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Regional Abrupt Climate Change Assessment in the U.S.: Comparing the Colorado and Columbia River Basins

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The Global Environmental Assessment project is a collaborative team study of global environmental assessment as a link between science and policy. The Team is based at Harvard University. The project has two principal objectives. The first is to develop a more realistic and synoptic model of the actual relationships among science, assessment, and management in social responses to global change, and to use that model to understand, critique, and improve current practice of assessment as a bridge between science and policy making. The second is to elucidate a strategy of adaptive assessment and policy for global environmental problems, along with the methods and institutions to implement such a strategy in the real world.

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Publication abstracts of the GEA Project can be found on the GEA Web Page at http://environment.harvard.edu/gea. Further information on the Global Environmental Assessment project can be obtained from the Project Associate Director, Nancy Dickson, Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University, 79 JFK Street, Cambridge, MA 02138, telephone (617) 496-9469, telefax (617) 495-8963, Email nancy_dickson@harvard.edu.

FOREWORD

This paper was written as part of the Global Environmental Assessment Project, a collaborative, interdisciplinary effort to explore how assessment activities can better link scientific understanding with effective action on issues arising in the context of global environmental change. The Project seeks to understand the special problems, challenges and opportunities that arise in efforts to develop common scientific assessments that are relevant and credible across multiple national circumstances and political cultures. It takes a long-term perspective focused on the interactions of science, assessment and management over periods of a decade or more, rather than concentrating on specific studies or negotiating sessions. Global environmental change is ,viewed broadly to include not only climate and other atmospheric issues, but also transboundary movements of organisms and chemical toxins. (To learn more about the GEA Project visit the web page at http://environment.harvard.edu/gea/ .)

The Project seeks to achieve progress towards three goals: deepening the critical understanding of the relationships among research, assessment and management in the global environmental arena; enhancing the communication among scholars and practitioners of global environmental assessments; and illuminating the contemporary choices facing the designers of global environmental assessments. It pursues these goals through a three-pronged strategy of competitively awarded fellowships that bring advanced doctoral and post-doctoral students to Harvard; an interdisciplinary training and research program involving faculty and fellows; and annual meetings bringing together scholars and practitioners of assessment.

The core of the Project is its Research Fellows. Fellows spend the year working with one another and project faculty as a Research Group exploring histories, processes and effects of global environmental assessment. These papers look across a range of particular assessments to examine variation and changes in what has been assessed, explore assessment as a part of a broader pattern of communication, and focus on the dynamics of assessment. The contributions these papers provide has been fundamental to the development of the GEA venture. I look forward to seeing revised versions published in appropriate journals.

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ABSTRACT

Paleo-climatic evidence and historical experience indicate the earth's climate system is capable of switching rapidly from one quasi-stable state to another. Current global assessments of anthropogenic climate change, however, do not fully account for such abrupt shifts, and instead generally assume the earth's climate will gradually warm over the next several centuries. Integrated assessments of abrupt climate change exist, but on a regional level. Here I examine two examples where knowledge of abrupt climate change is applied to the management of natural resources, including water in the Colorado Basin and salmon in the Columbia Basin. The effectiveness of the Severe-Sustained Drought study (SSD), an assessment of the socioeconomic impacts of long-term term drought in the Colorado Basin, is analyzed in the context of three inter-related characteristics - saliency, legitimacy, and credibility. Based on semi--structured, open-ended interviews with assessment participants and regional stakeholders, the SSD clarified positions of competing water interests and expanded awareness of potential drought impacts, but did not modify Colorado River water management or policies. Design characteristics had limited influence on assessment effectiveness (or lack of); the timing of publication and political and legal factors constraining alternative policy options for water distribution were more influential determinants. Absent a crisis, there appear to be few incentives for water managers to implement SSD policy recommendations. In the Columbia River Basin, the crisis of declining salmon stocks appears to motivate the consideration of alternative policies which recognize the role of decadal shifts in oceanic productivity. Although actual management strategies remain unchanged, the framing of the debate over salmon restoration has shifted from one focused solely on freshwater habitat to one that more fully recognizes the oceanic influence on salmon mortality.

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ACRONYM LIST

AC	Advisory Council for the SSD
ACC	abrupt climate change
CIG	Climate Impacts Group
IPCC	Intergovernmental Panel on Climate Change
JISAO	Joint Institute for the Study of the Atmosphere and Oceans
MWD	Metropolitan Water District of Southern California
NPPC	Northwest Power Planning Council
PNW	Pacific Northwest
PDO	Pacific Decadal Oscillation
SSD	Severe-Sustained Drought Assessment

INTRODUCTION

As the number and resolution of paleoclimatic and historical climate observations has improved over the last two decades, so too has our knowledge that climate is capable of changing in surprising ways. Examples include reorganizations in deep ocean circulation, decadal drought in North America, and apparent shifts in the frequency and magnitude of the El Nino Southern Oscillation. In each case, physical change in the climate system is abrupt, occurring over years to decades, is spatially widespread, from continental to global, and involves shifts from one stable state to another, each lasting from years to millennia.

Despite these recent discoveries, global assessments of climate change generally assume there will be a gradual warming of earth's climate over the next several centuries. On the regional level, however, there are examples of abrupt climate change (ACC) assessment in the United States, including the Colorado Basin Severe-Sustained Drought (SSD) study, and the Pacific Northwest (PNW) Regional Assessment, which includes the Pacific Decadal Oscillation (a type of abrupt change) in its assessment repertoire. It is unclear why regionally-focused assessments seem to address abrupt climate change more than global efforts, but it may be a function of the difficulty in obtaining consensus on low probability, high impact events in large international assessment projects (Patt, 1999). The purpose of this study is two-fold: 1) to compare experience in the Colorado and Columbia River Basins and begin sketching a picture of how abrupt change science can be utilized in integrated assessments, 2) to examine the factors that influenced SSD effectiveness and determine the degree to which they're encompassed by the Global Environmental Assessment Project conceptual framework.

BACKGROUND

A major challenge to global environmental assessments is identifying regional impacts of global phenomena. In the case of anthropogenic climate change, for example, current models are not yet capable of reliably resolving regional impacts, and thus the debate has primarily focused on the magnitude and rate of mean global temperature change. One of the strengths of the paleoclimate and historical records is that each is composed of geographically discrete data sets, allowing for regionallevel definition of past climate events. While past events are not forecasts of the future, they can be useful analogies for probing societal vulnerability to, and the level of preparation for, abrupt climate changes.

Climate science

Tree ring and lake sediment data indicate there were likely two long-term droughts in North America during the last 700 years, occurring in the late 13th and 16" centuries (Fritts, 1965; Stable et al., 1985; Grissino-Mayer, 1996; Meko et al., 1995; Woodhouse and Overpeck, 1998). These so-called "megadroughts" exhibit the characteristics of ACC in that they 1) began quickly (in a few years), 2) covered a large portion of the western United States, and 3) persisted for two decades in some areas. Data coverage is best for the Southwestern U.S., which experienced a 20-year drought from approximately 1580-1600 AD. While the mechanisms driving decadal drought are unclear, sustained North American droughts of the past 1,500 years correspond to extremes in sea-surface temperature in the Sargasso Sea (Keigwin, 1996; Woodhouse and Overpeck, 1998), which it turn seem to be related to the strength of deep Atlantic convection (Bianchi and McCave, 1999).

Depending on the region in question, historical data can provide a detailed record of abrupt climate shifts. For example, the southwestern U.S. has suffered multi-year droughts in historical times (e.g., during the mid-1950s; Cook et al., 1998), but nothing on the order of the late 16th century event. In the Pacific Northwestern U.S. (PNW) there is a unique climatic feature known as the Pacific Decadal Oscillation (PDO), which shifts states roughly every 20 years (Mantua et al., 1997). In the warm (cool) phase of the PDO, temperatures in the Idaho, Oregon, Washington are significantly warmer (cooler) than normal, and precipitation is significantly lower (higher) (Mote et al., 1999). Salmon mortality off the coast of Oregon and Washington generally increases during the warm phase of the PDO, when sea surface temperatures in the Northeast Pacific tend to be warmer and less biologically productive than normal. In addition, flow in the Columbia River generally decreases by -10% during the warm PDO phase (relative to the long-term average), exacerbating the effects of poor oceanic conditions on salmon survival (Mote et al., 1999). Thus, historical data indicate the PNW has abrupt shifts in climate, which are analogous to climate events apparent in the paleoclimatic record of the southwestern U.S.

Assessment

Awareness of ACC in scientific circles has increased substantially in the last five years, as indicated by the large number of recent papers on this topic (e.g., Overpeck, 1996; Broecker, 1997; and sources cited therein). Interest is also emerging in the U.S. news media, reflected by stories on deep-ocean circulation shifts in *The New York Times* (Stevens, 1998; 1999) and *The Atlantic Monthly* (Calvin, 1998), and megadrought coverage in *The Washington Post* (Suplee, 1998), *The New York Times* (Stevens, 2000) and national news broadcasts. Despite increased attention given to abrupt climate changes, their treatment in global assessment efforts is limited. Preliminary analysis of environmental assessments indicates that large consensus-based assessment bodies tend to avoid treatment of low probability, high impact events, such as disintegration of the West Antarctic Ice Sheet (Patt, 1999). The limited mention of abrupt climate change in the Inter-governmental Panel on Climate Change (IPCC) reports is consistent with this finding (IPCC, 1996). Although anthropogenic climate change is treated from an integrated standpoint by the IPCC, Working Group I summarizes abrupt change and climate surprises in a brief literature review on the physical aspects of millennial-scale shifts during the last glacial interval. The possibility of abrupt change is downplayed, due primarily to the lack of precedent for shifts of similar magnitude during interglacial times (IPCC, 1996). Similarly, there is limited mention of ACC in both the Summary for Policy Makers and the Technical Summary of the Working Group I Report.

