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Introduction

The classification and understanding of climate change as a phenomenon was framed in the Natural Hazards tradition. However, recent literature regarding human-ecosystem linked adaptation to climate change builds on the best of the Natural Hazards tradition without suffering from its inherent technocentric flaws. This literature has a more ecocentric focus and framework-- it utilizes much hazards theory, but develops new frameworks for inquiry based upon sustainability, resilience, and broad democratic-based adaptation possibilities (Holling 1978, O'Riordan 1976). As climate change is both a natural and technological hazard, it is unlike other hazards typically examined in geographic inquiry (Burton, et al. 1993). Climate change has relatively-slow onset but will be a pervasive condition. It is imbedded in and crosses multiple spatial and temporal scales, and while occurring on the global level, must also be mitigated and adapted to on the local level. The complexity of the multiple spatial and temporal features of projected anthropogenic climate change: more extreme weather events, higher average temperatures, and higher variability, ripple successively through liked human and natural systems (Kates 1985, Smit et al. 2000). This has forced a new sub-field to develop and alternative frameworks to emerge that can recognize the inherent, as well as benefit from, uncertainty. In natural hazards, uncertainty is something to be minimized, but in the climate adaptation sub-field, it is something to be better understood and managed.

This paper will explore the contribution of the Natural Hazards field to environmental management and Geography while also describing new frameworks, evolved from traditional hazards inquiry into the climate change vulnerability and adaptation field. It will also describe the author's development of an empirically-based research program to explore adaptation of U.S. water resources management to the uncertainty of climate change and variability in the U.S. at the river basin scale. Water resources managers need to proactively plan for current climate variability as well as greenhouse gas-induced climate change in order to safely, efficiently, and equitably allocate water resources among human and ecosystem needs. It is important for basin decision-makers to envision future basin water demands under the uncertainty of climate variability and change for basin infrastructure operation, policy adjustment, and long-term planning. This may involve reassessing and ultimately changing existing water use priorities and paradigms as finite and variable delivery of water changes under increasingly complex human institutional, population, and environmental maintenance circumstances. The researcher has chosen to investigate four representative U.S. basins: the Colorado River, the Platte River, and the Delaware River, as well as the Everglades, in order to gain a diverse national perspective of water management adaptation to climate variability and change. A research structure based upon the IPCC-derived Adaptation Policy Frameworks enables the researcher to investigate how basin physical and institutional attributes influence the integration of climatic uncertainty into water management. This research utilizes qualitative methods, including interviews and questionnaires,

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to survey diverse basin stakeholders. The study will generalize from the specific to provide lessons learned in order to better inform more sustainable and equitable U.S. water management.

Climate Change as a Hazard

For individuals familiar with common natural hazards, such as floods and tropical cyclones, it is found that one the best predictors of an effective mitigating response is personal experience with such an event (Tobin and Montz 1997). The recency, magnitude, and recurrence interval also have a role in the perception of typical hazard events. This includes a fundamental assumption that the future will be similar to the past. Crisis episodes additionally play a role in hazard response as collective action is energized after a catastrophic event. Rapid policy, legislative and infrastructural changes to the status quo often take place after such a calamity. However, the effect of experience can also be limiting, as decision-makers use past knowledge of their experiences to choose an alternative among many for what they view as the best course of action (Burton et al. 1993).

Considering the above caveats, global climate variability and change presents a particularly difficult challenge for decision-making response, even for experienced water managers accustomed to fluctuations in hydrologic delivery and its accompanying water management adjustments. Variations in climate in the 21st Century, due to both green-house gas-induced climate change and existing nested climate variability, present a new type of challenge to water managers as they cannot necessarily base future management decisions on what was effective in the past. Although global circulation models (GCMs) have been reasonably accurate in projecting the global consequences of climate change and variability, regional climate models (RCMs) are in their infancy and are still a largely imperfect tool (IPCC 2001a). Although the technology is advancing quickly to integrate climate decision-making into water, there is still much room for policy and scenario developments that address the implications of catastrophic and gradual changes of climate on the hydrologic delivery of water as well as its concomitant effects on water allocation and management.

