CHAPTER 7

Limits to Assessment

An Example from Regional Abrupt Climate Change Assessment in the United States

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As the number and resolution of paleoclimatic and historical climate observations have improved over the past 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 Niño Southern Oscillation. In each case, physical change in the climate system is abrupt, occurs 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 that climatic changes can be abrupt, 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 assessments in the United States, including the Colorado River Basin Severe-Sustained Drought Assessment (SSDA), and the Pacific Northwest Regional Assessment, which addresses, among other issues, the Pacific Decadal Oscillation (a type of abrupt change). It is unclear why regionally focused assessments 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, and Chapter 6). The purpose of this chapter is threefold: (1) to begin to understand how abrupt climate change science can be utilized in integrated assessments by examining the SSDA in the Colorado River Basin, (2) to examine the factors that influenced SSDA effectiveness and their relationship to the issue domain framework presented in Chapter 1, and (3) to compare the SSDA with key elements of the Columbia River Basin experience, which had a different outcome. A key issue that emerges from this study is that even well-designed assessments may lack effectiveness, due to the presence of institutional constraints that limit progressive management options. Paleoclimatic evidence of previous abrupt climate change events appears to be an inadequate catalyst for institutional change, but ongoing crises may provide the necessary motivation for consideration of alternative policy options.

Background

A major challenge to global environmental assessments is identifying regional effects 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 average global temperature change. One of the strengths of the paleoclimatic and historical records is that each is composed of geographically discrete data sets, allowing for regional-level definition of past climate events. While past events do not forecast the future, they can be useful analogies for probing societal vulnerability to, and the level of preparation for, abrupt climate changes.

Tree ring and lake sediment data indicate that during the past 700 years North America likely experienced two long-term droughts, occurring in the late thirteenth and sixteenth centuries, respectively (Fritts 1965; Grissino-Mayer 1996; Meko et al. 1995; Stahle et al. 1985; Woodhouse and Overpeck 1998). These so-called "megadroughts" exhibit the characteristics of abrupt climate change in that they began quickly (over just a few years), covered a large portion of the western United States, and persisted for two decades in some areas. Data coverage is best for the southwestern United States, which experienced a 20-year drought from approximately A.D. 1580 to 1600. 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 may be related to the strength of deep Atlantic convection (Bianchi and McCave 1999).

Depending on the region in question, historical observations can provide a detailed record of abrupt climate shifts. For example, the southwestern United States suffered multiyear droughts in the past century (e.g., during the mid-1950s; Cook et al. 1998), but nothing on the order of the late sixteenth century event. In the Pacific Northwest, 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 phase of the PDO, temperatures in Idaho, Oregon, and Washington are significantly warmer than normal, and precipitation is significantly lower (Mote et al. 1999). Salmon mortality off the coasts 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. Salmon survival is further exacerbated by low flow in the Columbia River, which decreases by about 10 percent during the warm PDO phase (Mote et al. 1999). Thus, historical data indicate the Pacific Northwest experiences abrupt shifts in climate, which are analogous to climate events apparent in the paleoclimatic record of the southwestern United States.

Awareness of abrupt climate change in scientific circles has increased substantially in the past five years, as indicated by the large number of recent papers on this topic (e.g., Broecker 1997; Overpeck 1996). 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. This is similar to other cases in which consensus-based assessment bodies tend to avoid treatment of low probability, high impact events (see Chapter 6 and Patt 1999).

While abrupt climate change is recognized by the Intergovernmental Panel on Climate Change (IPCC) as an important topic with potentially serious consequences, regionally focused integrated assessments are required to better understand the impact of abrupt climate change on modern socioeconomic systems. One such example is the SSDA, 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 SSDA, 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 SSDA, despite its sophisticated design, had little impact on water management or policy in the Colorado Basin.

The Colorado River Basin

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, the Colorado 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). The Colorado River is subject to two primary demands, consumptive and nonconsumptive. The former includes municipal, industrial, and agricultural uses that require taking water from the river, and the latter includes recreational, hydroelectric, and environmental uses that require leaving water in the river. Increasing demand for water in the southwestern United States limits flow to such an extent that the Colorado River often fails to reach the sea (Fradkin 1995).

The 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 (Table 7-1; Getches 1997; MacDonnell et al. 1995). 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, U.S. 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 a predictable, reliable water supply.

Table 7-1. ***Primary Water Allocation Components of the Law of the River***

Law of the River component	*Allocation*	*Method*
Colorado Compact, 1922	75 million acre-feet (maf) every 10 years from Upper to Lower Basin	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/yr, Arizona 2.8 maf/yr, Nevada 0.3 maf/yr	Absolute
Colorado River Basin Project Act, 1968	8.23 maf per year release from Glen Canyon Dam	Absolute

Notes: The Colorado River Basin (Figure 7-1) is divided into the Upper Basin (Colorado, Wyoming, Utah, and New Mexico) and the Lower Basin (California, Arizona, and Nevada). The hydrological division between the two sub-basins is Lee's Ferry, Nevada, also known as the Colorado Compact Point.

