# Rethinking Vulnerability on the Colorado River

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## INTRODUCTION

In October of 1995, *Water Resources Bulletin*, the former journal of the American Water Resources Association, devoted an entire issue to the findings of the "Severe, Sustained Drought in the Southwestern United States" study (*see* Young, 1995). That project (hereafter termed the "SSD study") examined the alarming but seemingly very remote scenario of modern-day catastrophic drought on the Colorado River, with the aim not merely of assessing system vulnerability to shortage and identifying potential drought impacts, but of informing and inspiring the institutional reforms needed to avoid any such future calamity. By most accounts, the study was ambitious and innovative, but just over a decade later and after the culmination of new "shortage sharing" negotiations, some key findings seem dated if not erroneous. The context for risk in the basin has changed, and understanding that change lies in the complex relationship between drought, water demands, and the prospect of chronic reductions in streamflows from climate change. This paper discusses these risks as a function of social and environmental vulnerability and alterations in physical conditions.

## THE SSD STUDY

The SSD study investigated the vulnerability of the modern-day Colorado River to a drought of severity and duration beyond anything theretofore seen in the historic record. The study initially used the paleo drought from 1579 to 1600, as documented in tree rings, followed by a wet 16-year recovery period, as the basis for hydrologic inputs into water models (Young 1995). An event of this magnitude was thought to pose the greatest threat to the two major reservoirs on the system (Powell and Mead), and thereby posed the greatest challenge to the interbasin, interstate and international allocation scheme codified in the Law of the River.[1] Water allocation models reflecting modern legal/institutional arrangements, infrastructure, and projected demand patterns were used to track and quantify impacts of the unfolding drought, while additional models and game theory techniques were subsequently applied to investigate a small set of potential coping strategies focusing primarily on new reservoir operations and water marketing/reallocation.

The study showed the system to be remarkably reliable during drought—so much, in fact, that the researchers decided to re-order the drought (i.e., all 22 years in the paleo drought were arranged from wettest to driest), thereby generating a period of 16 consecutive years of below average flows with an annual mean of 9.57 MAF (million acre-feet), compared to a long-term term average typically estimated at nearly 15 MAF. This re-ordering was estimated to lengthen the return interval range of the event from 400-700 years (in its original form) to 2,000-10,000 years. In the scenario, once the run of drier than average years begun, Lake Powell took only a dozen years to drop to dead storage (where it remained for 7 years). Lake Mead, however, fared dramatically better, hovering near 20 MAF (about two-thirds full) until Powell was empty, only then dropping sharply, but still never falling beyond a low of 7.5 MAF (Figures 1 and 2). In the worst year of the SSD scenario for water deliveries, roughly 59% of projected Upper Basin consumptive demands went unmet, compared to just 3% in the Lower Basin; shortages in the Lower basin were primarily confined to surplus uses. In short, the system was found to be quite effective in serving existing Lower Basin consumptive uses (although instream uses suffered), with most problems limited to Lake Powell and Upper Basin users. This, as of 1995, was our collective assessment of system reliability in a seemingly worst-case scenario.

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[1] The basin is legally divided into an Upper and Lower Basin at Lee Ferry, with Lake Powell providing the upstream storage needed to ensure compact-specified water deliveries to serve downstream interests, which then pull water from Lake Mead. The 1922 compact allocates 7.5 MAF (million acre-feet/year) to each Basin, and a treaty later (1944) provided 1.5 MAF/year for Mexico, for a total apportionment of 16.5 MAF/year. This total is higher than actual annual flows, a problem magnified by compact rules that appear to obligate the Upper Basin to allow almost the full Lower Basin and Mexican obligations to pass downstream before the Upper Basin can take its share.

THE CURRENT DROUGHT

Upon publication, the SSD study received only modest attention; in fact, up to 2001, much of the interbasin debate was focused on the allocation of Lower Basin *surpluses* (USBR, 2001). This situation did not change until after the new millennium when an ongoing series of dry years lowered natural inflows into the basin: 62% of the 30-year average in 2000, 59% in 2001, 25% in 2002, 51% in 2003, 49% in 2004, 105% in 2005, 73% in 2006, 68% in 2007, and 102% in 2008.[2] Coincident with this modern drought was a precipitous decline in storage, shown in Figures 1 and 2 with the year 2000 matched up with year 6 of the SSD scenario to synch the start of reservoir declines in the actual and hypothetical drought scenarios. In both traces, Lake Powell drops quickly (Figure 1), slightly less so in the SSD scenario only because the re-ordered drought starts out with the least severe years at the beginning. The traces for Lake Mead diverge radically (Figure 2), however, suggesting a very different story than envisioned in the SSD.

