to synthesis efforts and inform decision making.

The four core principles of Water Diplomacy are central to both the program and students' academic and personal development as interdisciplinary water professionals. Students in the program attest that the WD perspective has shaped their research questions, the types of collaborations they pursue, and their post-graduation plans. Through discussions and a brief survey, we see evidence of this effect. For example, one student's career goals have shifted from a domestic to an international focus with the aim of working at the intersection of ecological and development issues. Another student explained that while her career goals haven't shifted, the types of collaborations she pursues have expanded beyond engineering to include political science and decision science.

Who are water diplomats?

Interdisciplinary professionals who contribute to the resolution of complex water problems that include: (i) multiple stakeholders with conflicting or divergent interests and (ii) sources of uncertainty in either or both the scientific or sociopolitical domain. Water diplomats facilitate sustainable water solutions by problem-solving with a mutual gains negotiation approach and synthesizing information across disciplinary boundaries and sociopolitical perspectives. Water diplomats are literate in multiple water-related academic and applied fields.

Challenges and Lessons Learned

As students in the WD IGERT program at Tufts, we are scientists conducting experiments for our dissertations while simultaneously the subjects of an experiment ourselves. Amid rapid growth, interdisciplinary doctoral education is a new frontier and each program is discovering new challenges and new solutions along the way (Graybill et al. 2006; Pinter et al. 2013). Many have written on this subject, highlighting the potential benefits of interdisciplinary education in solving cross-discipline problems (Nyquist and Woodford 2000; Derrick et al. 2011) while also acknowledging the difficulties, namely in aligning targeted programs with student learning outcomes (Borrego and Cutler 2010), developing successful departments for interdisciplinary studies and pursuing careers as tenured academics (Gewin 2014). Here we discuss three challenges and offer our lessons learned in tackling them through the WD IGERT program: 1) managing uncertainty while creating actionable knowledge, 2) trading off disciplinary depth with interdisciplinary breadth, and 3) balancing program and student development.

Managing Uncertainty and Creating Actionable Knowledge

The complexity of resolving water issues can be immobilizing when one considers the technical, social, political, and economic implications of a single decision. In addition, each component carries uncertainty in the estimate – whether it is in model error, projections about future climate, or imbedded in complicated politics and behaviors. Accounting for these uncertainties is a daunting challenge. WD IGERT students share a common perspective that we must find ways to recognize and manage uncertainty without being paralyzed by it. New interest in socio-hydrology in water research (Sivapalan et al. 2012) and recent efforts by the National Science Foundation for research on coupled human and natural systems were motivated by the recognition that modeling a system from the technical perspective often does not capture system complexities, and that the scope should be expanded to consider social dynamics (NSF 2014b). Similarly, WD IGERT students share a common view that a technical solution is one element in solving a water issue, but that more often than not it does not serve as a complete solution for all stakeholders. As student researchers we carefully incorporate information we know is uncertain, often qualitative in nature, to better represent the system (or issue) as a whole and arrive at feasible solutions.

One main motivation for acknowledging uncertainties in our work is the desire to create actionable knowledge. Actionable knowledge refers to the knowledge needed to have external validity and relevance to the context of the problem (Argyris 1996). The phrase "actionable knowledge" has been defined in many contexts

specific to climate (Meinke et al. 2006), water (Islam and Susskind 2012), and doctoral research in general (Coghlan 2007). Based on discussion and surveying within the WD IGERT program, students are largely more interested in actionable research, developing feasible methods and solutions that the broader community can use and understand, rather than addressing a narrowly defined disciplinary question through theoretical contributions. This underlying commonality among students in the program has helped foster cross-collaborative research projects such as screening level models, review articles, and the use of Geographic Information Systems to answer questions covering a wide range of water issues. However, one major challenge in creating actionable knowledge when there are many unknowns and uncertainties in the system is the number of assumptions needed in order to construct a reasonable and tractable framework. As a first step towards creating actionable knowledge, WD IGERT students clearly communicate the scope, assumptions, and uncertainties in their individual work. Through collaborations with other researchers and partners (e.g., the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, The Global Environment Facility, etc.), students from IGERT and other interdisciplinary programs can contribute to a synthesis of knowledge for decision making.

Knowledge Tradeoffs: Expanding Depth vs. Breadth

Graduate students are continuously evaluating how to balance their time: whether to broaden their skill sets by spending time learning a new concept or method, enrolling in more classes, or taking an internship, versus keeping a narrower focus by digging deep into their specific discipline and moving on a more direct path toward graduation. The challenge of expanding one's breadth across subjects versus depth in a single focus area is further exacerbated for interdisciplinary students who may value the more "winding" path as a primary part of the experience, and are similarly expected to spend a significant amount of time outside their disciplines. The NSF-IGERT program formalizes this particular tradeoff in a "T-exercise," where students identify their current breadth/depth ratio along with goals to expand and deepen through the program. The concept of a "T-shaped water professional" originated in the 1990's in the management and business literature (Hansen and Von Oetinger 2001). Uhlenbrook and Jong (2012) from UNESCO-IHE and McIntosh and Taylor (2013) adapted the T-exercise to identify the skills and knowledge necessary to create "water professionals of the future," who are innovative in solving water problems and in creating new cross-disciplinary approaches. Others in the literature have developed a similar concept, defining one's "tree" with interdisciplinary branches and a disciplinary trunk (Gewin 2014).

Figure 1 illustrates the T-exercise, where "T" is a metaphor to frame the balance of disciplinary depth and interdisciplinary breadth required to address complex and emerging water problems. The vertical section of the "T" represents disciplinary knowledge (focused and deep) while the horizontal blocks represent knowledge across disciplines (broad and multifaceted). WD IGERT program elements support students in creating an individualized curriculum ("T" depth) that is transferrable across disciplines ("T" width).

One important component of the "T' is the student's previous exposure to either interdisciplinary or disciplinary water knowledge. This can highly impact a student's experience, as those who join with strong prior interdisciplinary experience may not find value in expanding their breadth while those that join without exposure to other disciplines may change the shape of their "T" significantly. The majority of student applicants for the WD IGERT program come from a strong disciplinary foundation and seek to increase the breadth of their water knowledge.

One way to navigate the tradeoff between breadth and depth is to collaborate with faculty and peers in other disciplines. Developing the literacy to engage in primary research papers with peers by applying methods across disciplines is a critical skill for an interdisciplinary professional and is a goal of many WD IGERT students. Several examples of methods applied include system dynamics modeling, multi-objective optimization, game theory and negotiation techniques for water conflicts, and methods for coding interview and qualitative data. One specific example from the WD IGERT is the development of a GIS-based

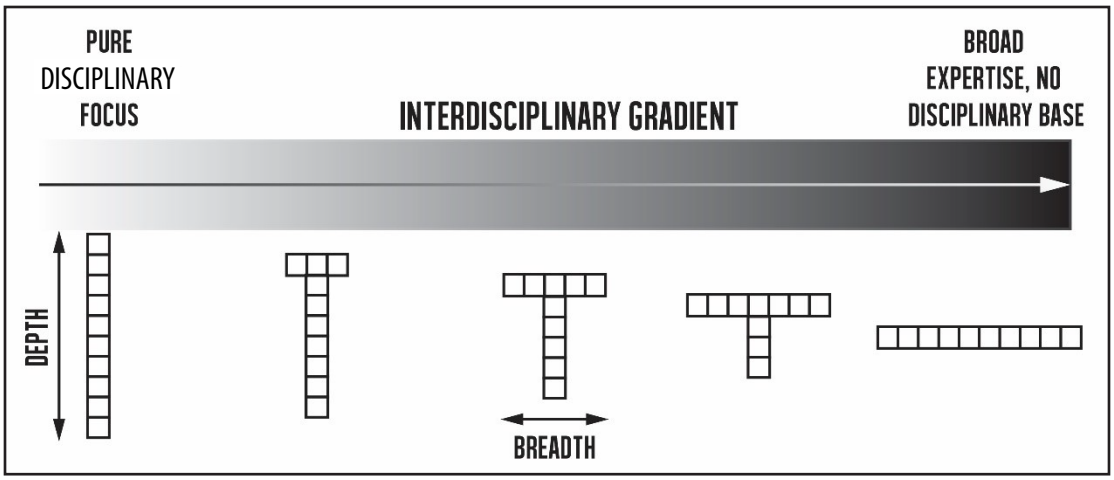


Figure 1. Interdisciplinary gradient and "T" exercise.

tool for indexing wetlands based on hydrology, a combined effort between water resources engineers and a biologist. Taking the time to work on collaborative projects, alongside a dissertation, is a way to broaden the "T" and gain experience in conducting interdisciplinary research. Another approach to broadening the "T" is applying methods from multiple disciplines in individual research. However, this approach takes substantially more time to do well and poses significant challenges for balancing disciplinary requirements with development of interdisciplinary expertise. The WD IGERT program is a platform designed to provide student leadership opportunities, resources for expanding the breadth of knowledge related to water, and work within the academic system to make relevant courses, retreats, and colloquia that support rigorous training.

Funding agencies and researchers have recognized the need for student programs to train participants in effective teamwork skills to address interdisciplinary problems, especially to succeed in receiving funding (Link et al. 2013, NSF 2014a). Specific NSF programs such as Coupled Natural and Human Systems (NSF 2014b), IGERT, and the new NSF Research Traineeship program (NSF 2015) are evidence of the call to expand interdisciplinary graduate education. Increasing efforts like these across the country will only encourage more students to take time and recognize their own "T" aspirations, perhaps an important step in defining personal career and academic goals to achieve with the help of an interdisciplinary program. We recommend that interdisciplinary programs provide the resources to expand the breadth of a student, while supporting the need to balance this with disciplinary knowledge. One way to understand this balance is for students in WD IGERT and similar programs to publically share lessons learned through blogs and academic publications.

Balancing Program and Student Development

The WD IGERT program aims to educate students in Water Diplomacy while simultaneously developing a program identity in this emerging field. The WD IGERT has designed several programmatic elements to stimulate both program and student development including a weekly colloquium and an annual retreat. The Water Diplomacy Colloquium is a weekly meeting of WD IGERT students and faculty that serves as a forum to discuss Water Diplomacy theory and practice and for students to test and present new ideas. Additionally, faculty and students from across Tufts University interested in the week's topics are invited to join the discussion. Together, students and faculty grapple with the definition of Water Diplomacy, explore research methods, and review case studies of water diplomacy concepts in practice. For students, this is both an exciting opportunity to contribute to a new concept and a delicate balance between program and personal development.

Given the time challenges and multiple commitments of IGERT students described

above, it is crucial that time spent in group activities and discussions is useful for student development. Through interviews of students in the program we found that most students agree that certain activities, such as discussions of research methodologies used across fields and establishing a common language for key interdisciplinary topics, are valuable for student development because they provide both the background and the vocabulary to collaborate efficiently across disciplines. In contrast, discussions aiming to advance the theory of water diplomacy were agreed to often be less useful. For example, debates over how to refine the process of applying water diplomacy were hard to connect to student work because few students have the opportunity to directly engage with active negotiations through their research. Additionally, the open ended nature of these discussions makes resolution within the allotted time difficult, cutting into time planned for student presentations and feedback. Advancing the theory and practice of Water Diplomacy is an important aspect of the program, but we have found that these discussions are better suited for a different forum such as the annual retreat held each fall over the course of a weekend. The aim of the retreat is to allow space for deep discussion, set goals for the coming year and foster a sense of community. We have found that away from weekday demands, there is space to fully engage in the subject and to connect the concepts to our individual research programs and plans. Another successful forum to delve into program development is the series of seminars dedicated to a particular aspect of Water Diplomacy. During one semester, two faculty members led a three-part series of talks on community engagement, an aspect of Water Diplomacy in need of further development, and invited students and faculty interested in the topic to attend. Focusing efforts on one aspect of Water Diplomacy and involving researchers from outside the core IGERT group made these events a success.

Since the inception of the WD IGERT program in 2011, our collective understanding of Water Diplomacy as a new field, including the methods used and research questions asked, has evolved. This evolution was shaped by the students and faculty involved who chose to allow the flexibility within the program structure that could facilitate such growth. Some students have used this flexibility to define the program in a way that fits with their research interests and home department requirements. For example, one student from the biology department found that extending water diplomacy concepts of stakeholder consultation and mutual gains to address ecosystem water needs was a novel contribution to the field, and a clear way to connect theoretical research questions with active policy debates. However, the developing nature of the WD field also challenged students to solidify research topics and explain their work to outside groups. For instance, the WD IGERT program requires that students address an interdisciplinary Water Diplomacy research problem in their qualifying exam proposal. Some students found that the evolving nature of the program made the integration of Water Diplomacy concepts into their research proposals more difficult. Clarifying the distinction between student expectations and program goals can ease this obstacle.

Flexibility has been an important strength of the WD IGERT. Student leadership in shaping the program, from setting annual group goals to chairing discussions on program improvement, has been critical to making the best use of this flexibility. Students are the best advocates for their own needs, particularly in newer interdisciplinary programs where advising faculty rarely were educated in similar environments. By taking an active role in program development students can ensure that time and group resources are used in a way that supports their progress. Faculty support for student initiatives and program flexibility facilitate such efforts.

Conclusion

Researchers and funding agencies recognize the need to expand programs that train students in effective teamwork skills for addressing interdisciplinary problems; the recent spike in related programs and calls for proposals is evidence of this recognition. In the field of water resources there is strong interest in interdisciplinary approaches to address global challenges such as water quality management, water for ecosystems, and public health. Universities across the country have developed programs to provide students

with an interdisciplinary education; the Water Diplomacy IGERT at Tufts University is one example of such programs. Despite progress and evidence of initial success, challenges and barriers to successfully implementing this interdisciplinary graduate training remain.

In this paper we offer a students' perspective on how the WD IGERT program has shaped our research, the struggles of interdisciplinary education, and recommendations for building an interdisciplinary graduate research program. In summary, we observe that in building a research community of students from varied backgrounds and departments, a program can benefit greatly from identifying core principles. For WD IGERT, these principles connected students on a level beyond research methods and questions, enhancing a shared vision.

We also offer a perspective on three challenges faced in development of the WD IGERT program. We find that although the complexity of resolving water issues that contain technical, social, political, and economic dimensions can be immobilizing, clearly stating uncertainties and assumptions helps students gain traction in analyzing complex systems. Next, we find that many students in interdisciplinary programs are challenged by the desire to increase the breadth of their knowledge while fulfilling disciplinary requirements. Collaborations within the WD IGERT group and with outside researchers and partner organizations allow students to gain exposure to different approaches while eliminating the need to become an expert in multiple fields. Further, collaborations with implementation focused and community based partners enable actionable science. Finally, the pursuit to strike a reasonable balance between program development and student development may take iteration. By taking an active role in program development students can ensure that the use of time and other resources facilitates their development; program flexibility and faculty support increase the success of student initiatives. The challenges discussed in developing the WD IGERT program are not unique to water, and therefore we intend for this discussion to help inform future interdisciplinary research efforts and provide guidance to students beginning their interdisciplinary educations.

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Bringing the Elephant into the Room: Integrating Risk into Interdisciplinary Water Programs

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Abstract: Problems that require risk management are usually cross-disciplinary in nature, which makes it difficult to educate students and professionals on common language, skills, and strategies. Recognition of the interdisciplinary nature of many water challenges in terms of quality, allocation, future supply, infrastructure, damages, etc. has led to the establishment of interdisciplinary graduate water programs. Motivated by experience in an interdisciplinary water program at Tufts University, this paper argues that explicit coverage of the subject of risk is an important component of an interdisciplinary water training program, and that understanding risk should be a core competency of a water professional. The literature on water education is reviewed, particularly regarding the core competencies of an interdisciplinary water professional. Existing interdisciplinary water graduate programs are also surveyed to identify if, and how, risk features in their program descriptions or curriculums. Our analysis found that risk was not mentioned as a core competency or key issue in any of the literature on interdisciplinary water education or training, and featured in only a few program descriptions or curriculums. Based on this analysis, we conclude that there is a significant need to address risk more centrally and explicitly in interdisciplinary water programs.

Keywords: *risk, water, interdisciplinary education, IGERT*

Risk plays a central role in most water challenges, and understanding and managing risk is essential for water professionals. Addressing complex water problems requires a common language to discuss risk and the ability to view risk from technical, social, economic, and political perspectives (Haimes 2009; UNISDR 2009). Often disciplinary approaches consider and assess risk from a specific perspective; however water problems are interdisciplinary and require additional training on alternative approaches for comprehensive risk analysis. Although there is always a balance between depth and breadth in interdisciplinary research and educational programs (Howe 2008), water professionals should at least be familiar with a broad range of risks and approaches to risk management. In recent years, the importance of interdisciplinary training in water has grown significantly, with a wide range of interdisciplinary graduate water programs emerging across the world. The growth of such programs raises the important and timely question of whether these programs are preparing the next generation of water professionals to analyze and address risk.

This paper is motivated by student experiences as fellows in a National Science Foundation Interdisciplinary Graduate Education Research Traineeship (IGERT) Water Diplomacy program at Tufts University (http://waterdiplomacy.org/). Students across disciplines have different vocabularies and conceptual frameworks for analyzing risk. Without a common language to bridge disciplinary perspectives on risk, it is quite difficult for a group to productively discuss research, since risk considerations play a critical role in almost all students' research (e.g., biology, engineering, hydrology, social science, political science, food and agriculture science), an issue the

group has recognized and sought to address through dialogue on risk. Over time, students in the Water Diplomacy IGERT program have gained a greater appreciation and understanding of risk as it applies to water issues and its analysis across disciplines.

This paper highlights the importance of explicitly addressing the various (and sometimes competing) conceptions of risk across disciplines and the value of understanding risk from various perspectives when analyzing and managing water challenges. Based on the gap identified in formal education on risk management in the IGERT program at Tufts University, the authors seek to systematically examine the role of risk in other interdisciplinary water programs. The remainder of this paper is structured as follows: we begin by exploring a number of key water issues in which risk and risk management play a central role. We then review the literature on interdisciplinary education and training for water professionals, focusing on what are considered to be the core competencies of water professionals. Finally, we look at current interdisciplinary water graduate programs and analyze the role of risk in their program descriptions and core curriculums.

Centrality of Risk Across Water Issues

A wide range of water issues necessitate interdisciplinary consideration of risk and risk management, e.g., water quality, water allocation agreements, climate adaptation planning, and infrastructure investments. In this section, we provide a few specific examples of major water challenges and highlight the importance of risk in each. The selection of these four topics is based on common themes and issues found in a review of interdisciplinary water programs (discussed in a later section).

1. ***Water Quality Concerns***
   Maintaining water quality at a suitable level for consumptive and non-potable uses is a public health concern as well as a technical problem. The U.S. Environmental Protection Agency (EPA) sets standards and regulations for chemicals in drinking water based on acceptable levels of risk, often determined by a combination of societal perception, cost of treatment, and consequence of exposure. Maintaining safe drinking water sources requires engineers to design and improve treatment methods, policy makers to act on legislation, and public health scientists and communicators to educate the public (U.S. EPA 2014a). Similarly, the EPA is responsible for protecting the environment itself, and therefore establishes total maximum daily loads for surface water (U.S. EPA 2014b), and monitors state/local environmental flow requirements that each require a risk assessment. Many are handled through the federal government's National Risk Management Research Laboratory, which is directed by the EPA to investigate risk reduction and exposure control between humans, the environment and contaminants.
2. ***Water Allocation Agreements***
   Determining the appropriate mechanisms for distributing shared water resources is one of the classic challenges in the water field (Wolf 1998, 1999). Particularly when dealing with transboundary water basins, political tensions are usually high, making agreements difficult. One of the reoccurring challenges is how to incorporate risk and uncertainty into agreements, as there is a tradeoff between flexibility and enforcement (Bookmann and Thurner 2006; Drieschova et al. 2008). While mechanisms to address flow variability are widely acknowledged to be important as a means of managing risk, very few existing agreements successfully incorporate such mechanisms (Fischhendler 2004; Drieschova et al. 2008).
3. ***Climate Adaptation Planning***
   At its core, climate adaptation is about managing risk associated with increasing variability and change in climatic and hydrologic systems and their impacts on coupled human and natural systems (Blaikie et al. 1994; IPCC 2012, 2014). Understanding the impacts of climate change necessitates understanding the risks in different sectors, such as agriculture, urban environments, and health, as well as identifying approaches to managing that risk. Resilience approaches and no-regrets decision-making focus on identifying options, investments and policies

that are desirable under current conditions in addition to uncertain future conditions as a means to manage risk (Gunderson 1999; Berkes et al. 2003; Walker et al. 2006; Heltberg et al. 2009; Folke et al. 2010). Frequently, such approaches address underlying vulnerability and adaptive capacity more generally, rather than attempting to address individual hazards, and thus are often closely aligned with development priorities.

4. ***Water Infrastructure Investments***
Water infrastructure investments are another topic where risk assessment plays a central role in determining the size and design of protection (U.S.ACE 2006). In fact, since 1983 the Army Corps of Engineers has used risk-based design (Principles and Guidelines) to select dam size and other types of infrastructure by maximizing the system net benefits, calculated by considering the damages avoided as benefits and subtracting the total annualized costs (Water Resources Council 1983). While water infrastructure design for planning and managing risk and reliability is considered a classic engineering problem (Yen 1970; Lund 2002; Mays 2011), the question of how society should manage risks *due* to infrastructure is broader and requires input from experts in urban planning, political science, and economics (Loucks et al. 2005). In the latest "report card" by the American Society of Civil Engineers (ASCE), much of the large infrastructure in the U.S. received a score of D or lower (ASCE 2014). Based on this report and similar ones by the National Research Council (NRC) and ASCE, many are re-evaluating the role of infrastructure as a means for risk protection and calling for new flexible design and nonstructural management options (ASCE 2014).

Interdisciplinary Water Education and Training

To gain a broader understanding of previous work on interdisciplinary education and training for water professionals, we conducted a literature review of articles published in the UCOWR journal, as well as other prominent articles on interdisciplinary education for water. A synthesis of the findings from this review is presented here.

The importance of interdisciplinary water training is widely acknowledged, although the extent of the focus of interdisciplinarity varies, with some articles emphasizing both natural and social sciences (Kirshen et al. 2004; Bourget 2006; Fort 2008; Viessman 2008; Campkin and Neto 2013; and Pinter et al. 2013), and others addressing integration solely across natural sciences and engineering (Graney et al. 2008; Lettenmaier 2008; Stakhiv 2008). Recognizing the interdisciplinary nature of water challenges, numerous articles tackled the debate between depth versus breadth in education for water professionals. Many expressed that programs are becoming "watered-down" in an attempt to cover more perspectives (Stakhiv 2008), while others acknowledged that traditional approaches were failing to train students to deal with contemporary challenges (Lettenmaier 2008). In contrast to a common theme that the technical quality of water professionals has declined over time, Layzer (2008) argues that most water challenges are not technical "water management" issues, but rather are "people management" challenges, and thus technical skills are not the most essential characteristics for water professionals. Considering the close relationship between water management and the discipline of civil and environmental engineering, it is perhaps not surprising that the majority of articles that speak to the value of interdisciplinary education are written by faculty or professionals in engineering (an exception is Fort 2008, written by a lawyer on water education for lawyers).

A number of articles discuss the experiences of different water programs. The famous Harvard Water Program (HWP) that began in 1955 (see Reuss 2003 for a review) was one of the first examples of a formal interdisciplinary water program that brought together professors and students in engineering, economics, and public policy to address the design of water resource systems for society (Maass et al. 1962). This program has been revered by many as successful in training participants to think about water problems from a systems analysis perspective and consider multiple objectives in designing water infrastructure and policies. Some have called for a resurrection of the HWP (Reuss 2003) or one that mimics it (Kirshen et al. 2004). Kaiser (2008)

documents the process of developing a successful water resources and hydrologic sciences program at Texas A&M, discusses the institutional challenges in building a multidisciplinary graduate program, and compares the tradeoffs of various models for developing such a program, an issue also addressed by Bourget (2008). Campkin and Neto (2013) found that relying on a diverse network of experts from the UNESCO Hydrology for the Environment, Life and Policy (HELP) Programme allowed them to break through some of the traditional barriers of interdisciplinary water programs and engage in co-learning in the Erasmus Mundus Master in Ecohydrology program.

Another initiative to develop a water program to train graduate-level students was led by the Army Corps of Engineers in recognition of a lack of trained interdisciplinary water professionals available for their own needs as well as the needs of other agencies (Bourget 2006, 2008; Viessman 2008). They identified the following themes as essential to an interdisciplinary water program: philosophy of planning, institutional considerations in water resources planning, social decision-making, ecology for water resources planning, engineering for water resources planning, economics for water resources planning, hydrology/hydraulics/climatology, and quantitative methods for water resources planning (Bourget 2006; Viessman 2008). Based on the development of an interdisciplinary water program at Tufts University, Kirshen et al. (2004) proposed that the fundamental elements of an interdisciplinary water program should include: systems analysis, science and technology of water, biological aspects of water, health and nutrition, and planning and policy of water. The National Science Foundation's IGERT program also promotes interdisciplinary graduate water programs, as described in Pinter et al. (2013) for the Southern Illinois University "Watershed Science and Policy" program, as well as the Tufts University "Water Diplomacy" program in which the authors are fellows. In a similar effort to increase skill sets of students working on water and climate issues, a group of academics and professionals created an inter-institutional interdisciplinary modeling course with two objectives: expose students to a range of modeling techniques from different disciplines and train students in developing teamwork skills. The course was developed by University of Nevada Reno (UNR), the Desert Research Institute (DRI), and University of California at Davis (UCD) and was offered in various formats in 2008, 2010, and 2012 (Saito et al. 2013). McIntosh and Taylor (2013) present a "T-Shaped Water Professional" concept to articulate how training programs can balance disciplinary depth with interest in a broader range of issues and describe how this concept has been applied in post-graduate education programs run by the International Water Centre and UNESCO-IHE. These programs focused on leadership training, organizational management, and collaboration, arguing that the goal of a water professional is to stimulate change, rather than be a technician, and that students already bring to such programs a depth of disciplinary knowledge through their professional and academic background.