The five components of the Law of the River listed in Table 7-1 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 divisions are based on a percentage of available supply. The Colorado Compact allocates water between the Upper and Lower Basins (Figure 7-1), with the latter guaranteed a volume of 75 million acre-feet (maf) every 10 years, regardless of available flow (MacDonnell et al. 1995). It is now known, however, that the baseline flow rate used to negotiate the Colorado Compact was significantly higher than the twentieth century historical average, implying that in low-flow years, the Upper Basin is more vulnerable to water shortage than is the Lower Basin (Brown 1988). In 1944, an absolute allotment of 1.5 maf/year was established for Mexico, marking 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, a phenomenon euphemistically known as over-allocation. Today, this is only physically possible because Colorado, Wyoming, Utah, and New Mexico have yet to utilize their entire allocation under the 1922 Colorado Compact (MacDonnell et al. 1995).

In 1948, Colorado, Utah, New Mexico, and Wyoming agreed to share water on a proportional basis under the Upper Basin Compact. This compact was driven by obligations to the Lower Basin and Mexico, as well as 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, Congress enacted the Colorado River Storage Project Act in 1956, which authorized the construction of several Upper Basin projects, including Glen Canyon Dam (Brown 1988). Glen Canyon Dam is the legacy of flow deliveries required by the 1922 Colorado Compact, and the initial overestimation 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

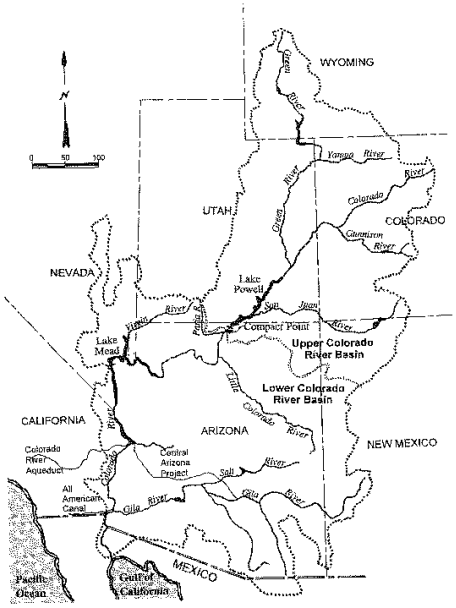

Figure 7-1. *Colorado River Basin*

that designated allotments for Lower Basin states (Table 7-1). With 75 maf/decade 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 River Basin Project Act established the Long-Range Operating Criteria for Upper and Lower Basin reservoirs, which require that a minimum of 8.23 maf/year be released from Glen Canyon Dam.[3] This absolute allotment removed the limited flexibility available in the Colorado Compact, which originally allowed for an *average* release of 7.5 maf/year over the span of a decade (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, in which expectations for minimum flows led to the building of 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 river.[4] Most of this water is held in Lake Powell and Lake Mead, massive reservoirs that serve to buffer the basin from short-term drought (and flood) events. Because these reservoirs were near capacity in the 1980s and 1990s, and demand for water continues to increase, much of the controversy in the Colorado Basin focuses on allocation of surplus water, that is, deliveries in addition to the minimum allocations listed in Table 7-1 (Getches 1997). As a result, there was generally little interest in short-term water shortages.

Long-term drought is taken into account primarily through the Long-Range Operating Criteria. The criteria specify reservoir operating rules that depend on projections of water supply and demand. One of the key factors used to determine available supply is the historical critical flow period, which occurred from 1952 to 1964.[5] 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 to 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).

Basin state representatives, the Bureau of Reclamation, and the Secretary of the Interior review the Long-Range Operating Criteria approximately every five years. 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 (Bureau of Reclamation 1997b). Despite repeated reviews and broadened participation in the review process during the past decade, there have been no changes made in the criteria since their original inception in 1968 (Bureau of Reclamation 1997a). 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 River Basin Project Act and to the political difficulty in altering rules that have become accepted operational norms.

The Severe-Sustained Drought Assessment

Tree-ring data reveal the existence of a late sixteenth-century 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 to determine potential water shortages (Meko et al. 1995; Stockton and Jacoby 1976; Tarboton 1995).[6] How sensitive are water resources in the Colorado Basin to a severe and sustained drought, and what options are available for impact mitigation? To answer these questions, the SSDA 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 extreme circumstances similar to the late sixteenth century drought event.

Using a model of basin hydrology, management facilities, and operating rules, the SSDA experts performed a gaming exercise to determine how representatives from Colorado Basin states would respond to the evolution of a 20-year drought event and to the decisions of other participants. While participants in the exercise were able to minimize impacts to consumptive users, nonconsumptive users such as hydropower generators, recreationists, 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 that guarantee the Lower Basin minimum flows. As a result, the model showed that 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, assessment participants recommended the creation of a federal interstate compact that would establish a commission with the technical credibility and political legitimacy to (1) better balance nonconsumptive and consumptive uses, (2) allocate water based on current demands rather than 1922 allocations, (3) establish proportional drought-sharing on a basin-wide scale, and (4) manage interstate water transfers and water banks to minimize the impacts of severe drought (Lord et al. 1995). In other words, the project participants argued for increased diversity of water management techniques to improve system resilience to water shortages. The participants concluded that current allocation rules outlined under the Law of the River lack the flexibility to mitigate drought impacts across the Colorado Basin. Preliminary discussions with SSDA authors, however, indicate that the assessment has had little impact on policy or management strategies in the Colorado Basin. One of the aims of my study was to determine why the assessment was ineffective in changing the status quo.