The 21st Century will be a time of great uncertainty and adaptation to climate change due to the resultant impacts on hydrology in the United States. Water managers and basin stakeholders should plan for a drought/flood emergency before water scarcity/abundance causes inadvertent under-over-allocations of water resources to undesirable uses in times of crisis (Baron et al. 2002, Hurd et al. 1999). Societal adaptation to environmental conditions is composed of the actions of society, individuals, groups and governments and is motivated by factors such as the protection of economic interests and the improvement of safety (Adger et al. 2005, Vorosmarty et al. 2000). Non-climate conditions also influence the sensitivity of linked ecological-societal systems and the types of adjustments made. These systems adapt to various stimuli, both climate and other catalysts, which interact to either exacerbate or ameliorate conditions (Smit et al. 2000). Exceeding the limits of social resiliency through denial of climatic reality will lead to agricultural production declines, financial failures, collapse of ecological and social support systems, and regional displacement and out-migration from vulnerable regions. The most gradual and tolerable response to climate change will come as a result of a well-informed public making collective decisions about the future of U.S. water resources allocation (Adger et al. 2005, Stakhiv 1998).

Adaptation Policy Frameworks for Water Management

Smit et al. (2000) claim that for managed systems, like the river basins chosen for this study, there is much opportunity for implementing adaptive measures in anticipation of climate change impacts. Information regarding climate change is critical for undertaking adaptation in such a context. Adaptations in highly managed systems are as much in response to anticipation of climate change impacts as they are to the climate change impacts themselves (Smit et al. 2000). Smit and Wandel (2006) and Keskitalo (2004) describe an Intergovernmental Panel on Climate Change (IPCC)-based framework for assessing adaptation in a region in order to develop locally customized adaptations to environmental change for their individual ecosystem and linked institution(s). Under this framework, the first objective of a study should be to observe the ways in which the physical environment is expected to change, as seen by a community stakeholders experience changing these conditions. This assures a focus on what is important to the community, rather than what the researcher assumes to be important or a focus on what data and information is currently available. A stakeholder analysis is necessary for understanding the institutional landscape, as a community's concerns and understanding of basin resources is critical to assigning importance and prioritization to resources (Keskitalo 2004). This framework then necessitates a bottom-up assessment and documentation of decision-making through which future adaptation to climate change can be integrated. The motivation behind this type of study is to explore what can be accomplished practically and to ameliorate vulnerability and local barriers to implementation. Accordingly, approaching this framework on a larger scale involves cross-community (and, cross-basin) comparisons. The final goal of such large scale research is to identify what features of communities and their linked environments facilitate or ameliorate vulnerabilities and what adaptive strategies have been effective in context (Smit and Wandel 2006).

Selection of the Study River Basins

The goal of this research is to provide an in-depth perspective on the risks of, and on adaptation to, the perceived effects of climate variability and change on the water resources management in four large, representative U.S. river basins: the Colorado River, the Platte River, and the Delaware River Basins as well as the Everglades. The physical environment and institutional structure(s) of each basin will influence the adaptations chosen for water management. The researcher is particularly interested in how climate information is used by decision-makers to adapt and formulate individual basins' water management strategies.

Changes in regional hydrologic conditions due to greenhouse gas-induced climate change will have varied but uncertain effects on society and ecosystems in the United States (Easterling et al. 2000, Hurd et al. 1999, IPCC 2001b.). Addressing current climate variability will prepare for future impacts on hydrology due to climate change (Waggoner 1991). Stakhiv (1998) claims that there is no specific set of actions, policies, or management measures needed to explicitly address climate change. Traditional and newly evolving methods of water resources management are viewed as applicable to both current climate variability and all but the most extreme scenarios modeled under double-CO_2 climates.

Four large, nationally important river basins have been chosen for this study due to their varied geographic areas and land use, hydrology and water use differences, multi-state or single

state nature, and regional differences as well as the researcher's familiarity with their characteristics and structure. The researcher completed her undergraduate thesis relating to the Colorado River, her Master's thesis on the Everglades, was born and raised in the Delaware River watershed, and has extensively researched the Platte River Basin. This background on each of the study basins is invaluable to understanding underlying geographies, selecting institutions within the basins that are most relevant for compiling meeting observations and recruiting interview participants, making initial study contacts with basin decision-makers, and negotiating schedules and associated travel plans. When choosing field sites for a study, it is important for the researcher to recognize and reconcile his/her inherent strengths and capacity to fairly and objectively conduct empirical research.