While ACC is recognized by the IPCC as an important topic with potentially serious consequences, regionally focused integrated assessments are required to better understand the impact of abrupt climate changes on modern socio-economic systems. One such example is the Severe Sustained Drought assessment (SSD), which examined the impacts and mitigation strategies for a 20-year drought in the Colorado Basin (Young, 1995). Prior to discussing the details of the SSD, it is first necessary to outline the context in which the assessment operated. As discussed in subsequent sections, this backdrop is essential to understanding why the SSD, despite its sophisticated assessment design, had little impact on water management or policy in the Colorado Basin.

COLORADO BASIN WATER MANAGEMENT & POLICY

The Colorado River is one of the most highly developed rivers in the world. From its headwaters in the Rocky Mountains to its ephemeral delta in the Gulf of California, it encounters multiple reservoirs, dams, and diversions. Throughout the Colorado Basin, the river is the primary source of water in an otherwise semi-arid region. Continual conflict over water rights has produced a complex legal structure for water distribution and some of the most notable environmental battles in the history of the United States (McPhee, 1971). Increasing demand for a variety of consumptive (municipal, industrial, agricultural) and non-consumptive (recreational, hydroelectric, ---and environmental) water uses limit flow to such an extent that the Colorado River often fails to reach the sea (Fradkin, 1995).

Law of the River

Apportionment of Colorado River water between the United States and Mexico, and within the seven U.S. basin states is governed by a set of rules for water allocation known as the Law of the River (MacDonnell et al., 1995; Getches, 1997; Table 1). These rules are based on the prior appropriation doctrine, which grants primary water rights to those who first put water to beneficial consumptive use (Wilkinson, 1985). Over the past 80 years, basin states have competed to ensure adequate water supply for their present and perceived future needs and to prevent other states from appropriating water. The result is a highly engineered and regulated system, where consumers have grown to expect predictable, reliable water supply.

The five components of the Law of the River listed in Table 1 are the primary determinants of water allocation in the Colorado Basin - they dictate which state (or country) receives water, the amount they receive, and how often they receive it. Absolute allocations are independent of total available water, while proportional division is based on a percentage of available supply. The Colorado Compact allocates water between the Upper and Lower Basins (Figure 1), with the latter guaranteed a volume of 75 million acre feet every 10 years, regardless of available flow (MacDonnell et al 1995). It is now known that the baseline flow rate used to negotiate the Colorado Compact is significantly higher than the historical average, implying that in low flow years, the Upper Basin is more vulnerable to water shortage (Brown, 1988). An absolute allotment of 1.5 maf/year was established for Mexico in 1944, and for the first time total allocation on the Colorado exceeded the historical average flow.[1] During years of average or below average flow, the Law of the River allocates more water than is actually available, euphemistically known as over-allocation.

In 1948, Colorado, Utah, New Mexico, and Wyoming, agreed to share water on a proportional basis under the Upper Basin Compact (Table 1). This was driven by obligations to the Lower Basin and Mexico, and the realization that river flows could be much lower than those on which the Colorado Compact was based.[2] To further minimize Upper Basin drought risk, in 1956 Congress enacted the Colorado River Storage Project Act, which authorized the construction of several Upper Basin projects, including Glen Canyon Dam (Brown, 1988). The Glen Canyon Dam is the legacy of flow deliveries required by the 1922 Colorado Compact, and the initial over-estimation of available water.

Water allocations guaranteed to the Lower Basin under the Colorado Compact cleared the way for the 1964 *Arizona v. California* Supreme Court decision that designated allotments for Lower Basin states (Table [1),3] With 7.5 maf/year from the Upper Basin, the Lower Basin was in the fortunate position of codifying absolute water supply for California, Arizona, and Nevada. In 1968, the Colorado Basin

Project Act established Long-Range Operating Criteria for Upper and Lower Basin reservoirs, which require that a minimum of 8.23 maf per year be released from Glen Canyon dam. [4] With this absolute requirement, the limited flexibility in the Colorado Compact (7.5 maf/year over 10 years) was removed (MacDonnell et al., 1995).

The Colorado Compact set the tone for subsequent components of the Law of the River by encouraging basin states to expect reliable, absolute water deliveries. In essence, it established a feedback mechanism, where expectations for minimum flows led to the building massive water storage and delivery structures, which further inflated allocation expectations. This construction/expectation cycle culminated in the annual minimum release from the Upper to Lower Basins of precisely 8.23 million acre feet.

Accounting for drought risk

Drought is accounted for in Colorado River water management in two ways. The first is structural - reservoirs in the Colorado Basin hold a total of approximately four times the historical annual average flow of the rivers.[5] Most of this water is held in Lake Powell and Lake Mead, massive reservoirs which serve to buffer the Basin from short-term drought (and flood) events. Since these reservoirs have been near capacity over the past several years, and demand for water continues to increase, much of the recent controversy in the Colorado Basin focuses on allocation of surplus water, that is, water deliveries in addition to the minimum allocations listed in Table 1 (Getches, 1997).

Long-term drought is taken into account primarily through the Long-Range Operating Criteria. The Criteria specify reservoir operating rules that are dependent on projections of water supply and demand. One of the key factors used to determine available supply is the historic critical flow period, which occurred from 1952 to 1964.[6] Simulations of future demand in combination with the 12-year low flow period indicate the possibility of supply shortages - that is, if the entire Upper Basin storage capacity cannot meet Upper Basin needs plus obligations to the Lower Basin and Mexico. In this scenario, the annual release of water at Glen Canyon Dam is limited 8.23 maf, limiting the amount of surplus water available to the Lower Basin. There is no provision in the Operating Criteria to authorize lesser flows, even during extreme drought years. In general, the Criteria deal primarily with allocating surplus water and guaranteed releases from Glen Canyon Dam (MacDonnell et al 1995). This optimism is similar to that expressed during the original Colorado Compact negotiations, where state negotiators quickly accepted forecasts of abundant water supply in the hope that it would ease interstate cooperation, at least in the short term (Brown, 1988; Hundley, 1975).

The Operating Criteria are reviewed approximately every five years by basin state representatives, the Bureau of Reclamation, and the Secretary of Interior. Beginning in 1990, participation in the review process expanded to include interested stakeholders, such as the Environmental Defense Fund, American Rivers, and the National Park Service.[7] Despite repeated reviews, and broadened participation in the review process during the last decade, there have been no changes made in the Criteria since their original inception in 1968. [8] In the words of one Reclamation official, "it's a rubber stamp process", apparently due to the limited flexibility allowed for the Criteria by the Colorado Basin. Project Act and the political difficulty in altering rules which have become accepted operational norms.

SEVERE-SUSTAINED DROUGHT ASSESSMENT

Tree-ring data reveal the existence of a drought event in the Colorado Basin that was both longer and more severe than the critical flow period currently used by the Bureau of Reclamation (Stockton and Jacoby, 1976; Meko et al., 1995; Tarboton, 1995).[9] How sensitive are water resources in the Colorado Basin to such an event, and what options are available for impact mitigation? To answer these questions, the Severe-Sustained Drought (SSD) project, composed of academically-based experts in Colorado River hydrology and policy, tested the capacity of regional reservoirs and the performance of the Law of the River under the extreme circumstances of the late 16th-century drought event.

Using a model of basin hydrology, management facilities and operating rules, the SSD authors performed a gaming exercise to determine how representatives from Colorado Basin states would respond to the evolving a 20-year drought event and to the decisions of other participants. While participants were able to minimize impacts on consumptive uses, non-consumptive uses such as hydropower generation, recreation, and endangered species were adversely affected (Henderson and Lord, 1995). For example, at the peak of the simulated drought, Lake Powell emptied and Lake Mead lowered substantially (Harding et al., 1995), resulting in annual hydropower generating losses of $600 million (Booker, 1995) and the local extinction of multiple fish species (Hardy, 1995). In general , the Upper Colorado Basin bears a greater drought risk, due primarily to existing compact guidelines which guarantee the Lower Basin minimum flows. As a result, deliveries for consumptive use in the Upper Basin fell to about half normal levels, whereas they were relatively unaffected in the Lower Basin (Lord et al., 1995).

To minimize drought impacts, study participants recommended a range of policy options to improve system resilience to water shortages, such as interstate water transfers and banking, and the creation of basin-wide commission to coordinate drought response. Basically, the authors argued for increased diversity of inter-state water management techniques - as those outlined under the Law of the River lacked the flexibility to mitigate drought impacts on a basin-wide basis. Preliminary discussions with SSD authors indicated that the assessment had little impact on policy or management strategies in the Colorado Basin. One of the aims of this study was to determine why this was the case - the methods used to address this question are detailed in the next section.

Methods

Semi-structured, open-ended interviews were performed with key people in the Colorado Basin, including the principal investigators of the SSD project and members of the SSD Advisory Council (AC) (Table 2). The AC included representatives from State Engineer's offices, state Departments of Natural Resources, the Central Basin Water District (California), the Upper Colorado River Commission, the Western States Water Council, the Colorado River Board of California, the Colorado River Water Conservation District, the Metropolitan Water District of Southern California, and several academic and practicing experts in water law. The AC was essentially a "who's who" of inter-state water management in the Colorado Basin, established to ensure that results of the SSD reached the appropriate stakeholders, and to provide a venue for feedback regarding study design and recommendations. The AC was established in the late 1980's at the end of the initial SSD scoping stage (Phase 1; Gregg and Getches, 1991), with the intent that comments and suggestions could be incorporated into Phase 2 (Young, 1995), the funding for which began in the early 1990's. Phase 2 was designed to include a more thorough assessment of environmental impacts and a gaming exercise to simulate the interactive decision-making process that would occur during an extended drought.