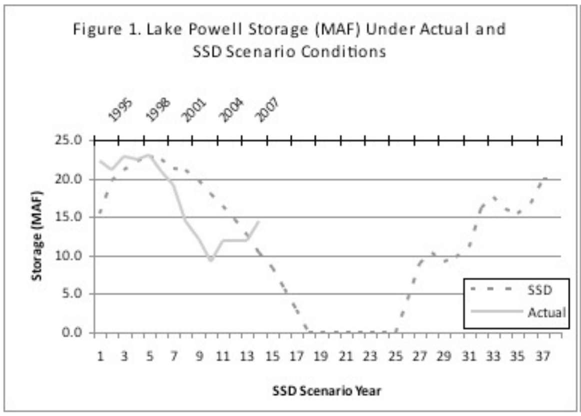

Figure 1. Lake Powell Storage (MAF) Under Actual and SSD Scenario Conditions

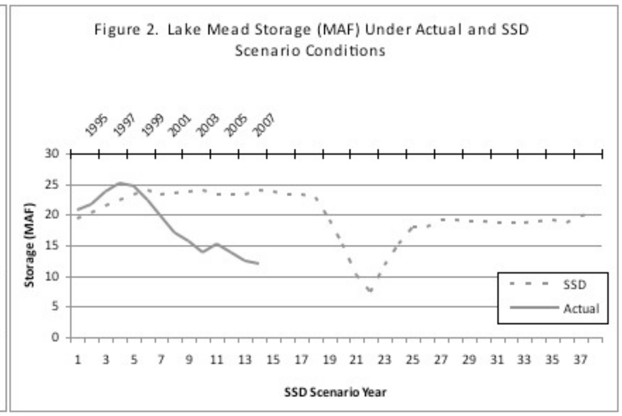

Figure 2. Lake Mead Storage (MAF) Under Actual and SSD Scenario Conditions

CHANGING VULNERABILITY

Lower Basin

The recent decline of Colorado River storage is generally attributed to drought. Indeed, the decreasing level of Lake Powell closely follows the decreasing trend in inflows expressed as virgin flow at Lee Ferry (Figure 3). Similarly, reduced storage in Lake Mead could be expected to reflect changes in Lake Mead inflows, which are primarily a function of Lake Powell releases. However, these releases are remarkably consistent during dry periods at 8.23 MAF/year (at least until Powell is empty), dictated more by legal requirements and hydropower regimes than hydroclimatic conditions.[3] Reclamation's provisional data suggests that inflows to Lake Mead have not changed significantly during the current drought compared to early 1990s. Compare Lake Mead in two critical 5-year periods: 1990 to 1994, and 2000 to 2004 (Figure 4). In both periods, inflows to Lake Mead are approximately 9 MAF/year, but while this was sufficient to keep storage levels stable in the first period, the second period featured a decline of roughly 9 MAF.

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[2] Statistics in this paper regarding inflows, storage, diversions, and consumptive use have primarily been compiled from records prepared by the U.S. Bureau of Reclamation (Reclamation). In many cases, these figures are later amended and updated, and much of the data regarding diversions and consumption since 2001 is provisional (as noted in the text). Inflow data is provided at: http://www.usbr.gov/uc/water/crsp/cs/gcd.html; demands are summarized in the Consumptive Uses and Losses reports (http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html) and the annual Decree Accounting Reports (http://www.usbr.gov/lc/region/g4000/wtracct.html). Deliveries from the Central Arizona Project are from http://www.cap-az.com/deliveries/index.cfm.

[3]Mead also receives inflows from tributaries (many ungaged) between the two reservoirs, estimated here (as is commonly done) at a constant 0.77 MAF/year.

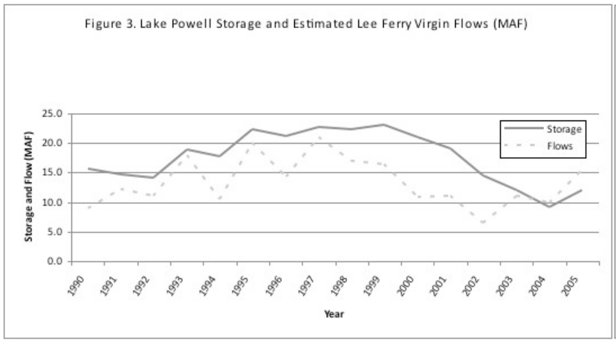

Figure 3. Lake Powell Storage and Estimated Lee Ferry Virgin Flows (MAF)

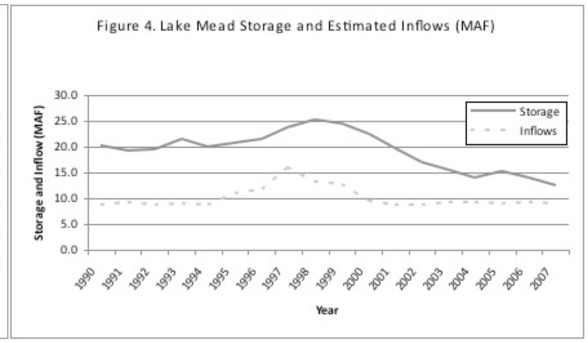

Figure 4. Lake Mead Storage and Estimated Inflows (MAF)