Interestingly, risk assessment and management did not feature in the discussion of key capacities for a water professional or as a component of a water curriculum in any of the articles reviewed. While competencies such as systems analysis, institutional and policy analysis, leadership skills, cooperation and negotiation, economics, and technical skills for water management were commonly mentioned, risk was not among them.

Risk in Current Water Graduate Programs

In addition to reviewing the literature on interdisciplinary education and training, the program descriptions and core curricula of interdisciplinary graduate water programs were systematically analyzed to determine if risk featured as a core competency or as a central program component. Table 1 provides a summary of these programs with the institution, website, and description of risk (if any). Only interdisciplinary programs that had an emphasis on water were included, which was broadly defined and included programs integrating natural and social sciences, as well as those focused on natural sciences and engineering. International and U.S. based programs were included for both degree-granting and certificate-based programs.

In our analysis, a program was considered to address risk when the concept was named in the program description, or in the course description

for any of the core (or required) courses. Based on these criteria, we identified very few programs that address risk. While it may be possible for students to take elective courses on risk, or risk may be featured in courses even when not mentioned explicitly in the descriptions (likely to be the case due to the centrality of this concept to so many aspects of water issues), if risk is not included explicitly in the core curriculum, it provides an indication of the value placed by the program on risk as a fundamental component in the program.

One program particularly stands out in contrast to this general finding: the Water Hazards, Risk and Resilience Masters (MSc) program at the University of Dundee (http://www.dundee.ac.uk/study/pg/waterhazardsriskresilience/). This MSc program is focused on natural hazard management and contextualizes its studies in the subject of water, a different approach than many others that start with an umbrella of water and pull in courses and topics from other disciplines. Additionally, the Certificate in Water Conflict Management and Transformation at Oregon State and the Integrated Water Atmosphere, Ecosystems, Education and Research IGERT program at Colorado State University are the only other programs identified that articulated risk as a central component of their program, although to a much lesser extent than the program at the University of Dundee. Considering the centrality of risk to complex water problems, it is surprising to see that risk is not a core component of more programs.

We also searched for graduate programs that *do* focus on risk to identify what subject areas discuss risk explicitly, and which could serve as models for water programs. One program could provide a particularly relevant example for water programs: the Societal Risk Management Program at the University of Illinois at Urbana-Champaign (http://cee.illinois.edu/SRM). Based on its description, the program concentrates on risk determination, risk evaluation and risk management for natural and human-made hazards, and disaster response and recovery. They state that "students in the program are exposed to content in reliability, risk and life cycle analysis; decision-making under uncertainty; performance assessment of deteriorating systems; the ethical, economic and political dimensions of risk management; the legal elements of regulatory mechanisms; risk perception and cognitive biases; risk communication; and post-disaster response and recovery." Although not focused explicitly on water, the types of challenges the program trains its students to address are very similar to the types of challenges many water programs seek to prepare their students to tackle. Apart from this specific program, most graduate programs focusing on risk come from a business or management perspective, suggesting that these fields could provide useful experiences and lessons to water graduate programs interested in incorporating risk more systematically into their curricula and activities.

Conclusion

Since many graduate programs are moving toward interdisciplinary studies as a platform for water education and problem solving, it is crucial to consider how cross-disciplinary topics such as risk management can be discussed and contextualized. Further, it is important to assess whether these programs effectively provide the resources and skill sets water professionals need to approach these interdisciplinary problems. While many programs acknowledge that interdisciplinary training is necessary to tackle complex water issues, few appear to have recognized that risk itself is an interdisciplinary topic of central importance to water challenges. This paper finds that risk is not specified as a core value of the curriculum in many interdisciplinary graduate education programs, counter to the presence of risk as a central concept in many major water challenges. Without training on risk, water professionals may miss or oversimplify important aspects of reaching solutions to water challenges and find their toolbox of resources and methods to address certain water problems to be limited. If a core competency of a water professional is to be proficient in understanding the language of risk as it relates to water, it seems fitting that interdisciplinary water programs should include risk in their courses of study. The authors urge current and future water programs to explicitly incorporate training on risk into their programs, certainly looking beyond the topic of water for examples of graduate programs in other fields that have successfully addressed risk assessment and management.

Table 1. Risk in interdisciplinary water programs.

Program Title	Institution	Website	Coverage of Risk in Curriculum
The Water Center-Interdisciplinary Watershed Sciences Minor	Colorado Mesa University	http://www.coloradomesa.edu/watercenter/index.html	None
I-WATER (Integrated Water Atmosphere, Ecosystems Education and Research)	Colorado State University	http://i-water.colostate.edu/	Yes - describes modeling as a key component to inform risk-based adaptation decisions
Graduate Certificate in Water, Environment and Development Studies	Florida International University	http://earthenvironment.fiu.edu/programs/graduate/grad-certificate-in-water-environment-and-development-studies/	None
Disaster Management PhD program	International Centre for Water Hazard and Risk Management (ICHARM and UNESCO), in coordination with National Graduate Institute for Policy Studies and Public Works Research Institute	http://www.icharm.pwri.go.jp/training/phd/phd_index.html	Yes - program description focuses on water-related risk management; unclear as to the specific courses
Integrated and Adaptive Water Resources Planning, Management, and Governance, 8-week certificate	McGill University	http://www.mcgill.ca/iwrm/online-iwrm-course	Yes - from perspective of water business risk assessment
Center for Water & Society Graduate Certificate in Sustainable Water Resources Systems	Michigan Tech University	http://www.mtcws.mtu.edu/education_gradcert.html	None
Water Science and Management	New Mexico State University	http://aces.nmsu.edu/academics/pes/water-science-and-manage.html	None
Certificate in Water Conflict Management and Transformation	Oregon State University	http://www.transboundarywaters.orst.edu/	Yes - "risk, uncertainty, and complexity" are included as a core element of the "Water and Ecosystems" component of the program
Water Resources Program (Water Resources Policy and Management and Water Resources Sciences degrees)	Oregon State University	http://oregonstate.edu/gradwater	None
Water Science and Engineering Initiative	Syracuse University	http://water.syr.edu/	None
Interdisciplinary Graduate Water Degree Program	Texas A&M University	http://takethenextstep.tamu.edu/water-degree-program-research-areas	None
Water Diplomacy Program	Tufts University	http://ase.tufts.edu/igert/waterdiplomacy/	None

Table 1 Continued.

Program Title	Institution	Website	Coverage of Risk in Curriculum
Water: Systems, Science and Society Graduate Certificate Program	Tufts University	http://www.tufts.edu/water/	None
Water Management MSc	UNESCO-IHE	http://www.unesco-ihe.org/water-management	None
IGERT in Climate Change, Water and Society	University of California Davis	http://ccwas.ucdavis.edu/	None
Water SENSE IGERT	University of California Riverside	http://watersense.ucr.edu/	None
Graduate Program in Water Science and Policy	University of Delaware	http://www.udel.edu/watersciencepolicy/index.html	None
Water Hazards, Risk & Resilience MSc	University of Dundee, Scotland	http://www.dundee.ac.uk/study/pg/waterhazardsriskresilience/	Yes - the courses focus on natural hazards and society, mapping, assessing, communicating risk
Water Institute Graduate Fellows program	University of Florida	http://waterinstitute.ufl.edu/WIGF/	None
Water Resources & Professional Science Masters (PSM) (including an IGERT program)	University of Idaho	http://www.uidaho.edu/cogs/envs-wr/academics/water-resources	None
Energy-Water-Environment Sustainability Program	University of Illinois	http://cee.illinois.edu/EWES	None
Water Resources Science Graduate Program	University of Minnesota	http://wrs.umn.edu/	None
Water Resources Program	University of New Mexico	http://www.unm.edu/~wrp/WRP_welcome.html	None
Water Resources Management Program	University of Wisconsin-Madison	http://grad.wisc.edu/catalog/degrees_waterres.htm	None
WARE (Interdisciplinary MS program in Water Resources)	University of Wyoming	http://www.uwyo.edu/ware/	None

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Water Diplomacy from a Duck's Perspective: Wildlife as Stakeholders in Water Management

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Abstract: Contemporary water management strategies call for the inclusion of ecological research in the decision-making process and emphasize environmentally sustainable management solutions. Most ecological information used in water management shares two problematic characteristics; 1) simplistic, phenomenological approaches and aggregated data that may not properly describe system behavior, and 2) a "zero-sum" perspective treating ecological water needs as constraints to management. We argue that the newly devised Water Diplomacy Framework (WDF) can help overcome these shortcomings. We also provide a simple and intuitive method for integrating ecological factors into the WDF. We suggest that treating ecological phenomena as "surrogate stakeholders" in water negotiations increases opportunities for discovering mutual-gains solutions and encourages a hypothesis-based approach to research on the ecology of water management. By differentiating between the "positions" and "interests" of ecological stakeholder surrogates, decision-makers can make greater use of the potential added value of ecosystem services in water management and avoid costly misunderstandings of the behavior of relevant ecological systems. We outline how the WDF can be applied to better integrate ecological factors into water management, and show how our approach could create synergies between endangered waterbird conservation and sustainable water management on the island of Oahu, Hawaii.

Keywords: *ecosystem services, endangered species, environmental flows, IWRM, mutual gains, waterbirds, water policy, wetlands*

Water management problems in the new millennium increasingly involve multiple stakeholders with competing interests, managing shared and limited water resources under a high degree of technical and scientific uncertainty (Molle et al. 2008; Wagener et al. 2010; Islam and Susskind 2013). Interdisciplinary approaches are essential to create sustainable and effective solutions for this new generation of complex water problems. Frameworks like Integrated Water Resources Management (IWRM) encourage integration of knowledge across fields like water resources engineering, economics, and political science to generate effective solutions to modern water resources problems (Al Radif 1999; GWP 2000; Biswas 2004; Molle et al. 2008). For the last 25 years, increasing global awareness of the importance of ecosystems and biodiversity for human well-being (ICWE 1992; Millennium Ecosystem Assessment 2005; Duffy 2009; Hough 2014) has prompted the developers of leading water management strategies to incorporate ecological factors into the decision-making process (Tharme 2003; Arthington 2012; Liu et al. 2013). We define ecological factors as any ecological phenomenon (e.g., a species, population, habitat, ecosystem function, ecosystem structure, etc.) that is of interest for water management. It is now widely acknowledged that ecological factors are important to consider in water management, because they are influenced strongly by management action (e.g., Kingsford and Johnson 1998), and can greatly affect management outcomes by affecting the provision of ecosystem services (Postel and Carpenter 1997; IUCN 2000; Richter et al. 2003;

Poff et al. 2003). The growing impetus to include ecological factors in water management is made especially clear by their explicit inclusion in the core principles of IWRM (defined as Ecological Sustainability; GWP 2000).

Recognition of the need to include ecosystems in water management decision-making motivated the creation of theoretical frameworks capable of internalizing ecological factors into the water management equation. Such frameworks include natural or environmental flows (Poff et al. 1997; Tharme 2003; Arthington 2012) and environmental water (Beesley et al. 2014), ecosystem services valuation (Postel and Carpenter 1997; Brauman et al. 2007), and blue and green water (Falkenmark and Rockstrom 2004, 2006). Including ecological factors advances the water management process by forming the conceptual nexus between the alteration of natural water regimes, the resulting degradation of ecosystems, and the potential negative effects of such degradation on human populations and stakeholders. In practice, however, most contemporary approaches to ecologically informed water management share two characteristics that we view as problematic (see Table 1A):

> **Problem 1.** Ecological factors used in water management research most often consist of coarse-scale ecological data (e.g., species richness), that are spatially aggregated, or they describe the behavior (response) of only one taxon or guild in an ecosystem, and thus may not adequately characterize the dynamics of the ecosystem.
>
> **Problem 2.** Ecological factors are typically presented or integrated into decision-making in the form of constraints on water management solutions, resulting in a focus on trade-offs and mutually-exclusive allocation of water between human and ecological needs.

Problem 1 arises when data are collected at large ecological or spatial scales in order to summarize the characteristics of the ecological systems affected by water management decisions, such as when the condition of a river is measured by the number of fish species within it (e.g., Cui et al. 2010). Such data are often used because they are relatively easy to collect and interpret, and they operate on scales similar to the hydrological models developed by engineers for comparing management strategies (Mollinga et al. 2006; Xenopoulos and Lodge 2006). Thus, these data are a convenient way to integrate ecological factors into management via hydrological models. Basing decisions of scale and resolution of ecological data on convenience increases the probability of mischaracterizing the behavior of the ecological system in question and missing important system dynamics that may have profound effects on management outcomes. For example, using the abundance of a single fish species as an indicator of ecological health and basing minimum flows for a river on that information might result in failure to detect shifts in community structure that occur independently of the abundance of the indicator species. Some animal species will shift their diets or feeding habits in different environmental contexts, thus having different impacts on other species in the system (e.g., Kushlan 1986); others cannot make such shifts, and are thus especially sensitive to hydrological alteration (Rubega and Inouye 1994). For example, Balcombe et al. (2005) found that some fish species in a floodplain river in Queensland, Australia dramatically changed their diets depending on river flow (flooding vs. non-flooding). Failure to detect such shifts in community structure might lead to unanticipated management outcomes, for example trophic cascades that affect ecosystem processes like primary productivity and nutrient retention (Brett and Goldman 1996; Baxter et al. 2004). Although this problem is of interest and will be touched upon in this paper, we are more interested in Problem 2, and will save a more in-depth analysis of Problem 1 for a later publication.

Problem 2 is driven by the process by which water management decisions are made, and the point at which ecological information is used in that process. Generally, ecological information is used later in the decision-making process, after management strategies have been decided upon, and it is used to place limits on operations or present ecosystem trade-offs that must be weighed (Mollinga et al. 2006; Chisolm 2010; Sanon et al. 2012; Willaarts et al. 2012). In the case of water

Table 1. (A.) Reference list of potential problems with current interdisciplinary water management approaches. (B.) Four selected tenets of the Water Diplomacy framework that are useful for improving use of ecological research in water management.

A.) Problems with contemporary water management	B.) Selected tenets of Water Diplomacy Framework
1. Information on ecological factors is often spatially aggregated or based on assumptions of surrogacy, and focuses on correlative rather than mechanistic relationships.	I. Defining analytical scale and boundaries using network and complexity theory II. Prioritizing actionable knowledge III. Treating water as a flexible resource IV. Using a negotiations approach based on mutual gains
2. Ecological factors are typically integrated late in the decision-making process, or treated only as constraints to management options.	

diversions for agricultural irrigation, for example, the infrastructure for irrigation will already have been decided upon, but the needs of riparian ecosystems for in-stream flow are considered post-hoc as a means of constraining withdrawals and ensure a minimum in-stream flow to support ecosystems (Richter et al. 2003; Mollinga et al. 2006). While this is one way to ensure that enough water is provided for specific ecological systems, such hard and fast rules fail to convey why constraints like minimum flows are set, and what role the allotted minimum flow plays in the affected ecosystem. There is little room for leeway or more creative solutions, particularly when water is scarce; furthermore, the "constraints", or zero-sum mindset can create negative public attitudes toward environmental water needs (Moore et al. 1996; Votteler 1998; Wallace et al. 2003). Zero-sum thinking can also become a self-fulfilling prophecy, whereby decision-makers ultimately create management that results in situations where benefits to stakeholders are mutually exclusive (Islam and Susskind 2013). For example, water management of the Danube River in Europe led to two failed management plans, the first favoring economic gain at the expense of ecological integrity, and the second favoring ecological restoration over economic development (Islam and Susskind 2013).

It should be noted that both problems 1 and 2 are natural results of the complexity and urgency of the water management issues faced by decision-makers; decisions are often made with limited monetary resources and time, leading to simplification of ecological metrics, and constraints are used as a precautionary measure to avoid unacceptable losses that might occur from misunderstanding ecological dynamics. This simplification of both options and data are considered necessary steps to include ecological factors in management when decision-makers may have poor understanding of ecological dynamics (Schiller et al. 2001). We do not question that decisions must be made under uncertainty - this is nearly a defining characteristic of modern water management - but we do not want water managers to limit themselves to low quality information and hard constraints when available knowledge may offer better solutions. Improved frameworks for integrating ecological information into water management should thus contribute to overcoming these problems while also making ecological data more accessible to decision-makers.

Water Diplomacy is an emerging water management framework that operates from a negotiations-based approach to decision-making in the context of complex water problems (Islam and Susskind 2013). Several of its core principles provide potential solutions to the problems outlined above, and we assert that methods integrating ecological factors into the Water Diplomacy Framework (WDF) can lead to improved solutions in water management. Currently, the WDF has no formal protocol to integrate ecological information. In this paper, we propose that ecological factors, especially focal species, can be easily integrated into the WDF when treated as "surrogate stakeholders"; that is, when such variables are treated in a functionally similar manner to actual stakeholders in the negotiations process of Water

Diplomacy. We suggest that considering ecological factors early in water allocation decision-making, and treating water allocation as a non-zero sum game (i.e., allowing for mutual gains), expands options for creating sustainable management solutions. Ecological factors like focal species (those of economic, cultural, ecological, or conservation importance), entire ecosystems, and indices of ecological integrity (e.g., Karr 1991; DePhilip and Moberg 2010; Clapcott et al. 2012) can act as surrogate stakeholders. We support this surrogate stakeholder approach for the sake of practicality, and not with any normative intention of asserting that species, ecosystems, or other natural phenomena are capable of having interests or have their own ethical standing; such philosophical questions are outside the scope of this paper. We do suggest, however, that this method makes complex ecological information more readily attainable to decision-makers and expands its possible use in creating feasible management solutions. We describe this approach below and illustrate how it expands management options in the case of water management on the island of O`ahu, Hawai`i (USA).

Advantages of the Water Diplomacy Framework (WDF)

The core tenets of the WDF (see Table 1B) include I) the use of network and complexity theory to define the scale of analysis and boundaries of the water management problem; II) an emphasis on "actionable" knowledge - that which is easily grasped by stakeholders and answers research questions crucial to decision-making - and applied research; III) treatment of water as a "flexible resource", acknowledging the potential importance of water throughout the hydrological cycle and the role of order of use in maximizing benefits to stakeholders; and IV) using a negotiations approach based in mutual gains (Susskind and Islam 2012; Islam and Susskind 2013).

Tenet IV is perhaps the most novel for water use negotiation and it is the most important of the concepts for overcoming Problems 1 & 2 identified above. The negotiations framework convenes stakeholders with potentially competing interests and uses mutual gains negotiations to create and highlight solutions that benefit the interests of all stakeholders (Islam and Susskind 2013). Mutual gains negotiations avoid zero-sum thinking and shift the dynamics of stakeholder interaction from competition to value creation, such that stakeholders can find mutually beneficial outcomes without sacrificing their self-interest (Fisher and Ury 1991; Susskind 2008). A chief goal of mutual gains is disabusing stakeholders of the notion that their interests can only be met at the expense of other stakeholders (Fisher and Ury 1991; Islam and Susskind 2013). Mutual gains or non-zero sum thinking is viewed by some as the best approach to overcoming water management issues, especially in the case of transboundary water resources (Islam and Susskind 2013; Dema 2014). As an ecologically-relevant example, a zero-sum view is that water can either remain in a wetland to support fishing or can be diverted for agricultural irrigation; a non-zero sum view recognizes that rainfall can be captured in a wetland for use by fish, and then infiltrate into groundwater for subsequent human uses (e.g., Musu 2001; cf. Dema 2014).

Mutual gains negotiation differentiates between the positions and interests of stakeholders with respect to the shared resource - this allows stakeholders to view one another not as constraints but as entities with flexible needs resulting from a particular set of values. Interests are the direct product of a stakeholder's values, defining what they actually need to get out of the negotiations process; this might be sufficient water to support agriculture, or the need for a diplomatic official to maintain face and protect the reputation of his or her constituents (Fisher and Ury 1991; Islam and Susskind 2013). Interests are the needs and values that motivate positions, the spoken, manifest demands or perspectives presented by a stakeholder during negotiations over the management of a shared resource. Positions might include an unwillingness to allow dam releases at certain times of year, or a request that a specific amount of water be set aside for irrigation (Fisher and Ury 1991; Islam and Susskind 2013). Interests, by contrast are tacit, often hidden, and ultimately less flexible. For example, it might be culturally or politically unacceptable to force farmers to abandon their lifestyles simply due to water demands, but the positions that arise from

these interests are often much more negotiable. If irrigation releases cannot be increased to match the position of rural farmers, the underlying interests of that position - that of making greater profit from the management of their land, and maintaining their livelihoods and lifestyles - might be satisfied by subsidizing transitions to more profitable crops with lower water demand, higher-efficiency watering equipment, or alternate forms of income through farmland management (e.g. ecotourism; Pooler 2013). These could sustain income, satisfying basic interests, while altering the farmers' position. Creative alternatives can satisfy the interests of a stakeholder while circumventing the problematic aspects of their original position; in this case, a demand for water diversions that might be untenable considering the rest of the system. This process of meeting interests - rather than positions - by providing benefits from sources originally external to the system is called "adding value" (Islam and Susskind 2013). Applying this framework to ecological systems would enable decision makers to treat ecological factors as potential opportunities for added value among stakeholders and not as constraints on available options (Problem 2).

Tenets I and III relate most strongly to the beginning stages of the WDF workflow, particularly in the process of convening stakeholders, defining the boundaries of the water resources problem, and exploring potential solutions (Islam and Susskind 2013). Using a network or systems approach (Tenet I) emphasizes functional linkages, be they ecological, economic, political, or social, between various stakeholder groups. Linkages might include economic benefits of water purification provided by a riparian wetland to a downstream city, the cultural importance of a fish migration to a First Nations people, or the exchange of virtual water between two countries through agricultural commerce (Allan 1998). The network approach can thus be used to model and internalize interest groups that might normally be overlooked or managed separately - such as endangered or economically important species. Understanding the relationships between stakeholders also helps recognize the broader boundaries of the water problem. While most traditional engineering approaches to water management delineate the watershed as the boundary of any water management problem, the effects of water management can be felt far beyond watershed boundaries. As an example, if pollution in a coastal city affects its fishing yields, neighboring states are affected even if they are not using that water but are sharing the economic burden through trade. This expanded view of the problem's boundaries identified through non-hydrological variables is known as the "problemshed". Ecological problemsheds might be limited to the watershed, or can extend far beyond it. Many waterbird species cross continents in annual migrations, passing through many watersheds, effectively linking the impacts of management within each of those areas (Bauer and Hoye 2014). Migratory birds have become a key driver in encouraging transboundary cooperation throughout the world, including U.S.A-Canada (Dorsey 1998), Israel-Palestine (Leshem et al. 2003), and U.S.A-Cuba (Boom 2012).

Expanding viewpoints to the problemshed level seems at first overwhelming and counter-productive, as though it might add too many constraints to the system. However, as part of the WDF, framing the problemshed and acknowledging the complex interactions of various system components in a network actually aids the process of adding value by increasing the pool of potential interests that can be aligned and satisfied.

Once the problemshed has been identified, Tenet III becomes important in designing integrated management solutions by expanding the ways in which water is viewed and valued within the system. Water is most often viewed as a finite resource - particularly as a sum of fresh surface or groundwater to be divided amongst interested parties. However, water has many other values and functions in ecosystems and economies that are often unacknowledged. Taking a narrower view reduces opportunities for mechanistic understanding of system behavior and for adding value in mutual gains negotiations. Following Tenet III, researchers should pay attention to the role that water plays in stakeholder interests throughout the hydrological cycle, and not focus only on, for example, water provision as its sole function. For instance, evaporating water from irrigation can influence regional meteorology,

changing rainfall patterns in nearby but separate watersheds (Lo and Famiglietti 2013). Water is also a highly effective transporter of nutrients, sediments, salt, and other chemical agents that may be beneficial or detrimental to human or natural systems, and failure to recognize this function can have severe consequences (e.g., Harris 1991; Schepers et al. 1991; Jaeger et al. 1999). For example, many wetland ecosystems provide under-recognized hydrological benefits to adjacent human settlements in the form of meteorological "oasis effects" (Polcher et al. 2008) and by recharging groundwater (e.g., van der Kamp and Hayashi 1998).

Employing Tenet III further enlarges the problemshed created by Tenet I, leading to a more holistic understanding of the system being managed and the impacts of potential management actions. Ultimately, these two tenets internalize stakeholders and processes that were formerly treated as external to water management problems, and could help to resolve Problem 2 (treating target species and ecosystem water needs as constraints), by facilitating mutual gains negotiation and including species as stakeholders, and Problem 1 (inadequate ecological metrics), by requiring a more systematic and thorough understanding of ecological dynamics than is typically considered.

Finally, Tenet II demands that data collected for water management are actionable (Islam and Susskind 2013). Actionable knowledge comes from applied research designed to answer questions about system dynamics that are of concern to stakeholders. Once previously-external stakeholders and linkages have been internalized (via Tenets I & III), targeted research creates a shared knowledge base for all stakeholders. This joint fact-finding process either reduces or clarifies and quantifies uncertainty about the dynamics of the system to be managed (Islam and Susskind 2013). It can also build trust and enhance cooperation for later mutual gains negotiations. To be actionable, research must be adequately detailed to describe important elements of the system's behavior, but also be in a format that can be easily integrated into the negotiations process. Thus, Tenet II could address Problem 1 by ensuring that ecological research is focused on processes important to the functioning of the ecological system(s) in question, thus enhancing integration into the decision making process. Finally, it addresses Problem 2 by necessitating that ecological data take a form amenable to a negotiations approach.