The U.S. Man in the Biosphere Program funded Phase 1, while the U.S. Geological Survey and the U.S. Army Corps of Engineers were the primary funders for Phase 2. Since these agencies provided financial support through a grant proposal process, they had little vested interest in SSD results, and were therefore not interviewed for this study. Additional funds came from the Metropolitan Water District of Southern California, the Upper Colorado River Basin Commission, and Water Resource Institutes at the University of Arizona, University of California, Colorado State University, Utah State University, and the University of Wyoming (Young, 1995). Many of these organizations were represented as SSD principal investigators or members of the AC, and were amongst the people interviewed.

Phase 1 and Phase 2 of the SSD assessment were the primary documents used for background information on study results and recommendations. Additional written materials covering historical documentation of the Law of the River, environmental controversies in the Colorado Basin, Bureau of Reclamation reservoir operating criteria and hydrological data, impacts of interannual climate variability on Colorado River flow, and the websites of multiple organizations in the Basin were essential to formulating interview questions and providing the historical, legal, and political context of water allocation in the Colorado Basin.

Results & Discussion

Environmental assessments can be evaluated both in terms of their effects and their effectiveness. Effects cover the entire range of consequences of an assessment, regardless of original intent, whereas evaluation of effectiveness is directly related to the intent of the designers and participants in an assessment process. For the purposes of this study, I define effectiveness as the degree to which each of the following three outcomes occurred (listed with increasing impact on water management and policy in the Colorado Basin):

1) water managers' framing of extreme drought changed from one based solely on historical experience to one that includes an extreme event from the paleoclimatic record;
2) methods by which drought risk is determined and included in the long-range management of Colorado Basin reservoirs were expanded to include tree-ring reconstructions of river flow; and
3) a diverse set of water allocation policies (along the lines of those suggested by the SSD) were created to better cope with the impacts of long-term drought on a basin-wide scale.

Almost without exception, interviewees found that the SSD changed their perception of extreme drought in the Colorado Basin. Many of the AC. members, while aware of tree-ring-based drought reconstructions, were not cognizant of the impacts such a drought would have on modem water uses. In this limited sense, the SSD achieved the first measure of effectiveness listed above - several water managers came out the assessment process with an expanded perception of the potential impacts of severe drought.

While awareness of pre-historic droughts increased as a result of the SSD study, this appears to have had little impact on Colorado River water management and policy. As discussed in the drought risk section, the Long-Range Operating Criteria for Colorado Basin reservoirs utilize a historical critical flow period (1952-64) for long-range supply projections, as opposed to the more severe late 16th-century event. Interviews with Bureau of Reclamation officials indicate this is due primarily to bureaucratic inertia and the politically-sensitive nature of using a more dire drought event. After using the same critical flow

period for the past 30 years, it is now accepted operational practice to make supply projections based on historical flows. Introducing a low-flow event based on non-standard hydrologic techniques would likely encounter opposition from state-level engineers. Furthermore, the use of the late 16th_century event would have the practical effect of limiting the amount of surplus water available to Lower Basin states, a politically unsavory consequence. In the words of one Reclamation official, "they [the basin states] don't want to hear a bleak story". Continued review of the Operating Criteria may change current decision-making patterns, but for the time being, the SSD appears to have fallen short in modifying the long-range operation of Colorado Basin reservoirs.

The most challenging measure of effectiveness for the SSD is the last - to what extent did assessment recommendations encourage flexible drought management policies in the Colorado Basin? All of the interviewees agreed the SSD had little or no impact on policies that would improve resilience to drought on a basin-wide scale. According to interviews with principal investigators, Advisory Council members, Bureau of Reclamation officials, and other water managers and experts, there were several factors that led to this ineffectiveness (Table 3).

Political-legal context

The highly political nature of water allocation in the Colorado Basin and the issues addressed by the SSD are critical to explaining both the effects of the SSD and its lack of effectiveness in encouraging alternative water management policies. Without exception, each person interviewed highlighted political barriers as the primary reason that policy recommendations in the SSD had little impact. In general, there is little interest in data that imply the river is over-allocated or that the current allocation rules are too rigid to adequately cope with severe drought. Interviews revealed that a basin-wide interstate compact commission is a politically-contentious topic, largely due to fears that such an arrangement would erode state-level control of water rights and allocation procedures. Advisory Council members from California and Arizona expressed little interest in the formation of a basin-wide commission - historically they've been able to successfully address their water needs without one. Indeed, the Law of the River is testament to the decades-long struggle of basin states to earn and retain water rights - it is not surprising that a perceived threat to that allocation would be unpopular. While a basin-wide entity would likely improve equitable sharing of water with Native American and environmental demands (Getches, 1997), it seems to be viewed by many states as zero-gain prospect, at best adding a layer of bureaucracy and preserving current allocations, at worst yielding water deliveries less than historical amounts.

Interview results also indicate that the establishment of interstate water banks between Upper and Lower Basin states is an unpopular idea, particularly in the Upper Basin. This is despite the fact that Colorado, Wyoming, Utah, and New Mexico have yet to utilize their entire allocation under the 1922 Colorado Compact (MacDonnell et al., 1995). Although the banks would in theory act as temporary water transfer devices, most likely from agricultural to municipal uses, there is a fear that this water would be lost permanently. This fear is not entirely unjustified, given growing demand in Upper Basin states and the continued requests for surplus water from Lower Basin states, particularly California. The Colorado River Water Conservation District, for example, which protects the water rights of 15 counties in west central and northwest Colorado, likens itself to David and California and Nevada to Goliath "casting a covetous eye on currently unused Colorado River Water".[10]

It appears that the primary effect of the SSD was to clarify the goals of competing water uses on the Colorado River, particularly between consumptive and non-consumptive (or instream) uses and between the Upper and Lower Basins. As highlighted in the summary chapter of the SSD:

> "Existing operating rules ... favor consumptive water uses over such non-consumptive uses as hydroelectric power generation, environmental protection, salinity control, and recreation. The extent of this favoritism... is out of all proportion to what are, arguably, the public values involved." (Lord et al., 1995, p. 942).

Three of the eight Advisory Council members interviewed found SSD principal investigators to be predisposed to protecting instream uses. In one case, an AC member recalled that the study helped him clarify the agenda of instream water use advocates. Furthermore, recommendations such as creation of a basin-wide commission and the establishment of interstate water banks had been previously suggested in other venues with limited positive reception from the basin states. With positions on these issues already established by groups represented in the AC, the SSD recommendations clarified different agendas - in the words of one AC member "we went in with stated positions on these issues, and study results weren't likely to change them".

Timing

The SSD study was published in 1995. Since this time, levels in Lakes Mead and Powell have been near capacity (Figure 2).[11] Together, these two reservoirs can hold more than three times the annual flow the of the Colorado River - when they're full, the concern for drought tends to be low. Rather than being focused on long- or short-term drought, the Colorado Basin states are currently preoccupied with allocating surplus water, driven by increasing demand rather than decreasing supply. Interviews across the three groups in Table 3 indicate that drought isn't a current concern in the Colorado Basin, let alone one that lasts nearly 20 years, and that the timing of SSD assessment seems to have prevented it from having a greater impact.

If a severe-drought crisis had coincided with the publication of the study, the result may have been significantly different. Indeed, in "closing water systems" such as the Colorado, crisis appears to be necessary to promote recognition of interdependent uses and negotiation of agreements amongst basin states (Pulwarty and Melis, 2000). As discussed in the next section, the crisis of declining salmon populations in the Columbia River Basin has led to the consideration of alternative management approaches, including recognition of the ocean's role in salmon mortality, and the once-radical idea of dam removal. Given the lack of a crisis event in the Colorado Basin, it may be premature to evaluate the effectiveness of the SSD assessment, as its findings and recommendations could yet be used in future drought scenarios.

Although the timing of SSD publication coincided with abundant water supply in the Colorado Basin, much of the West was in the grip of drought during the Advisory Council meetings in 1991 and 1992. During this time, water levels in Lake Powell were at their lowest since the initial filling of the reservoir and storage in Lake Mead dropped by nearly 4 million acre-feet compared to the wet years of the mid-1980's (Figure 2). Both Arizona and California, for example, faced limits to surplus water from the Colorado River, and strict conservation programs were enacted in southern California and Las Vegas (Fradkin, 1995). Thus, discussion of long-term drought was quite timely, as the impacts of drought were occurring in the states represented by AC members. If timing was a primary determinant of the

ineffectiveness of the SSD, then it appears to require a drought more severe than the 1987-92 event to consider policy alternatives like those suggested in the SSD. Also, limited advertising of study results to the general public precluded the accumulation of political support necessary to make these policy changes. During the early 1990s, the AC members were apparently the only stakeholders intimately aware of both the ongoing drought event and the policy implications of the SSD.