The Colorado River and Platte River Basins are dependent upon water from snowmelt that varies from year to year. States in the Colorado River Basin allocated the River's water in the 1922 Colorado River Compact. The Basin has a long history of litigation, especially between states and between the Upper and Lower Basins. The ENSO events in the early 1980s and the 2004 drought highlighted the need for proactive water allocation in times of excess precipitation and drought (Pielke et al. 2005, Pulwarty and Melis 2001, Service 2004). Likewise, the Platte River, on which Nebraska depends for the majority of its irrigation water, is dependent upon snowpack from the states of Wyoming and Colorado (NRC 2005). Water resource shortages and concerns under current conditions highlight the circumstances of numerous similar U.S. basins to climate variability and change. Indeed, watersheds with the greatest vulnerability to the variations in climate are located overwhelmingly in the West (Hurd et al. 1999). Current water management system inadequacies, like insufficient instream flow to maintain ecosystems and endangered species, and over-allocation of irrigation water under current climatic variability, underscore the difficulties that may result due to future anthropogenic climate change. Snowpack, both containing less SWE and melting earlier in the season, would decrease water supplies to already water strapped basins like the Colorado and Platte Rivers (Rowe et al. 1994, Waggoner 1991, Vorosmarty et al. 2000).

The Everglades in South Florida and the Delaware River Basin, though located in humid temperate and subtropical climate regimes, are not immune to the impacts of climate change. Sea-level rise and changes in precipitation delivery will occur in these regions. Projected impacts include the inundation of land surface, saltwater intrusion to aquifers, increased/decreased salinity in estuaries, drought/flooding, and projected increases in extreme storm and hurricane frequency and severity (Easterling et al. 2000, Mulholland et al. 1997). These effects, coupled with large and rapidly increasing human populations and concentrated urbanized land cover, will make water resources and their coupled human populations more vulnerable to the effects of climate change (Hurd et al. 1999).

Ongoing Research Program

The research questions for this study query how water resource decision-makers in four large U.S. river basins use climate information to formulate management adaptation strategies. They include:

- What climatic and hence water supply changes do basin stakeholders expect for the river basin under future predicted climate change?

- What models, planning tools, and management strategies have been planned, or implemented to better understand and plan for climate variability and change?
- What water resource management strategies are planned or have been implemented to address the implications of climate change in each basin?

The ultimate objective of this research is to elucidate the uniqueness of the adaptation of water resources management under climate change for each basin as well as enable the researcher to generalize from the specific to assess what adaptation strategies worked in context for each of the study basins and hence draw some lessons learned from the four basins for application to the U.S. as a whole.

For each river basin, ten basin stakeholders are being invited to participate in the study as interview subjects. The researcher has striven to represent the diversity of basin views by selecting equally from state and federal government officials, agency managers and scientists, industry representatives, non-governmental organization (NGO) representatives, Native American groups, and members of the public. Due to the logistics of conducting such in person and phone interviews, ten per basin was chosen as both feasible in the time allotted and manageable for compiling information.

Proportional randomly sampled surveys are being used to complement the data collected through basin interviews. The researcher draws samples of the stakeholders relative to the proportion of each exclusive basin decision-maker group. Approximately 15-20 persons per basin are being selected to participate. This data is being collected in a closed manner, in comparison to the more open interview format.

This data is being compiled and sorted based upon basin and stakeholder type. In order to assess and compare water management in such diverse systems, a standardized rubric had to be selected. Smit et al. (1999) describe a framework for assessing adaptation to climate change specifying three core elements: adaptation to what?, who or what adapts?, and how does this adaptation occur? The authors recommend general differentiated concepts and attributes for assessing how adaptations occur. These include purposefulness (spontaneous/automatic or planned/strategic), timing (anticipatory or reactive), temporal scope (short term or long term), spatial scope (localized or widespread), function/effects (prevent, tolerate, change, restore, etc.), form (institutional, technological, legal, etc.), and performance (cost, implementability, equity, etc.). Most of these attributes are descriptive and are intended to separate out the different forms of adaptation selected (See Figure 1).