Understanding the Assessment through Interviews

Semistructured, open-ended interviews were performed with 26 key people in the Colorado Basin, including the principal investigators of the SSDA project and members of the SSDA Advisory Council (Table 7-2). The council included representatives from state engineer 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 council was essentially a "who's who" of interstate water management in the Colorado Basin, established to ensure that results of the SSDA reached the appropriate stakeholders and to provide a venue for feedback regarding study design and recommendations. The council was established in the late 1980s at the end of the initial SSDA scoping stage (Phase 1; Gregg and Getches 1991), with the intent that comments and suggestions could be incorporated into the subsequent stage (Phase 2; Young 1995), the funding for which began in

Table 7-2. ***Colorado Basin Interviewee Affiliation***

Professional affiliation		*Advisory council representation*	
SSDA investigators	9	Upper Basin	4
State engineers	5	Lower Basin	3
Reclamation officials	5	Upper and Lower Basin	1
Miscellaneous organizations	4		
External experts	3		
Total	26		

Notes: The left-hand column includes all interviews performed for the SSDA study. 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; 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 individuals in the left-hand column, eight served as members of the Advisory Council, with their geographic allegiance noted.

the early 1990s. Phase 2 was designed to include a more thorough assessment of environmental impacts and a gaming exercise to simulate the interactive decisionmaking process that would occur during an extended drought.

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

Phases 1 and 2 of the SSDA were the primary documents used for background information for 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 to providing the historical, legal, and political context of water allocation in the Colorado Basin.

Interview Results and Factors Leading to Ineffectiveness

Environmental assessments can be evaluated both in terms of their effects and their effectiveness. Effects cover the entire range of consequences of an assess-

ment, regardless of original intent, whereas effectiveness is directly related to the intent of the designers and participants in an assessment process. For the purposes of this study, I defined 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 SSDA) were created to better cope with the impacts of long-term drought on a basin-wide scale.

Almost without exception, interviewees revealed that the SSDA changed their perception of extreme drought in the Colorado Basin. Many of the SSDA Advisory Council members, while aware of drought reconstructions based on tree rings, were not cognizant of the impacts such a drought would have on modern water uses. In this limited sense, the assessment achieved the first measure of effectiveness listed above—several water managers emerged from the assessment process with an expanded perception of the potential damage of severe drought.

While awareness of prehistoric drought increased as a result of the SSDA study, this awareness 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 less extreme historical critical flow period (1952–1964) for long-range supply projections, as opposed to the more severe late sixteenth-century event. Interviews with Bureau of Reclamation officials indicate the choice of using the former flow period 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 these historical flows. Introducing a low-flow event based on nonstandard hydrologic techniques would likely encounter opposition from state-level engineers. Furthermore, the use of the late sixteenth-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 Bureau of Reclamation official, "[the basin states] don't want to hear a bleak story." Continued review of the Long-Range Operating Criteria may change current decisionmaking patterns, but for the time being, the SSDA appears to have fallen short in modifying the long-range operation of Colorado Basin reservoirs.

The most challenging measure of effectiveness for the SSDA is the third outcome on the list—to what extent did assessment recommendations encourage flexible drought management policies in the Colorado Basin? All of the interviewees agreed the assessment had little or no impact on policies that would

Table 7-3. *Primary Factors Influencing the Effectiveness of the SSDA Policy Recommendations*

Factors	*Principal investigators*	*Advisory committee*	*Bureau of Reclamation*
Political-legal context	X	X	X
Timing*	X	X	X
Choice of drought scenario*	X	X	
Consumptive uses protected	X		
Follow-up, continuity*	X		

Notes: * denotes factors that could potentially be influenced by assessment design—others were beyond the scope of the assessment. Each row of the table represents a key determinant of SSDA effectiveness (see text for details). The interviewees were separated into three groups (principal investigators, advisory committee, and Bureau of Reclamation), each represented by a column. The Xs represent those factors that each group believed were important determinants of effectiveness.

improve resilience to drought on a basin-wide scale. According to interviews with principal investigators, SSDA Advisory Council members, Bureau of Reclamation officials, and other water managers and experts, several factors led to this ineffectiveness (Table 7-3).

Political–Legal Context The highly political nature of water allocation in the Colorado Basin and the issues addressed by the SSDA are critical to explaining both the effects of the assessment 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 SSDA had little impact. In general, decisionmakers have 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 reveal that a basin-wide interstate compact commission, the primary recommendation of the SSDA participants, is a politically contentious topic, largely due to fears that such an arrangement would erode state-level control of water rights and allocation procedures. SSDA 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), the idea seems to be viewed by many states as a zero-gain prospect, at best adding a layer of bureaucracy and preserving current allocations, at worst yielding water deliveries lower 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,

states 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 the biblical David, and California to Goliath "casting a covetous eye on currently unused Colorado River water" (CRWCD 2000a).

One effect of the SSDA was to clarify the goals of competing water uses on the Colorado River, particularly between consumptive and nonconsumptive uses and between the Upper and Lower Basins. As highlighted in the summary chapter of the assessment:

> Existing operating rules . . . favor consumptive water uses over such nonconsumptive 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, *942*).

