Intermountain West Climate Summary
A product of
The Western Water Assessment
Issued May2009
Vol. 5, Issue 3

Water Resources Decision-Makers and their needs for Decadal Climate Prediction

Andrea J. Ray, NOAA Earth Systems Research Lab & NOAA-CIRES Western Water Assessment

[This is a revised version of an article that originally appeared in the "U.S. CLIVAR Variations," newsletter in September 2008, Vol. 6, No. 2. http://www.usclivar.org/pubs.php]

Prediction of climate variability on decadal time scales is a particularly rich arena for applications as many natural resource management decisions are made in the context of decadal and multi-year variations in climate. This is because the resources themselves have decadal-scale lifecycles. The U. S. Climate Variability and Predictability Research Program (CLIVAR) seeks to identify the potential for predictions of the upcoming decade and through 2018. For example, what key predictands are prime targets for skillful decadal forecasts, and what phenomena possess potential predictability? Key questions on the applications side include what societal issues are sensitive to climate at these time scales, what climate information is useful, can actions be taken that minimize adverse affects or take advantage of opportunities, and what are the pathways for integrating decadal-scale forecasts into decisionmaking?

Answers to these questions are the jumping off point for interactions between climate and applications researchers and potential users of this research. Although the decadal prediction problem is still in its infancy (Vimont and Newman, 2007), discussions at this stage among climate and applications scientists and potential users of decadal predictions will allow two-way learning in which scientists learn about users' needs, and users learn about what is predictable and are involved in the development of prediction products. In developing successful applications of climate information, iterative, two-way interactions between scientists and users has been shown to be successful in producing usable science (Lemos and Morehouse, 2006).

This article describes two examples of interactions with Colorado reservoir managers and municipal water managers, and reflects on some of their needs and opportunities for use of decadal information. Other opportunities in water-related sectors, include agriculture (vineyards, orchards) -- drought mitigation/planning, fire management, and public health.

Managing the Colorado River

The U.S. Bureau of Reclamation (Reclaimation) manages the Colorado River under the Colorado Compact of 1922. That compact, ironically, divided the river's supply based on decadal-scale period of higher than average flows in the early 20th century (Figure 1). There have been multi-year and decadal periods of high and low flows since, and in previous centuries as well (Meko, et al 2007). Reservoirs were designed as a buffer against periods of low flow, allowing the Upper Basin to consistently use its allocation under the compact even during drought. Wet years refill storage, and extended decadal and longer periods of above and below average flow determine system yield more than long-term averages (Bureau of Reclamation, 2007a). In the summer of 1999, Lake Powell was essentially full with reservoir storage at 97 % of capacity; inflow that water year had been 109% of average (Bureau of Reclamation, 2008). But from 2000 through 2008, inflow to Lake Powell has been below average in all but two years (2005 and 2008), reflecting the drought conditions experienced in the Upper Colorado River Basin.

This drought and concerns about climate change have peaked the interest of Reclamation managers in the climate of the next decade and beyond. Although reservoir storage increased in 2008 to about 58% of capacity, it will take years, perhaps decades, for the system to recover to capacity, because average inflows are closely balanced with releases to meet compact requirements (Fulp, 2005). Reclamation's planning process includes several key time scales from days to the two-year "24-month study" which is revised monthly, to decades (Figure 2). These river operations and planning studies are the basis for estimating storage in individual reservoirs and the Colorado River system as a whole. These studies use NOAA reservoir inflow outlooks for the current water year, but rely on historic average flows beyond the current year. The inflow outlooks incorporate seasonal climate outlooks when they add skill; and have sometimes been qualitatively adjusted to persist known drought conditions (Brandon, 2005). Reclamation