Preliminary Findings

Study findings, to date, indicate U.S. water management is largely reactive to climatic stressors as opposed to proactive in examining the full range of hydroclimatic variability for water resource planning and management purposes. From a sample of what will be a more comprehensive and extensive dataset at the completion of the study, it appears that the Colorado Basin is the most advanced in terms of addressing the impacts of climate variability and change on basin water resources. This is not to say that the basin's institutions are effectively adapted to contend with the complex issues of climate change, but that for nearly one hundred years the Colorado Basin has contended with an over-allocated water resource in a dry climate, and therefore seems to have a head start. Due to a severe drought, lasting over the past eight years to

the present date, and due to the recently signed Seven States Agreement addressing the uncertainty of hydrologic water delivery and allocation, climactic uncertainty has been a prominent topic of discussion at a number of Basin conferences and public meetings. Alternately, the Delaware River Basin is reputed to have the most comprehensive interstate river basin compact in the Nation. Since the 1960s, when New York City attempted to commandeer the Delaware's flow from downstream users during an extreme drought, the Delaware River Basin Commission has been working to develop reservoir capacity, develop instream flow allocations, and equitably apportion water resources in the basin while managing and improving water quality. However, as of this date, the basin has suffered three major floods in two years, including the June 2006 record flood event. As a result, much communication on the effects of climate change in this basin has revolved around increased hydroclimatic delivery of water which induces flooding. This discussion has not significantly included other likely variability and change- induced scenarios. In the Everglades Basin of South Florida, water managers and stakeholders are anticipating effects to human and natural systems as a result of altered hydroclimatic delivery of water, sea-level rise, and altered storm activity. However, the Comprehensive Everglades Restoration Plan (CERP) has taken the full concentration of all the concerned agencies' and interests' time, and as a result, there has been minimal work commenced on longer term (> 40 years) ecosystem planning. Basin stakeholders and managers are just beginning to prioritize quantifications of water in the Everglades in times of surplus and drought. In the semiarid High Plains and dependant upon out-of state and –basin snowpack, the Platte River Basin is altering management strategies to better accommodate ecosystem needs. These strategies are designed to specifically address habitat conservation and ecosystem restoration for endangered species. Prominent Basin endangered species, including the whooping crane, have necessitated stakeholders consideration of instream flow allocations, and to finding solutions for water conservation through more efficient irrigation technology, federal purchases of agricultural water rights for ecological use, and generally the consideration of future uncertain climate conditions and their impacts on agriculture.

For the final study findings, it will be informative to see how the intersection of each basin's human and physical geographies have informed their management strategies (or lack there of) for addressing the water resource impacts of climate change. Interestingly, although stakeholders and managers in the basins have different stakes in the use and allocation of water, they often recount a shared experience when identifying how water management decisions were either correctly or incorrectly informed by climatic information. Many study participants also claim that climate variability is more of a driver for management policy that climate change considerations. Preliminarily, these findings are in keeping with traditional Hazards research, which notes that much of U.S. hazard response is reactive, and needs to move to a more proactive response (Hewitt, 1983). This assertion is especially relevant with regard to the possible threats to human and ecosystem well-being from climate change and variability.

Conclusion

It is envisioned that this study will be completed by May 2008, and when complete will provide a baseline assessment for the study river basins, as well as serve as a tool/model for other U.S. basins who would like to conduct water management adaptation assessments. This work represents a novel contribution to climate change research by addressing, empirically, how U.S.

water resource decision-makers in diverse geographic basins determine water management adaptations under the uncertainty of climate variability and change. This research builds on a newly evolving area of literature regarding how the anticipation of uncertain events, such as climate change, influence U.S. water resource managers' decision-making. When complete, it is hoped that this study will further the role of physical and human geography and nature-society interactions in providing multidisciplinary knowledge, to bridge the gap between science and policy, and in informing applied environmental management.