Ecological Factors as Surrogate Stakeholders

Although the Water Diplomacy Framework (WDF) has characteristics that would improve how ecological factors can be integrated into water management, there remains the problem of fitting ecological factors conceptually within the framework in such a way as to be implementable. We propose that this can best be done by treating ecological factors as surrogate stakeholders; that is, as entities that have specific interest and position analogs that can be integrated into mutual gains negotiations and potentially used to add value, rather than simply act as constraints.

For actual stakeholders, positions are the external manifestation of internal interest; an ecological factor's position is a combination of its response to manipulations of the water resource, and societal and cultural values attributed to that response. In other words, a surrogate stakeholder's position is its observed reaction to changes in the hydrological regime, as indicated by a chosen set of ecological indicators, plus some social determination of whether those changes are good or bad for the system. Examples of ecosystem positions may include an increase in native emergent aquatic plant cover, an increase in dissolved oxygen or aquatic nutrient load, increased salmon abundance, or decreased sediment transport. In the case of a target or focal species approach, a species' position might be described by increased or decreased abundance — perhaps with respect to the fulfillment of an ecological role (e.g., Soulé et al. 2003), increased reproductive success, an expanded range, etc. The positions of ecological surrogate stakeholders are products of a purely phenomenological understanding of ecosystem dynamics; they are based on simple observations of how a target species or ecological indicator responds to changes in the system. What an ecosystem is observed to do in response to a management action dictates its

position with respect to a resource. However, the implications of this behavior - that is, its value, whether it is considered good or bad - cannot be provided by the surrogate stakeholder.

Unlike real stakeholders that can articulate their own values, the value of management outcomes with respect to surrogate stakeholders' positions must be based on values attributed a-priori by some external agent. In other words, it is unclear whether the behaviors listed above (increases in abundance, changes in dissolved oxygen) are considered negative or positive until they are given some value in the context of the socio-ecological system. In a given hydrological system, if 95% of avian diversity is lost when water levels rise more than 60 cm in a pond, that is the ecosystem's response, but it is not an informative position unless given some value by society at large or some subset within it. If decision-makers and other stakeholders have decided that avian declines are unwanted, then the behavior described above shows a negative consequence to be avoided. The position of the ecosystem is thus that the pond's water should not rise beyond that threshold. In this way, the "position" of an ecological factor is a combination of its observed behavior and cultural values that specify whether certain behaviors are desirable or undesirable. This level of analysis is where most water management frameworks stop ecological analysis, and incorporate these dynamics into water management plans as direct constraints. The Water Diplomacy Framework encourages ecological research to proceed to deeper levels of analysis when treating ecological factors as surrogate stakeholders.

Because they are not actual stakeholders that can be consulted directly, ecological surrogate stakeholders' positions and interests are determined by empirical ecological research. The "interests" of an ecological system are causal, mechanistic relationships that explain the observed phenomena of position analogs. Just as a farmer's interests explain the underlying values that bring about their manifest positions, ecological interests are the actual causes that generate an ecological factor's observed response to changes in the hydrology of the system. A wetland's position might be that marshgrass diversity (a desirable trait of the system, in this case) decreases after water levels are reduced by residential water use. The wetland's interest is the mechanism causing this response; perhaps lower water levels allow competitive exclusion of some marshgrass species by others. Other means of maintaining marshgrass diversity - perhaps the use of occasional floods or physical disturbance like mowing - might satisfy the wetland's interests (i.e., the need to maintain species diversity, a desired trait in the ecosystem) without compromising residential water needs as apparently necessitated by its original position. Focal species' interests are typically behavioral and more analogous to the interests of human stakeholders; for example, beavers build dams to increase their reproductive fitness and survival (Naiman et al. 1988). Mechanistic understandings of these behaviors can lead to better management of human-wildlife conflicts caused by such behaviors. Several devices have been designed to prevent beaver dams from flooding roads and residential areas using detailed knowledge of the behavioral cues beavers use for dam-building (Payne and Peterson 1986; Nolte et al. 2000; Jensen et al. 2001). These devices save managers the energy and expense of beaver control alternatives like killing or relocation, while beavers are able to perform their natural behaviors undisturbed and without causing destructive floods.

Because Water Diplomacy is an emerging framework, and because our suggested role for ecology within this framework is particularly new to water management, we are unable to find any concrete examples of our suggested approach in action. However, cases exist that validate different aspects of our approach. One of the most famous examples of the enhanced, mutual-gains outcomes that can be created using a negotiated approach is the New York City Watershed collaboration. In the 1990's, the City of New York was getting about 90% of its water from the rural Catskill-Delaware watershed, and due to land practices within the watershed, the quality of this water was at risk (Hoffman 2010). Rather than forcing cooperation from farmers in the Catskill-Delaware, the city negotiated a memorandum of agreement with them that led to mutual gains (Daily and Ellison 2002; Postel and Thompson 2005). Instead of spending an estimated $6 billion on a water filtration plant

with $300 million annual operating costs, the city spent $1.5 billion on helping farmers improve their lands to prevent erosion and contaminated runoff. Landowners were able to voluntarily participate in a program they helped design and received funding for restoration and enrichment of their properties (Postel and Thompson 2005).

The recent trend among conservation biologists toward including more detailed, mechanistic research (especially regarding behavior) in wildlife conservation (Reed 2002; Blumstein and Fernandez-Juricic 2004; Caro 2007) illustrates the increased utility of seeking ecological "interests" when solving environmental problems. Inquiry into the behavioral and physiological mechanisms of observed species responses has led to improved predictions of species distributions in response to climate change (Kearney et al. 2010), risk of pest establishment (Kumar et al. 2014), and effectiveness of protected areas (Kujala et al. 2011).

The ability of ecological factors to provide added value in negotiations is readily apparent in recent research on ecosystem services; the services provided by wetlands are especially relevant to water conservation. While constructed wetlands have been used for decades to treat wastewater effluent and simultaneously provide wildlife habitat (e.g., Worrall et al. 1997), more recent developments like the Qunli stormwater park (Saunders 2012) and the reconstruction of the Bezai community in China (Wang et al. 2006) extend the concept to impressive scales. These integrated eco-urban environments require an understanding of wetland ecology, and yield simultaneous benefits in wildlife support and stormwater treatment (Campbell and Ogden, 1999; Wang et al. 2006; Scholz et al. 2007).

To illustrate specifically how our proposed framework might lead to better water management solutions, we describe below a hypothetical application of our framework to water management on O`ahu, Hawai`i.

Case Study: O`ahu, Hawai`i and Endangered Waterbirds

The island of O`ahu, Hawai`i supports a rapidly-growing human population under vulnerable hydrological conditions. Nearly 100% of the island's natural freshwater is stored in basal aquifers that are threatened by overdrafting and sea level rise (Lau and Mink 2006; Liu 2007). Intense urban development and recent declines in agriculture have reduced infiltration and increased runoff (Ridgley and Giambelluca 1991; Giambelluca et al. 1996). This leads to floods and the contamination of offshore waters, which threatens tourist beaches, offshore fisheries of cultural importance, and coral reefs (Banner 1974; U.S. EPA et al. 2004; Leone 2006; U.S. Bureau of Reclamation 2008). The island's limited freshwater originally supported extensive coastal freshwater marshes, of which 70% have been lost to development (van Rees and Reed 2014), leading to declines in the island's endemic waterbird species, of which only 6 of the original 27 species remain (Scott et al. 2001). Four of these species still persist in breeding populations on O`ahu, where increasing habitat protection is considered a key part of ensuring the persistence of their populations (Reed et al. 2011; USFWS 2011).

Water resources management on the island has until recently been considered inefficient and possibly inequitable (Derrickson et al. 2007; Gopalakrishnan 2007), and has focused primarily on addressing only one aspect of the hydrological cycle, the availability of freshwater, at the expense of other important factors like runoff and infiltration (Oceanit et al. 2007; U.S. Bureau of Reclamation 2008). Additionally, it has largely neglected the ecological systems, like near-shore fisheries, coral reefs, and coastal wetlands, which are all affected by water and land management on the island. The resulting water management plans focus only on a single group of stakeholders - those interested in increased groundwater and freshwater availability - and suggest management techniques like deep injection wells, desalination plants, or diversions of highly contested river flows to meet increasing water needs (Oceanit et al. 2007; U.S. Bureau of Reclamation 2008). These strategies are likely to be very costly, have potential environmental impacts, and are unlikely to be socially acceptable in the context of past water resources disputes on the island (Gopalakrishnan et al. 2005).

By expanding the problemshed to include the island's historical context of wetland loss due to land development and water diversions (van Rees

and Reed 2014) and the economic and cultural importance of coastal and near-shore ecosystems (Birkeland 2004; Carl 2010), one can add a suite of ecological surrogate stakeholders and their relevant ecological processes (services) to the decision-making process (Tenets I & III). Their positions (for example, endangered waterbirds require increased wetland habitat, and coral reefs and fisheries require less-polluted runoff) might not be met by currently supported methods of increasing freshwater availability. Including these surrogate stakeholders in the decision-making process can yield added value to certain management strategies that are capable of meeting multiple needs simultaneously (Tenet IV).

For example, constructed wetlands are an increasingly popular and highly successful water management tool for reducing floods, increasing groundwater infiltration, and filtering sediment and nutrients from runoff (Magmedov et al. 1996; Mitsch and Gosselink 2000; Thompson 2002). Such wetlands may be an excellent solution to many of O`ahu's water management problems, and would cost a fraction of the expense of alternatives under consideration (Oceanit et al. 2007; U.S. Bureau of Reclamation 2008). Increased coastal wetland cover could reduce and purify runoff that is harming offshore ecosystems, while serving other stakeholder interests in reducing floods and potentially increasing groundwater recharge. At the same time, they could provide habitat for endangered waterbirds and offer opportunities for ecotourism and environmental education. Wetlands are often constructed specifically as habitat for waterbirds (Davis 2008; Rajpar and Zakaria 2013) and wetlands designed for hydrological benefits could likely be easily managed to provide habitat for endangered waterbirds at the same time (Zhang 2008). Applied ecological research into the habitat use and selection by endangered waterbirds (e.g., their movement habits and indicators of habitat quality), or the effects of different types of runoff on coral reefs and culturally important fish would yield further information on how best to implement mutual-gains solutions. If, for example, endangered waterbirds had less need for larger wetlands for breeding, but instead benefitted more from smaller "stepping-stone" wetlands to facilitate movement throughout the landscape (Amezaga et al. 2002), a smaller, more decentralized approach to wetland design might be used while de-centralizing runoff control benefits. This higher level research into the interests of relevant ecological factors would clarify the feasibility of targeted, integrated solutions to multiple water management problems on the island.

While it is beyond the scope of this paper to quantitatively evaluate the economic, social and political benefit of such an integrated solution, it does provide a clear example of how the inclusion of ecological surrogate stakeholders expands water management options to include mutual gains solutions that might ultimately result in more sustainable outcomes. Detailed analysis of the economic and social benefits of such a proposal would be necessary before choosing such integrated methods over more traditional approaches.

Discussion

Treating ecological factors as surrogate stakeholders would allow decision-makers and water managers to take advantage of the benefits of the WDF, especially the ability to develop mutual gains solutions. Understanding the interests of ecological surrogate stakeholders requires hypothesis-driven, rather than purely observational research, and thus involves the integration of ecological theory into data collection for water management decision-making. Such hypothesis-driven research, performed in the context of established theory, is generally thought to be a more effective form of scientific inquiry than purely observational studies (Platt 1964). In this way, viewing ecological factors as surrogate stakeholders can create the impetus for more rigorous scientific inquiry into the dynamics of hydrological and ecological systems, and drive progress in the ecology of water management. This research is also encouraged by the tenets of the WDF (Tenets I, II, & III) that call for internalization of ecological surrogate stakeholders characteristically left out of water management, recognition of the complete problemshed created by ecological linkages within the managed system, and the need

for research to be targeted to important applied issues. Finally, viewing ecological factors as surrogate stakeholders simplifies their involvement to a format that may be more accessible to decision-makers with no background in ecological science. Ecological information then becomes packaged in a way that is more familiar to politically-trained professionals and can be integrated into their general workflow. This method also shifts the integration of ecological factors in engineering approaches from a constraint near the end of the decision-making process to a surrogate stakeholder at the beginning of the process, when there is greater flexibility in the selection of management options.

As noted earlier, constraints with regard to ecological systems are often part of a precautionary approach to water management employed under conditions of uncertainty. The difficulty of actionable ecological research in water management problems is partly responsible for this uncertainty; studies often have a limited timeframe and budget. Additionally, the type of large-scale ecological manipulations needed to anticipate the effects of management decisions are often infeasible, and comparative studies can be confounded by differences between different ecological and hydrological systems (e.g., Mazzacano and Black 2008). The precautionary approach is typically the most prudent approach under such circumstances of forced uncertainty, but it should be acknowledged that opportunities for mutual-gains outcomes can be missed if this precautionary approach becomes a default, even in cases where better ecological information is available.

While our goal is to emphasize how more effective management solutions can be discovered by taking a mutual-gains negotiations approach reaching beyond such constraints, it should be acknowledged that for all natural systems there exist certain boundaries and constraints that are non-negotiable. That is, there is always a point at which ecological systems can no longer sustain processes and services, and no amount of ecological research or negotiation with surrogate stakeholders can circumvent such constraints. Our suggestion is not that our methodology allows ecological limitations to be bypassed altogether, but instead that receptiveness to new information and an adaptive approach to decision-making can yield superior management outcomes where time and information are available. Understanding the ecological positions and interests - especially those which are entirely non-negotiable - is at the core of this process, and empirically-supported environmental regulations that delineate the ecological "bottom line" greatly facilitate its functioning.

Additionally, the role of the environmental negotiator deserves careful attention; individuals that represent the interests or positions of environmental factors may not be at liberty to negotiate freely on the condition of natural resources that are often held in the public trust. It is consequently important to give adequate consideration to the social values we described that ultimately attribute positive or negative value to ecological interests, and insure that the needs of affected parties are acknowledged therein.

We do not claim that advocating the use of ecological factors as surrogate stakeholders in water management is novel or unique. The idea has been thoroughly discussed in business ethics literature, with specific regard to the more philosophical questions avoided in this text (Starik 1995; Jacobs 1997; Phillips and Reichart 2000; Driscoll and Starik 2004). Additionally, the idea of integrating human and wildlife resource needs has been prominent and heavily debated for some time, gaining special attention with the creation of reconciliation biology in the early 2000's (Rozensweig 2003; Geisler 2010). We propose that our more formalized approach may provide a convenient theoretical framework for implementing the type of ecological thinking generated by reconciliation biology in cases where resource-sharing is both necessary and unavoidable. This is especially important in cases where natural systems are given lowest priority among many stakeholders competing for use of a water resource. The growing emphasis on integrated water resources management requires constant improvement of the contributions of various disciplines to the process of water management, and we believe the approach outlined above may be the next step forward for the successful interaction of ecological science and water management. In order to implement this new perspective, further research is needed to define the types of ecological metrics that are most amenable to understanding surrogate stakeholder positions and interests while

minimizing cost and effort. Additionally, applied, hypothesis-driven research will help inform more contextually appropriate water policy and strengthen ties between ecological experts and the decision-makers who govern water management.

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Nature of Transboundary Water Conflicts: Issues of Complexity and the Enabling Conditions for Negotiated Cooperation

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Abstract: Water access, demand, usage and management become complex due to the crossing of multiple boundaries: political, social and jurisdictional, as well as physical, ecological and biogeochemical. This paper focuses on a particular class of complex water problems: the allocation of transboundary water (TBW) among competing riparians with conflicting needs. The complexity in TBW allocation lies in the dynamic consequences of competition that arise from the interconnections and feedbacks among actors, processes and institutions operating in the knowledge and political communities. Consequently, many TBW allocation issues become contingent upon the dynamic changes that occur within the knowledge and political communities as well as the interactions and feedback occurring between these two communities. In addition to understanding and addressing the contingent contextual factors that span the knowledge and political communities, resolving complex TBW problems also needs to be guided by contextual application of two global principles – equity and sustainability – as anchors to accommodate the values and interests of the stakeholders involved in a TBW problem. This paper examines the process that led to the relatively successful resolution of conflict over allocating the waters in the Indus basin between India and Pakistan. Using the Indus water treaty as an illustrative case, the paper identifies three enabling conditions that underlie the effectiveness of negotiating a treaty and its continuous efficacy in addressing TBW problems. The paper argues that effective resolution of complex TBW problems is rooted in the nature of the negotiation process, the provisions in the negotiated agreement and the establishment of institutional means to solve emergent problems that are related to the original agreement.

Keywords: *contingency, Indus Treaty, joint commission, mutual benefits, negotiation, third party*

Water access, demand, usage, and management become complex because of many boundaries: political, social, and jurisdictional, as well as the physical, ecological and biogeochemical boundaries that operates in a specific context. While scientific formulation and engineering solutions are necessary to address complex water problems, societal and political contexts are also an integral part of long-term solutions. The most challenging water problems are framed within contested terrains in which various stakeholders compete to protect their own interests within frameworks created by political boundaries, markets, institutions, laws and social norms, in addition to scientific research and technological expertise.

The origin of many complex water problems lies in the dynamic consequences of competition, interconnections and feedback that are spread across variables that operate in the knowledge and political communities. Consequently, science alone cannot solve complex water problems that involve policy issues, and policy ideas uninformed by science are no more effective. In this paper, we focus on a particular class of water problems: allocation of international water. Over 276 river basins cross national boundaries (TWAP 2013). While the majority of the international river basins

are shared between two countries, there are 13 basins that are shared between 5 and 8 countries, and five basins are shared between 9 and 11 countries (UNDP 2006).

Changes in population growth, socioeconomic conditions, and ecosystem functions and services are creating more demands on available fresh water resources. Some estimates suggest that the demand for water is projected to grow by over 40 percent by 2050, and over half of the global population could be living in water-stressed conditions (WWAP 2012). This mismatch between supply and demand for fresh water is expected to intensify and may become exacerbated by the mismanagement of water resources, transboundary conflicts, impacts of climate change, development trajectory of countries and the growing rate of urbanization in developing countries (Agnew and Woodhouse 2011; Srinivasan et al. 2012; Brown and King 2012; Islam and Susskind 2015). Such mismanagements may lead to more tensions and conflicts among competing users (Judge 2013; Starr 1991) because some of the basins are shared by countries not only with different interests and economic needs, but also with fragile governance structures and a history of conflict.

The long history of disputes over water is documented in myths, legends, and contemporary academic analyses (Hatami and Gleick 1994; Toset et al. 2000; Wolf 2007). In recent years, we have seen upstream-downstream tensions - between India and Bangladesh, Ethiopia and Egypt, Pakistan and India, and Israel and Jordan - as well as clashes among agricultural and energy interests for water. Yet, the historical evidence of violent conflicts over water is significantly less than the evidence of negotiated cooperation to resolve TBW disputes (Yoffe et al. 2003; Wolf 1999). Beyond this historical pattern and in terms of theoretical reasoning, the literature on TBW points to contingent possibilities of cooperation over sharing TBW. In other words, the competing claims and demands on TBW by its riparians can lead to either conflict or cooperation. Therefore, it is necessary to understand the factors that give rise to conflict and cooperation as contingent and not necessary outcomes. It follows that we need to look for ways to identify the factors that prevent conflict and promote cooperation, as well as consider constructive conflicts as a means to secure enduring cooperation.

The global understanding of cooperation currently rests on the application of the values of equity and sustainability as normative principles in addressing and resolving TBW issues. In the Berlin rules, Articles 5-9 specify the principle of equity and its contingent interpretation, while Articles 12-16 establish the application of the meaning of sustainability and its contingent interpretations (Berlin Rule 2004). These two guiding principles stand as global norms not only because they are encoded in the Berlin Rules, but also because of their progressive evolution from the 1997 UN Convention (UN Convention 1997), which in turn emerged from the 1966 Helsinki Rules (Helsinki 1966). Using these two principles as anchors, this paper identifies the enabling conditions of enduring cooperation among riparians in sharing transboundary water.

The Complex Problem of Addressing Transboundary Water Disputes

Transboundary water allocation remains a focal issue in a range of water literature (Biswas 1992; Gleick et al. 2002; Prescoli and Wolf 2009; Wolf 2010; Subramanian et al. 2012; Dellapenna et al. 2013 and references therein). TBW cuts across political boundaries and includes surface water, underground water and interconnections between the two (Subramanian et al. 2012). Notably, with a few exceptions, dispute over TBW has not led to major armed conflict (Allan and Mirumachi 2010; Prescoli and Wolf 2009). This is often attributed to the effectiveness of governance (Agnew and Woodhouse 2011) in using bilateral or third party mediated negotiation (Jarvis and Wolf 2010; Priscoli and Wolf 2009; Biswas 1992; Earle et al. 2010). These agreements or treaties are further sustained by a water regime that continues the process of negotiated cooperation among competing stakeholders. This serves as a ground of optimism to not only rely on mediation in resolving water conflicts, but to also make further advances in the efficacy of mediation to address emerging disputes.

Not all TBW allocation issues are complex, even where there is a dispute (Islam and Susskind

2014 and 2013). However, some TBW issues are complex (e.g., Mollinga 2007; Earle et al. 2010; Prescoli and Wolf 2009; Islam and Susskind 2013), their intricacy rooted in coupled human and natural system interactions (Liu et. al. 2007; Saravaran 2008; Petersen-Perlman et al. 2012). A key reason for this complexity is the uncertainty of interactions between issues and actors that function in the political and knowledge domains of water management, arising from the different political needs, boundaries, knowledge, know-how, management capacity, and political power of the disputants. These conditions can be present singly or in interaction with each other in a dispute, and thereby constrain the choices available to stakeholders finding mutually acceptable solutions.

Defining the allocation of TBW as a complex problem - rooted in the interactions and feedbacks within and between knowledge and political communities - shifts our focus from seeking efficient tradeoffs from primarily rational perspectives to identifying and negotiating the needs of multiple stakeholders with competing - and often conflicting - values and interests. Thus, a purely economic framework that balances supply with demand and promotes only technocratic interventions fails to account for other values important in managing water as a resource. However, these other values affect TBW policy debates and are generally framed within two communities engaged in water-resource management, referred to in this paper, as the knowledge community and the political community.

The knowledge community includes actors and activities in the technical sphere of water research, water management, and water policy. One key outcome from this community is the formulation and widespread adoption of the integrated water resources management (IWRM) as a comprehensive approach to realizing the value of sustainability. The IWRM now enjoys a paradigmatic status, and hence by usage is normative in scope and application (Gallego-Ayala 2013).

Alongside the knowledge community, the political community also affects water resource management. Decision making processes within the political community involve not only input from the knowledge community, but the perceived legitimacy, necessity and effectiveness of proposed actions that are aligned with community values. The political community includes both actors and activities that are engaged in governmental policy, and the non-governmental activism of civil-society groups who seek to frame the underlying values of governance that affects water allocation priorities.

For example, the nature of complexity introduced by the political community can be understood in terms of negotiation on the meaning of a criterion like equity. The meaning varies from seeking equitable allocation among different sectors of the economy and polity (for example, agriculture, energy, urban), to providing poor communities access to affordable water as well as establishing sustainable practices of water usage to affect generational equity. A key focus of this community has been the equitable allocation of water to disadvantaged populations and protecting vulnerable ecosystems (Giordano and Wolf 2001).

The two globally understood guiding principles of cooperation in TBW issues - sustainability and equity - are evident in the values and activities of the knowledge and political communities as described above (Brown and King 2012). As a result, we can no longer consider them as dispensable options in an economic tradeoff, say to achieve efficient pricing of water or efficient allocation of water, but as embedded in the complexity of deliberation and decision making that arise from the dynamic interactions of the knowledge and political communities.

These two goals of governance provide normative anchors to advance the important values and interests of stakeholders involved in resolving TBW conflicts within a particular context. Therefore, today the complexity of water problems is contingent not only on the nature of changes that are taking place in the knowledge and political communities, but also in the ways sustainability and equity manifest themselves within a particular context in the midst of competing demands of multiple stakeholders.

Complexity Introduced Through Growth in Know-how in the Knowledge Community

The ongoing growth and refinement of natural, societal, and technological knowledge continues to provide solutions to water problems. This

enhancement in knowledge and informed action creates flexibility in the availability and efficient use of water, for example, through the use of grey water; mapping and accessing aquifer water; desalination of water; and addressing ecological water needs. In this context, effective use of knowledge is crucial for creating new options for competing stakeholders and resolving water disputes (Islam and Susskind 2013). In doing so, however, this growth in knowledge also introduces uncertainty about problems (like climate change), and gives rise to the identification of new problems (like ecosystem vulnerability). Consequently, the efficacy of this knowledge has also become contingent upon the uncertainties associated with the generation, appreciation, perception, and implementation of this knowledge base. For example, what are the impacts of climate change on water availability? At what space-time scales are these impacts important for decision making?

Complexity Introduced Through Competing Values and Interests in the Political Community

The political community adds new problems and solutions as well, thereby, increasing the ambiguous nature of understanding and resolving water problems. The nature of TBW conflicts is dependent on a constellation of interacting societal factors, adding uncertainty to the issues of water use, access, and equity. For example, the conflicting developmental needs of riparian states in terms of economic growth, pattern of urbanization or industrialization and agricultural productivity lead to competing water needs (Agnew and Woodhouse 2011). Two other factors further expand the scope of the conflicts. One is the emergent conventions on water management; for example, how "integrated use of water" conflicts with the established convention of "prior use." The second is the growing commodification of water (e.g., creation of water markets and full-cost water) conflicting with the equity of access and cost (Prescoli and Wolf 2009).