Three of the eight SSDA Advisory Council members interviewed found assessment principal investigators to be predisposed to protecting nonconsumptive uses. In one case, a council member recalled that the study helped him clarify the agenda of nonconsumptive 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 key issues already established by groups represented in the SSDA Advisory Council, the SSDA recommendations clarified different agendas—in the words of one council member "we went in with stated positions on these issues, and study results weren't likely to change them."

Timing and Crisis The SSDA study was published in 1995. Between 1995 and the time of this study, levels in Lakes Mead and Powell have been near capacity (Figure 7-2; Bureau of Reclamation 2000). Together, these two reservoirs can hold more than three times the annual flow of the Colorado River. When they're full, the concern for drought tends to be low. Rather than focusing on long- or short-term drought, the Colorado Basin states are currently preoccupied with allocating surplus water. Interviews across the three groups listed in Table 7-3 concur that drought isn't an immediate or long-range concern in the Colorado Basin, and that the timing of SSDA during abundant water years 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 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 among basin states (Pulwarty and Melis 2001). 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

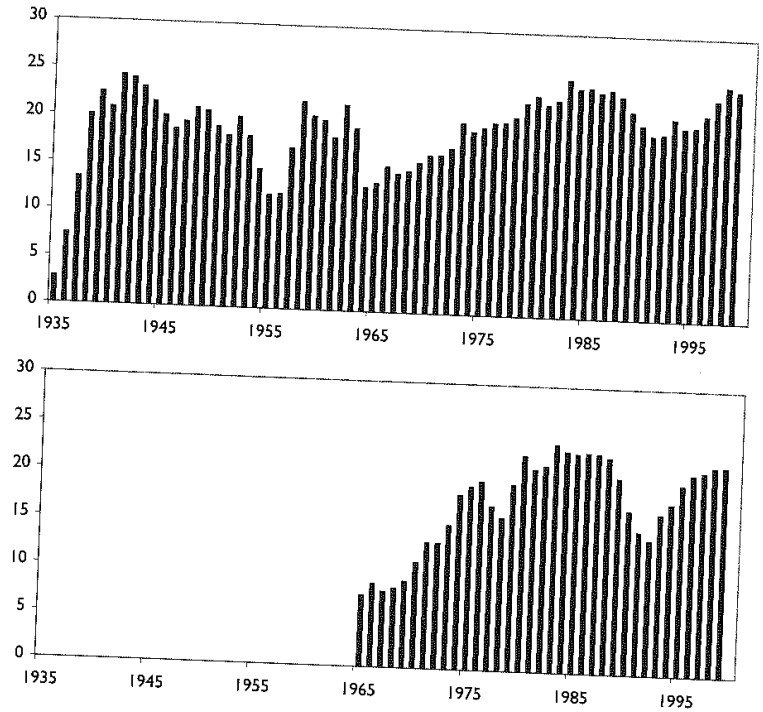

Figure 7-2. ***Annual Average Volumes for Lake Mead (top) and Lake Powell (bottom), 1935–1999 (in millions of acre-feet)***

Colorado Basin, it may be premature to evaluate the effectiveness of the assessment, as its findings and recommendations could yet be used in future drought scenarios.

Although the timing of publication may be important, another key timing element is that of decisionmaker involvement in the assessment. Much of the West was in the grip of drought during the SSDA Advisory Council meetings in 1991 and 1992. During that 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 maf compared with the wet years of the mid-1980s (Figure 7-2). 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, the SSDA was quite timely from a decisionmaker standpoint because the impacts of drought were occurring in the states represented by council members. If poor timing undermined the effectiveness of the SSDA, then influence on policy appears to require a drought more severe than the 1987–1992 event.

Finally, limited dissemination of study results to the general public precluded the accumulation of political support necessary to change policy. During the early 1990s, the SSDA Advisory Council members were apparently the only stakeholders intimately aware of both the ongoing drought event and the policy implications of the assessment.

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 SSDA principal investigators revealed concern that the drought scenario chosen for analysis was too extreme. In particular, the low probability of the event may have prevented the assessment from registering with stakeholders in the Colorado Basin. Further interviews, however, indicate that only a minority of SSDA Advisory Council members and investigators believed that the low probability of the drought prevented its full consideration by water managers. In most cases, interviewees felt that the historical occurrence of severe drought, even if only once in the past 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 SSDA participants appear to have chosen an event that was salient to decisionmakers in the region.

The drought scenario used in the assessment was based on water flows estimated using tree ring widths, but with the flows rearranged in time. The rearranged scenario ordered annual values such that each year during the hypothetical 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 rearranged drought was the event on which the entire 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 that funded the study—the Metropolitan Water District of Southern California (MWD)—doubted the credibility of the rearranged scenario. Correspondence between the MWD and the study organizers indicate the MWD found the rearranged scenario to have no hydrological basis, and therefore not appropriate for use in the assessment. Referring to the rearranged drought, an engineer from the MWD wrote to SSDA 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. (Matusak 1994)

The MWD repeatedly made attempts to comment on the SSDA report, but most of the comments, including doubts about the rearranged scenario, were left unaddressed (Matusak 1997, 2000). This apparently is the result of both the linear

nature of the assessment process and skepticism of the MWD's motivations. Although the SSDA lasted for nearly 10 years, each stage of the project built on the previous stage—to make the major changes requested by the MWD would have required that the study be completely redone, an unrealistic request given funding constraints. Also, the MWD has expressed serious reservations about the need for a basin-wide commission, because majority-based voting in such an arrangement might have led to reduced water supplies for California (Matusak 1997, 2000). Because establishment of a basin-wide entity was a primary SSDA recommendation, it is possible that the MWD chose to discredit the study on technical grounds. Interviews with assessment organizers indicate that skepticism of the MWD's motivations was a major reason that comments about the rearranged drought scenario were not taken into account.