Choice of drought scenario

Assessments of abrupt climate change are faced with the difficult task of addressing low probability, high impact events that adequately represent the range of climate variability in a region, while simultaneously steering clear of examples so extreme that nobody pays attention (i.e. that lack salience). For example, initial discussions with SSD principal investigators revealed some concern that the drought chosen for analysis was too extreme. In particular, the low probability of the event may have prevented the SSD from registering with stakeholders in the Colorado Basin. Further interviews, however, indicated that a minority of both the SSD investigators and AC members believed that the low probability of the drought prevented its full consideration by water managers. In most cases, interviewees felt that the occurrence of severe drought, even if only once in the last 500 years, was adequate justification to consider the implications of such an event for current and future water allocation policies. Thus, despite the limited precedence for analogous drought events, the SSD participants appear to have chosen an event that was salient to users in the region.

The drought scenario used in the SSD assessment was based on water flows estimated using tree rings, but with the flows rearranged in time. The rearranged scenario was created by ordering annual values such that each year during the 20-year event had progressively lower flow (Tarboton, 1995). Although the total volume of Colorado River flow over the entire drought remained the same, the timing of the flows was altered to create an event even more extreme than that in the paleoclimatic record. Despite original intentions to determine the impacts associated with both scenarios, the re-arranged drought was the event on which the entire SSD assessment was based. This scenario was used to create a "worst case" contingency for testing the ability of the regional reservoirs and the Law of the River to cope with extreme, and perhaps unrealistic, drought.

One of the groups which funded the study, the Metropolitan Water District of Southern California (MWD), doubted the credibility of the re-arranged scenario. Correspondence between the MWD and the study organizers indicate the MWD found the rearranged scenario to have no hydrological basis, and therefore should not have been used in the assessment. Referring to the rearranged drought, an engineer from MWD wrote to SSD organizers in 1994:

> "Considering its nature, it is possible that water resources managers will dismiss the findings, conclusions, and recommendations contained in the report due to the authors' choice of assumption for the representative drought." [12]

The MWD repeatedly made attempts to comment on the SSD report, but most of them, including doubts about the re-arranged scenario, were left unaddressed.[13] This apparently is the result of both the linear nature of the assessment process and skepticism of Metropolitan's motivations. Although the SSD lasted for nearly 10 years, each stage of the project built on the previous stage - to make the major changes requested by MIND would have required that the study completely redone, an unrealistic request given funding constraints. Also, Metropolitan has serious reservations about the need for a basin-wide commission, because majority-based voting in such an arrangement could lead to reduced water supplies

for Califomia.[14] Since establishment of a basin-wide entity was a primary SSD recommendation, it is possible that MWD chose to discredit the study on technical grounds. Interviews with SSD organizers indicate that skepticism of Metropolitan's motivations was a major reason comments about the re-arranged drought scenario weren't taken into account.

Consumptive uses protected

Several of the SSD investigators indicated that one reason the assessment was ineffective was due to the ability of the Colorado Basin water distribution system to protect consumptive water uses. Using the Law of the River in its current form, it was determined that damages to consumptive uses during a severe-sustained drought could be significant in the Upper Basin, up to $350 million per year during the most severe portion of the drought, but still minor compared to non-consumptive use impacts. With additional management options, such as water transfers, marketing, and retaining water, at high elevations to minimize evaporation, overall damages to consumptive uses could be minimized even further, to the point that consumptive damages were reduced by greater than 80% (Booker, 1995). In other words, even when subjected to the most severe drought of the past 500 years, the system of reservoirs, dams, and aqueducts on the Colorado River could sustain most consumptive water use, at least at current demand levels. In this sense, the SSD may have assuaged fears that long-term drought would have devastating impacts on agricultural, industrial, and municipal uses, thus resulting in little or no change in current policies or management strategies. Curiously, this response was not observed amongst Advisory Council Members or Bureau of Reclamation officials.

Follow-up, continuity

The SSD study, which lasted nearly 10 years in total, went through a variety of funding uncertainties and leadership changes. Originally conceived by a group of academically-based water resource experts, the initial source of funding was through a grant award from the U.S. Man in the Biosphere Program, which in the mid-1980s funded the Phase 1 scoping stage (Gregg and Getches,1991) Similarly, Phase 2, designed to elaborate on the findings of Phase I and incorporate stakeholders through the Advisory Council process, was primarily funded through grant awards from the U.S. Geological Survey and the U.S. Army Corps of Engineers. Several other organizations also provided support for Phase 2, although the contributions were minor in comparison. As the SSD came to a close in 1994-1995, project finances were running low, and it was necessary to cobble together funding from multiple sources to ensure the study could be completed.

Partly as a consequence and partly as a cause of its patchy funding history, the SSD study had several different leaders through its 10-year life-span. Leadership changed between investigators at the University of Colorado and Arizona, to Utah State University; then finally to Colorado State University. By the time the study had neared completion, funding had run out, and many of the authors, with responsibilities to teach and explore new research, had little incentive to actively pursue publication of the SSD. Through the exceptional efforts of a few individuals, the study was eventually published in the peer-reviewed *Water Resources Bulletin*, which was then published in total by the Powell Consortium as a monograph on severe-sustained drought. [15] There were no additional efforts to further publicize the study.

Although the SSD lasted several years, there was little opportunity for the principal investigators to incorporate significant changes into the assessment design or methodology, particularly once the study had begun. If the funding history were more stable, and the leadership more continuous, it is conceivable that such comments could be fully incorporated into alternative assessment scenarios, allowing for multiple iterations based on continued communication between the principal investigators and stakeholders. In this sense, the SSD is a somewhat traditional, linear assessment, as opposed to the more dynamic and long-term regionally-based efforts now emerging in the U.S. It is of course impossible to know whether a more responsive assessment would have yielded a different outcome. In the Columbia River Basin, it appears that the existence of two such organizations, the Pacific Northwest Regional Assessment and the Northwest Power Planning Council, facilitate the utilization of abrupt climate change information.

SALMON RESTORATION IN THE COLUMBIA RIVER BASIN

The Columbia River drains an area comparable in size the Colorado Basin, but has nearly 10 times the annual flow of the Colorado River (Skogerboe, 1982). As a result, conflict over consumptive water use in Oregon, Washington, Montana, and Idaho is essentially nonexistent compared the contentious history of water rights in Colorado Basin. Non-consumptive or instream uses are the primary source of conflict in the Columbia Basin - particularly the balancing of hydropower generation and salmon habitat preservation. A total of 79 different hydropower projects provide nearly 80% of the region's electricity (Wilkinson and Conner, 1987), making the Columbia Basin one of the most heavily developed and managed river systems in the world. As a result of hydroelectric development, over-harvesting, habitat degradation, and production of hatchery fish, wild salmon populations in the Columbia Basin declined precipitously during the 20th century.

In 1980, Congress enacted the Pacific Northwest Electric Power Planning and Conservation Act, which established the Northwest Power Planning Council (NPPC), an interstate body charged with creating and coordinating regional plans for hydropower development and salmon conservation. Using proceeds from the Bonneville Power Administration, which markets hydropower from federal dams, the Council funds an ambitious salmon restoration program costing over $130 million per year (Lee, 1995). Engineering efforts of epic proportions have been undertaken for the purpose of salmon recovery, including: fish ladder construction to facilitate upstream migration of adult salmonids; hydropower turbine screens, barging programs, and increased dam spillage to aid downstream migration of juveniles; and the production of millions of hatchery fish to offset human impacts on wild salmon. Despite these efforts, salmon populations continue to decline. In the early 1990s, several salmon stocks on the Snake River, a major tributary to the Columbia, were listed under the Endangered Species Act (Larmer, 1999).

Superimposed on this general decline is decadal-scale variability in salmon abundance, which only recently has been linked to periodic shifts in oceanic productivity. The primary mode of decadal climate variability in the Pacific Northwest is the Pacific Decadal Oscillation (PDO) - a shift in North Pacific oceanic and atmospheric conditions that appears to occur roughly every 20 years (Hare and Francis, 1995; Mantua et al., 1997). Salmon mortality along the coast of Oregon and Washington generally increases during the warm phase of the PDO, when sea-surface temperatures in the Northeast Pacific tend to be warmer and less biologically productive. During the cold phase, climatic effects tend to opposite those in the warm PDO phase, improving the chances for salmon survival.

The purpose of this section is to determine if and how knowledge of shifts in oceanic productivity is used in the management of salmon in the Columbia Basin. By comparing this case to the SSD assessment experience in the Colorado Basin, the object is to outline key factors influencing the transfer of abrupt climate change science into regional-level resource management. Based on these two cases, it appears that the primary factors motivating application of this information is political advantage and the presence (or absence) of crisis events.

Methods

Semi-structured, open-ended interviews were conducted with climate assessment experts from the Pacific Northwest (PNW) (Table 4). This primarily included members of the PNW Regional Assessment, also known as the University of Washington's Joint Institute for Study of the Atmosphere Oceans Climate Impacts Group (JISAO-CIG). Given the time constraints of this study, and that a primary responsibility of the PNW Regional Assessment is to routinely interact with resource managers in the region, I used these interviews as a barometer for the use of abrupt climate change information in the PNW. Discussions with CIG members were supplemented with interviews of key people familiar with the impacts of climate variability on salmon populations in the Columbia Basin, covering academic, industry, and state and federal agency perspectives.

The recent report from the PNW Regional Assessment (Mote et al., 1999) was a primary background document used in this study. Additional written materials including historical accounts of salmon management in the Columbia Basin, Northwest Power Planning Council documents, studies on the use of interannual climate information in the Pacific Northwest, and the websites of multiple organizations in the Basin were essential to formulating interview questions and providing the historical and political context of salmon management in the Columbia River Basin.