Interaction Effects of the Political and Knowledge Communities Necessitate a Contingent Approach

There is an increased awareness that community specific solutions that work for simple and complicated problems usually will not work for complex problems and may contribute to the complexity itself. Given the contextual conditions that operate within the political and knowledge communities and the complexities that arise from their interactions, a more flexible framework than IWRM is needed to resolve TBW problems (Biswas 2004; Saravanan et al. 2009). A key argument for the lack of progress in operationalizing IWRM is the explicit recognition that the political community creates obstacles that distort or displace the objectives of integrated use of water (Metlay and Sarewitz 2012; Donaldson 2001). Therefore, effective resolution of complex TBW problems will require a contingency approach to negotiation that seeks creative options for mutual gains through negotiation among stakeholders with competing interests that span both the political and knowledge communities.

Negotiated Resolution of TBW Problems as a Contingent Process

A contingent negotiated approach - as a means to both characterize TBW problems and seek their resolution - offers a promising framework. In addition to the contingencies that are inherent in addressing competing needs and equitable allocation of TBW resources, the negotiation process itself is subject to a variety of contingencies (Bercovitch et al. 1991). This is because TBW issues are context specific, not only in terms of basin characteristics, but also in terms of the knowledge capacity, development trajectories and power asymmetry of stakeholders.

Put simply, neither the nature of the problem in terms of water allocation, nor the efficacy of solutions to resolve the problem can be pre-specified by theory or politics. Rather, both have to be discovered on the ground, through context specific means and with the involvement of stakeholders spanning the knowledge and political communities. It also means taking account of sustainability and equity – as the two overarching normative anchors of water governance – which the knowledge and political communities have framed through their interactions. The operational meaning of these two anchors rests in specific contexts, which in the context of TBW is a shared basin.

Among scholars, it is sometimes mentioned that each basin is unique, and hence, no universally generalizable prescriptions to solve TBW problems exists. Nevertheless, in practice, we find effective solutions to TBW problems not only exist but endure. We argue that the solutions rest on certain enabling conditions, supplemented by a set of situation specific conditions that are helpful in affecting negotiated resolution of a TBW problem. In the context of the dispute over sharing the Indus water the paper provides the specification of three enabling conditions. The paper further argues that variation in the context of TBW problems will call for the existence or emergence of different set of situational or sufficient conditions to make the enabling conditions operational in practice. In this paper, we are using the Indus Water Treaty signed by India and Pakistan to illustrate the nature of complexity and contingency as they give rise to the enabling conditions of the negotiation process, as well as the continuing relevance of these conditions to sustain cooperation in solving TBW problems.

The sharing of Indus basin water between India and Pakistan remains a paradigmatic case to showcase the success of contingent negotiation in resolving TBW conflicts. The choice of the Indus Water Treaty case is motivated by two criteria. First, in the context of complex TBW problems, the Indus case has often been cited as a successful example of cooperation. Thus, the Indus case functions as an "influential case," one that is used as a basis to "check the assumptions of a general model or claim in literature" (Seawright and Gerring 2008, p. 303). Here, we use the Indus case to illustrate the enabling conditions of negotiation in the design, operation, and outcome of the negotiation process. The second is the fact that the Indus Treaty not only continues to operate today, but also addresses new issues that have emerged over time, thus demonstrating the resilience of negotiated cooperation. Given these two criteria, the Indus Water Treaty case offers a unique opportunity to inquire into the underlying factors that led to the successful resolution of a TBW problem, which continues to remain effective over time. It is these underlying - hopefully somewhat generalizable - process factors that this paper refers to as enabling conditions in the context of the negotiation process and negotiated outcomes.

We argue that these enabling factors may also transfer to other contexts as long as the situation specific conditions (or sufficient conditions) of securing them, are present or possible. What further justifies the status of these conditions as enabling is the continuing validation of the process factors in the field of conflict resolution (Jarvis and Wolf 2010; Fisher et al. 2011; Islam and Susskind 2013). Here, we focus on identifying the enabling conditions, even beyond the chronology and particular case attributes of the Indus negotiation process as discussed in Biswas (1992) and supported by Rai and Patnaik (2012) and Khan (2013).

Enabling Conditions in the Indus Case

I. Existence and recognition of interdependency among contending stakeholders

For any TBW problem to become a subject of negotiation, the existence and recognition of competing, often conflicting, values and interests are necessary. Such recognition can be manifested through a variety of contingent methods, one of which is having a capable and committed mediator that the parties seek and agree to rely upon.

The capability of the mediator rests on having requisite political authority, technical expertise and fiscal capacity that the parties don't possess. The mediator remains involved with the stakeholders on a long-term basis with sustained activism, thereby keeping the focus and the pressure on reaching a negotiated resolution. Having a capable mediator engaged on a continuing basis increases familiarity, reduces mutual vulnerability, and hence, the perceived risk among the stakeholders. In TBW disputes, stakeholder participation at the beginning of the negotiation process is integral to the effectiveness of negotiation (Kranz and Mostert 2010).

The negotiation of the dispute over Indus water between the two newly independent countries of India and Pakistan began in 1952, mediated first by David Lilienthal, the former head of Tennessee Valley Authority, and later by Eugene Black, the President of the World Bank. The engagement was initiated first by an invitation from the Prime Minister of India, nevertheless, from the very

beginning, Lilienthal made sure that he remained neutral by recognizing the vulnerabilities of both parties; that of Pakistan's in terms of its downstream location and that of India's in terms of its future water needs. At the same time, he also established the ground rules of negotiation with regard to relying on engineering facts, developing the Indus basin as a single unit, and using the financial assistance from the World Bank as the primary criteria for reaching an agreement.

Like his predecessor Lilienthal, Eugene Black, also offered his mediation service directly to the political heads of both countries. Throughout the process, Black initiated and maintained direct and personal contact with the heads of states of India and Pakistan. The negotiation process relied on a working group composed of engineering teams representing India, Pakistan, and the World Bank to come up with the engineering provisions of a long-range plan. The purpose of the Bank's representation in the working group was to mediate technical differences and serve as an impartial adviser to both sides. Thus, an enabling condition for effective negotiation lies in the mediator's ability to bring the recognition of interdependency among active stakeholders.

II. Focus on framing mutual interests via joint fact finding and creating mutual benefits

Achieving an agreement for sharing a competing resource requires the mediator to be involved in the identification of mutual benefits and costs to the stakeholders, as well as devising the instruments of securing the benefits and minimizing the costs. To keep the parties engaged and ensure long term sustainability of the agreement, parties need to explore mutual gains options in terms of creating economic, social, and environmental benefits for all as outcomes of the process (Granit 2010; Islam and Susskind 2012). Eugene Black, through the World Bank, implemented the mutual gains approach by formulating and negotiating financial assistance packages for infrastructure and a package of economic assistance to induce both sides to arrive at a negotiated agreement.

The focus rested on interests only rather than on the favored positions of each side. This allowed for the circumvention of the zero-sum fears of the stakeholders and shored confidence in the process of discovering mutual gains. Inclusive framing of interests also supported the recognition and importance of all parties in the dispute. Accurate technical knowledge of and management capacity to clearly understand how much one party can secure the benefits through unilateral action, and how much can be gained through negotiation, generate confidence in both sides in framing interests on a long-term and mutual gain basis.

In the Indus case, the principles of negotiation as adopted by Black and the World Bank, kept the focus on creating a joint framing of a long-range plan that would result in mutual gains for the two countries. The benefits were exclusively based on functional needs as opposed to political considerations and did not consider past claims and negotiations. The working group, composed of engineers from both sides as well as those working for the Bank, agreed to identify benefits in terms of water needs based on the amount of cultivable, irrigable land in both countries and the need for engineering works related to water resource development. Each step of the process was subjected to joint fact finding, verified by the Bank's engineering team. However, accepting the accuracy of the data did not automatically bind the two parties to any plan submitted by either side. The countries remained free to formulate separate plans, thereby, ensuring their continuing participation focused on gaining future benefits. Although the plans formulated by both countries were based on similar estimate on the total water availability in Indus, they differed on the amounts to be allocated to each other.

To break the impasse over competing allocation claims, Black offered the World Bank's own proposal in order to keep the negotiation process alive. While India promptly accepted the proposal to move the negotiation to its final agreement, Pakistan objected on the ground of unfair consequence in terms of its vulnerability to the water controlled by India. In recognizing Pakistan's concern over its limited water storage capacity and also that of India's over its storage capacity and financial cost for creating link canals, the World Bank included both items as criteria to be addressed in a comprehensive plan.

Furthermore, the Bank offered assistance to Pakistan in building a storage facility on an Indus

tributary rather than relying exclusively on the water flow from Indus controlled by India. The Bank addressed one of India's key concerns, reducing the costs of the replacement works for India. The Bank further promised financial assistance to build two dams in Pakistan, one in India, and link canals in both countries. It also provided additional financial assistance to Pakistan in foreign exchange to shore up its economy. Thus, clear specification of the costs and benefits, allocation of costs to both countries based on the principle of commensurate benefits, and the willingness of the World Bank to bear additional costs enabled the framing of immediate and long-term mutual gains for both sides, paving the way for both sides to sign a treaty in September 1960.

III. Formation of a joint body to monitor agreements and address new problems as they emerge

To effectively deal with contingencies, the negotiation of an agreement must facilitate the formation of a water regime that can realize the proposed mutual gains via monitoring and upholding the responsibilities of the stakeholders. The involvement of a neutral third party and the design of joint bodies (often in the form of joint river commission) are critical factors that facilitate such regime, because different designs lead to different forms of cooperative mechanisms (Kranz and Mostert 2010; Granit 2010). In operational terms, this involves adequate provision of resources for continuing joint fact finding as well as devising mechanisms to monitor the terms of the agreement. Capacity enhancement of water authorities to act on jurisdictional needs and responsibilities is a crucial condition for the stakeholders to reach agreements without the continuing facilitation by an outside mediator. The investments in capacity building also reduce the suspicion among the stakeholders that one party may later take advantage of the vulnerability of the other.

In the Indus case, the Treaty provided for the formation of a permanent Indus Commission. The Commission was composed of two Commissioners, a hydrology expert from each country to oversee the implementation of the treaty. One particular point of agreement was that the allocation of cost of replacement works was to be based on commensurate benefits for the country. The Commission was scheduled to meet once a year with meeting location alternating between the two countries for the purpose of identifying areas of cooperation in implementing the treaty, resolving any questions that arise in treaty implementation, and submitting an annual report documenting the level of cooperation. A process of referring disagreements to a neutral expert was also established, failing which, a Court of Arbitration was specified to act as the final resort.

Beyond monitoring treaty agreements, the long-term efficacy of finding mediated solutions rests on the water regime functioning as a professional learning community. This requires enhancing the management capacity of the water regime in order for it to sustain and improve its technical capacity to improvise solutions that emerge beyond the initially agreed treaty. The formation and operation of such a regime promotes a common language with which to exchange technical information and make on-the-ground adjustments and improvements in respective jurisdictions. The fact that the Indus Commission is still operational, and that it aids both sides to provide updates on the nature of the water problems, testifies to the enabling function of institutional learning in the sustenance of the water regime.

Concluding Remarks

Allocation of Transboundary waters of a basin and related issues of water access, demand, usage, and management become complex due to crossing of political, social, jurisdictional, physical, ecological and biogeochemical boundaries. The complexity in TBW water allocation lies in the dynamic consequences of competition arising from, interconnections and feedback operating across variables, processes, actors and institutions in the knowledge and political communities. The complex nature of TBW sharing is intensified by the emergence and increasing acceptance of the two guiding principles of equity and sustainability as goals of effective resolution. Using the Indus Treaty as a successful case of negotiated resolution of a TBW problem, the paper identified three enabling conditions that led to a negotiated treaty with enduring resilience.

The first enabling condition is the existence and recognition of interdependency among contending stakeholders. Such recognition can be manifested through a variety of contingent means, one of which is having a capable and committed mediator that the parties seek and agree to rely upon. The second enabling condition is sustaining a focus on framing mutual interests via joint fact finding and creating mutual gains. Achieving an agreement on sharing water resource requires the mediator to help the riparians to identify mutual benefits and costs as well as devising the instruments of securing them over time. The third enabling condition is forming a joint body or commission to monitor agreements and address new problems as they emerge. The success of such commission rests on becoming a water regime that supports the realization of the proposed mutual gains via monitoring and upholding the responsibilities of the riparians, but also effectively deal with disagreements as they arise. These three conditions are defined as enabling, because they find general support in the conflict resolution literature and they directly contribute to the endurance of the treaty.

Referring to these three conditions as enabling does not mean that they operate in a formulaic fashion. The relative presence or absence of these enabling conditions may offer a quick accounting of the reasons for the relative success or failure of negotiated resolution of TBW conflicts. However, there are other situational factors that will affect the relative efficacy of each of the enabling conditions in a negotiation process. Given the complexity and contextual nature of TBW issues, these situational factors cannot be pre-specified as they are contingent on the issues of a specific basin and the stakeholders that are involved in a dispute. To illustrate one such situational factor, would be specifying the operational meaning of environmental sustainability for a given basin. The specification depends not only on the changing hydrological characteristics of a basin, but also the changing economic needs of riparians and the involvement of stakeholders and their interests spanning the knowledge and political communities - local, regional, and global. Thus, in contrast to the 1960s, when the Indus Water Treaty was enacted, in considering water allocation for the Indus today we need to be cognizant of international laws and conventions that recognize equitable access and adequate provision of water as a right. Furthermore, the emergence and addressing of new issues - for example, impact of climate change on water availability - may become important. We plan to address identification of such situational conditions to ensure long term viability of any TBW agreement.

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The Columbia River Treaty Renegotiation from the Perspective of Contract Theory

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Abstract: This paper contributes to the literature on transboundary water agreements by analyzing the Columbia River Treaty renegotiation from the perspective of contract theory. Contract theory has become a powerful part of the economics toolbox but it is much less well known outside of the discipline than game theory. We demonstrate the importance of the concept of contract completeness in identifying efficient contractual arrangements that can consider the tradeoffs of increased flexibility. The limited objectives of the first treaty meant that it was possible to write a complete contract. Climate change and more complex stakeholder interests have moved any future agreement into the realm of incomplete contracts. Alternative types of incomplete contracts are considered as potential future treaty arrangements. The approach used in this study should provide a more general framework for working through potential treaty designs from an efficiency standpoint.

Keywords: *dam operations, flood control, hydropower, incomplete contracts, international river basin, transboundary water management*

The Columbia River Treaty (CRT), signed between Canada and the United States in 1961, led to the construction of three dams in Canada that provided benefits to the U.S. through increased hydropower production and flood control. However, the future of the CRT is uncertain. Either country can exit the agreement starting in 2024 with a ten year advance notice. There were extensive stakeholder outreach meetings in both Canada and the U.S. in the years leading up to 2014 which have attracted a great deal of interest and substantial interaction with a diverse set of interests reflecting the central position that the Columbia River plays in the region.

The objective of this paper is to assess the potential continuation of the existing treaty and alternatives from a contract theoretic perspective. Contract theory is a framework developed in economics for understanding the general nature of exchange. The existing literature on transboundary water management and agreements has almost exclusively used game theory (e.g., Rogers 1969; Frisvold and Caswell 2000; Kilgour and Dinar 2001), which was a significant improvement on the "mutual benefit" approach that ignored the role of strategic behavior (Dufournaud 1982). Game theory plays an important role within contract theory, but contract theory provides a more general framework that we find adds significant additional insights.

To pursue our objective, we start by economically characterizing why Canada and the U.S. were motivated to go to the trouble of negotiating the existing CRT. We then consider what has changed since the existing treaty was signed to understand how incentives may have changed for either country to seek an alternative contractual arrangement. We conclude by analyzing the performance of alternative contractual arrangements in terms of their efficiency and feasibility.

Two important events occurred in the Columbia River Basin (CRB) in the first half of the 20th Century that increased the economic value of water storage to the U.S. The first was a growing population in areas of the CRB that were prone

to flooding. The area at highest risk is around Portland, Oregon. A large flood occurred in 1948 resulting in 50 deaths and the complete destruction of the second largest city in Oregon at the time. The other factor was the construction of large hydroelectric dams on the Columbia River during the Great Depression. Given promising storage potential in Canada, the two countries initiated talks that led to the signing of the treaty and the construction of Mica, Duncan, and Keenleyside Dams which were completed between 1967 and 1973. The extent of the CRB is shown in Figure 1 where the lighter gray portion is Canada and the darker gray is the U.S. Figure 2 gives a sense of how the flow of the river was altered. It was common to see flows over 400,000 cubic feet per second before the CRT, compared to only one observation this high after the Canadian dams were completed.

The terms of the CRT are fairly simple. Canada receives half the value of the potential hydropower generation annually, which is referred to as the Canadian Entitlement. They are also on-call to mitigate flood risk when conditions arise. There is some disagreement across sources of the various

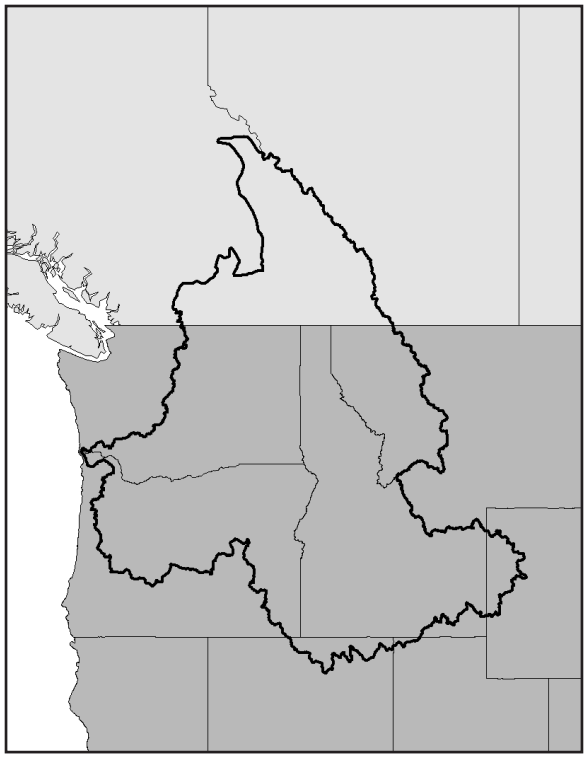


Figure 1. The boundary of the Columbia River Basin in Canada (light gray) and the United States (dark gray).

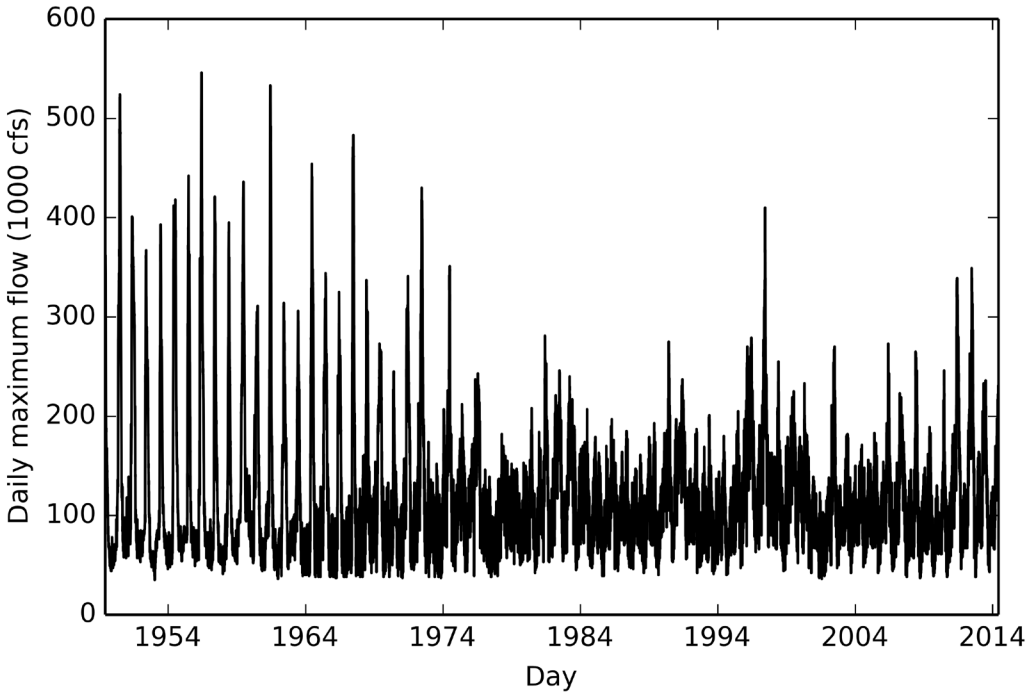


Figure 2. Average daily peak flows before and after storage dam construction (source: United States Geological Survey).

benefits of the CRT and it is beyond the scope of this paper to review them in detail, but a few numbers help put costs and benefits in perspective. Not needing additional electricity at the time, Canada sold their share of electricity to U.S. utilities for the first thirty years of the CRT at a value of $254 million. This covered the cost of construction for the three dams. Since 2004, Canada has received their share of power generation annually (U.S. Army Corps of Engineers and Bonneville Power Administration 2009). Benefits for hydropower and flood control vary each year, but are estimated to be in the hundreds of millions of dollars. The United States Army Corps of Engineers (2001) has estimated damages prevented by Columbia storage regulation during 1972, 1974, 1996, and 1997 at about $260, $306, $227 and $379 million.

Before proceeding to the technical discussion in the next section, it is worth considering why the current agreement is being considered for renegotiation given that the hydropower and flood benefits are large compared to the costs of constructing the storage dams in Canada. Among stakeholder groups in the U.S., the hydropower industry has argued most vociferously that the Canadian Entitlement should be based on *actual* rather than potential hydropower production. They argue that the gap between the two is wider than was expected at the time the CRT was negotiated because of constraints on operations due to the influence of the Endangered Species Act and flow augmentation for ecological benefits (U.S. Entity 2013). Second, flood control mainly benefits the Portland region, while costs are imposed on electricity rates throughout the Pacific Northwest, and Seattle in particular. Hydropower interests state that the cost of flood control should be borne at the Federal level by the U.S. taxpayer in accordance with general flood policy for the Federal government (U.S. Entity 2013).

The other source of contention over the existing treaty is the narrow scope of benefits and costs. The population of Washington grew from 2.3 million in 1950 to about 7 million currently (U.S. Census Current Population Survey). This has brought a number of new interests that extend beyond hydropower and flood control to the table. The attractiveness of the region to migrants is in part driven by environmental amenities (Schmidt and Courant 2006). This increases the value of ecosystem services like fisheries, which have been directly harmed by dam operations. Tribal groups in both the U.S. and Canada have also become much more politically active in seeking to exert their senior fisheries rights. Recreation activities like boating are also often at odds with flow management for hydropower and flood control. Drawing down reservoirs in the winter allows for additional storage capacity in the spring if it is needed to prevent flooding. However, lower river levels impede fish passage. Low lake levels can persist into the mid-summer if snowmelt is late, which hurts boating recreation. The Columbia Basin Project provides irrigation to almost 700,000 acres of agricultural land in Washington State, and irrigation interests have expressed dissatisfaction with operating reservoir levels for flood control. Finally, climate change has significantly increased uncertainty over future flood and drought conditions, drawing the efficacy and equity of the existing treaty into question as well.

The consequence of these developments is that the management of the Columbia River has become much more complex due to the increase in the scope of stakeholder interests. As we describe in the next section, from the perspective of contract theory this takes us from the realm of a complete to an incomplete contract. The degree of contract completeness is a critical component to consider when assessing the feasibility and efficiency of potential agreements. For a consideration of the effect of increased uncertainty on the renegotiation of the CRT from a legal perspective see Cosens (2010).

A Contract Theoretic Analysis

In this section we define contracts as a framework for exchange, and characterize the relationship between the structure of information, the structure of contracts, economic incentives, and the distribution of economic outcomes. We then characterize various alternative contract designs in the context of the CRT.

Contracts as a Model of Exchange

While the term "contract" is commonly used in the vernacular, it has a specific meaning in

economics, and is defined as "a statement of the rights and obligations of each party to a transaction or transactions" (Bannock et al. 2004, 72). There are a number of familiar situations that require what can be thought of as a formal contract, such as an apartment rental agreement or the leasing of farmland. However, these provide a limited view of the role that contractual agreements actually play in the world. In fact, almost every economic transaction can be viewed as a type of contract. Most people do not think of themselves as being a party to a contract when they buy apples at the grocery store, but the concept of the market as a basis for allocating scarce resources is just a particular type of contract.

Contract theory has developed a powerful taxonomy that provides substantial guidance in thinking about the forces influencing the characteristics of an exchange. Economists use this to compare contracts in terms of efficiency, which simply refers to the net benefits generated by the terms of the exchange. Part of this analysis is the explicit consideration of whether a contract is amenable to all parties. Another important use of this taxonomy is that by observing what types of contracts are used in certain situations we can better understand the nature of the exchange, the objectives of transacting parties, and the supporting institutions that facilitate exchange. For example, historically most farmland leases were informal without any written terms, but increasingly they are formal written contracts. Evidence suggests this increase is due to the fact that more lessors are now retired farmers who are somewhat removed socially and geographically from farming. Traditional informal contracts with lessees that are harder to monitor and enforce with distance are becoming less desirable than those with legally binding formality (Allen and Lueck 1992).

This raises an interesting question. Given the costs of negotiating and the restrictions of operating under the CRT, why didn't the U.S. and Canada simply develop an informal, flexible process of managing the river rather than entering into a relatively precise 50 year contract?