Consumptive Uses Protected Several of the SSDA investigators indicated that one reason the assessment was ineffective was due to the ability of the established Colorado Basin water distribution system to protect consumptive water uses. With the Law of the River in its current form, the assessment determined that damages to consumptive uses in the Upper Basin during a severe-sustained drought could be significant—up to $350 million per year during the most severe part of the drought—but still minor compared with nonconsumptive use damages. 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 reduced by greater than 80 percent (Booker 1995). In other words, the assessment found that 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 uses, at least at current demand levels. In this sense, the assessment 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 among SSDA Advisory Council members or Bureau of Reclamation officials.

Follow-up and Continuity The SSDA study, which lasted nearly 10 years in total, went through a variety of funding uncertainties and leadership changes. The initial source of funding was through a grant award by the U.S. Man and 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 1 and incorporate stakeholders through the advisory council process, was primarily funded through grant awards by 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 assessment 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 completion of the study.

Partly as a consequence and partly as a cause of its patchy funding history, the SSDA study had several different leaders through its 10-year lifespan. Leadership changed between investigators at the University of Colorado and Arizona, to

Utah State University, back to the University of Arizona, and 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 SSDA. Through the exceptional efforts of a few individuals, the study was eventually published in the peer-reviewed *Water Resources Bulletin,* and then republished by the Powell Consortium as a monograph on severe-sustained drought.[7] There were no additional efforts to further publicize the study. As a result, the assessment became an academic document, therefore minimizing public uptake of its results and implications.

Although the SSDA process 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 had been more stable and the leadership more continuous, it is conceivable that changes could have been fully incorporated as alternative assessment scenarios, allowing for multiple iterations based on continued communication between the principal investigators and stakeholders. In this sense, the assessment is a somewhat traditional, linear assessment; as opposed to the more dynamic and long-term regionally based efforts now emerging in the United States. It is of course impossible to know whether a more responsive assessment would have yielded a different outcome. The Columbia River Basin assessment process, however, appears to have benefited from a more dynamic approach, suggesting that a different outcome may have been possible for the SSDA, had it used a similar methodology.

The Issue Domain Framework and the SSDA

The issue domain is a broad concept, including the actors involved in the issue, their beliefs, and their strategies for dealing with the issue; the actors' institutions; the decisions, policies, and agreements that emerge from the institutions; and the potential impacts of these behaviors on the natural environment itself. The SSDA is an interesting case study because it was well designed in terms of legitimacy, salience, and credibility, yet in the end it was largely ineffective. This case highlights the importance of other issue domain factors, such as institutional and timing constraints, that are key determinants of effectiveness.

Legitimacy

At the outset of this research project, I assumed that SSDA participants were largely from academic institutions, and the users of the study were primarily funding agencies, such as the U.S. Geological Survey and the U.S. Army Corps of Engineers. It was originally hypothesized that the scope of participation in the SSDA study eroded assessment legitimacy among excluded stakeholders—those whose interests were potentially affected by assessment recommendations but who were not directly involved in the assessment. Subsequent research, however, indicates that many key stakeholders were directly involved in the assessment as part of the SSDA Advisory Council. While the actual authors of the assessment were largely from an academic background, the council included representatives from the state engineer's offices, state departments of natural resources, the Upper Colorado River Commission, the Colorado Water Conservation District, and others. Given this broad representation—both between the Upper and Lower Basin and covering consumptive and nonconsumptive water uses—people interviewed for this study generally viewed the assessment as having legitimate representation.

Salience

One of the primary challenges facing assessments of abrupt climate change is issue salience. Abrupt climate changes tend to occur infrequently, often separated in time by decades or centuries, and therefore few stakeholders have experienced the impact of these events. At the beginning of this study, I hypothesized that the low probability of the SSDA scenario prevented it from being salient to stakeholders in the Colorado Basin. Interviews with SSDA Advisory Council members, however, reveal that the drought event was salient to stakeholders. Most of the council members interviewed (six of eight) 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 council during the early 1990s (SSDA 1992). Overall, the interface between science (SSDA principal investigators) and policy (SSDA Advisory Council members) appears to have been sufficiently porous to ensure that the scenario that formed the basis of the assessment was salient to most water managers in the Colorado Basin.

A minority of the stakeholders interviewed indicated that the low probability of the drought scenario used in the assessment did affect their perceptions of assessment results, insofar as they felt that it was highly unlikely that such an event would occur again. In this respect, 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 had been relaxed, the assessment process may have allowed for the inclusion of an additional drought scenario, thus improving the overall salience of the assessment.