Results & Discussion

The recent scientific connection between variable climatic conditions and salmon populations has been quickly assimilated into the debate on how to restore salmon populations in the Columbia Basin. Over the last five years, the framing of the debate has shifted from one focused on freshwater habitat as the primary zone of salmon mortality to one that more fully recognizes the role of the ocean, where salmon spend most of their lives (Bisbal and McConnaha, 1998, 1999; ISAB, 1999). A 1996 amendment to the original 1980 Northwest Power Planning Act now mandates the NPPC to "consider the impact of ocean conditions on fish and wildlife populations" when planning restoration efforts (Northwest Power Planning and Conservation Act, section (4)(h)(10)(D), 1996).

Partly as a result of the 1996 Amendment, the NPPC advocates minimal freshwater constraints on salmon diversity to allow salmon populations to better cope with a variable oceanic environment. Advocates of this view, including representatives of the Northwest Power Planning Council, argue that management strategies must take into account both freshwater and oceanic habitat, and the natural variability in each. For example, competition between hatchery and wild salmon over limited resources could be limited if hatchery production were reduced during intervals of poor ocean conditions.[16] Water spills from reservoirs could also be timed not to maximize total number of juvenile fish migrating downstream, but to increase their diversity, thus improving chances for oceanic survival (Bisbal and McConnaha, 1998). A broad diversity of life histories is the primary means by which salmon adapted to past climatic and

oceanic variability - constraints on this diversity from hydropower development, habitat degradation, and hatchery production serve to increase salmon mortality in the long-term, In further recognition of the habitat continuum between the ocean and freshwater environments, the NPPC highlights the need for research into the role of estuarine and oceanic river plume conditions in salmon ecology. By improving conditions in the Columbia River estuary and plume to approximate pre-development characteristics, overall salmon survival should benefit as a consequence (Bisbal and McConnaha, 1998).

The crisis factor

While the management strategies advanced by the Northwest Power Planning Council are in a formative stage, discussion of more radical habitat restoration on the Snake River, a major tributary to the Columbia, has reached a critical juncture. Spurred by the early 1990s Endangered Species Act listing of the four remaining Snake River salmon stocks and their continued spiral toward extinction, the breaching of four Lower Snake River dams is now considered as a viable option by federal agencies in the latest salmon recovery plans.[17] This crisis is in part prompted by the spring 2000 deadline from the Clinton administration for the Army Corps of Engineers, Bonneville Power Administration, and National Marine Fisheries Service to create a restoration plan for the endangered species (Larmer, 1999). Of course, breaching of Snake River dams is controversial, particularly for those industries that rely on the dams for barge transportation and hydropower. The Columbia River Alliance, which represents aluminum, wheat growing, and other industrial interests in the Basin, argues that breaching is "unreasonable course of action" that is "economically harmful and will not an help recover salmon".[18] Industry groups argue that factors other than dams, such as over-fishing and poor oceanic conditions, exert the dominant control on salmon populations (Barker, 2000). Many environmental interests, Native American tribes, and fisheries organizations counter that breaching must occur to save the salmon from extinction (Larmer, 1999). According to one fisheries expert, "minor modifications in the system aren't working ... the dams need to be removed". The controversy has reached the highest levels of government, with both of the year 2000 presidential candidates offering their opinions on whether or not the dams should be breached (Mapes, 2000; Seeyle, 2000).

The continued crisis of depleted salmon stocks is a major factor influencing the incorporation of abrupt climate change information into the Columbia Basin salmon recovery debate. Those wishing to minimize the freshwater habitat restrictions desire more aggressive salmon conservation measures to improve the diversity and hence resilience of salmon to natural variability, while those interests that benefit directly from the dams use high oceanic salmon mortality to justify status-quo measures of juvenile salmon barging, hydropower turbine screens, and the like. The opposing views can be caricatured as follows: if ocean conditions can't be controlled, then 1) management actions in freshwater habitat must be dramatically altered to help salmon cope with variable oceanic conditions, or 2) management actions to further improve freshwater habitat are relatively futile. In the contentious environment of balancing the needs of economic development with salmon habitat preservation, it appears that knowledge of variable oceanic conditions is employed to advance existing political agendas.

Inter-basin comparison

While political controversy over natural resources is also a key factor in the Colorado Basin, the Severe Sustained Drought assessment lacked a crisis event comparable to that in the Pacific Northwest. Crisis often clarifies key issues and offers an opportunity to revise entrenched resource management policies, clearing the way for new approaches that were once infeasible for technical or political reasons

(Gunderson, Holling, and Light, 1995). In the Columbia Basin, for example, management approaches that take into account recent scientific advances are now being considered. There is a movement away from command-and-control strategies to one that acknowledges uncertainty in oceanic survival and advocates the application of ecological principles. The most noticeable example of this shift is the serious discussion of dam breaching on the Lower Snake River.

In the Colorado Basin, historic and tree ring-based flow data indicate water supplies are over-allocated, but basin states have grown to expect minimum amounts of water, and exert political pressure to ensure these allocations continue or improve with time. Since severe drought has not yet impacted the Colorado Basin in its modem structural and institutional state, water managers have little incentive to re-evaluate current interstate water policies. Recent intra-state water marketing and transfers in California and discussion of interstate banking in the Lower Basin indicate this is changing, but it is unclear how advances in water allocation flexibility will improve the basin-wide response in a severe, sustained drought. For the time being, it appears that constraints imposed on interstate water management by the Law of the River, and the long history of competition over scarce Colorado River water, prevent the adoption of the institutional recommendations advocated by the SSD assessment. A somewhat more open and adaptive management system in the Columbia Basin, led by the Northwest Power Planning Council and the PNW Regional Assessment, seems to facilitate the consideration of progressive management approaches.

Independent of political and legal circumstances that inhibit or promote the use of abrupt climate change information, structural and climatic factors may lead to more frequent crises in the Pacific Northwest. In the Columbia River Basin, the effects of poor oceanic conditions are exacerbated by the phalanx of dams that salmon encounter in their migration to and from the ocean. In the Colorado Basin, on the other hand, the construction of Hoover and Glen Canyon Dams dramatically increased basin states buffer against multi-year drought.[19] During the 1987-92 drought event, for example, no major restrictions were placed on the basic allocations outlined in the Law of the River, despite the fact that reservoirs were at their lowest levels in the last 30 years.[20] Thus, dams serve to facilitate water resource management in the Colorado Basin, mitigating the impacts of water shortage, while frustrating salmon management in the Columbia Basin, by contributing to habitat degradation. The result appears to be a greater likelihood for crisis, and hence weighing of alternative policy options, in the Pacific Northwest.

Climatically, salmon management in the Columbia Basin is more likely to experience crisis events - at least with respect to the Pacific Decadal Oscillation, which changes phase roughly every 20 years. Not only is their historical experience from previous phase shifts, but there is also the imminent threat of similar changes occurring in the near future. In the case of the Colorado Basin, a drought like that outlined by the SSD study has no adequate historical analog, and thus there is no institutional memory of the magnitude or impacts of such an event. Furthermore, the apparent low probability of the SSD scenario could invite resource managers to write off the possibility of it occurring while they're in a policy or management position.

RELEVANCE TO GEA CONCEPTUAL FRAMEWORK

The research framework of the Global Environmental Assessment project identifies three qualities of assessments that have been useful in previous empirical studies (Clark, 1999). They include saliency,

legitimacy, and credibility. If an assessment is salient, it addresses issues of concern for potential information users or stakeholders (those affected by assessment policy recommendations). If it is not salient, user needs mismatch information provision, and the assessment is generally ineffective. Legitimacy is closely tied to who participates (and who doesn't) and the nature of the participation. In general, an assessment lacking full participation of stakeholders will lack political legitimacy. Credibility refers to the perceived quality of the scientific expertise in the assessment. Assessments lacking credibility can be criticized on technical grounds (but often for political reasons) and tend to be ineffective. The primary factors that determine salience, credibility, and legitimacy include historical context, and the characteristics of the assessment and its users (Figure 3). The purpose of this section is to 1) discuss the Severe-Sustained Drought assessment in the context of these qualities, and 2) to determine the degree to which the GEA framework encompasses the pertinent factors influencing the effectiveness of the SSD.

Legitimacy

At the outset of this research project, I assumed that SSD participants were largely from academic institutions, and the users of the study were primarily funding agencies, such as the United States Geological Survey or the U.S. Army Corps of Engineers. It was hypothesized that the scope of participation in the SSD study eroded assessment legitimacy with excluded stakeholders - those interests potentially affected by assessment recommendations, but not directly involved in the assessment. Subsequent research has indicated that many key stakeholders were actually involved in the SSD, as part of the Advisory Council. While the actual authors of the SSD assessment were largely from an academic background, the Advisory Council included representatives from State Engineer's offices, state Department of Natural Resources, the Upper Colorado River Commission, the Colorado Water Conservation District, and others. Given this broad representation, between the Upper and Lower Basin, and covering both consumptive (agriculture, municipal, industrial) and non-consumptive (hydropower, recreational, environmental) water uses, the study was generally viewed as having legitimate representation by those people interviewed for this study.

Salience

One of the primary challenges facing assessments of ACC is issue salience. Abrupt climate changes tend to occur infrequently, often separated in time by decades or centuries, and therefore there are few stakeholders that have experienced the impact of these events. At the beginning of this study, I hypothesized that the low probability of the SSD scenario prevented it from being salient to stakeholders in the Colorado Basin. Interviews with Advisory Council members, however, reveal that the drought event was salient to stakeholders. Most of the AC members interviewed (6 of 8) indicated that the occurrence of such an event in the past implied that similar events could occur in the future, and this was reason enough to better understand the impacts of extreme drought. These sentiments echo the initial approval of the drought scenario by the Advisory Council during the early 1990s.[21] Overall, it appears that the interface between science (SSD principal investigators) and policy (AC members) was sufficiently porous to ensure that the scenario which formed the basis for the assessment was salient to most water managers in the Colorado Basin.