We will leave this question unanswered momentarily to first define a contract more formally. Following Bolton and Dewatripont (2005, Ch. 11), abbreviated as BD from here on, we define a contract to be between two parties that only have an option to contract with each other over n potential services abbreviated by a_i where $i = 1,\ldots, n$. Canada is the seller of water storage related services and the U.S. is the buyer of these services. The assumption that there are no other potential parties to contract with is often a convenient simplification, but in the case of the CRT it is perfectly reasonable. Variation in weather that affects run-off timing and magnitude is a source of stochasticity, which we will think of as creating a set of possible states of the world. The state of the world at the point in time where the service is provided is not known when the contract is defined. Denote the potential states of the world by θ_l for $l = (1,\ldots, N)$. The price paid, P_i, by the buyer for the service that goes to the seller is a function of the service provided. The seller incurs some cost that depends on which service is provided and the state of the world it is provided in, which is represented by $\gamma(a_i, \theta_l)$. The net benefit to the seller from the transaction is $P_i - \gamma(a_i, \theta_l)$. For the buyer there is also the potential to make an investment I ex ante that increases the benefit they receive from water storage services. The payoff to the buyer from the transaction is $U(a_i, \theta_l, I) - P_i$, where $U(.)$ is assumed to be increasing at a decreasing rate as a function of investment level. As will be demonstrated, the efficiency of alternative incomplete contracts is completely driven by the buyer's ex ante investment choice, which leads us to the concept of completeness of a contract.

The ability to write a contract also depends on observability and enforcement ex post. Many economic transactions are plagued by problems of non-observability and non-enforcement, but this is not one of them. It is easy for the U.S. to observe that the service that Canada states they will provide is indeed provided, for obvious reasons. There is no uncertainty over the quality of the product. There also does not appear to be a problem with enforcement. This cannot always be taken for granted with agreements between countries, as can be seen by the number of disputes taken to the World Trade Organization for mediation.

Contract Completeness

A critical dimension over which a contract is evaluated is in terms of its completeness. A

complete contract is one where the contract specifies (a, P) for every possible θ. This simply means that every potential state of the world can be described ex ante and the parties can specify terms of trade for every possible θ. An incomplete contract is one where it is prohibitively costly for the buyer and seller to write a contract that specifies service and price for all potential states of the world. The distinction is important because a complete contract prevents efficiency loss that occurs from opportunistic behavior ex post. A strict dichotomy between complete and incomplete contracts is often used in theoretical work for simplification, but it is probably unrealistic to assume that any actual contract can be fully complete. It is more realistic to think of a contract as being nearly complete, or to compare two contracts where one is more incomplete than the other. For simplicity, we use the definition of a complete contract from Hart and Moore (1999) who consider the parties to be boundedly rational: *A complete contract is one in which the contract has not failed to specify terms for any obvious potential future scenarios relevant under the contract.* How can we distinguish between a more or less complete contract? For practical purposes, one observable ex post indicator is whether or not there have been legal actions brought by one party in response to the other party. Lawsuits are costly and will only be carried out if there is some ex ante uncertainty about the outcome, implying imperfect specification of rights and responsibilities under the contract, which in turn is an indication of contract incompleteness.

For the original treaty negotiation, the uncertainty over the state of the world in any given year was due to weather variability that affected the amount of water storage the U.S. would demand. The solution was to write a contract stating that Canada would operate dams to maximize potential hydropower production with the additional provision that flood prevention services were to be provided on-call at the request of the U.S. Is this a fully complete contract? There could have been a scenario where Canada deviated from the agreed upon water storage services, or where the U.S. reneged on their payment of the Canadian Entitlement. Either country could have tried to make the case that the state of the world was outside of the bounds of what was considered possible when the treaty was signed. While there has been opposition to how the river has been managed, neither country deviated from the terms of the treaty, nor have there been extreme years over the lifetime of the treaty with flood conditions and droughts. Therefore, it makes sense to think of the current CRT as a functionally complete contract.

We can now formally state what we think is the major change in the nature of the treaty negotiations today compared to fifty years ago. The original CRT is a functionally complete contract in relation to its stated goals, but any future agreement will almost certainly be incomplete because of climate change and the increased dimensionality, heterogeneity, and informational uncertainty of stakeholder interests. Take climate change first. While the science behind climate change is well established, there is an ever growing appreciation of the uncertainty over the rate of greenhouse gas emissions and subsequent changes in climate (Dufresne et al. 2013). As a result, the U.S. and Canada cannot realistically define all potential states of the world, particularly from a probabilistic standpoint.

Even more consequential is the expansion of both the number and heterogeneity of stakeholder interests at the table in contract negotiations. This large diversity of interests has made it essentially impossible for each country to define an optimal water storage service for their constituents that addresses the dizzying array of possible future states of the world pertinent to a CRT contract. For Canada, it is difficult to define the costs of water storage services in terms of lost fishery benefits. For the U.S., how are all of the various interests to be weighted? How will those weightings change over time? In other words, what enters into the utility function of the U.S., and how do these dimensions relate to each other? This is a difficult political economy problem that is essentially impossible to definitively answer (as shown by Kenneth Arrow's famous "Impossibility theorem" (Arrow 1950)). The existing CRT considered both hydropower and flood control, but that was relatively simple. Storage services were optimized for hydropower until flood conditions arose, which then took priority.

When considering the feasibility of a complete contract, the question is not whether it is technically impossible to characterize all states of the world and agree to terms in each case that leads to a contract being incomplete, but that the cost of writing the contract is greater than the ex post inefficiencies that arise from incompleteness (Crocker and Reynolds 1993). Overlay climate change with a diverse array of interests that have varying political influence over time and it is nearly impossible, or at least enormously costly, to write a complete contract.

Investment Decisions and Hold-Ups

Before examining the effect of incompleteness on a renegotiated treaty, we use our description of a complete contract to consider why it made sense to agree to a treaty in the first place. An important time-invariant characteristic of the basin is that there is greater storage potential in Canada than the United States simply due to the characteristics of the landscape. Had most of the storage potential been in the U.S. there would likely be no need for a contract between the two countries given that Canada is upstream.

Another factor that made a treaty more likely were required investments. There is substantial theoretical and empirical support for the idea that long-term contracts arise when an investment is required for the seller to produce the good, or to increase the value of the service to the buyer. To be clear on terms, a long-term contract is one that establishes terms of repeated transactions ex ante (Joskow 1985). Canada had to build the storage dams in order to supply the U.S. with water storage services, but the absence of a long-term agreement would be a problem because there is no other potential buyer. Canada would seek to avoid a hold-up problem that arises because the sunk investment generates quasi-rents that would put the U.S. in a stronger negotiating position (Klein et al. 1978). However, this type of strategic investment without a guaranteed agreement with a buyer is not unusual. Governments and private firms often make investments strategically to lure companies to their region without a formal contract specifying this as a condition. The aspect of the CRT that is important here is that the U.S. is the only potential buyer of water storage services. This is what Oliver Williamson (1983) called a "dedicated asset" and defined to be an investment made by a supplier who can only sell the resulting product to a specific buyer. It is also referred to as a relationship-specific investment. Joskow (1985) hypothesized that a prediction of Williamson's model is that the buyer and seller will agree to longer term contracts that avoid repeated bargaining, for which he found empirical support in the context of the coal industry. Therefore, the requirement of a relationship-specific investment provided a strong incentive for a long-term contract like the CRT.

Hold-up problems can also arise for buyers, which is why it is interesting that the U.S. built the hydroelectric dams before the CRT. Our contract theoretic model would predict that the negotiating position of the U.S. is weaker now than in the initial negotiations because the dams have already been constructed. Is there evidence of this? One way to view the Canadian Entitlement is that the allocation of 50% of potential hydropower production, rather than actual production, is simply an easier way of incorporating flood control benefits into the price. The split of 50% of net benefits is an important benchmark because it is the Nash equilibrium for this type of game (Binmore et al. 1986; Frisvold and Caswell 2000). However, an alternative case can be made that the gap between actual and potential that goes to Canada was due to the stronger negotiating position resulting from the U.S. having already made the hydropower investments.

Alternative Incomplete Contract Designs

Given that any future agreement will be incomplete, we now consider feasible contractual arrangements in general terms, assess their relative efficiency, and evaluate their durability.

The simplest type of incomplete contract to consider is a spot contract. The attractive feature of a spot contract is that the parties do not have to incur the cost of thinking through and negotiating over potential future states of the world ex ante. The parties to a potential contract simply observe the state of the world (including their expectations for the future) and negotiate contract terms a and P for a one-time transaction, where a and P are the contracted service rendered and the price for that service as previously defined. The problem with a spot contract is that it may lead to an inefficient

level of investment by the buyer. We will first show this generally and then in the context of the CRT. Following the simplification described in BD, we discretize benefits and costs of three potential outcomes: $U(a_i, \theta_l, I) \in \{0, \phi(I), \Phi(I)\}$ and $\gamma(a_i, \theta_l) \in \{0, c, C\}$, where conditional utility levels $\phi(I) < \Phi(I)$ and costs $c < C$ are defined such that outcomes in terms of high/low benefits/costs are $0 < \Phi(I) - C < \phi(I) - c < \Phi(I) - c < \Phi(I) - 0$. Any positive amount of service incurs some cost and the highest value service requires the highest possible cost. This means that the maximum surplus is realized by $\Phi(I)$ at a cost of c ($\Phi(I) - c$). There is always a service option ex post that makes this outcome achievable, but the rightmost value, high benefits without service costs ($\Phi(I) - 0$), is infeasible.

This set-up makes the buyer's ex ante investment decision the sole determinant of the contract's efficiency. Why should investment decisions be so important looking ahead given that the hydropower dams on the U.S. side and the storage dams in Canada have already been built? It comes down to the net benefits of potential investments in the U.S. that would be chosen in the absence of Canadian storage services provided under the CRT. Investing in infrastructure for water storage, flood control, and fish passage in the U.S. has an opportunity cost equal to the investment in some alternative infrastructure. There is a significant amount of discussion of these types of investments in the U.S. stakeholder feedback documents.

The spot contract can be shown to lead to a less efficient level of investment compared to what is globally optimal by specifying the optimization problem in each case. Normalizing the cost of investment so that $\kappa(I) = I$, the following maximization problem for the buyer identifies the most efficient level of investment, $I^*, max_{I \geq 0}\{\phi(I) - I\}$. This problem is solved where the marginal return on investment equals 1: $\phi'(I^*) = 1$, which can be shown by differentiating the objective function, $\phi(I) - I$, with respect to I and setting equal to zero.

For the spot contract, the surplus is split evenly between the buyer and seller so that each receives $(\phi(I) - c) / 2$). The optimal investment level for the buyer can be found by solving $\max_{I \geq 0}\{(\phi(I) - c) / 2 - I\}$, which gives $\phi'(I^*) = 2$. Investment is subject to diminishing marginal returns due to concavity of the objective function, so an outcome with a higher marginal return implies lower investment. Because the marginal return on investment is higher under the spot contract than under the efficient contract, it follows that the spot contract induces underinvestment by the buyer.

If there is a loss in efficiency with the spot contract from not being able to specify terms ex ante, it makes sense to consider a contract that addresses this problem. One possibility is a contract where the buyer and seller agree to a particular service at a set price ex ante that will be provided no matter the state of the world that is realized. This is often called a sales contract. In the CRT context this could be thought of as a specific plan for dam operations at a particular price under any given foreseeable state of the world. If river flows are such that these dam operations are optimal, then the contract is executed. If not, there is an incentive for both parties to want to renegotiate. Renegotiation may not seem like a problem, but as Hart and Moore (1988) showed in a landmark paper the most efficient contract is not achievable when the two parties make relationship-specific investments and there is an incentive for renegotiation. The reduced efficiency occurs because the potential for renegotiation is recognized ex ante at the time the buyer makes their investment decision. Assuming that the two parties are assumed to evenly split the additional surplus for the renegotiated contract relative to the original contract, and making some additional assumptions on the probability distribution of the stochastic process that the parties face, it can be shown that the sales contract also leads to underinvestment relative to the complete (efficient) contract, but it outperforms the spot contract.

Two other alternative, incomplete contracts that are mirror images of each other are the *buyer-employment* and the *seller-employment* contract. Their common element is that they try to build in flexibility to avoid renegotiation by allocating control over which service to provide ex post to one of the parties. The original motivation for the buyer-employment contract was the firm-employee contractual relationship. The firm pays the employee's salary, and then within agreed upon limits that can be defined as the set of acceptable services A where $a \in A$, specifies the services for

the employee to provide ex post under the contract. With the seller-employment contract the seller gets to choose a from A ex post while the contract is in force.

Despite the additional flexibility there is still an incentive for renegotiation. With the buyer-employment contract, the buyer will choose a corresponding to the high service for any predetermined price because $\Phi(I) - P > \phi(I) - P$. For the seller-employment contract the seller will choose a corresponding to $\gamma(a_l, \theta_l) = 0$ no matter what price is pre-specified. In both cases each can be convinced to renegotiate because there is an alternative service and price that leads to a larger total surplus of $\phi(I) - c$ that would be split equally leaving both better off. Again, foreseeing the potential for renegotiation causes the buyer to make an inefficient ex ante investment decision.

Implementation of the buyer-employment contract is fairly easy to envision as a form for a new CRT. The U.S. would pay Canada the same amount every year, or a lump sum that corresponds to the present value of this stream of equal valued payments, and in return the U.S. tells Canada exactly how to operate their dams. The obvious concern for Canada is that there may be some state of the world where the dam operations preferred by the U.S. impose significant costs due to potential impacts on fisheries or recreation. If that state were to occur, then Canada would likely renegotiate to some different operation schedule. The U.S. would agree because the additional cost relative to its most preferred operation is less than the amount transferred from Canada. However, this likely affects the investment decision for the U.S. It is more difficult to conceive of a seller-employment contract as an outcome due to concerns over catastrophic events like flooding around Portland that would limit the set A that the U.S. would agree to allow Canada to choose from.

Could either the buyer-employment or seller-employment contract outperform the sales contract, and are any of these choices realistic contractual arrangements for a renegotiated CRT? While the content of the position reports are clearly strategic, they do provide some useful information on how each country views the feasibility of the alternative contract designs we have discussed. Canada believes that if the existing CRT were terminated, the outcome would be the spot contract based on the statement *"If the two countries cannot agree on changes within the Treaty framework, there is almost no hope that an entirely new Treaty could be negotiated."* (BC Ministry of Energy and Mines 2013, 21).

The U.S. does not take the same position. Consider the statement *"The minimum duration of the Treaty post-2024 should be long enough to allow each country to rely on the Treaty's planned operations and benefits for purposes of managing their long-range budgets, resources plans, and investments, but adaptable enough to allow responses to new information and changing conditions."* (U.S. Entity 2013, 3). There are a number of other references to moving to an incomplete contractual arrangement such as *"The strategy for adapting the Treaty to future changes in climate should be resilient, adaptable, flexible…"* (U.S. Entity 2013, 3). The general tenor of the U.S. report is to move to an arrangement generally fitting into the buyer-employment contract where the U.S. chooses the service ex post and Canada receives compensation at a price reflecting the high cost service, such as *"identify reasonable compensation to Canada for economic losses and operating costs"* which refers to the provision of flood control (U.S. Entity 2013, 5).

While it is beyond the scope of this study to make a definitive assessment of efficiency, there is clearly value in considering the sales contract design as a potential compromise. It is likely that it would be more efficient than the spot contract and more politically feasible than the buyer-employment design promoted by the U.S. One caveat is the possibility that a spot contract repeated over time would lead to the adoption of informal terms that develop between the two countries that allow them to have flexibility in the most efficient way possible. This type of arrangement is referred to as a relational contract. Relational contracts have been shown to perform well in some contexts when two parties have repeated interactions without a finite horizon on the relationship (Baker et al. 2002). The point we hope to have demonstrated is that considering how to incorporate flexibility into a new long-term arrangement is very complicated when trying to compare alternatives, but this can be greatly simplified through the use of contract theory.

Conclusion

The intent of this paper is to contribute to the literature on transboundary water agreements by analyzing the Columbia River Treaty renegotiation from the perspective of contract theory. Contract theory has become a powerful part of the economics toolbox, but it is much less well known outside of the discipline than game theory, which has been the primary tool for analyzing these types of agreements to date. Game theory is nested within contract theory, but the latter provides additional insight. Our analysis starts from the position that the fundamental change in the current renegotiation compared to the original treaty negotiation is that any future agreement will be more incomplete than the existing agreement due to the increased complexity of stakeholder interests and climate change. Alternative types of incomplete contracts are identified in the literature and applied in the context of managing the flows of the Columbia River. The approach used in this study should provide a more general framework for working through potential treaty designs from an efficiency standpoint.

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Assessing Outputs, Outcomes, and Barriers in Collaborative Water Governance: A Case Study

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Abstract: As freshwater supplies become increasingly threatened by overuse, pollution, and changes in climate, governing bodies have begun to recognize the urgent need for flexible, sustainable solutions to water use and management. Collaborative governance of water resources has arisen as a widespread strategy to develop such solutions in a way that integrates diverse stakeholder needs and works to create consensus-driven management actions. Directly linking the outputs of collaborative processes to improved water sustainability is difficult even on a local scale. However, examining diverse collaborative governance processes, particularly the outputs and outcomes produced and barriers faced, is necessary as these processes continue to flourish at a multitude of scales and settings. In 2005, the state of Colorado initiated a collaborative governance process to assess its existing water resources and future water needs; the information gathered through this endeavor is now being used to inform the creation of Colorado's first statewide water plan. Using data from 28 in-depth interviews with key participants in this process, this paper highlights not only what outputs and outcomes may be produced through a high-stakes collaborative process, but also what barriers exist to producing desired outputs (and therefore, consequent outcomes). Gaining a better understanding of outputs, outcomes, and barriers within a statewide collaborative water governance process can provide insight into improving future decision-making processes and evaluations of those processes in a variety of natural resource arenas.

Keywords: *basin roundtables, Colorado, IBCC, process evaluation, water policy*

Numerous experiments in the collaborative governance of natural resources, particularly water resources, have emerged rapidly since the 1990s (Kenney et al. 2000), leading some scholars to characterize the 21st century as "the era of the collaborative state" (Koontz and Thomas 2006, 111). Broadly, collaborative governance processes bring together a wide variety of stakeholders in a decision-making context to "carry out a public purpose that could not otherwise by accomplished" (Emerson, Nabatchi, and Balog 2012, 2). These processes often include various governmental and public stakeholders, repeated face-to-face discussions among participants, and a mission to build consensus, typically within a new, locally-scaled forum initiated by a public agency (Ansell and Gash 2008).

Since their emergence, collaborative governance processes have been hailed as the panacea for failures associated with traditional, top-down modes of governance. Such failures may include high cost, politicization, and unsuccessful or incomplete implementation (Ansell and Gash 2008). Because collaborative processes attempt to promote mutual understanding, trust, and agreement among stakeholders, these processes may "have greater legitimacy than traditional approaches that rely on the legal authority provided bureaucracies by legislatures" (Sabatier et al. 2005, 6) and result in solutions that are more feasible to implement.

However, evaluating whether collaborative processes are truly more effective at promoting resource sustainability than traditional modes of governance is challenging for a variety of reasons. Collaborative groups face difficulty in defining resource boundaries, assembling appropriate decision-making bodies, and facilitating accountability among members who

share governance responsibilities (Bloomquist and Schlager 2005). Additionally, they often must work within a larger governance regime where the "existing norms of agency authority and administrative inflexibility act as the most critical obstacles to collaboration" (Ananda and Proctor 2013, 105). In other words, the actions of collaborative groups may be constrained by the pre-existing institutional structures in which they function, which may limit their potential for more effective governance. Finally, participants in collaborative processes often face difficulties collecting reliable, long-term environmental data that clearly demonstrate the causal effect of a process upon a resource, especially when management goals are vague or the process is poorly funded (Leach and Sabatier 2005). When a collaborative governance process sets out to deal with non-biophysical components of resource management such as resource allocation and policy change, measuring the process's effect on improved resource sustainability becomes particularly challenging.

In addition to these challenges about what can and should be evaluated, the question of *who* should be tasked with evaluating the effectiveness of collaborative processes is critical. While a third-party evaluator may be able to provide more objective feedback on a process by assessing it based on a priori benchmarks, some scholars argue for the importance of "participatory evaluation" by the process participants themselves or by an evaluator who has been thoroughly integrated into the process (Conley and Moote 2003). As a result, many studies that attempt to evaluate collaborative governance processes rely on "organizational outcomes," such as participants' *perceptions* of environmental change, as measures of success (see Leach and Sabatier 2005, and Koontz and Newig 2014, for examples). This reliance on perceptions, combined with the difficulties associated with collecting objective environmental data described above, can lead to an overemphasis on positive environmental impacts known as the "halo effect" (Leach and Sabatier 2005) and calls into question whether participants should both set and evaluate the benchmarks by which a process's success is determined. Despite these difficulties, relevant evaluations of how these time- and resource-intensive processes function and what outcomes actually arise from them are extremely important to participants, facilitators, policymakers, funders, advocates, and academics alike (Conley and Moote 2003). Without such evaluations, future collaborative processes cannot be improved, and currently effective processes may not be properly supported.

In their exploration of the difficulties associated with evaluating collaborative governance processes, Koontz and Thomas (2006) emphasize the importance of focusing on the outcomes, in addition to the outputs, of a collaborative process. Unfortunately, the inconsistent use of output and outcome measures, whether done purposefully or mistakenly, "undermines the effectiveness of performance management systems" (Koontz and Thomas 2012, 770), making it difficult to determine whether or not a process is truly effective at achieving its goals. Thus, carefully separating the outputs - the "plans, products, and other tangible items generated by collaborative efforts" - from their resulting outcomes - the "effects of outputs on environmental and social conditions" - can be a crucial first step in measuring the success of a collaborative process (Koontz and Thomas 2006, 113). In addition, closely examining the barriers that collaborative groups face when attempting to produce outputs (which then restrict the range of possible outcomes) can further inform a thorough study of how such processes can be evaluated.

This paper applies the ideas presented above concerning the evaluation of collaborative processes to a statewide collaborative water governance process currently underway in Colorado, USA, in order to investigate *what types of outputs and outcomes can be produced through a collaborative water governance process, and what barriers collaborative water governance processes face in producing desired outputs*. This research does not seek to evaluate whether the process in question is effective, but instead asks what opportunities and constraints exist in relation to this process, a necessary step in determining the benchmarks and methods by which the process can be evaluated. In the absence of valid and holistic environmental data associated with this process, the social and organizational outputs and outcomes of the collaborative process will be the focus of this paper. While these are not of primary concern in and of themselves, carefully identifying and analyzing

them can help to determine if they "create or contribute to on-the-ground problem solving" (Kenney 2000, 10).

While many of the findings are broadly applicable to collaborative processes that govern other natural resources, those who make decisions about water must take into account the unique aspects of collective action problems, resource connectivity, and a complicated history of legal allocations in many places, making it a particularly interesting area in which to examine collaborative governance and its evaluation. Furthermore, while an examination of the outputs, outcomes, and barriers in one collaborative water governance process is certainly not representative of all cases, the highly in-depth, qualitative nature of this case study lays the groundwork for further research by providing insight into important aspects of evaluation that can be examined across a broader range of collaborative governance processes in the future.

Case Study: Colorado's Basin Roundtables

Water in the state of Colorado is managed through a complex legal structure of water rights allocated under the prior appropriation doctrine to users who divert water for beneficial use. Following a severe drought in 2002 in which many water rights holders did not receive their full water allocations, Colorado's primary water management agency, the Colorado Water Conservation Board (CWCB), began a comprehensive analysis of the state's water supplies. As part of this analysis, a collaborative process was initiated in order to better understand water issues from the perspectives of a variety of stakeholders on a local scale. Basin Roundtables, groups of diverse stakeholders from each of the state's eight hydrologic river basins plus the Denver Metro area, were created to collaboratively assess each basin's water needs and devise consensus-based recommendations for water management in the face of uncertain changes in future climate and population growth. In addition to their advisory function, each Roundtable is authorized to grant state-provided money to entities proposing water-related projects that meet the Roundtable's goals, a process that occurs regularly at each Roundtable's monthly or bi-monthly, face-to-face meetings. Simultaneously, a second collaborative group called the Interbasin Compact Committee (IBCC) was established with the goal of facilitating discussion among the Roundtables concerning statewide water issues and future supply gaps (CWCB 2015). The analysis and recommendations derived from this process (referred to as the "Roundtable process" going forward) are currently being used to inform the development of Colorado's first statewide water plan, a large-scale effort to manage an increasingly scarce resource in a state that has an unparalleled impact on the rest of the western United States' water management.

Research Design and Methods

This research uses an exploratory case study approach (Yin 2003) to investigate the types of outputs, outcomes, and barriers that exist in a collaborative water governance process. The Roundtable process serves as the broader case study and each Roundtable serves as an individual unit of analysis in order to capture both the individuality of the Roundtables as well as their common set of rules and procedures. Along with extensive observations of IBCC and Roundtable meetings, 28 in-depth interviews (Rubin and Rubin 2005) were conducted with participants from a variety of stakeholder groups from each Roundtable in order to better understand the mechanisms underlying the Roundtable process as a whole, the inner-workings of each Roundtable individually, and the interactions among the Roundtables, the IBCC, and the CWCB. Interviewees were selected based on the stakeholder group and geographical location they represent (in order to ensure variety), as well as their roles as key participants in the process as observed by the researcher or mentioned specifically by other interviewees. Importantly, while the interviewees represent a wide variety of perspectives on the process, they do not definitively represent the views of other members on their Roundtables or in their stakeholder groups. However, selecting a diverse sample of interviewees and ensuring anonymity helped to reduce interviewee response bias associated with discussing the successes and challenges of the process. Information gathered from interviews was also supplemented by public process documents, such as financial reports or

notes from events hosted by the Roundtables.