According to interviews with both principal investigators and SSDA Advisory Council members, the assessment never emerged onto a broader political agenda or received significant media attention, despite its credentials of salience and legitimacy. Major environmental issues tend to have attention cycles characterized by (1) 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. 2001). An assessment that fails to change with the times, altering its participation in concert with the stage of the issue attention cycle, will tend to be ineffective.

The primary reason the SSDA did not make it to the emergent stage was the absence of a crisis event. If an extreme drought had occurred coincidentally during the assessment process, then it is quite likely that the impact of the assessment on water policy in the Colorado Basin would have been different. The primary issue for the assessment is not its adaptation 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 the assessment addressed—a low probability event that in all likelihood would not occur during the assessment process. Many of the assessments studied in this book tend to focus on chronic environmental problems such as global warming, ozone depletion, and acid rain. As a 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 chronic environmental problem and its 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.

Credibility

The drought scenario used in the SSDA was also generally credible to SSDA Advisory Council members. Despite the unusual severity and duration of the drought, most members of the committee felt that it was a reasonable case for testing management of Colorado River water resources under extreme circumstances (see Choice of Drought Scenario section, above). One notable exception was the Southern California Metropolitan Water District. The MWD doubted the validity of the re-arranged drought scenario and suggested the unrealistic flows would preclude adoption of the SSDA recommendations by water resource managers. Given that the drought used in the SSDA was an altered version of the tree-ring record, the MWD criticism seems reasonable. However, the MWD had openly opposed the formation of a basin-wide commission and recognized that the use of a more severe drought scenario in basin reservoir management would result in less frequent deliveries of surplus water to the Lower Basin. While politically motivated questioning of SSDA credibility by the MWD is difficult to document, it is not surprising that an entity tasked with managing the water supply for 18 million people in southern California (MWD 2000) would be skeptical of information that could potentially interfere with its responsibilities.

Evolution of the Issue Domain

One of the primary factors that influenced the effectiveness of the SSDA 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 states' water allocations. Previous studies of Colorado River water law (e.g., Brown 1988) and interviews from this study with principal investigators of the assessment, SSDA 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.

In the Colorado Basin, institutional characteristics inhibiting progressive interstate water management were the primary determinants of SSDA effectiveness. 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 et al. 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 who make decisions are primarily those in the Bureau of Reclamation and state engineers' offices, and the edifices include the multitude of water storage and conveyance structures throughout the region. If one were to implement a well-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. Indeed, the negative influence of political and legal factors appears to be the case for the SSDA, where ineffectiveness was more a function of institutional characteristics than design factors.

Institutions serve as a filter for assessments, either promoting or inhibiting evolution of the issue domain. The term "evolution" is used here not to imply an improvement, but rather a clear change in stakeholder beliefs, strategies, or institutions due to an assessment or an external crisis factor. The SSDA had two primary effects on the issue domain in the Colorado Basin: it raised stakeholder awareness of the potential magnitude of long-term drought and its attendant impacts, and it clarified competing interests among stakeholder groups. In issue domain terms, the beliefs of stakeholders developed, but their strategies and behaviors for coping with long-term drought remained unchanged. As outlined above, this is primarily due to the institutional setting of the issue domain. Given the right circumstances, the issue domain may eventually evolve to formally acknowledge paleoclimatic droughts via altered behaviors and institutional characteristics, but the assessment on its own was unable to catalyze these changes.

The Columbia River Basin

The Columbia River drains an area comparable in size to the Colorado Basin, but the Columbia has nearly 10 times the annual flow of the Colorado River (Skogerboe 1982). As a result, conflict over consumptive water uses in Oregon, Washington, Montana, and Idaho is essentially nonexistent compared to the contentious history of water rights in the Colorado Basin. Nonconsumptive uses are the primary sources 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 percent of the region's electric-

ity (Wilkinson and Conner 1987), making the Columbia one of the most heavily developed and managed river systems in the world. As a result of hydroelectric development, over-fishing, habitat degradation, and hatchery fish production, wild salmon populations in the Columbia Basin declined precipitously during the twentieth 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 more than $130 million per year (Lee 1995). Engineering efforts of epic proportions have been undertaken for 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. Despite these efforts, salmon populations continue to decline. In the early 1990s, several salmon stocks in the Snake River, a major tributary to the Columbia, were listed under the Endangered Species Act (Larmer 1999).

Superimposed over this general decline in wild salmon stocks 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 coasts of Oregon and Washington generally increases during the warm phase of the PDO, when sea-surface temperatures in the Northeast Pacific Ocean tend to be warmer and less biologically productive. During the cold phase, climatic effects tend to improve 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 SSDA 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, the primary factors motivating application of this information appear to be institutional flexibility and the presence (or absence) of crisis events.

Understanding Adoption of PDO Information through Interviews

Semistructured, open-ended interviews were conducted with climate assessment experts from the Pacific Northwest (Table 7-4). This primarily included members of the Pacific Northwest 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 given that a primary responsibility of the Pacific Northwest Regional Assessment is to routinely interact with resource managers in the region, I used the JISAO-CIG interviews as a barometer for the adoption of abrupt climate change information in the Pacific Northwest. Discussions with JISAO-CIG members were supplemented with interviews of key people familiar with the impacts of climate variability on salmon populations in the Columbia Basin. These discussions covered academic, industry, and state and federal agency perspectives.