A minority of the stakeholders interviewed indicated the low probability of the chosen drought event did affect their perceptions of assessment results, in so far as they felt it was highly unlikely that such an event would occur again. In this case it may have been helpful to include another drought scenario in the

assessment based on a more recent, less extreme event. Of course, this would have required additional investments of time and money, perhaps an unrealistic expectation for a study with such a long and complex funding and leadership history. If time and budgetary constraints were relaxed, it may have allowed for the inclusion of an additional drought scenario, thus improving the overall saliency of the SSD assessment.

According to interviews with both principal investigators and AC members, the SSD assessment never emerged onto a broader political agenda or received significant media attention, despite its credentials of saliency and legitimacy. Major environmental issues tend to have attention cycles characterized by: I) a pre-emergent stage when knowledge and activity related to the issue is concentrated in limited scientific and management circles, 2) an emergent stage when media and political attention dramatically increases, and a much larger group of stakeholders becomes involved in the assessment, and 3) a post-emergent stage, when general public and high-level political interest in the topic wanes, but assessment activity continues with an altered group of stakeholders (Clark et al., 1998). As summarized by Clark (1999), an assessment that fails to change with the times, altering its participation depending on the stage of the issue attention cycle, will tend to be ineffective.

The primary reason the SSD didn't make it to the emergent stage was the absence of a crisis event. If an extreme drought had occurred coincidentally during the assessment, then it is quite likely that the impact of the SSD on water policy in the Colorado Basin would have been different. The primary issue for the SSD is not how it adapted to evolving media and political attention, but the absence of an event required to move the issue of extreme drought onto a broader stage in the first place. This is largely due to the topic which the SSD addressed - a low probability event that in all likelihood would not occur during the assessment process. Many of the assessments studied in GEA tend to focus on chronic environmental problems, such as global warming, ozone depletion, and acid rain. As result, these matters have a salience advantage over environmental issues more periodic or infrequent in nature (such as extreme drought in a discrete geographic region) because the environmental problem and assessment tend to occur simultaneously. Thus, the timing of an assessment relative to the impacts on which it focuses is an important factor influencing assessment salience, and hence effectiveness. While somewhat tautological, this finding bodes poorly for other assessments that attempt to anticipate the effects of low probability, high impact climate events.

Credibility

While the drought scenario used in the SSD was salient for most Advisory Council members, it lacked credibility for at least one stakeholder group, the Southern California Metropolitan Water District (MWD). Beginning in 1994, a series of letters from Metropolitan to SSD organizers repeatedly raised concerns that the re-arranged drought scenario had no hydrological basis, and therefore should not be used as the representative drought for the SSD. Unfortunately, these comments came after the AC had already achieved consensus on using the re-arranged scenario, and work on the project had already begun. Ideally, these dissenting views would have been incorporated into the assessment, but the linear nature of and limited fording for the SSD precluded this possibility.[22]

Although the criticism of the chosen drought scenario seems entirely reasonable, MWD is not without political motivation for critiquing the SSD on technical grounds. Metropolitan both opposes the formation of a basin-wide commission and recognizes that use of amore severe-drought scenario in basin

reservoir management would result in less frequent deliveries of surplus water to the Lower Basin. While any such motivation is difficult to document, it appears to have been an important factor leading MWD to question the re-arranged scenario before study publication, and more fundamental questioning of the use of tree-rings for flow reconstructions after the study was published.[23] Given that Metropolitan is tasked with managing the water supply for 16 million people in southern Califomia[24], it is not surprising that it would cast a doubtful eye on any information that could potentially interfere with these responsibilities.

Expanding the Conceptual Framework

One of the primary factors that influenced the effectiveness of the SSD assessment is the political-legal context of water management in the Colorado Basin. A long history of conflict over water in this semi-arid region has produced an intricate arrangement of interstate compacts, a Supreme Court ruling, an international treaty, and federal statutes that dictate which state receives water, the amount they receive, and how often they receive it. Previous studies of Colorado River water law (e.g., Brown, 1988) and interviews from this study with principal investigators of the Severe-Sustained Drought assessment, SSD Advisory Council members, and Bureau of Reclamation officials, indicate the Law of the River places formidable restrictions on water allocation in the Colorado Basin, and would likely inhibit flexible basin-wide mitigation of severe drought impacts.

While earlier GEA research considered the political context in which assessment processes occur (GEA, 1997; Fisher-Vanden, 1997; Connelly et al., 1998), it is unclear where these constraints fit into the current GEA conceptual framework. On one hand, it seems logical to classify political-legal context as part of historical context (Figure 3). As defined by Clark (1999), however, this factor does not include the types of political and legal issues encountered in the SSD effort. The issue attention cycle is more relevant to the timing of the SSD and the recurrence interval of the scenario on which the it was based. Alternatively, user characteristics may be an appropriate heading under which political-legal context could be classified, if user openness were broadened to include institutional openness, or the degree of freedom granted to assessment users in existing political and legal contexts. This usage is substantially different than user openness as defined by Clark (1999), however, and may be better captured in a additional category, that I refer to as institutional characteristics.

In the Colorado Basin, institutional characteristics inhibiting progressive inter-state water management were the primary determinants of SSD ineffectiveness. An institution is defined here as the "the sets of rules or conventions that govern the process of decision making, the people that make and execute these decisions, and the edifices created to carry out results " (Gunderson, Rolling, and Light, 1995). In the case of the Colorado Basin, the rules or policies governing decision making are outlined by the Law of the River, the people that make decisions are primarily those in the Bureau of Reclamation and State Engineer's offices, and the edifices include the multitude of water storage and conveyance structures throughout the region. Institutional openness is a measure of the degree to which assessment users can act on assessment recommendations. If one were to imagine a perfectly designed assessment, in terms of participation, the treatment of uncertainty and dissent, and the science-policy interface, larger political and legal factors may still prevent it from being effective, even if it addresses salient issues, uses credible science, and is politically legitimate. This appears to be the case for the Severe Sustained Drought assessment - where ineffectiveness was more a function of institutional characteristics than factors influencing the proximate pathways in Figure 3. This additional category can either promote or inhibit

effectiveness, serving as a filter for assessments that in other respects (timing, user and design characteristics, etc.) would have been effective (Figure 3).

The geographic scale on which' institutions operate seems to be an important factor influencing institutional openness. It is difficult to imagine the intricate legal constraints encountered by the SSD in an international environmental assessment. In many of the cases addressed by GEA, it appears that the assessments have produced, or attempted to produce, legal mandates (e.g. the Montreal Protocol) rather than be constrained by them. Perhaps this is a function of scale - common bodies of law within countries may facilitate the formation of Colorado Basin-like legal trappings, while preventing similar structures from existing on a international level. How unique are the institutional characteristics of the Colorado Basin, and to what extent are they encountered on different spatial scales? Are these characteristics an important determinant of assessment effectiveness in these different settings?

CONCLUSIONS

The Severe-Sustained Drought Assessment presents a unique case for the study of environmental assessments. It was well-designed in terms of the factors influencing salience, legitimacy, and credibility, yet had little impact on management techniques or policy. 'The principal investigators of the Severe-Sustained Drought assessment were both innovative and sophisticated in their approach, creating a product that was not only multi-institutional and interdisciplinary in origin, covering everything from tree ring-based river flow reconstructions to sociological analyses of drought mitigation options, but also utilized a spatial scale of analysis that reflects the interconnected nature of water resource management in the Colorado Basin. The assessment involved experts from around the region, and actively sought the participation of key water managers, offering them the opportunity to guide and provide feedback on assessment structure and process. It's as if the SSD principal investigators were to a certain extent prescient of results from the GEA project, and took the necessary steps to pave the proximate pathways to effectiveness.

My point is not to argue that the SSD represents some sort of assessment "holy grail", but rather to highlight it as the type of case necessary to supplement the current GEA conceptual framework. Using cases like it we can evaluate the environment in which well-reared assessments either flourish and reach the elusive state of being effective or wither into a set of moribund documents that collect more dust than interest from decision-makers. The SSD clearly had its faults. A drought scenario taken directly from the tree ring record, for example, rather than the re-arranged version, would have improved credibility with some stakeholders, and its implications for water policy would have been similar. It did, however, avoid major pitfalls, such as addressing issues based on the presumed interest of decision-makers, or failing to involve an adequately diverse group of stakeholders. Clearly, careful and thoughtful design is crucial to ensure an assessment can function in a politically contentious environment.

If the SSD was so well designed then why was it ineffective? Largely this is due the legal constraints that confound efforts to create a water management system more resilient to long-term drought. As a result of the semi-arid setting of the Colorado Basin, and the high demand placed on the river from a variety of uses, conflict over water rights has generally been resolved through formal legal arrangements that create expectations for reliable water flows. Expectations for predictable supply in turn require extraordinary engineering efforts to limit natural hydrological variability. Many of the recommendations

of the SSD, which seem quite reasonable from an academic standpoint, are politically contentious in reality because they challenge the status quo of interstate water policy - policy that has been hammered out over decades of political conflict and negotiation.