The interviews were digitally recorded, transcribed verbatim, and coded using QSR NVivo 10 qualitative analysis software and an a priori codebook derived from the research question and important themes from the relevant literature on collaborative governance to provide greater focus. However, the researcher also remained open to emergent themes that appeared across interviews and coded for these as well. Detailed summaries of the coded information pertaining to individual Roundtables were then created and used by the researcher to examine patterns and themes across Roundtables. All interview quotes presented below are followed by an alphanumeric code that identifies the Roundtable in which the interviewee primarily participates alongside an arbitrary interview number that does not correlate to the interviewee's stakeholder group. Table 1 lists the Roundtable names and their corresponding codes, as well as the stakeholder groups of the interviewees. Importantly, although one interviewee may represent multiple stakeholder groups, that person is counted only once under his or her primary or formal stakeholder group association (e.g., a local government official may also own a farm, but is listed under "local government" rather than "agriculture").

Findings and Discussion

Interviewees were asked a series of questions about Roundtable activities and accomplishments, rapport-building among participants, and proposed policy and management alternatives in order to better understand the outputs and outcomes of the Roundtable process. Interviewees also mentioned outcomes, successes, or results of the process in a number of other areas of the interviews, including those that discussed goals, outreach to the community, and interactions with other stakeholder groups. Although not directly asked about factors that limited their ability to produce desired outputs, the vast majority of interviewees identified at least one barrier related to some aspect of the process. Importantly, interviewees were not asked to objectively assess the successes and challenges of the Roundtable process, but instead to narrate their experiences as participants.

Table 1. Interview Subjects by Basin and Stakeholder Group.

Basin Name	Basin Code	Agriculture	Environment/ Recreation	Industrial/ Water Provider	Local Government	Other	Basin Totals
Arkansas	AR		1		1	1	3
Colorado	CO		1	1	2		4
Gunnison	GN	1	1		1		3
Metro	MT		1	2		1	4
North Platte	NP	1	1		1		3
Rio Grande	RG	1	1	1			3
South Platte	SP	1	1		1		3
Southwest	SW		1	1	1		3
Yampa/White/Green	YWG	1	1			1	3
Stakeholder Totals		**5**	**9**	**5**	**7**	**3**	**29***

*Note: one interviewee refused to be recorded; thus, the interview could not be formally analyzed with the other 28.

Outputs

Table 2 lists the most common types of outputs of the Roundtable process, as identified by interviewees: funded projects, increased contact with the public (through forums such as town hall style meetings or the production of short "guidebooks" aimed at public education, for instance), and policy documents or tools (such as white papers). Outputs were distinguished from outcomes using Thomas and Koontz's (2006) definition of outputs as "plans, products, and other tangible items generated by collaborative efforts" (113).

While these outputs may seem fairly typical for many collaborative processes, two important nuances are worth exploring here. First, when interviewees discussed policy tools or documents as an output, they typically described not only the tool or document itself, but the impact that it has had or is expected to have on policy or society. In other words, Roundtable participants are consciously and strategically looking ahead to the outcomes that will ideally result from the outputs they produce. Second, while funded projects such as renovating a reservoir or installing a new diversion structure on a stream are clearly tangible outputs, the *process* of funding projects also served a secondary function within the collaborative process. The Roundtables are allotted funds by CWCB, which they then distribute to selected entities proposing projects or studies relevant to the Roundtable's goals. Participants across the Roundtables argue that the process of funding such projects is perhaps the most important incentive to keep participants actively committed to collaboration:

> Well, one thing that has kept this process alive not just in the Gunnison basin but throughout the state is this [funding process]. That gives the Roundtables an actual function… I'm sure it saved the [Roundtable] process statewide because it at least gave the Roundtables a specific purpose where they could take action and see things happen. (GN-01)

Moreover, the process of deciding which entities will receive funding and what criteria each Roundtable will use to make this decision, has created a forum for focused discussions on topics important to Roundtable members:

> Well, I think the grants…tend to drive some of what we do because we have to have discussion about the grants, so it gives us a way to focus on what our priorities and criteria [are]. (CO-03)

While the process of deciding which projects to fund is often lengthy and contentious, it provides participants with a productive forum for breaching

Table 2. Major Outputs Identified by Roundtable Participants.

Output	Roundtables that Identified Output	Relevant Quotation(s)
Funded Projects	All Roundtables	"We're good at spending money…and having a lot of projects in the pipeline" (RG-03). "So that's an example of where we took the [available] funding, initiated a [project]…that lead ultimately to legislation to try to solve a problem. So that goes directly to meeting our need" (AR-02).
Increased Public Contact through New Forums or Educational Materials	All Roundtables	"We've had some meetings with the general public just to let them know what the Roundtables are for, what we're doing and why we're doing them" (SP-02).
Policy Documents or Tools	AR, CO, GN, MT, SP, YWG	"So, the Metro has written white papers on conservation, reuse, and new supply" (MT-01). "Our nonconsumptive flow evaluation tool I think was really useful and unusual in the way we put it together" (CO-03).

difficult issues that otherwise may not have surfaced in a collaborative process driven by consensus rules, a topic that will be discussed further under the Barriers section below.

Outcomes

The most commonly identified outcomes - defined as the "effects of outputs on environmental and social conditions" (Koontz and Thomas 2006, 113) - are listed in Table 3. Importantly, these outcomes are multi-faceted, affecting both the social dynamics of the participants within the Roundtable process (e.g., community building, increased teamwork) as well as people outside of the Roundtable process (e.g., increased diversity of participants in dialogues about water, increased public knowledge). Some outcomes can be associated with specific outputs. For instance, Roundtables initiate local events such as community meetings (an output), providing new forums for public participation and education. These may directly contribute to the outcome of creating a public that is more knowledgeable about water issues, though it is likely not the only output leading to this outcome. Other outcomes, such as increased rapport and teamwork among Roundtable participants, may not be directly linked to a single output; however, they may be indirectly connected to the process of producing certain outputs such as funded projects in which Roundtable members must work together to arrive at a unified decision, as described above.

Importantly, the outcomes identified here are inherently linked to participant perception and recall. Because the outcomes that participants describe are often not objectively measured (impossible in some cases), it is important to remember that perception is not reality. For instance, a number of participants perceive a more educated public as an outcome of the Roundtable process. To objectively test this perception, pre- and post-surveys of public knowledge about Colorado's water issues that could somehow isolate the Roundtables' influence from other influences would be needed to determine if the Roundtable process was indeed responsible

Table 3. Major Outcomes Identified by Roundtable Participants.

Outcome	Roundtables that Identified Outcome	Relevant Quotation(s)
Community Building and Increased Rapport among Participants	CO, GN, MT, NP	"That was one of the biggest things with the Roundtables, was rather than special interest groups, we became people. Yeah, it literally, very much more, became a community" (CO-02). "I think that you spend this much time together, you get to know each other… when you develop trust between people even if they have different agendas and different goals, they tend to be able to have…a worthwhile civil discussion on how we meet those different agendas and goals" (MT-02).
Increased Diversity in Water Conversations	CO, SW, YWG	"I think that one success… has been to bring more people into the water conversation, and it has introduced environmental and recreational communities to the conversation…and it's put everybody in the same room" (CO-01).
Increased Public Knowledge	GN, NP, RG, SP	"I think the Basin Roundtable process around the state is invaluable for keeping people informed and educated about water…I think the people of the state of Colorado have become better aware and educated about water because of the Roundtable process" (NP-01).
Learning/Increased Teamwork among Stakeholder Groups	All Roundtables	"I think [the Roundtable has] really been successful in… understanding the perspectives of other individuals, whether it's [municipal and industrial], or ag[riculture], or nonconsumptive uses and how we have to coexist, and how we have to work together, and how can we best utilize the resource" (AR-03).

for an increase in public knowledge. Outcomes relating to changes in the physical environment as a result of Roundtable actions were not included here because they were not emphasized directly by study participants. Despite these issues, qualitatively investigating outcomes is necessary because it allows the researcher to understand the range of possible outcomes, as well as which ones are seen as most important by participants in the process.

Barriers

Interviewees stressed a number of barriers to producing desired outputs, which inherently restrict the range of possible outcomes stemming from a collaborative process (see Table 4). Some barriers, such as limited water supplies and compact obligations, pertain directly to the resource in question and the pre-existing policies governing that resource. For instance, if a basin is obligated by an interstate compact to provide a specific amount of water each year to another state, the basin's Roundtable is inherently limited in what it can do to change the use or management of that water without foregoing compact obligations. Other barriers, such as lack of information or underrepresentation of certain stakeholder groups, are more directly related to process function itself. For example, most Roundtables only have one to three participants who specifically represent nonconsumptive (environmental and recreational) water uses, whereas ten to twenty times that number of participants may advocate on behalf of consumptive interests (agriculture, industry, domestic supply). This underrepresentation of nonconsumptive interests

Table 4. Barriers to Outputs Identified by Roundtable Participants.

Barrier	Roundtables that Identified Barrier	Relevant Quotation
Bureaucratic/Political Issues	CO, GN, MT, SP, SW, YWG	"[Legislation requiring high efficiency water fixtures] seems to us like a no-brainer tiny baby step in a much more difficult progression of things we're going to have to do to meet the gap, and we can't even do that, right? So, why would we want to count on going down this path of huge amounts of progression on conservation without even taking the first steps?" (MT-01).
Lack of Information or Data	AR, RG, SP, SW, YWG	"If you don't know how much water you need, how can you say where you have a gap?" (SW-02).
Limited Water Supplies	AR, CO, GN, MT, RG, SP, SW	"Well, the whole basin is over-appropriated, so we're water poor basically as a rule… you know we're in a dry cycle and the climate… so that's it basically" (RG-03).
Low Participation (by Members or Important Stakeholder Groups)	CO, GN, MT, NP, RG, SP, YWG	"I'm a true believer in the transparency but I'm also a true believer that people have to get involved, you know? And they're pretty nonchalant about it … including you know, state senators and you know, elected officials, etc." (SP-03).
"Red Tape" or Permitting Issues	AR, SP, SW, YWG	"…actually accomplishing [a specific change in water management] will only occur when the parties involved are willing to change NEPA and the permitting process to where it is actually less burdensome" (YWG-02).
Underrepresentation of Certain Stakeholder Groups	AR, CO, GN, MT, NP, SW, SP, YWG	"I think the recreation and environmental stuff is an important need, but it's probably underrepresented… in other words, you have these two representatives from every jurisdiction and then you have the ten sort of 'at-large' reps, and there's one for the environment and one for recreation" (AR-02).
Water Law, Water Rights, and Compact Obligations	AR, CO, GN, NP, RG, SW, YWG	"…we don't want to be in a position of causing compact administration on the [Colorado] river, which would further target the demise of agriculture and…cause chaos" (CO-01).

may prevent certain outputs - policy statements on environmental flows, for example - and reduce outcomes that may eventually follow from these outputs, such as greater conservation priorities placed on nonconsumptive attributes by state-level policymakers. Similarly, Roundtable members, aware of the contentiousness of certain political issues, may avoid the risk of generating an output addressing said issues. For example, widespread resistance to legislation promoting high efficiency water fixtures may prevent participants from promoting said legislation (an output), undercutting the possibility of large-scale societal change in which this solution to excess water use is seen as socially and politically valuable (an outcome).

Two additional barriers were identified by interviewees specifically concerning the constraints associated with working in a *collaborative* process as opposed to a top-down resource governance process. Due to this distinction, they are not listed in Table 4 but will be discussed separately here. First, because many collaborative groups work within a multi-level governance structure of interconnected groups and agencies, there is often a question about the fundamental power that a collaborative group has to create desired outputs. To illustrate this, some Roundtable participants perceive their collaborative group authority as strong because of their ability to distribute funds that directly contribute to tangible outputs as discussed above. Other participants view the Roundtable groups as limited in their power because they have no legislative authority to actually build projects or pass laws:

> [T]he Roundtable has no legal authority to do anything except present nice plans, so that's been the disconnect from the very outset…you know, this is just an exercise in futility because even if you come up with the best plan, you still can't implement it - you have no authority. (GN-01)

This issue is particularly complicated for the Roundtables, who must work together with another collaborative group (the IBCC), as well as with a state agency (the CWCB) that may influence Roundtables' decision-making activities through provisions of certain funding and data.

An additional barrier that the Roundtables face in producing desired outputs through a collaborative process lies in the foundational concept that most collaborative governance processes rely primarily on consensus-based decision-making models (Kenney 2000). Ideally, consensus-based models foster the development of organizational attributes such as improved trust and social capital among stakeholders, which some scholars assume to have a "cause-and-effect relationship" with "on-the-ground success" (Kenney 2000, 39-40). Interestingly, all interviewees in this study described their Roundtable as typically reaching some sort of consensus, despite providing slightly varying definitions of consensus. However, these overarching claims about achieving consensus may be due in part to a belief held by the interviewees that consensus is appropriate and what *should* result from a collaborative process. In other words, "[c]onsensus, we are told, is not merely a logical and inevitable product of the search for truth, but is something with a strong social value" (Kenney 2000, 41). Aside from the fact that many of the most controversial issues are simply not taken up by collaborative groups working under consensus rules, a number of interviewees cited additional reasons for why their Roundtables typically reach consensus, such as the "weeding out" of controversial voices through a lengthy and often taxing process (consensus by attrition) and the lack of knowledge about the needs of different geographical areas represented by some Roundtables (consensus by lack of information). Thus, consensus rules may limit the variety of outputs produced in a process working under collaborative norms by reducing comprehensive, informed participation and hampering discussion of controversial subjects that may not easily lead to unified agreement on a specific management action or plan.

Conclusion

In the field of natural resource management, the implementation of collaborative governance processes has become a popular response to issues associated with traditional modes of governance and increasingly complex socio-environmental conditions. Through an in-depth, qualitative exploration of a collaborative water governance process currently underway in Colorado, a variety of social and political outputs and outcomes were identified. While this analysis did indeed rely on process participants' inherently subjective

perceptions and recall, examining the landscape of possible outputs and outcomes from a collaborative process, and differentiating outputs from outcomes, is a crucial step in creating more sophisticated evaluation tools and relevant benchmarks for process evaluation, whether one is using third-party or participatory evaluation methods.

Importantly, a number of barriers to producing desired outputs related to the resource, the decision-making process, and the norms associated with collaborative governance were identified. Accounting for the spectrum of barriers to desired outputs in a collaborative process, as done in this analysis, pushes evaluations of such processes beyond simple measures of goals achieved, to a recognition of the specific limitations to effectiveness faced in each collaborative process. Understanding such limitations, especially in the context of outputs and outcomes, can help agencies implementing collaborative processes and leaders within the processes devise ways to overcome them, evaluate process effectiveness, and ultimately implement more successful future governance processes that promote increased resource sustainability.

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The Nile and the Grand Ethiopian Renaissance Dam: Is There a Meeting Point between Nationalism and Hydrosolidarity?

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Abstract: The soon-to-be completed Grand Ethiopian Renaissance Dam (GERD), which will be the largest hydroelectric power plant and among the largest reservoirs in Africa, has highlighted the need for expanding traditional integrated water resources management to better include the cultural, social, and political complexities of large water infrastructure in development projects. The GERD will store a maximum of 74 billion cubic meters of water corresponding to approximately the average annual outflow of the Nile from the Aswan high dam. Undoubtedly, the GERD will be vital for energy production and a key factor for food production, economic development, and poverty reduction in Ethiopia and the Nile Basin. However, the GERD is also a political statement that in one stroke has re-written the hydropolitical map of the Nile Basin. The GERD has become a symbol of Ethiopian nationalism or "renaissance" (hidase in Amharic). A contrasting concept to nationalism is hydrosolidarity. This concept has been put forward to better stress equitable use of water in international water management challenges that would lead to sustainable socioeconomic development. We use the opposing notions of nationalism and hydrosolidarity at three different scales, everyday politics, state policies, and interstate and global politics to analyse some aspects of the new hydropolitical map of the Nile Basin. We argue that nationalism and national interests are not necessarily negative standpoints but that there may instead be a meeting point where regional and national interests join with hydrosolidarity principles. We believe that this meeting point can maximize not only the common good, but also the good from a national interest point of view. For this, it is important not increase collaboration instead of being locked in to the historical narrative of nationalistic culture and historical discourse. This would benefit and improve future sustainability.

Keywords: *Nile, Egypt, hidase, Ethiopian nationalism, conflict, transboundary, water*

The Nile River plays a crucial role in the economics, politics, and cultural life of its eleven riparian countries and more than 370 million inhabitants. The population of these countries is expected to double within the next three to four decades. This means that an astonishing three-quarter of a billion people will be dependent on the Nile for their livelihood. In 2025, Egypt´s population is expected to reach about 97 million and Ethiopia's, 127 million. Both countries will then experience physical water scarcity (Egypt by about 630 m^3 and Ethiopia by about 840 m^3 per year and capita). Ethiopia and the upper Blue Nile generate about 85% of the total Nile River flow. The 1959 agreement between Egypt and Sudan, however, has allocated 75% of the total flow to Egypt and 25% of the flow to Sudan. Several regional developments in 2011 and 2012 have added to the complexity of the situation. Popular uprisings in a number of Arab countries, especially Egypt, brought hope

for improvement in the Middle East and North Africa (MENA) region regarding democracy and human rights standards. In 2011, Sudan was divided into two countries. At the same time, Ethiopia launched the construction of the Grand Ethiopian Renaissance Dam (GERD). Approximately 30% of the funding for the dam was secured from China (The Economist 2011), and the remainder is funded by the Government of Ethiopia through the selling of bonds and donations, both within Ethiopia and internationally (Water Technology.net 2014). Earlier, Egypt threatened war if Ethiopia tried to block the Nile flow and the response from Ethiopia stated that no country could prevent its use of the Nile waters (Time 2013). However, Ethiopia's economic development requires better use of the hydropower and irrigation potential of the Nile (the Harmon doctrine). Egypt, whose only water source is the Nile, in turn declared that it would not give up its share of the river's waters. After the sudden death of the Ethiopian Prime Minister Meles Zenawi in 2012, however, a joint Egyptian, Sudanese, and Ethiopian committee was formed to evaluate the downstream effects of the dam. At the same time, neither Egypt, nor Ethiopia has chosen to sign and ratify the UN Convention on the Law of the Non-Navigational Uses of International Watercourses, which entered into force on 17 August 2014.

The objective of this paper is to use the opposing notions of nationalism and hydrosolidarity at three different scales namely, everyday politics, state policies, and interstate and global politics to analyse some aspects of the new hydropolitical map after creation of the GERD in the Nile Basin. We briefly first introduce the concepts of nationalism and hydrosolidarity as two mechanisms at play in the Nile Basin. Then, we discuss common drawbacks of the traditional integrated water resources management principles and difficulties involved in applying such principles in, for example, the Nile Basin, followed by a discussion on the role of scales in nationalism and hydrosolidarity in the Nile Basin. We close with summarizing comments.

Nationalism vs. Hydrosolidarity

The construction of GERD is part of the larger Millennium Project initiated by the current Ethiopian People´s Revolutionary Democratic (EPRDF) regime. The EPRDF took power in 1991 with a view to creating a "national consensus", i.e., "to enable the whole society to have a shared vision with respect to national issues on development and building a democratic system" (EFDR 2005). As such, the project represents a shift from a "politics of difference", associated with ethnic federalism, to emphasizing "unity in diversity", and is designed to bring together the country's more than 80 ethno-linguistic groups. Hence, GERD has become a symbol of Ethiopian nationalism or "renaissance" (*hidase*; a newly coined word in Amharic, linking the Ethiopian initiative with wider Neo Pan-Africanist ideas of African revival; Orlowska 2013; Arsano 2007; see also Clapham 1995 and Belachev 2009). After its completion, GERD will be the largest hydroelectric power plant and one of the largest reservoirs in Africa. Water is vital for energy production and a delimiting factor for food production, economic development, and poverty reduction in Ethiopia and the Nile basin. The GERD will generate 6000 MW per year and store a maximum of 74 billion cubic meters of water (mean annual inflow to the Aswan dam is ~84 billion cubic meters of water). At the same time downstream countries have raised concern regarding the changed streamflow and effects on environment and ecology that the dam will induce. In spite of its potentially huge impact on downstream conditions, studies on environmental and ecological effects of the dam have been scant. Egypt, Ethiopia, and Sudan agreed to set up a Tripartite National Committee (TNC) of four members from each country to follow up and conduct the studies recommended by the International Panel of Experts (IPoE; Ethiopian Ministry of Foreign Affairs 2014). The IPoE recommended two studies to be conducted by the TNC; a water resources/hydropower system simulation model and a transboundary environmental and socioeconomic impact assessment (Horn Affairs 2014). The Tripartite National Council recently held its second meeting in Cairo (October 2014). It has been stated that at present about 40% of GERD is completed (Ahram 2014). The first stage of the dam will be operational from June 2015 and will produce 700 megawatts of electricity.

As opposed to "*hidase*" or nationalism that can be seen as a top-down national-scale ideology, the notion of hydrosolidarity has been launched as a

way to guarantee water access from an equitable standpoint (Lundqvist 1999; Gerlak et al. 2009; 2011). Hydrosolidarity builds on human ethics and person to person empathy which is a bottom-up approach and implies that water use will not jeopardize the use of water by downstream riparians (Falkenmark 2005; Falkenmark et al. 2009). Moreover, hydrosolidarity aims to ensure that the outcomes of new water infrastructure as well as water management are "socially and environmentally sustainable, promote economic development and ensure community cohesion within a decision-making process that makes the necessary local compromises transparent" (Bjornlund and McKay 2003). In essence, the notion of hydrosolidarity correlates with a good faith interpretation of the principle of equitable and reasonable utilization and participation as expressed in article 5 of the UN Convention on the Law of the Non-Navigational Uses of International Watercourses:

> "Watercourse States shall in their respective territories utilize an international watercourse in an equitable and reasonable manner. In particular, an international watercourse shall be used and developed by watercourse States with a view to attaining optimal and sustainable utilization thereof and benefits therefrom, taking into account the interests of the watercourse States concerned, consistent with adequate protection of the watercourse."

Solidarity in general is significant in producing cooperation between different groupings in order to meet the needs of their members (e.g., Grey and Sadoff 2007; Sadoff and Grey 2008). Sustainability needs to be taken into consideration as it protects future generations and guards intergenerational fairness.

Both Ethiopian nationalism and the hydrosolidarity concept emphasize the need for cooperation at present while also upholding the significance of sustainability, but from different viewpoints, as mentioned above. As such, they offer effective starting points for investigating present-day conditions of environmental concern and also future-oriented policies and actions. It should be noted that we do not regard nationalism as a negative standpoint in this paper. The "*hidase*" is a uniting element that works partly as a top-down national-scale process, but partly also as a bottom-up uniting process. This is exemplified by the GERD funding in which the Ethiopian Government has issued bonds targeted at Ethiopians in the country and abroad (The Economist 2011). Without a broad, bottom-up unifying process this funding would not have been possible. Thus, nationalism and the national interests both in Ethiopia and Egypt should be seen as a starting point for negotiating the ways both countries can reach their economic goals by maximizing the total benefits of the Nile River water. For this to occur it is not a matter of either nationalism or hydrosolidarity. Hydrosolidarity should not necessarily be seen as a benefit that is given away due to solidarity principles. Instead, hydrosolidarity, with its emphasis on recognition of water use as a multinational issue, should be viewed as a way to expand the benefits available to each riparian nation, carrying water management beyond simple advocacy of national interests alone. Thus, national interests and hydrosolidarity have an important meeting point. In the case of GERD this would be to highlight benefits to Egypt that would not have happened without the dam construction. A practical example of this is the decrease in evaporation occurring in the Ethiopian highlands. By collaboration and by minimizing evaporative losses for the entire Nile Basin storage system, the completed GERD could actually mean larger long-term inflow to the Aswan Dam as compared to the situation before the GERD (e.g., Mulat and Moges 2014). Thus, the agreement of Egypt for construction of the GERD and the cooperation of both countries in handling the short-term risks and negative effects during the filling of the dam could lead to long-term and sustainable benefits to both Egypt and Ethiopia that otherwise would not have been possible. On the other hand, for this to occur greater collaboration between the countries and increased tolerance for short-term national costs and inconveniences is necessary in order to reach these sustainable long-term benefits.

Integrated Water Resources Management (IWRM)

The case of GERD highlights a number of questions that have great importance beyond the dam itself, such as water sharing in transboundary rivers, collective claim making processes, and

global economic development. Large hydraulic projects in transboundary river basins suffering from water scarcity naturally lead to contest surrounding water management. For example, in the Nile Basin there is a historical, nationalistic rivalry between Egypt and Ethiopia on the one hand, and on the other, uniting historical and cultural elements such as the relationships between the Coptic Church and the Orthodox Ethiopian Church (e.g., Rubenson 2009). The overarching question is how ideas about water management and economic development are generated, transformed, and reconfigured in the face of economic, social, and political realities in the Nile countries. Integrated water resources management (IWRM) has been brought forward during the recent decades to solve the intricacies of all water resources related planning and management. However, it is more and more acknowledged that the monolithic, complicated structure of IWRM does not work in practice for complex international river basins with a multitude of hierarchies (e.g., Biswas 2010). The main weakness of IWRM is its tendency to tackle water policy and related conflicts from a commodity perspective, to a great extent overlooking the human and social dimensions of the process. Water disputes are not just over commodities and property rights, but also closely linked to aspects of justice and fairness (Anand 2007). Furthermore, dam-based development is a process with important gender based social consequences regarding relations, identities, and distribution of resources (e.g., Mehta 2011). Lately, the working model of transboundary, bi- and multilateral governmental cooperation has been discussed as a potential approach for situations involving the multitude of authority structures present in large and complex water basins (e.g., Cascao et al. 2012; Earle et al. 2010). There is, however, still no comprehensive working methodology that can systematically attempt to bridge ethnical and religious borders while also considering differing cultural and historical values. Thus, there is an urgent need to explore different ways in which multinational social realities, expressed through economic, cultural, and political realms, may be combined with integrated water resources management principles. The interconnectedness of economic development has to be considered alongside social, cultural, and political dynamics that shape sustainability and ultimately nationalism and/or hydrosolidarity in the Nile Basin. Historical, social, political, and institutional processes are often at play in river water disputes (e.g., Elimam et al. 2008; Madani and Hipel 2007). These interconnected processes foster the ways individuals and organizations perceive their claims on river water, the extent to which individuals partake in collective action to influence the state or other institutional actors, the ways state policies relate to the collective interests of different groups, and the interest of various states in recognizing and dealing with the claims of other states (Anand 2007). As such, management of water resources is linked to macro policy issues like global security, environmental protection, good governance, poverty eradication, and human rights. At the same time, water management issues connect to micro dynamics of daily social interactions, gendered impact, identity constructions, and cultural repertoires.