To understand how the risk of shortage in meeting demands from Lake Mead has changed, a revised analysis must go beyond drought and a traditional supply-side analysis. For Lake Powell, 2000-2004 looks very different than 1990-1994 because of reduced drought inflows, but for Lake Mead, the difference is mostly explained by the growth of Lower Basin demands. Reclamation provisional data suggest that Lower Basin consumptive uses (defined here as the sum of deliveries from the mainstem to Arizona, California, and Nevada, and treaty-required deliveries to Mexico) in 2000-2004 versus 1990-1994 grew by approximately 1 MAF/year (from 8.7 to 9.7 MAF/year), sufficient to pass the threshold that determines whether or not Lake Mead is stable or declining. Key to this increased consumption was the completion of the Central Arizona Project (CAP), which allows Arizona to use its Colorado River entitlement to offset groundwater depletions. The project was "substantially completed" in 1994, and very quickly was put into full operation. Mainstem deliveries to CAP averaged 1.5 MAF/year from 2000 to 2004, roughly 3 times higher than the CAP demand projections used in the SSD study (derived from assumptions in the 1991 Annual Operating Plan and economic modeling that assumed CAP water would be prohibitively expensive for many users). This erroneous assumption, more than any other single item, explain why the SSD and actual drought traces for Lake Mead differ so significantly.

Upper Basin

The possibility of drought causing shortages in the Upper Basin remains a valid concern, but assessing vulnerability is again a more complex story. Since the extremely dry year in 2002, analysts in the Upper Basin have speculated about whether or not a drought-inspired "call on the river" is a real possibility, how that legally-complex issue would be determined, and how a call might be administered. A call would be triggered if storage in Powell precluded fulfilling the compact-defined delivery requirement of 75 MAF over 10-years (or 82.3 MAF including half of the Mexican obligation). Although this is a scenario worth considering, as in the Lower Basin, this focus on extreme drought must be coupled with concern over a more chronic concern: in this case, the threat of decreased mean flows due to climate change. Most climate models suggest future declines this century in Colorado River flows—as described in Appendix U of the 2007 Environmental Impact Statement (U.S. Bureau of Reclamation, 2007). A modest decline of 10 percent would mean a roughly 1.5 MAF/year reduction in average annual supplies. Under many legal interpretations, this full amount would come out of the Upper Basin apportionment.

Ironically, the Upper Basin already "lost" roughly this amount last century as estimates of the mean flow of the river were reduced. This familiar story involves the error of compact negotiators in the 1920s that unwittingly used the hydrology from an exceedingly wet period to over-allocate the river. Due to this error, the Upper Basin for many years has reluctantly assumed that their reliable annual share of the river may be closer to 6 MAF than the promised 7.5 MAF. Should impacts of climate change reduce this value further, as in this scenario to 4.5 MAF/year, then shortages can quickly go from theoretical to real, as Upper Basin consumption (from 1996 to 2000) averaged 4.4 MAF/year (accounting for evaporation losses). Certainly responses to this climate change scenario would not play out without legal and political wrangling and a search for engineering solutions, but the central message is unchanged: extreme droughts are a real concern, but assessing their impact on water supply vulnerability requires considering other factors, namely long-term changes in average demands and inflows.

LOOKING FORWARD

The drought has prompted several management innovations aimed at balancing the regional water budget. One of the first and most significant accomplishments has been the enactment and accelerated implementation of the "Interim Surplus Guidelines," which includes California's 4.4 Plan to reduce its annual use of the river (USBR, 2001). California's Colorado River consumption averaged 5.0 MAF/year during the 1990s, but since 2003 has not exceeded the state's formal apportionment of 4.4 MAF/year. Similarly, while urban growth continues at a rapid pace throughout the basin, several major southwestern cities have accomplished this without a corresponding increase in water consumption. Another major accomplishment is the new interim operational guidelines for shortage sharing and the modified reservoir operating regimes (including some anticipated in the SSD research) that better protect storage (USBR, 2007). These guidelines not only outline a more orderly and phased schedule of reductions when reservoirs start to decline, but establish a framework through 2026 for cooperative learning and planning among Federal and state interests focused on new baseline supply estimates. The new rules also include a program allowing some conserved water ("intentionally created surplus") in the Lower Basin to be marketed to support new or, potentially, existing demands elsewhere. The program is new, and thus untested, and has caps on the amount of water available, but is does institutionalize an incentive for demand management that heretofore was largely absent in the Law of the River. Efforts to reduce "regulatory wastes" (such as over-deliveries and reservoir spills) are also underway, as is the search for remaining opportunities to augment river flows.

Looking back, it is fair to conclude that the SSD project was a major step forward in thinking about drought on the Colorado River. But to the extent that the study was intended to illuminate the vulnerability of Colorado River water users to shortages, the scenario considered was ultimately too narrow to capture the complex interplay between drought, growing demands, and the then-nascent research about climate change and the assumption of hydrologic stationarity. Today, it no longer takes a significant SSD-quality event to cause significant disruptions to water supplies, and any such disruptions are not confined to Upper Basin users (as the SSD analysis suggested). Largely due to our ongoing experience with real drought, the research community now has a significantly better understanding of the forces that shape vulnerability on the Colorado River, and has the attention of water managers and other public policy officials to an extent not enjoyed by the SSD research team.

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