In a management settings such as the Colorado Basin, it appears that crisis is a prerequisite for broaching new policy options. Previous studies of natural resource management systems imply that surprise and crisis are the inevitable consequence of command-and-control resource management techniques (Gunderson, Holling, and Light, 1995). In the Columbia River Basin, for example, the continued crisis of potential salmon stock extinctions has driven the new science of estuarine and oceanic salmon ecology to the forefront of the debate on whether or not dams on the Lower Snake River should be breached. Mitigation options have expanded beyond typical technical fixes, to the once radical realm of decommissioning major structural elements of a water management system. The Colorado Basin, on the other hand, has experienced several near crises in the past 20 years, but none have been of sufficient magnitude to cause serious reconsideration of current drought contingency plans.

In two systems with a seemingly infinite number of confounding variables, it is difficult, if not impossible, to determine why one has progressed to the point of considering new management and policy options while the other has not. Nevertheless, speculative comparison of the two cases raises some interesting questions. The existence and magnitude of external crisis events is an important factor, but different internal institutional characteristics may also play a role. In the Columbia River Basin, the Northwest Power Planning Council has established itself as an important basin-wide voice in the salmon debate by guiding salmon restoration and hydropower development and acting as an information clearinghouse on related technical and policy issues. A similarly independent and well funded interstate council does not exist in the Colorado Basin to coordinate long-term water management. In this sense, salmon management in the Columbia Basin is more akin to a distributed assessment system, where "integrated networks of research, assessment, and management bridge numerous levels, and include sustained, long-term interactions between scientists, decision-makers, and stakeholders "(Cash, 2000). To what extent do the Columbia and Colorado River examples resemble distributed versus more centralized management configurations? What factors led to this difference? Can this help explain why the SSD was largely ineffective? What role does the Pacific Northwest Regional Assessment have in the larger salmon assessment system? Through pursuing such questions, we will begin to understand the institutional characteristics that both influence and characterize well-designed assessment processes.

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TABLES

Table 1. Primary water allocation components of the Law of the River

Law of the River	Allocation	Method
Colorado Compact, 1922	75 million acre-feet (maf) every 10 years from Upper	Absolute
Mexican Water Treaty, 1944	1.5 maf per year from Upper and Lower Basin to Mexico	Absolute
Upper Basin Compact, 1948	Colorado 51.75%, Utah 23%, Wyoming 14%, New Mexico 11.25% of available supply	Proportional
Arizona v. California, 1964	California 4.4 maf, Arizona 2.8 maf, Nevada 0.3 maf	Absolute
Colorado River Basin Project Act, 1968	8.23 maf per year release from Glen Canyon Dam	Absolute

* The Upper Colorado Basin includes Colorado, Wyoming, Utah, and New Mexico; the Lower Basin includes California, Arizona, and Nevada. The hydrological division between the two sub-basins is Lee's Ferry, Nevada, also known as the Colorado Compact Point (Figure 1).

Table 2. Colorado Basin Interview facts[25]

Total interviews	26		
SSD investigators	9	Advisory Council members	8
State Engineers	5	Upper Basin	4
Reclamation officials	5	Lower Basin	3
Misc. organizations	4	Upper and Lower Basin	1
External experts	3		

Table 3. Primary factors influencing the effectiveness, of the SSD policy recommendations

Factors	Principal Investigators	Advisory Committee	Bureau of Reclamation
political-legal context	*x*	*x*	
*timing**	*x*	*x*	*x*
*choice of drought scenario**	*x*	*x*	
consumptive uses protected	*x*		
*follow-up, continuity**	*x*		

*Factors that could potentially be influenced by assessment design-others are beyond the limited scope of the assessment .

Table 4. Pacific Northwest Interview facts[26]

Total interviews	9
Climate impacts experts	4
Fisheries experts	2
Industry representative	1
NPPC representative	1
External expert	1

FIGURES

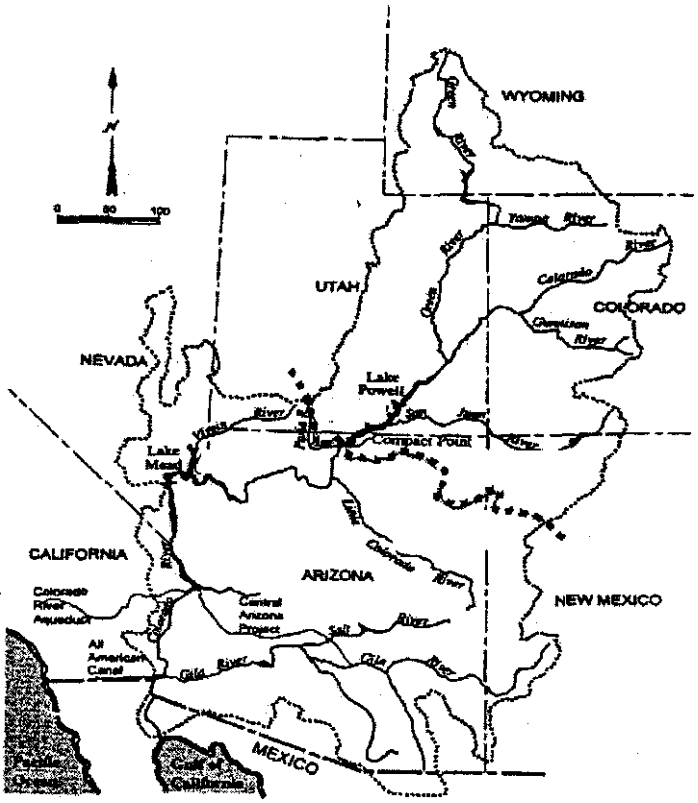
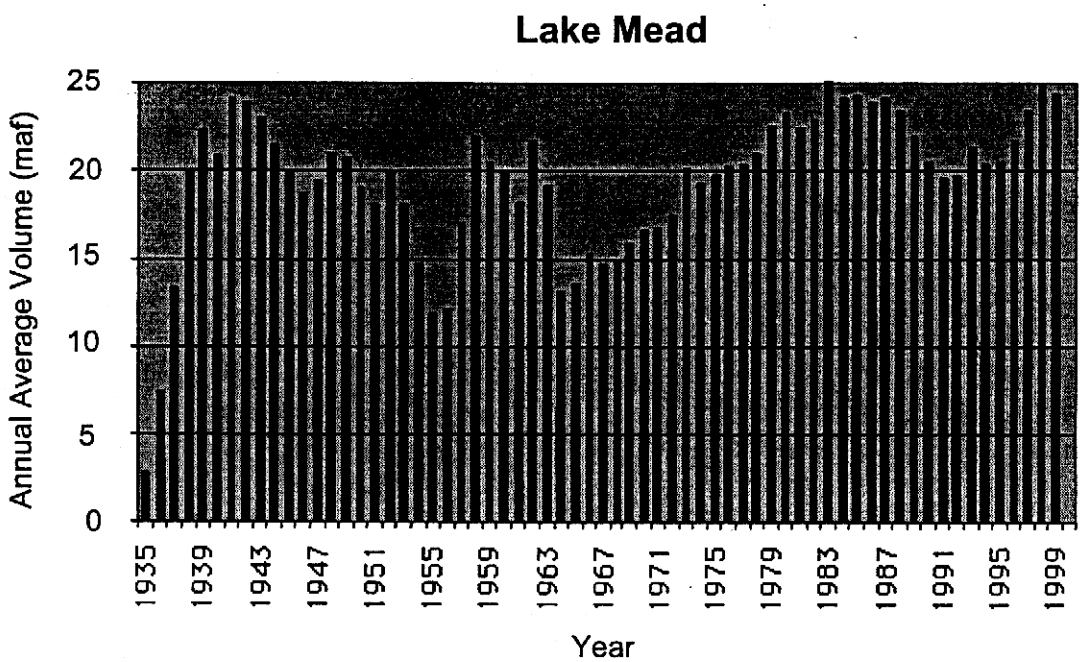


Figure 1. Map of Colorado River Basin. The intersection of the dashed and the Colorado River is Lee's Ferry, Nevada, the hydrologic division point between the Upper and Lower Basins (from Sangoyomi and Harding, 1995).



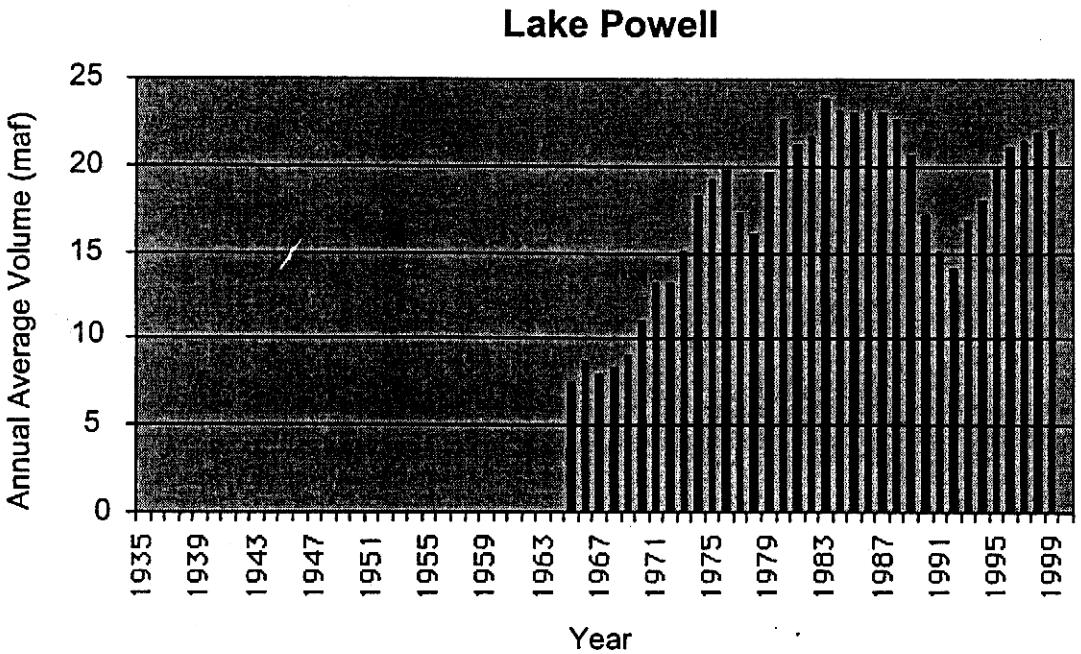


Figure 2. Annual average volumes for Lake Mead and Lake Powell 1935-present.