The strengthening of the Nile identity and highlighting the cultural heritage of the Nile together with increased dialogue and poverty eradication could be an approach to better bring about a just water allocation as compared to the traditional IWRM approach (Tvedt 1998; University of Bergen 2012). Common heritage, history, and cultural identity most likely play strong roles at the village level as well as at the national level. Also, religion is at the centre of everyday life on an individual, family, and village level. Traditionally, these aspects have been given very small space in practical water problem solving, yet are often important reasons why water projects are not successful. Thus, there is a need to further explore these issues and factor them into traditional IWRM approaches.

Scales in Nationalism and Hydrosolidarity in the Nile Basin

In the Nile River basin, the role of negotiation of nationalism and hydrosolidarity can be said to have effects at three levels of scale: everyday politics, state politics, and interstate and global politics.

(1) At the individual everyday level, the political identity shapes and is shaped through religious beliefs, national narratives, and cultural perceptions of the right to the Nile water. Local water organizations have an important role in water

negotiations among community members and claim making vis-à-vis state policy institutions. Large dam constructions often lead to internal forced migration and affect the daily lives of many communities. Thus, structural forces are likely to shape the daily realities of water refugees. There is no specific estimate of the number of people that have been/will be resettled to make room for dams and reservoirs in Ethiopia. Estimates for GERD vary between 5,000-20,000 people that need to be relocated around the construction site of the GERD (e.g., International Rivers 2008). Relocated people are reportedly being compensated, but it is not clear to what degree. According to Veilleux (2013) locals express hope that the GERD project will bring them benefit. They appear, however, to be unsure of what a dam actually is, though they understand that it will cause the river to flood the valley. Community meetings for affected people are informing about the impacts of the dam on their livelihoods.

Large reservoirs need comprehensive health management components not to increase the number of water borne and water related diseases in the area (WHO 2015). The area around the Grand Renaissance reservoir will consist of a 5 km buffer zone for malaria control that will not be available for settlement. There are also other health issues related to GERD that are not yet resolved. Parasitic diseases are the second most frequent cause of outpatient morbidity in Ethiopia (e.g., Fentie et al. 2013). The nearby Lake Tana is experiencing large problems with water related diseases. Hookworm is the predominant intestinal parasite, followed by *Ascaris lumbricoides*, and *Schistosoma mansoni*. About 30% of all children are stated to have multiple parasitic infections in areas close to Lake Tana. Without precautionary planning, similar health problems may result from the construction of the GERD.

Dams such as GERD affect men and women in significantly different ways, as they are likely to aggravate gender inequality (e.g., Mehta 2011). The displacement of vulnerable communities disrupts their traditional social ties and economic activities (Farmer 2006). Reportedly, this increases incidents of domestic violence, limits women's mobility and reduces their control over resources (Ibid). Such consequences often trigger mass mobilizations of people, especially women, to oppose dams and related development policies (Shiva 2006).

Globally, NGOs are the guardians of water as a social and cultural good. Within the context of economic development, NGOs have an important role in empowering marginal groups, strengthening local capacity, and promoting cooperation. At the same time, they are part of the symbolic and political order in which they operate (e.g., Tvedt 1998). The World Commission on Dams (2000) underlines that development needs should be formulated through an open and participatory process and that comprehensive assessment of all options should be made giving social and environmental aspects the same weight as technical, economic and financial factors. Large-scale development projects such as the GERD often take place without the consultation of women or assessing the gendered impact of the project (Obbo 2011). So far in the GERD case, participatory processes are non-existent, and a social impact assessment has not yet been undertaken. The absence of participatory mechanisms hampers a gender-sensitive development that is known to provide perspectives that meet the needs of affected communities and individuals at large (Ibid.). NGOs promote the advance of democracy, mass mobilization, poverty alleviation, and social justice in many countries of the Nile Basin, and are thus important actors in constructing perceptions and attitudes towards development and social change. Particularly, NGOs have an important role in bringing attention to the impact of large development projects on women. Local water management organizations are an important arena to assess the social impact of GERD and investigate the ways they attempt to alleviate the negative consequences of GERD on individuals and communities. As sites where water and environmental policies are formulated and implemented, these local organizations provide avenues to analyse the inter-linkages between global discourses of rights and freedoms, regional inter-state conflicts over water, national policies and discourses related to GERD, and everyday practices related to sustainable development and social cohesion. Moreover, local water organizations are also appropriate sites for promoting a vision of just, democratic, and ecologically sustainable use of water resources. Additionally, NGOs are regional and global players who have a significant role to play in the promotion of social and environmental

justice and sustainable development at the local level in the Nile Basin. Finally, NGOs can partake in shaping a global discourse on environmental justice and hydrosolidarity. Hydrosolidarity may be relevant even considering authoritarian regimes. In the example of the GERD, the NGO International Rivers has highlighted several potential safety issues, negative environmental impacts and consequences for the downstream flow. The Nile Basin Initiative, an organisation for the Nile's riparian states, advocates a more equitable allocation of the water and has tried to moderate Egypt's historical control.

(2) At the state level, processes of negotiation in formulating and implementing water-related policies become more important. These include interactions between state institutions and policies of economic development on one hand, and between these institutions and local organizations and interest groups that are affected by state policies on the other hand. The role of international development assistance in shaping water-related policies needs is also important. National cultures and identities play an important role in shaping attitudes towards the Nile in general and shaping the risk of emerging conflict between Egypt and Ethiopia in particular. The Nile has been the connecting link between Egypt and Ethiopia for thousands of years. Starting from the 3rd century A.D., the Nile connected early Ethiopian Christianity with the Alexandrian Coptic Church that has continued uninterrupted for 1600 years (Ayele 1986; Erlich 2002). Consequently, despite their differences, Ethiopia and Egypt have several similarities. Both societies have witnessed millennia long constructive relations between different religions. In Egypt, the Coptic Church has played a significant role within the Muslim majority society. An example of this is the mediating role that the church has taken over the dispute on the Renaissance Dam (Al Monitor 2014). In Ethiopia, some of the oldest Muslim and Jewish communities live side by side with communities of the Orthodox Ethiopian Church. Their long history, however, has also been filled by disputes. Ayele (1986) notes that during a 7-year famine period, 1066-1072 A.D., in Egypt, the Egyptian Khalifah believed that Ethiopia might have deflected the course of the Nile. Thus, he sent emissaries and gifts to the Ethiopian king to persuade him to let the Nile return to its course (Wallis Budge 1934). The long history between these two main balancing powers of the Nile Basin is pitted with similar incidences, and the historical Egyptian fear over changes in the river course of the Nile has now become a reality through construction of the GERD. The exact impact of the dam on downstream countries is not presently known. Assumedly, during the filling of the reservoir, 11 to 19 km^3 of water per year could be lost. This could cause two million farmers to lose their income during the period of filling the reservoir (Al Jazeera 2013).

In response to these concerns, Ethiopia, Egypt, and Sudan agreed to form an international Panel of Experts after the construction of GERD began, in order to review the GERD's social and environmental impacts on downstream nations. The 10-member panel submitted its first report to the governments in June 2013. The panel found need for more details in the impact assessment of the GERD (International Rivers 2014). In January 2014, after a series of high-level meetings between the three governments, discussions broke down. In April 2014, Ethiopia's Prime Minister invited Egypt and Sudan to another round of talks over the dam. In August 2014, a Tripartite Ministerial-level meeting agreed to set up a Tripartite National Committee (TNC) meeting over the dam. The first TNC meeting took place in September 2014 in Ethiopia (All Africa 2014). At present, Egypt, Ethiopia, and Sudan have agreed to select two European advisory offices to carry out technical studies on the Renaissance Dam and its effects on the Nile water share of the downstream countries (All Africa 2015). Consequently, technical cooperation is leading to increasing political partnership at state level.

(3) At the interstate and global level, nationalism and hydrosolidarity may shape the role global water discourses and politics play in the Nile Basin. Particularly, political processes of deliberation and negotiation in the shaping of general principles and legal norms governing the relationship between riparian states in view of environmental effects and climate change need to be addressed. In economic terms, Ethiopia will most likely see a much needed development boost. The unavoidable expropriations for construction and flooding will, however, increase the urgency of agenda items such as property rights, livelihood, individual petitioning and access to legal remedies. Similarly, culturally motivated land rights

and rights of indigenous populations will inevitably challenge the response capacity of the Ethiopian government to ensure the rights of protected minorities. Once completed, the economic added value generated by the dam will pose a challenge with regard to claims of local social and economic rights and their relationship to foreign investors and loan providers. As a developing country, Ethiopia is under international legal obligation to ensure the economic, social and cultural rights of their citizens progressively and to the maximum of their available resources. Moreover, while multiple stakeholder perspectives are increasingly emphasized in the general discourse on water management and water rights, international agreements provide limited or no legal standing for entities other than states. The paradigm on water management has changed in many respects, but the existing formal framework remains profoundly conservative. Meanwhile, the building of GERD is undertaken in an uncertain international situation. The major actors, Egypt and Ethiopia, subscribe to incompatible legal regimes regarding the Nile. Egypt refers to the 1959 agreement and historically based arguments of custom. In contrast, Ethiopia rejects both the validity and applicability of such claims, referring to the colonial taint of the agreement and the fact that it did not include Ethiopia at its origin. The situation is potentially dangerous as there is virtually no agreement on anything apart from the diplomatic inventions between Egypt, Sudan, and Ethiopia during the last year.

Over the past 40 years, human rights have become a significant part of the established political vocabulary of international actors. In international relations, protecting human rights is a mainstreaming tool and a common denominator capable of bridging different political standpoints. This notion can be both upheld and criticized on a number of different grounds, depending on the choice of perspective. While economic, social, and cultural rights easily can be held to mutually reinforce the most common notions of development, more individually oriented rights can potentially pose a challenge to broader socio-economic development. The utility aspect of development often becomes difficult to reconcile with diligent legal protection of individual human rights. This normative tension between individual human rights based claims and the political priorities of development will be further accentuated with increasing emphasis on sustainability in the discourse, when solidarity with unborn generations is pitted against the immediate needs of today´s poor.

Summarizing Comments

We argue that the seemingly divergent concepts of nationalism and hydrosolidarity can be used together to better understand cultural, social, and political aspects of water management challenges and how these relate to sustainable development. The GERD highlights a number of questions that have relevance beyond the dam itself, such as water sharing in transboundary rivers, collective claim making processes, and economic development globally. Using the GERD as a case study, we identify three different scales for the role of politics in nationalism and hydrosolidarity; everyday politics, state policies, and interstate and global politics. At the individual everyday level, the identity shapes and is shaped by religious beliefs, national narratives, and cultural perceptions of the right to water. Local water organizations as well as NGOs have an important role in water negotiations among community members and claim making vis-à-vis state policy institutions. At the state level, processes of negotiation in formulating and implementing water-related policies become important. These include interactions between state institutions and policies of economic development on one hand, and between these institutions and local organizations and interest groups that are affected by state policies on the other hand. At the interstate and global level, nationalism and hydrosolidarity can shape the potential for global water discourses and politics at play in the Nile basin. Particularly, political processes of deliberation and negotiation in the shaping of general principles and legal norms governing the relationship between riparian states are important.

We also argue that national interests and hydrosolidarity have an important meeting point. For this meeting point to occur we believe that short-term negative implications of water management decisions have to be carefully managed by intensified collaboration in order to reach the more long-term sustainable goals. Thus, the meeting point between

national interests and hydrosolidarity means that advantages and benefits from cooperation to a great extent exceed the benefits that otherwise would have been reached by not collaborating. In case of GERD there is a severe lack of collaboration between Egypt, Sudan, and Ethiopia. Only intensified collaboration and detailed studies on the management of the GERD can bring out benefits that can potentially improve living conditions in all countries within the Nile Basin.

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Aligning Climate Change Adaptation Planning with Adaptive Governance: Lessons from Exeter, NH

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Abstract: Adaptive governance has been recognized as an integrative approach for analyzing the social, institutional, ecologic, and economic aspects of decision-making to build resilience against climate change. Although closely aligned with adaptive co-management and ecosystem management, adaptive governance is a distinct framework that explicitly focuses on decentralized decision-making through social processes such as collaborative learning, networking, and the promotion of cross-sectoral partnerships to enhance adaptive capacity. In this paper, we explore an ongoing engagement process for climate change adaptation planning in Exeter, New Hampshire, and its alignment with key principles of adaptive governance. Climate change poses multiple challenges to Exeter, including increased flooding, reduced low flows, water quality degradation, and associated threats to estuarine ecosystems and public health. Engagement strategies include community conversations, workshops, experiential activities, and a community advisory board comprised of different stakeholder representatives (Citizens' Working Group) collaborating with the scientific team on water resources modeling and scenario analysis. We present important lessons about conveying expectations and timeframes of technical modeling to participants, developing multiple forums for interaction between researchers and other stakeholders, and making climate change locally relevant to residents by drawing connections to the community's experiences, cultural memory, values, and upcoming decisions. This study contributes to the literature on adaptive governance and climate change adaptation by evaluating stakeholder involvement in a local institutional setting, an important arena where adaptation decisions must be deliberated. It is also among the first studies to evaluate the ways in which a climate change adaptation stakeholder engagement process aligns with adaptive governance principles, particularly through boundary objects and experiences.

Keywords: *boundary objects, collaborative planning, community based participatory research, flooding, Integrated Water Resources Management, public health, resilience, transdisciplinary research*

Prior research has described community-based adaptation planning as "a bottom-up strategy that starts with changes and pressures experienced in peoples' daily lives" (Rayner and Malone 1997, 332). Similarly, adaptive governance is a concept that addresses the bottom-up evolution of institutions for the management of shared assets, particularly common pool resources and other forms of natural capital (Hatfield-Dodds et al. 2007). Adaptive governance has been defined as the "evolving and locally context-specific balancing and integration of alternative interests through participatory engagement between governments and communities facilitated by the integration of local and scientific knowledge" (Nelson et al. 2008, 4). It has been recognized as an integrative approach for analyzing the social, institutional, ecologic, and economic aspects of decision-making to build resilience against climate change (Garb et al. 2008; Lynch and Brunner 2010; Raynor and Malone 2000). Although closely aligned with adaptive co-management (Armitage

et al. 2007; 2008; Plummer and Armitage 2007) and ecosystem management (Szaro et al. 1998), adaptive governance is a decentralized decision-making process that uses techniques such as collaborative learning, networking, and promotion of cross-sectoral partnerships (Brunner 2010; Kallis et al. 2009). It is a response to the failure of top-down, expert-driven approaches to decision-making to successfully address complex socioecological problems such as climate change. Adaptive governance "suggests factoring the global climate change problem into thousands of local problems, each of which is more tractable scientifically and politically than the global problem" (Lynch and Brunner 2010, 6). Cash and Moser (2000) underscored the critical gap between the top-down assessments of the Intergovernmental Panel on Climate Change (IPCC) that aim to understand large-scale phenomena and the contextualized initiatives that enable local decision-makers to adapt to the local-scale impacts of climate change. They described the need for decision-support processes that provide: "(1) multiple connections between researchers and decision-makers that cut across various levels (polycentric networks)" of governance; and "(2) sustained and adaptive organizations that allow for iterated interactions between scientists and decision-makers" (Cash and Moser 2000, 242).

It is important to emphasize that adaptive governance, like other governance approaches, utilizes science to inform decision-making. However, adaptive governance is distinguished by the types of knowledge considered to be policy-relevant and the engagement processes through which knowledge is integrated with decision-making (Nelson et al. 2008). Although there is no comprehensive synthesis of best practices for researchers wishing to facilitate adaptive governance through their work, Dietz et al. (2003; 2013) and Nelson et al. (2008) provide guiding principles. These include: 1) clarifying common goals with stakeholders; 2) building on local communication and governance structures; 3) seeking out and integrating local knowledge; 4) balancing complementary knowledge systems (e.g., local knowledge and scientific/external knowledge) to inform planning and policy processes; 5) implementing, evaluating, and refining policy in local contexts; 6) transferring lessons learned across local, regional, and national contexts.

While many studies have explored the viability of an adaptive governance framework for complex and uncertain multi-stakeholder resource management problems, very few studies have evaluated its applicability to community-scale climate change adaptation planning. This study contributes to the literature on adaptive governance and climate change adaptation by evaluating stakeholder involvement in a local institutional setting, an important arena where adaptation decisions must be deliberated. It is among the first studies to evaluate the ways in which a climate change adaptation stakeholder engagement process aligns with adaptive governance principles.

In this paper, we present a case study of an ongoing engagement process developed for the Climate Adaptation Plan for Exeter (CAPE) project. The overall CAPE project objectives are to: (1) develop a science-based, integrated climate change adaptation strategy for Exeter; and (2) implement, evaluate, and document the collaborative planning process and share the project results as a model for other coastal and estuarine communities. In this paper, we focus on the second objective by examining the extent to which our community engagement process aligns with key principles of adaptive governance. We explore adaptive governance as a framework for adaptation planning because stakeholders themselves identified several principles of adaptive governance as valued outcomes of the CAPE project (e.g., bringing together diverse stakeholders, connecting scientists with citizens and community groups, meeting regularly with citizens, and sharing knowledge). Specifically, we address the following research questions in this paper: 1) what were the challenges and opportunities associated with aligning these engagement strategies with adaptive governance principles, and 2) what lessons were learned that might enhance future adaptation planning efforts in community contexts? Documenting our engagement process in a case study format aids in clarifying the social relationships and institutional

factors that will influence the final outcomes of the CAPE project, including which climate change adaptation strategies are ultimately pursued by the community.

Case Study

The Great Bay National Estuary Research Reserve (GBNERR) is located in southeastern NH and includes 20,172 acres of open water, wetlands, and upland zones. The 1,084 mi^2 watershed that drains into the reserve is heavily forested and has extensive wetlands, but is also becoming increasingly urbanized (currently 9% of the watershed area) (Mills 2009). The major climate change stressors in the region include increases in air and water temperatures, sea level rise, and changes in precipitation and runoff patterns, including larger storms and floods.

Our transdisciplinary team comprised of social and biophysical scientists, engineers, and town staff, is undertaking a collaborative planning effort to develop an integrated climate change adaptation strategy for one of the towns situated on a river that drains into GBNERR in order to develop a prototype for managing the developed portions of the watershed under climate change. Specifically, the case study area is the portion of the Town of Exeter in the Exeter/Squamscott River Basin, which includes most of the town's area and is located just upstream of Great Bay (Figure 1). The Squamscott River, tidal in nature, is located downstream of the dam in the center of the downtown.

Exeter's population is approximately 14,000, with over 18% of the population over the age of 65 (U.S. Census 2010). The median household income is $74,350 (NHES 2015), although there is diversity in socioeconomic status and housing conditions. For example, there are approximately

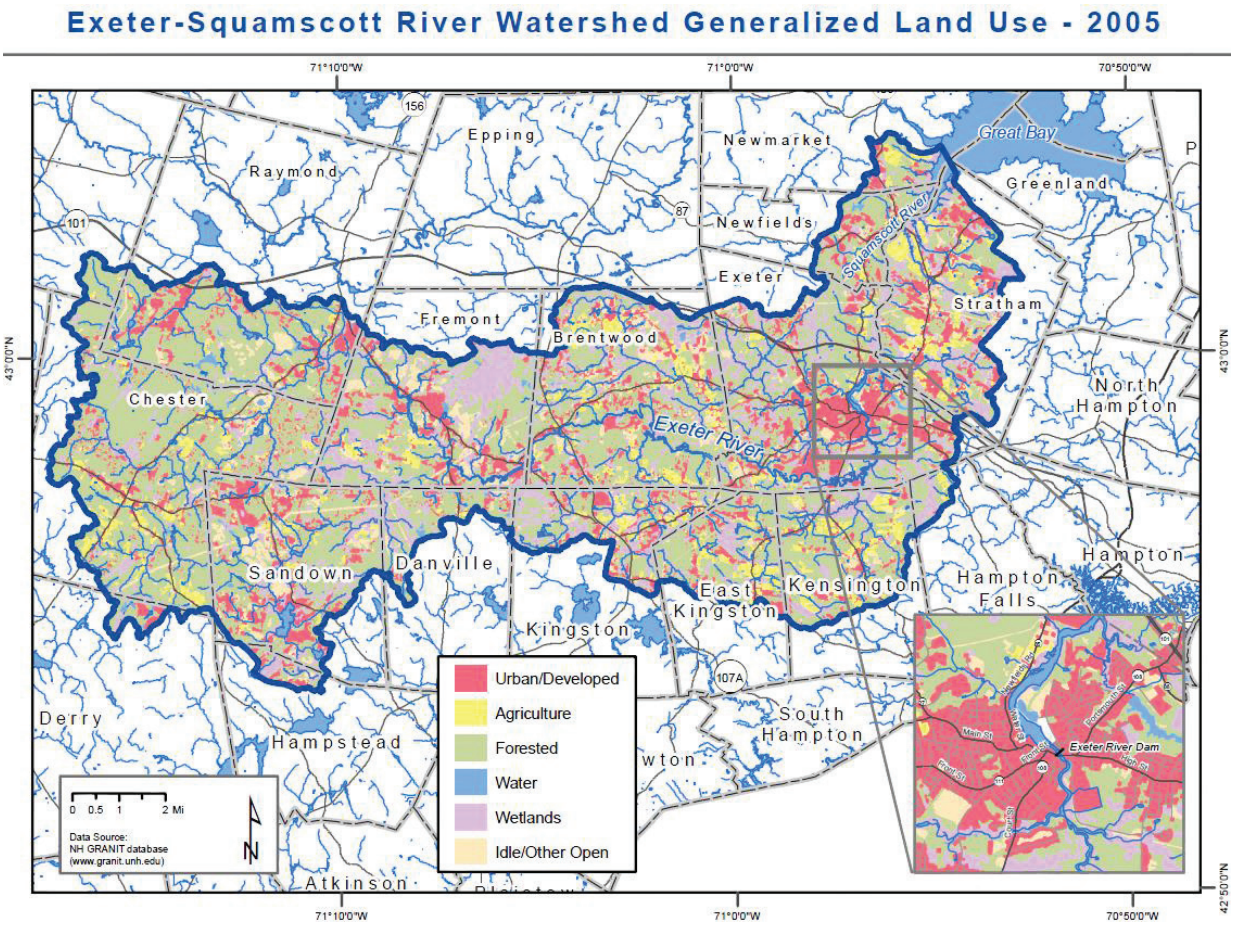


Figure 1. Map of study area. Please visit Wiley Online Library at http://onlinelibrary.wiley.com/ for color version.

901 manufactured housing units, many of which are highly vulnerable to flooding.

Climate change will exacerbate Exeter's present challenges related to: 1) tidal and non-tidal river flooding, 2) stormwater drainage, 3) nonpoint source pollution and water quality, and 4) the protection and restoration of downstream marshes and fisheries. These challenges were identified in the proposal phase by reviewing recent studies for the area (Mills 2009) and consulting with town officials. These stressors related to climate change also have the potential to significantly impact public health (e.g., injuries and illnesses associated with flooding and exposure to contaminated water, the stress associated with possible evacuation, and the risk of being stranded in flooded neighborhoods without access to medical and social services). Since the water-related stressors in the case study area are interconnected, they can be most effectively managed in an integrated fashion. To help translate climate change and sea level rise into impacts on the community, the team employed flood, stormwater, hydrologic, and water quality simulation models. Additionally, they are developing a flood adaptation decision-support tool and an ecosystem process model.

Alignment of Engagement Strategies with Adaptive Governance

To examine the alignment of our engagement strategies with adaptive governance, we will review how each of these strategies functioned as a **boundary object** and/or a **boundary experience**. A **boundary object** is typically described as a product (e.g., map, model, field notes, images, and other types of information) that different stakeholder groups can use in different ways to share knowledge (Bowker and Star 1999) and interact with the study team (Cash et al. 2002; 2006). Boundary objects aid in the translation of information by providing common points of reference for dialogue (Chrisman 1999) and drawing attention to different interpretations and meanings (Fischer and Reeves 1995). Boundary objects can aid decision-making in situations of incomplete knowledge, nonlinearity, and diverse interests (Mollinga 2008; 2010). They can also include intermediate versions of a product that stakeholders can react to and agree upon before the final version is developed (Marick 2014; Star and Griesemer 1989; Wenger 1998). For example, in the CAPE project, several iterations of GIS maps showing locations that were vulnerable to flooding under different climate change scenarios were shared with town staff and other stakeholders. The map content and format were adjusted to reflect stakeholder input, so that the final versions were acceptable to town staff, researchers, and other community members. Boundary objects are flexible enough to adapt to local needs, but retain enough immutable content to maintain integrity across applications (Star and Griesemer 1989; Wenger 1998).

The role of boundary objects in adaptive governance has been widely discussed in the literature (Carlile 2002; Folke et al. 2005; Garb et al. 2008; Fuller 2009; Brunner and Lynch 2010; Crona 2012). Boundary objects are used to develop a shared language that enables stakeholders to cross disciplinary or cultural barriers (Carlisle 2002, 446). They also offer stakeholders a new vocabulary to discuss problems and a foundation for re-framing concepts to align with multiple perspectives (Fuller 2009, as cited in Kallis et al. 2009, 637; Lejano and Ingram 2009). Importantly, this new vocabulary helps to facilitate conversations between scientists and other stakeholders.