Table 7-4. *Pacific Northwest Interviewee Affiliation*

Total number of interviewees	9
Climate impacts experts	4
Fisheries experts	2
Industry representative	1
NPPC representative	1
External climate expert	1

Note: Interviewees included experts on the socioeconomic impacts of climate variability and change from the Joint Institute for the Study of Atmosphere and Ocean-Climate Impacts Group, 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 Columbia River Alliance (an industry group); 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.

I used the recent report by participants of the Pacific Northwest Regional Assessment (Mote et al. 1999) as a primary background document 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 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.

Interview Results and Inter-basin Comparison

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 past 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.[8] This is a significant change in management of the Columbia River and reflects an awareness of the oceanic component of salmon ecology.

Partly as a result of the 1996 amendment, the NPPC advocates limited hatchery production and hydropower generation to allow salmon populations to better cope with a variable oceanic environment. Advocates of this view, including representatives of the NPPC, 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 reduced if hatchery production were reduced during intervals of poor ocean conditions (NPPC 1999). Water spills from reservoirs could also be timed not to maximize the total number of juvenile fish migrating downstream, but to increase their diversity, thus improving chances for oceanic survival (Bisbal and McConnaha 1998). Broad biological diversity is the primary means by which salmon populations adapted to past climatic and oceanic variability—constraints on this diversity from hydropower development, habitat degradation, and hatchery production serve to increase salmon mortality over 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 predevelopment characteristics, overall salmon survival should benefit as a consequence (Bisbal and McConnaha 1998).

While the management strategies advanced by the NPPC are in a formative stage, there is clearly the institutional desire and monetary support to pursue progressive fishery management techniques. On the Snake River, a major tributary of the Columbia, the breaching of four dams has been considered as a viable option by federal agencies in salmon recovery plans.[9] The early 1990s Endangered Species Act listing of the four remaining Snake River salmon stocks and their continued spiral toward extinction spurred this radical approach. The crisis was also partly prompted by the spring 2000 deadline from the Clinton administration for the U.S. Army Corps of Engineers, Bonneville Power Administration, and National Marine Fisheries Service to create a restoration plan for the endangered species (Larmer 1999).

Breaching of Snake River dams was controversial, particularly for those industries that rely on the dams for barge transportation and hydropower. The Columbia River Alliance, which represents aluminum manufacturers, wheat growers, and other industrial interests in the basin, argued that breaching was an "unreasonable course of action" that was "economically harmful and will not help recover salmon" (Lovelin 2000). Industry groups argued that factors other than dams, such as over-fishing and poor oceanic conditions, exerted the dominant control over salmon populations (Barker 2000). Many environmental interests, Native American tribes, and fishery organizations countered 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 became part of the U.S. presidential election in 2000, with both candidates offering their opinions on whether the dams should be breached (Mapes 2000; Seelye 2000).

The continued crisis of depleted salmon stocks was a major factor influencing the incorporation of abrupt climate change information into the Columbia Basin salmon recovery debate. Those wishing to minimize freshwater habitat restrictions desired more aggressive salmon conservation measures to improve the diversity and hence resilience of salmon to natural variability, while those benefiting directly from dams used high oceanic salmon mortality to justify status quo measures of juvenile salmon barging, hydropower turbine screens, and the like. In the contentious environment of balancing the needs of economic development with salmon habitat preservation, it appears that knowledge of variable oceanic conditions has been employed by both sides to advance existing political agendas.

Timing and Crisis The frequency of climatic anomalies is a key difference between the Columbia and Colorado cases. Abrupt climate change information is more likely to be assimilated into the salmon management debate in the Columbia Basin because the PDO changes phase approximately every 20 years. The last PDO shift in the mid-1970s provides a historical analog for resource managers to better understand the impacts of future PDO changes on salmon populations (Mantua et al. 1997). A drought like the one outlined by the SSDA study has no adequate twentieth century analog in the Colorado Basin, and thus there is no institutional memory of the magnitude or impacts of such an event. Furthermore, it is likely that a PDO phase shift will occur in the near future, therefore providing motivation for stakeholders in the Pacific Northwest to utilize PDO information. The apparent low probability of the assessment scenario could invite resource managers in the Colorado Basin to write off the possibility of it occurring during their policy or management tenures.

Structural factors may lead to more frequent salmon management 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 multiyear drought.[10] During the 1987–1992 drought, for example, there was enough water in Lake Powell and Lake Mead to prevent major restrictions on the basic allocations outlined in the Law of the River (CRWCD 2000b). Thus, dams facilitate water resource management in the Colorado Basin, mitigating the effects of water shortages; they conversely frustrate salmon management in the Columbia Basin by contributing to habitat degradation, thus increasing the likelihood of crisis and the consideration of alternative policy options.

Institutional Constraints 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 et al. 1995). In the Columbia Basin, 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.

The SSDA lacked a crisis event comparable to that of salmon extinction in the Pacific Northwest. Because severe drought has not yet affected the Colorado Basin in its modern structural and institutional state, water managers have little incentive to re-evaluate current interstate water policies. Recent intrastate water

marketing and transfers in California and discussion of interstate banking in the Lower Basin indicate a changing political environment, but it is unclear how advances in water allocation flexibility will improve the basin-wide response to a severe sustained drought. For the time being, it appears that constraints imposed on interstate water management by the Law of the River and by the long history of competition over scarce Colorado River water prevent the adoption of the institutional recommendations advocated by the assessment.