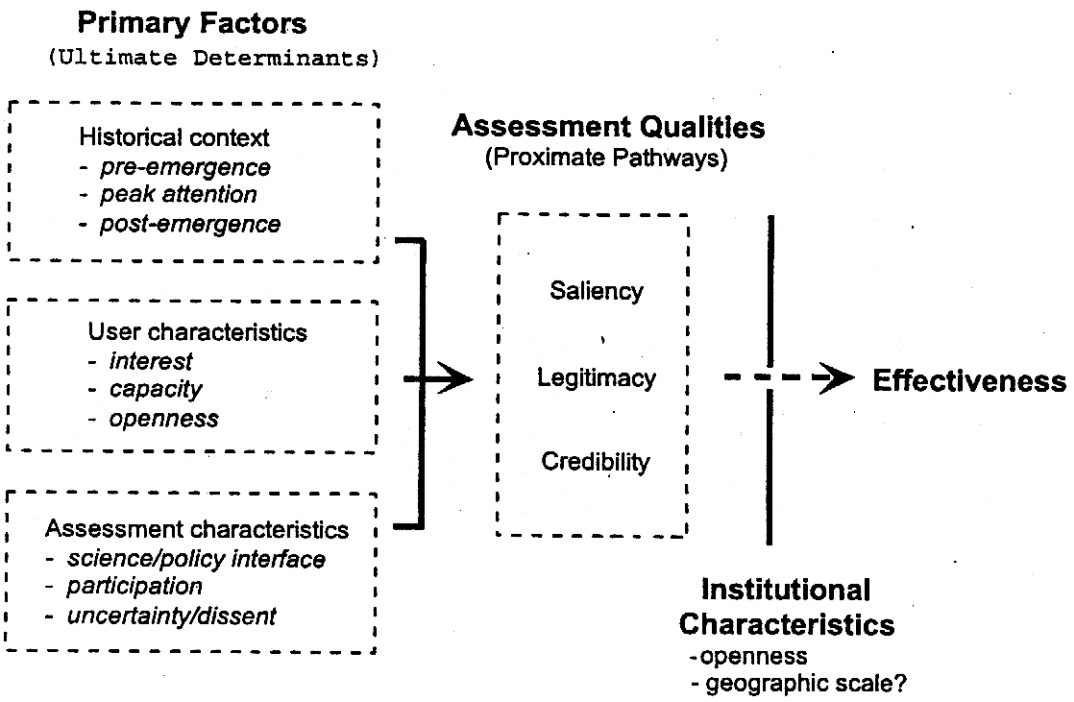


Figure 3. Modified GEA conceptual framework

ENDNOTES

[1] Total allocation had reached 15.75 maf/year at Lee's Ferry, Nevada (7.5 maf for the Upper Basin, 7.5 maf for the Lower Basin, and the Upper Basin's share of the Mexico allotment of 0.75 maf), compared to 15.1 maf/year historical average flow. The historical average is calculated from the Bureau of Reclamation's natural flow database for the Colorado River at Lee's Ferry, Nevada (1905-2000). Natural flow is calculated by adjusting for the effects of consumptive use withdrawals, reservoirs, and dam releases under the Law of the River. It is an estimate of what flow would have been with human intervention in the river system.

[2] Average Colorado River flow at Lee's Ferry from 1930 to 1939 was 13.1 maf (Reclamation natural flow database).

[3] Allotments for Lower Basin states were originally outlined in the 1928 Boulder Canyon Project Act, which also authorized construction of Hoover Dam (MacDonnell et al., 1995).

[4] This is calculated by adding the 7.5 maf allotment for the Lower Basin, plus 0.75 maf for Mexico, minus 0.02 maf tributary inflow between Glen Canyon Dam and Lee's Ferry. The Colorado Basin Storage Act also authorized the Central Arizona Project, an aqueduct to allow Arizona to use its full entitlement of 2.8 maf.

[5] Total reservoir capacity in the Colorado Basin is approximately 60 maf, four times the annual average flow of -15 maf (from Fulp, T., *Management of Colorado River Resources*, Bureau of Reclamation, Lower Colorado Regional Office, 1999).

[6] As listed in the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado Basin Project Act of September 30, 1968 (P.L. 90-537). During the critical period in the natural flow database, flows averaged 12.2 maf/year at Lee's Ferry, Nevada.

[7] Public Comments matrix, 1995 Review of the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, Bureau of Reclamation, U.S. Department of Interior, 1997.

[8] Fact sheet, 1995 Review of the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, Bureau of Reclamation, U.S. Department of Interior, 1997.

[9] The severe drought occurred from 1579 to 1598, with an annual average flow at Lee's Ferry of ~11 maf,

[10] See the following URL: <http://www.crwcd.gov/map.html>

[11] Reservoir volumes for Lake Powell at Glen Canyon Dam (1965-2000) and Lake Mead at Hoover Dam (1935-2000) Bureau of Reclamation, U.S. Department of Interior, 2000.

[12] Comments excerpted from a letter to Robert Young, at the time leading the SSD, from J. Matusak, Metropolitan Water District (October 31, 1994).

[13] Based on personal communication with J. Matusak and formal written comments presented by J. Matusak at the Symposium on Climate Variability, Climate Change, and Water Resource Management, Colorado Springs, CO, October, 1997.

[14] Based on written comments noted in preceding footnote.

[15] The Powell Consortium is a collaborative group of water research centers based at universities around the Colorado Basin. For , more details, see the following URL: <http://wrri.nmsu.edu/powell/>

[16] Based on panel comments from the July 1999 NPPC symposium entitled "Ocean conditions and the management of Columbia River Salmon". For further details see <http://www.nwppc.org/ocean/ocean_3.htm>

[17] The proposed dam breaching involves removing the earthen portion of four Lower Snake River dams, leaving the hydropower portions in tact, but allowing salmon to freely pass without encountering either fish ladders or turbines (Larmer, 1999).

[18] Comments from interviews with Bruce Lovelin of the Columbia River Alliance and the CRA website: <http://www.teleport.com/~cra/>

[19] Recent events indicate that increased resilience to short-term drought has increased the risk of severe flooding in the Colorado Basin. In 1995, the January forecast underestimated spring runoff by 5 maf (Pulwarty and Melis, 2000). Fortuitously, reservoirs were low as a result of the 1987-92 drought, and could easily absorb the extra inflow. Had the reservoir levels been higher, as in 1983, severe flooding would have likely occurred. In the late spring of 1983 a severe flood event led to unusually high water levels in Lake Powell, which in turn required unprecedented water releases from Glen Canyon Dam. The dam was severely damaged by the high volume flow, to the point that Bureau of Reclamation engineers doubted its structural integrity (Fradkin, 1995). The consequences of Glen Canyon Dam failure and the subsequent draining of Lake Powell would have been catastrophic. This nearly instantaneous release of 23 million acre-feet would cause severe downstream flooding, the potential collapse of Hoover Dane, and a drastic reduction in the system's ability to deliver water to millions of users.

[20] Based on interview with representative from the Colorado River Water Conservation District.

[21] According to the SSD progress report to the U.S. Geological Survey, covering activities from October 1, 1991 to September, 30, 1992.

[22] For further discussion see Choice of drought scenario section.

[23] Based on formal written comments presented by J. Matusak at the Symposium on Climate Variability, Climate Change, and Water Resource Management, Colorado Springs, CO, October, 1997.

[24] According to Colorado River water facts on Metropolitan's website: <http://www.mwd.dst.ca.us/pr/crr/crrl.htm>

[25] Interviewees included SSD principal investigators from the University of Colorado, University of Arizona, and Utah State University with expertise in law, economics, hydrology, sociology, and public administration. Additional interviewees included State Engineers or their equivalents from Nevada, Wyoming, Arizona, Utah, and the Metropolitan Water District of Southern California; officials from the Bureau of Reclamation's Lower and Upper Colorado Regional Offices and the Commissioner's Office in Washington, DC; representatives from the Colorado River Board of California, the Colorado River Water Conservation District, the Western States Water Council, and the Upper Colorado River Commission; and water resource policy experts not directly involved in authoring the SSD from the University of Wyoming, and University of California, and the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. Of the additional group, eight served as members of the Advisory Council, with their geographic allegiance noted.

[26] Interviewees included: experts on the socio-economic impacts of climate variability and change from the JISAO-CIG, and the Center for Analysis of Environmental Change, Oregon State University; fisheries experts from the National Marine Fisheries Service and the University of Washington; a representative from the industry-group the Columbia River Alliance; a representative of the Northwest Power Planning Council; and a climate and resource policy expert from the Environmental and Societal Impacts Group at the National Center for Atmospheric Research.