A **boundary experience** is a term developed by our engagement team to explicitly call attention to the dynamic and iterative process through which groups of stakeholders share knowledge and co-produce boundary objects with the project team. While this procedural component has been implicit in prior scholarship pertaining to boundary objects (Carlile 2002; Lejano and Ingram 2009; Munaretto et al. 2014), we contend that it is helpful to recognize it explicitly so that the dynamic interplay between process and product - the essence of transformative social learning (Pelling et al. 2008; Parkins and Mitchell 2005) - can be more critically evaluated. We found that some of the greatest challenges and opportunities of our engagement process were situated at this nexus.

Engagement Process

In transdisciplinary research on community resource management problems, there is a growing

expectation for community members to be actively engaged in the research process (Commonwealth of Australia, 2008). The CAPE project utilized a Community Based Participatory Research (CBPR) approach (Israel et al. 2005), in which community stakeholders partner with the research team on all aspects of the project including clarifying goals, refining the methodology, and interpreting results. While CBPR is widely utilized in public health to improve the adoption, implementation, and sustainability of community-based interventions, its application to adaptive governance and its relevance for promoting specific researcher-stakeholder interactions supportive of democratic decision-making remains inadequately explored. Thus, we chose CBPR over other approaches to examine its application to a climate change adaptation planning process, and to enable researchers and stakeholders from different disciplines to learn about how engagement approaches commonly used in public health may translate across sectors to inform water-related decisions.

Specific engagement activities utilized during the first 18-month phase of the project included community conversations, workshops, and experiential activities (e.g., walking groups and field tours). In addition, we created a Citizens' Working Group (CWG) that provided direct feedback to the scientific team on water resources modeling and scenario analysis. Details about specific engagement strategies are described below, and in Table 1.

Community Conversations

The first community-wide CAPE engagement event was held in the spring of 2013, at Exeter High School. This was a "community conversation" in which team members from New Hampshire Listens (NH Listens) designed a deliberative dialogue entitled "Floods, Rains, and Rivers" to explore the community's values and perceived vulnerabilities associated with climate change. NH Listens works with local and statewide partners to bring people together for productive conversations that complement traditional forms of government meetings, such as town hall or school board meetings (NH Listens 2014). Recruitment was conducted through email, announcements at public meetings, advertisements, and personal contact. Additionally, project staff met with several key communities of interest prior to the event. **Communities of interest** are a community of people who share a common interest, goal, or knowledge about an issue (Henri and Pudelko 2003). These included a local retirement community, a resident-owned manufactured housing community, high school students, conservation groups, and a group of mothers with young children. In addition, staff of NH Listens trained a group of high school students as facilitators who helped to lead each small group discussion.

The participants (n=63) were split into nine groups, each of which was led by a facilitator from NH Listens and a youth facilitator to explore different issues and challenges facing the Exeter community. This event was designed as an opportunity for stakeholders to clarify goals, identify local assets, and discuss ideas to effectively plan for a changing climate. The narratives from the conversation were analyzed qualitatively and grouped into themes. Evaluation surveys indicated that the community conversation served as an effective boundary experience in terms of enabling participants to consider different perspectives and become better informed about local climate change issues. Of the survey respondents (n=40), 75% reported that they would participate in another community conversation.

Another activity initiated at this event was a mapping exercise in which participants identified "areas of importance" or locations where they perceived vulnerabilities for people, infrastructure, and natural resources. Participants marked these locations on large paper maps, which were subsequently developed into a GIS. This activity provided a visual snapshot of town assets and resources that could be impacted by flooding, and also generated a discussion in which at-risk populations (e.g., older adults) who might suffer stresses associated with extreme weather events were identified.

These tangible products served as starting points for developing indicators such as the location, depth, and areal extent of flooding of infrastructure, natural resources, and community places to inform the flood modeling. They have also proven useful

Table 1. Summary of lessons learned regarding engagement strategies, their function as boundary objects/experiences, and alignment with adaptive governance principles.

Engagement Strategy	Role as Boundary Object/Boundary Experience	Alignment with Adaptive Governance Principles
Community Conversations	• Explores the community's values and perceived vulnerabilities associated with climate change • Provides a forum for stakeholders to share perspectives, identify local assets, needs, and ideas to effectively plan for a changing climate • Generates interest in more sustained participation for subsets of stakeholders (e.g., Citizens' Working Group) • Promotes inter-generational dialogue • Initiates co-production of boundary objects such as maps, narratives, and inputs for models	• Clarifies common goals and different perspectives with stakeholders. • Promotes collaborative learning and social networking • Develops a foundation for analytic deliberation (structured dialogue involving scientists, end-users, and interested citizens, informed by analysis of key information about socio-ecological systems (Dietz 2003, 2013)
Workshops with Town Staff	• Enables the team to check in regularly with town decision-makers, and to identify individuals who wish to be more involved in certain stages of the modeling process (e.g., checking discrepancies) • Provides a mechanism for piloting and refining boundary objects (e.g., testing educational materials, explaining preliminary model results) • Promotes opportunities for the CWG and the research team to interact with town leadership	• Builds on local governance and communication structures • Enables climate change adaptation planning to be linked to specific local decisions • Supports multiple connections between researchers and decision-makers • Helps to ensure that scientific outputs will be viewed as credible, legitimate, and salient (Cash et al. 2002)
Experiential Activities	• Connects technical and non-technical stakeholders • Provides a 'bridge' to link various boundary objects with lived experiences (e.g., by connecting scientific information with community values and cultural memories; creating a diverse portfolio of activities that are not entirely dependent on model results) • Aligns with Carlile's (2002) pragmatic view of boundary objects as a means of representing, learning about, and transforming knowledge to support a public policy process	• Integrates complementary knowledge systems (e.g., local knowledge and scientific/external input) to inform planning and policy processes • Promotes collaborative learning and networking • Supports iterative interactions between scientists and decision-makers
Citizens' Working Group (CWG)	• Provides a forum for 'vetting' boundary objects and experiences and tailoring them for different groups • The CAPE CWG expressed interest in learning about what other communities in the state are doing in terms of hazard mitigation and climate adaptation planning. For example, other communities have enrolled in the National Flood Insurance Program's Community Rating System, which reduces insurance premiums in jurisdictions in which flood hazard mitigation activities are implemented (FEMA, 2014)	• Clarifies common goals and different perspectives with stakeholders. • Builds on local communication and governance structures • Facilitates connections between researchers and decision-makers across institutional levels (e.g., Board of Selectmen, Town Staff, clergy, and representatives of manufactured housing communities) • Integrates complementary knowledge systems • Supports transfer/exchange of knowledge with other communities
Modeling and Scenario Analysis	• Provide a scientific basis for adaptation planning; highly valued by stakeholders • Models may be communicated and shared with diverse groups by 'nesting' them within a portfolio of boundary experiences (e.g., community conversations, experiential activities, workshops) and linking them to other boundary objects, such as a decision support tool • Nesting may support adaptive governance by allowing stakeholders to connect future scenarios to past and present experiences, cultural memories, and town values	• Integrates complementary knowledge systems • Provides a foundation to support policy implementation and evaluation

as boundary objects because they translate local knowledge that the technical team can incorporate into scientific modeling efforts. The technical models have provided quantitative details about the depth and damage caused by present and potential future flooding, which augments this qualitative local knowledge.

This dynamic interplay of knowledge was iteratively improved through subsequent meetings and field tours with town staff. Other locations in the town where flood damages occur or could occur were identified, enabling the list of vulnerabilities to be continuously expanded and specified. For example, some of these additional locations included sewage pump stations, recreation areas, several culverts, and the new Gilman Pond well. Town emergency management staff identified areas that are cut off from emergency services during flood events. The team also mapped wetlands that will be threatened by increased riverine and coastal flooding as well as permanent sea level rise. Additional indicators of flood damages under present and future climates include the direct expected value of property and content damage costs to buildings, as well as indirect costs, such as evacuation expenses and lost work time.

Citizens' Working Group (CWG)

The CWG is a local stakeholder advisory board (n=20) designed to meet with the CAPE team on a regular basis. It includes representatives from the Exeter Select Board, local businesses, non-profits, faith-based organizations, the Exeter River Study Committee, and residents of various neighborhoods. Residents from manufactured housing communities, among the most vulnerable to flooding, are also represented. Participants were recruited at our community conversation; anyone interested was invited to join. Additional members were recruited through the University of New Hampshire's Cooperative Extension program.

This citizen input group was designed to enable the CAPE modeling team to develop products that are legitimate, credible, and salient for the community in order to align with the functions of boundary objects described by Cash et al. (2002). This resulted in boundary products that were useful for priority audiences: the town's decision-makers and the town boards that advise them. Nine meetings were held over the first 18 months of the project. Evaluation surveys demonstrated that the overall response to the CAPE team's preliminary models was good; the team scored an average of '4' on a scale ranging from 1 (poor) to 5 (best). Notably, participants reported substantial improvement in the researchers' use of clear language over the 18 months (e.g., less technical jargon, more understandable words). Prior research has shown that clear language is a key feature of successful boundary objects (Clark et al. 2011). Respondents commented that the information being produced by the CAPE project was extremely important to the town.

Workshops with Town Staff

In 2012 and 2013, the CAPE team held meetings with town staff and CWG members. The 2012 meeting provided an opportunity for stakeholders and researchers to interact and discuss prior research about the impacts of climate change to the region. In 2013, the CAPE team hosted a half-day meeting at Exeter Town Hall to present the project's progress during its first year. This included reviewing the first year's engagement activities, discussing preliminary findings, and envisioning next steps. The primary audience was town officials, staff, and civic leaders, with approximately 25 people attending each workshop. Survey data (n=18) indicated that participants felt the meetings were successful overall. For example, using an ordinal rating scale, participants at the 2013 meeting reported that CAPE was very successful at promoting greater communication between groups in Exeter, increasing awareness of natural resources and how they relate to climate change impacts, and improving communication between scientists and citizens. Survey results also indicated that the workshop enabled participants to better comprehend both technical and outreach components of the project. When asked, "How can CAPE help you do your work/become a more informed citizen?", common themes among answers were to provide more information about the effect of climate change on natural resources such as tidal marshes, and provide information regarding the economic and social costs of storm

impacts. Participants also wrote in suggestions for improving graphs and educational presentations that the team has since adopted. Another outcome has been the growing involvement of other town staff (such as emergency services personnel) fostered through informal networking opportunities at these workshops (Figure 2).

Experiential Activities

Aligning with Lejano and Ingram's (2009) view that successful collaboration depends upon continuous trust-building activities the CAPE team engaged in several activities to connect climate change to local experiences, cultural memory, and values. Two examples are described below.

a) ***Tour of Vulnerable Locations with Exeter Assistant Fire Chief.*** In August 2014, the Exeter Town Planner arranged a tour of the town with the Assistant Chief of the Exeter Fire Department to review vulnerable flooding locations. The group spent several hours identifying roads and homes that had experienced flooding since 1995. This tour was very valuable to the technical team because it enabled them to ground-truth the model results regarding the extent and depth of floods. Additionally, this tour provided important information about the flood response actions of residents that informed the development of an adaptation decision-support tool that the team is currently completing. For instance, the tour revealed some home flood-proofing measures that residents had adopted (e.g., sump pumps), which can be incorporated into the tool as an adaptation option. In addition, the tour enabled the project team to learn about the emergency services the town provides during floods, such as boats, rafts, swift-water rescue operations, and a limited number of generators to deal with power cuts that often coincide with flood events. During recent storms, residents living in certain neighborhoods have been stranded due to flooding of surrounding roads (Figure 3).

These images and narratives help capture the town's 'cultural memory' of these events. The experiences and images shared by the Assistant Fire Chief during the tour are types of boundary objects that will enable diverse stakeholders and the modeling team to consider how climate change may directly impact residents' daily lives.

b) ***Marsh Walk for Flood Elevations.*** In November 2014, the CAPE team led a walk with the CWG at a community park along the tidal Squamscott River to mark flood elevations with different colored flags representing three different sea level rise and coastal flooding scenarios (Figure 4).

This activity served as a very meaningful boundary experience. Several CWG members commented on the importance of being together outdoors, sharing knowledge about the importance of the marsh for ecosystem health, and using the flags to visualize the effects of different scenarios on this critical community resource.



Figure 2. The CAPE team delivers a Year 1 in Review presentation to the town on December 12, 2013.



Figure 3. Emergency personnel on Court Street during the March 16, 2010 storm.



Figure 4. The CAPE team and CWG members mark current and future flood height elevations associated with different climate change scenarios at Swasey Parkway.

This activity not only helped the team to connect with the CWG, but also created an interactive process that reinforced the community's values. During the initial community conversations, residents emphasized the importance of the marsh ecosystem as a nursery for fish and other wildlife (including the alewife, the town's symbol) and identified Swasey Parkway as an important place to exercise, spend time outdoors, and enjoy nature. Evaluation of experiential activities was conducted using visual analysis methods (Knoblauch et al. 2008) in which photographs were interpreted by participants and members of the research team.

Modeling and Scenario Analysis

As described previously, several hydrologic, hydraulic, water quality and ecosystem models are being developed by the CAPE team with input from CWG members and town staff to describe present conditions and how they might change under various climate and land use change scenarios (Figure 5). The models will also be used to explore adaptation strategies that the town can employ to respond to changes in climate and land use in the Exeter-Squamscott River watershed over time.

During the first 18 months of the project, the CWG was primarily involved with evaluating outputs from the models that predict the riverine and coastal flooding, urban drainage, water quality, and ecosystem impacts of climate change without any additional control or adaptation measures. Figure 5 displays the modeling sequence employed to determine climate change impacts to Exeter and the linkages with a decision-support tool to guide adaptation decisions. Since few municipal-scale climate-change adaptation projects have integrated models of flooding hazards of riverine, stormwater and coastal origin combined with water quality, land use, and ecological sub-models, our analysis of stakeholder participation throughout the modeling process is critical for guiding subsequent integrated modeling efforts (Figure 5).

The involvement of the CWG and other local experts (such as the town's engineer, planner, and public works staff) in the model review process enabled discrepancies in the model results to be identified and corrected. For instance, these consultations prompted the team to collect water surface elevation data in the Squamscott River as well as use a different hourly rainfall distribution for the 24-hour design storms used to simulate flooding from extreme precipitation events under different climate change scenarios. While this complex integrated modeling approach helps to provide credible scientific inputs to the adaptation planning process, delays in the modeling process have also made the engagement process more challenging.

Discussion

Several important lessons from this ongoing study could benefit future climate change adaptation studies at the community scale. For example, various actions could have been taken

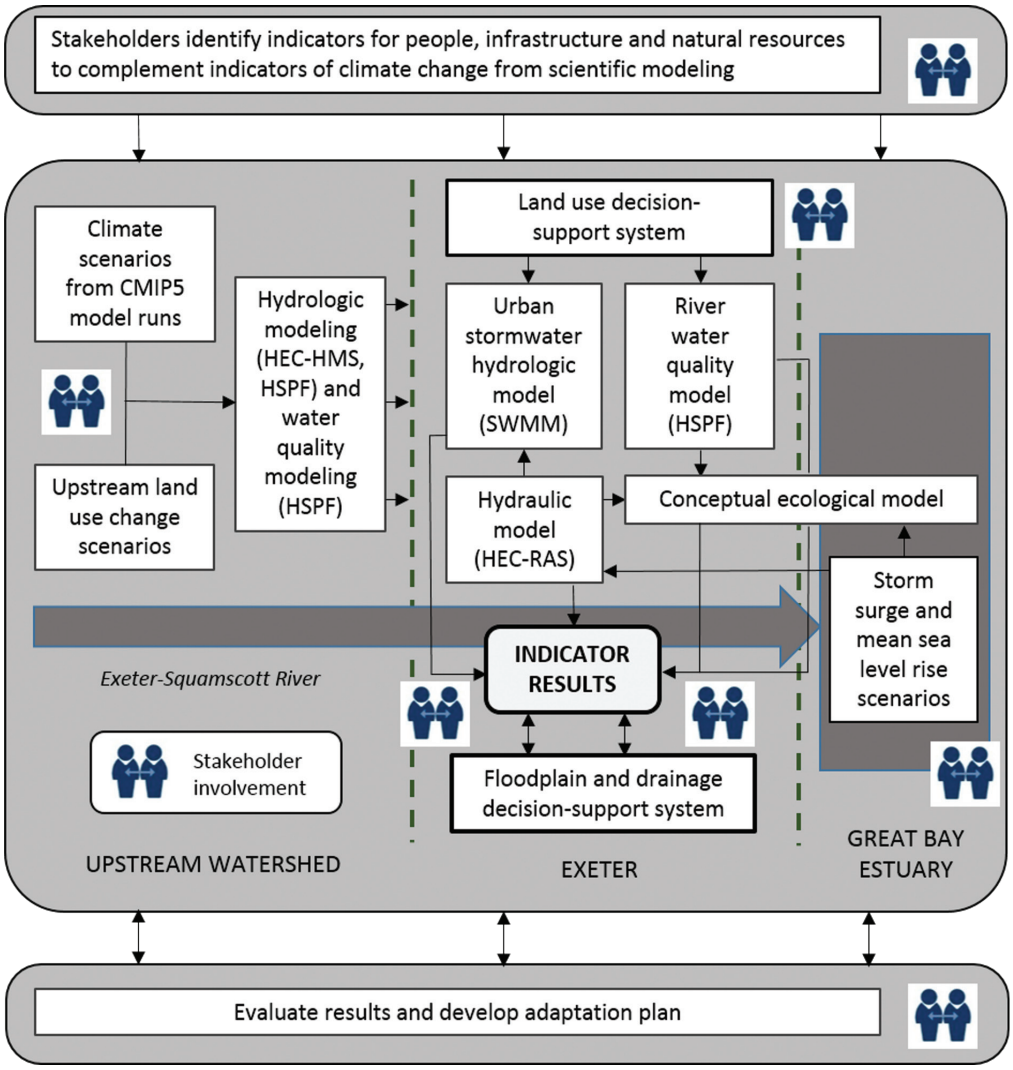


Figure 5. Stakeholder involvement with simulation modeling and decision-support tools - flow chart.
- CMIP = Coupled Model Intercomparison Project
- HSPF = Hydrological Simulation Program – Fortran
- HEC-HMS = Hydrologic Engineering Center – Hydrologic Modeling System
- SWMM = USEPA Stormwater Management Model
- HEC-RAS = Hydrologic Engineering Center – River Analysis System

earlier to better manage stakeholder expectations during the intensive modeling process. Since our initial framing of the CWG's role emphasized the simulation modeling component, many stakeholders came to view the completion of modeling as a necessary condition for any meaningful dialogue about the project. In addition, many CWG members perceived their primary role to be verifying the models and interpreting the results, thus limiting their participation in other aspects of the project in which their contributions would have been beneficial. Because of this perception, when model results were not still complete by the fall of 2014 due to the complexity of model integration and calibration, the CWG requested that meetings be suspended until results were complete.

An important lesson from this experience was that we unintentionally focused on a particular set of boundary objects (the models) to such an extent that they became barriers to designing boundary experiences instead of enabling them. Notably, neither the tour with the Assistant Fire Chief nor the flood elevation walk were

predicated on complete model results, and these types of boundary experiences could have been intentionally designed into the engagement process from the beginning.

A related issue is that although the town's interest in scientific models was a catalyst for bringing stakeholders together, it was sometimes challenging to engage the CWG and other stakeholders in sharing their local knowledge and cultural memories. In accordance with adaptive governance principles (Dietz et al. 2003; Nelson et al. 2008; Nilsson and Swartling 2009; Simonsen 2010; Brunner 2010), the CAPE team believed that local knowledge and shared experiences would be essential to the development and implementation of the adaptation plan. However, as observed in other studies (Dietz 2013; Dietz et al. 2003), stakeholders may have been more familiar with a top-down, expert-driven process in which scientific outputs are viewed as a panacea for resolving complexities and reducing uncertainties, rather than as inputs for analytic deliberation.

Other scholars provide valuable lessons pertaining to the challenges inherent in aligning collaborative planning with adaptive governance in local contexts (Porthin et al. 2013; Proctor and Drechsler 2006; Simonsen 2010; Lynch and Brunner 2010; Borisova 2012). For example, Bronen and Chapin (2013) examined governance and institutional strategies for climate-induced community relocations in Alaska. They learned that community residents and government agencies concurred that relocation was the only adaptation strategy that can protect lives under extreme environmental threats. The authors identified policy changes and components of a toolkit that could facilitate community-based adaptation when environmental events threaten people's lives. Policy changes included the creation of an adaptive governance framework to offer communities a continuum of responses ranging from protection in their current location to relocation to new sites. In alignment with adaptive governance, key components of the toolkit included local leadership and integration of social and ecological well-being into adaptation planning.

Similar findings have been reported internationally (e.g., Kallis et al. 2009). For example, in a study of adaptive governance in Pakistan, Mian (2014) noted that overall flood governance may not improve unless there are better cross-linkages between key actors and networks across the disaster prevention/management continuum. The authors noted the importance of strong leadership from a local champion for promoting adaptive governance in communities. We learned a similar lesson in the CAPE study, as the Town Planner and the Assistant Fire Chief played critical roles in facilitating linkages between various stakeholder groups and the research team.

Young and Lipton (2006) studied social relationships and civic participation in an Andean community facing climate change impacts to their agricultural livelihoods. They found that participation in local institutions was invaluable for both individual households and the community's social capital (Young and Lipton 2006; Mayer 2002). Furthermore, they found many informal institutions operating within the community through personal ties and mutual assistance. High levels of civic participation and informal ties were also found in the CAPE project, as evidenced by the high number of community organizations in which the stakeholders participated (including town government, conservation committees, religious groups, youth leadership organizations, education, and emergency response). Social network analysis is being used to further evaluate these relationships. Research suggests that this capacity for collective action through community institutions may play an important role in plan implementation and compliance (Robbins 1998).

In a study focused on developing a water management plan in Florida, Borisova et al. (2012) designed a collaborative process to build a better understanding of stakeholder perceptions of water quality problems and water policy. The authors found that stakeholder conflicts were associated with perceived flaws in the structural and procedural characteristics of the stakeholder engagement process (e.g., suboptimal watershed stakeholder representation on committees, limitations in information

sharing between stakeholder groups). Notably, the CAPE project achieved good representation from town staff and certain community groups initially, but faced similar challenges and trade-offs in sustaining participation from these groups while simultaneously trying to extend outreach efforts to other groups (such as local businesses) who were under-represented.

Mollinga (2008; 2010) and White et al. (2008) emphasize that transdisciplinary research projects require the integration of modeling, mapping, and communication products to support adaptive governance, and that such integration requires a concerted, long-term effort. Although the CAPE team made concerted efforts to develop these different types of boundary objects concurrently, it was a challenge to do so within a two-year time frame given the complexity of the modeling process.

Lastly, we turn to the question of transferring lessons learned from the CAPE project to other contexts. Although Exeter is a relatively small community, there is a diversity of stakeholder interests, including homeowners and businesses with high-value waterfront properties, other large land owners, conservation groups, citizen cooperatives, and manufactured housing communities. Thus, many of the lessons learned from the CAPE project may apply to other communities with similar interest groups. However, one group that is notably absent in CAPE is the agricultural sector, which can be a powerful voice in other communities (Young and Lipton 2006) and would have added complexity to the outreach process. Similarly, we did not face challenges associated with non-English speaking populations or other literacy barriers, which would require additional resources.

Another benefit of working in a geographically small community that may limit the transferability of our experiences to other contexts is that the travel time required to meet with different stakeholder groups is minimized. The CAPE team was able to visit different locations easily, and the community has a distinct town center that provides accessible meeting places for engagement activities. In larger or more dispersed communities, this may be significantly more challenging.

To facilitate learning across contexts, the CAPE team participated in a Science Collaborative Transfer Project workshop funded by NOAA's National Estuarine Reserve Research System (NERRS). One of the key lessons shared was the importance of making climate change locally relevant (e.g., using boundary objects and experiences to draw connections to local decisions and values). However, we also learned that it is important to be sensitive to possible negative connotations that can arise from media portrayals of "flood-impacted communities" and potential economic losses in real estate value.

One strategy that can be helpful regardless of community size is to seek out individual "point-persons" who are trusted members of the community and/or represent particular stakeholder interests. We recommend taking adequate time at the beginning of a project to identify important social networks and point-persons, so that engagement resources can be targeted towards cultivating these relationships. For example, in the CAPE project, the Town Planner, the CWG, clergypersons, Cooperative Extension professionals, and representatives of manufactured housing communities played critical roles in extending outreach efforts.

Conclusion

The CAPE project has generated many learning opportunities for stakeholders and the project team due to the complex subject matter and the necessity of coordinating intensive technical modeling with community engagement. The engagement process aligned with several important principles of adaptive governance, including clarifying common goals with stakeholders, building on local communication and governance structures, and balancing the informational needs of different stakeholders through boundary objects and experiences that integrate complementary knowledge systems. Other adaptive governance principles, such as implementing, evaluating, and refining policy in local contexts and transferring lessons learned across contexts, were not as evident during the first phase of the project and will require more time to assess as the project evolves. For example, we have not yet reached the stage of the project in which we review the

complete model results with the community and discuss adaptation options.

In summary, lessons learned from the CAPE project underscore the importance of having contingency plans to keep participants engaged if models are delayed, creating multiple forums for interaction between researchers and community members, and making climate change locally relevant through a dynamic interplay between boundary objects and boundary experiences (e.g., drawing connections to local experiences, cultural memory, values, and upcoming decisions).

By developing a more comprehensive portfolio of boundary objects, as well as emphasizing the importance of designing boundary experiences for analytic deliberation, our team can better support Exeter in its climate adaptation planning efforts while simultaneously enabling other communities to learn from this process.

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