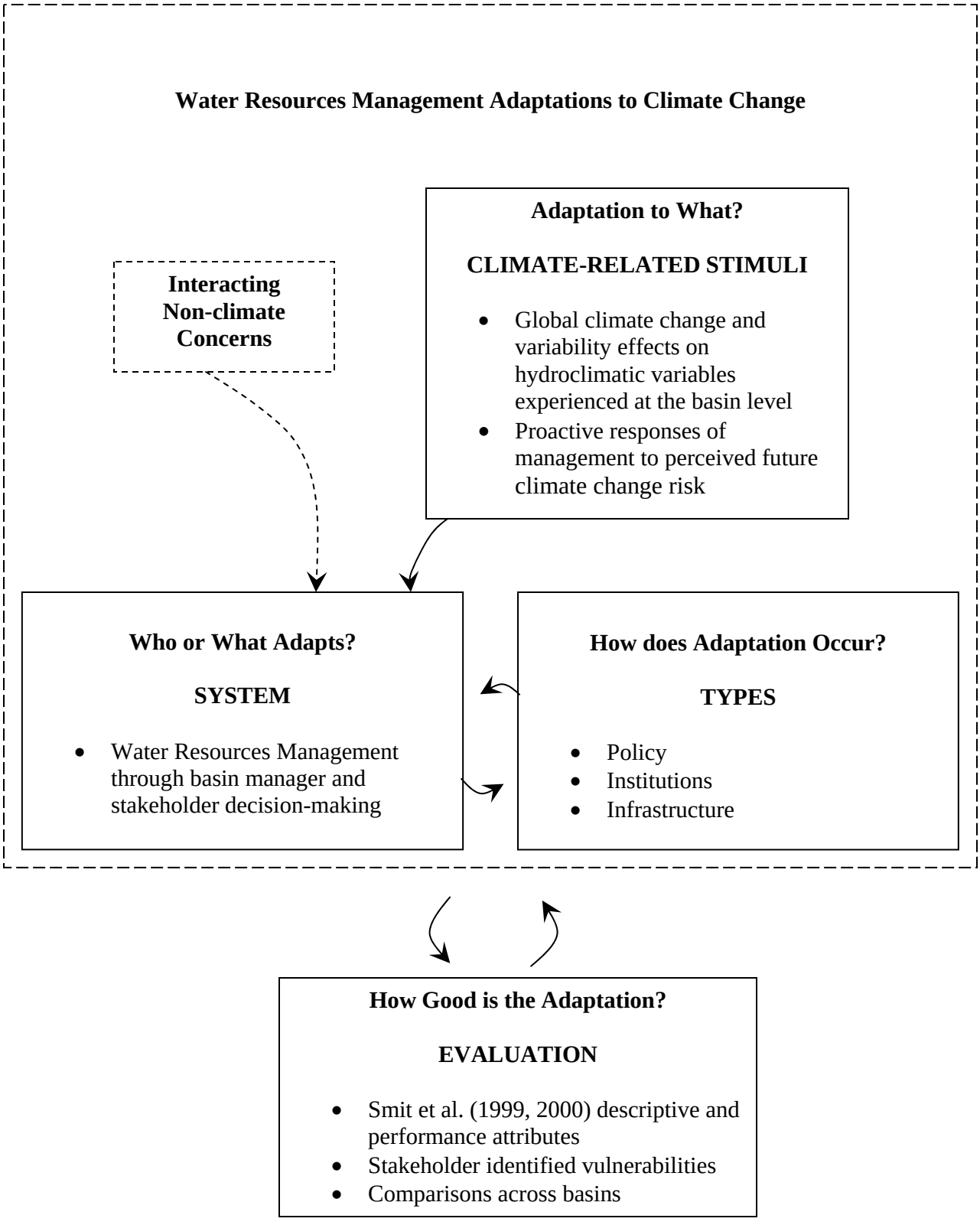

Figure 1. Water Resources Management Adaptation to Climate Change and Variability at the basin level (modified from Smit et al. 2000, incorporates Smit and Wandel 2006, Keskitalo 2004, and Lim et al. 2005).

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