In the Columbia Basin, a more open and adaptive management system led by the NPPC and the Pacific Northwest Regional Assessment, seems to facilitate the consideration of progressive management approaches. The NPPC 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. 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, decisionmakers, and stakeholders" (Cash 2000). The NPPC and the Pacific Northwest Regional Assessment have the funding and stability to facilitate long-term interactions between scientists and decisionmakers. These organizations, in addition to the ongoing decline in salmonid populations, played a primary role in the rapid assimilation of abrupt climate change information into the salmon restoration debate. While the use of abrupt climate change information in the Columbia Basin is in its infancy, making it difficult to see concrete examples of new management approaches, there is clearly political and institutional desire to use the information to the greatest extent possible.

Conclusions

The SSDA 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 it had little impact on management techniques or policy. The principal investigators of the assessment were both innovative and sophisticated in their approach, creating a product that was multi-institutional and interdisciplinary in origin, covering everything from tree ring-based river flow reconstructions to sociological analyses of drought mitigation options. It 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 it actively sought the participation of key water managers, offering them the opportunity to guide and provide feedback on assessment structure and process. In many ways, the assessment was an exemplary process, incorporating several of the design factors that have been shown in other chapters to lead to effectiveness.

My point is not to argue that the SSDA represents an ideal assessment, but rather to highlight it as an example of a case in which it is necessary to look beyond design factors under the immediate control of those managing the assessment. Using cases like it we can evaluate the environment in which a well-

designed assessment either flourishes and reaches the elusive state of effectiveness or withers into a set of moribund documents that collect more dust than interest from decisionmakers. The assessment had its faults. A drought scenario taken directly from the tree ring record, for example, rather than the re-arranged version adopted by the assessment, would have improved credibility with some stakeholders, and its implications for water policy would have been similar. The assessment did, however, avoid major pitfalls, such as addressing issues based on the presumed interest of decisionmakers, or failing to involve an adequately diverse group of stakeholders. Careful and thoughtful design is crucial to ensure that an assessment can function in a politically contentious environment.

If the SSDA was so well-designed, then why was it ineffective? Largely this is due to the institutional constraints that confounded 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 assessment recommendations, 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.

Previous studies of natural resource management systems imply that surprise and crisis are the inevitable consequences of command-and-control resource management techniques (Gunderson et al. 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 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, a prime example of command-and-control management, has yet to experience an event to prompt serious reconsideration of current long-term drought contingency plans. While the drought of 1987–1992 led to strict conservation programs in southern California and Las Vegas (Fradkin 1995), the magnitude of this event was inadequate to catalyze a basin-wide crisis.

In two river basin 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 points. The existence and magnitude of external crisis events is an important factor, but different internal institutional characteristics also play a role. In the Columbia River Basin, the NPPC and the Pacific Northwest Regional Assessment have the mandate and stability to act as long-term basin-wide networks for research, assessment, and resource management. An independent and well-funded interstate body like the NPPC does not exist in the Colorado Basin to coordinate water management. If such an organization did exist, and if it were tasked with balancing consumptive and nonconsumptive uses, as well as Upper

and Lower Basin interests, the SSDA would have resonated in the Colorado Basin more than it did. Stakeholders who could benefit from a basin-wide commission are interested in creating such an organization, while those who stand to lose their current water allocation are not. Ironically, the creation of a basin-wide commission that could coordinate severe drought response, a primary recommendation of the assessment, appears necessary to ensure the efficacy of assessments like the SSDA. Therefore, it seems that an external influence, on par with the salmon crisis in the Pacific Northwest, is necessary for the Colorado Basin to construct the flexible institutional framework essential for response to a massive drought event. Hopefully it will not require the actual occurrence of a 20-year drought.

Notes

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 the 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 without human intervention in the river system.

2. Average Colorado River flow at Lee's Ferry from 1930 to 1939 was 13.1 maf (Bureau of Reclamation 1999), well below the total allocation of 15.75 maf/year.

3. This flow 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.

4. Total reservoir capacity in the Colorado Basin is approximately 60 maf, four times the annual average flow of approximately 15 maf (Bureau of Reclamation 2000).

5. 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.

6. The severe drought occurred from 1579 to 1598, with an annual average flow at Lee's Ferry of approximately 11 maf.

7. The Powell Consortium is a collaborative group of water research centers based at universities around the Colorado Basin. For more details, see http://wrri.nmsu.edu/powell/.

8. Northwest Power Planning and Conservation Act. 1996. Section (4)(h)(10)(D).

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

10. 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 2001). Fortuitously, reservoirs were low as a result of the 1987–1992 drought, and they could easily absorb the extra inflow. Had the reservoir levels been higher (as was the case in 1983), severe flooding likely would have occurred. In the late spring of 1983, a severe flood 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 a Glen Canyon Dam failure and the subsequent draining of Lake Powell would have been catastrophic. This nearly instantaneous release of 23 maf would have caused severe downstream flooding, the potential collapse of Hoover Dam, and a drastic reduction in the system's ability to deliver water to millions of users.

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