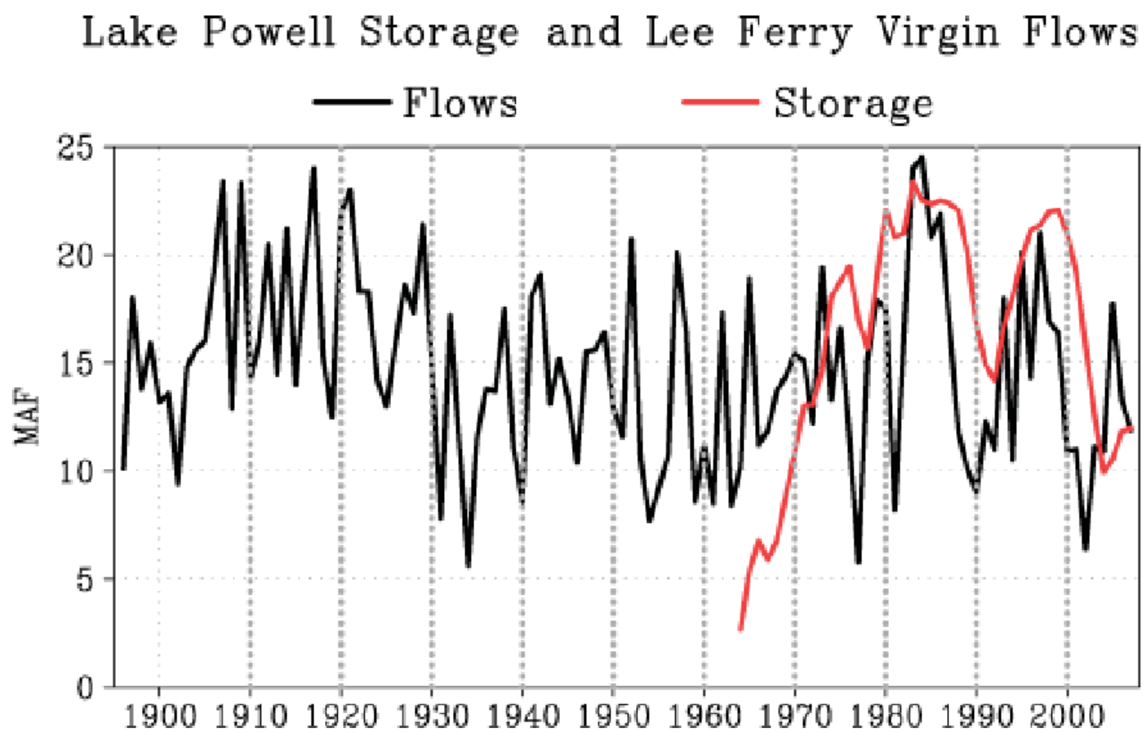

Figure 1: Annual storage, or maximum contents in Lake Powell plotted with annual inflows at Lee Ferry (in red). Illustrates the decadal variability of flows into Lake Powell, represented by Lee Ferry flows. The reservoir took longer than anticipated to fill (until 1982), partly attributed to a below average period in the 1960s and 1970s. 1965 was the first full water year for Lake Powell operations; flow data begins in 1896; the average flow into the reservoir over this period is about 15 million acre-feet, although the longterm average is the subject of debate (US Geological Survey, 2004). Figure created by J. Eischeid with flow data from the Upper Colorado River Commission, storage data from Bureau of Reclamation.

scientists are currently assessing methods for incorporating climate information beyond two years, and are very interested in interannual-to-decadal information (Bureau of Reclamation, 2007a). This process results in estimates of storage and reservoir levels, and operating plans for releases from the reservoirs for the next two years, which then feed into other planning, such triggers for shortage or surplus sharing, "equalization" of storage at Lakes Powell and Mead, and the Western Area Power Authority's hydropower contracts and marketing plans. Recreation is also affected. Hite Bay Marina on Lake Powell became inoperable in 2003 – when might reservoir levels allow it to return to operations, or should investments be made in another marina? Low levels at Lake Mead have closed several boat ramps and over $10 million has been spent to keep others open (Fulp, 2005).

The operating guidelines for the Colorado River were recently revised to include interim operating criteria out to 2026 for managing shortages due to drought (Bureau of Reclamation, 2007b). The planning process took advantage of new paleoclimate reconstructions of streamflow to extend the record of climate variability used in evaluating the risks of long term drought. A Climate Technical Workgroup developed an appendix on incorporating climate change information into Reclamation's Colorado Basin planning studies is the most extensive use yet of climate information (Bureau of Reclamation, 2007b). For their work, this group received the Department of Interior "Partners in Conservation" award. In this process, Reclamation was very concerned with testing new operations under a wider range of possible droughts, including decadal scale droughts (Bureau of Reclamation, 2007b).

What decadal climate information would be useful for reservoir management? From the vantage point of 2008, managers are interested in an indication of where in the drought cycle the system might be, i.e. what is the likelihood of the drought continuing, and what is the likelihood of a wet period that could refill the reservoirs? Reclamation develops "shorter look-ahead" studies for less than 20 years that anticipate the potential for shortage sharing, for example. "Longer look ahead" studies beyond 20 years are also conducted and both could benefit from decadal-scale information in anticipating surpluses or shortages,

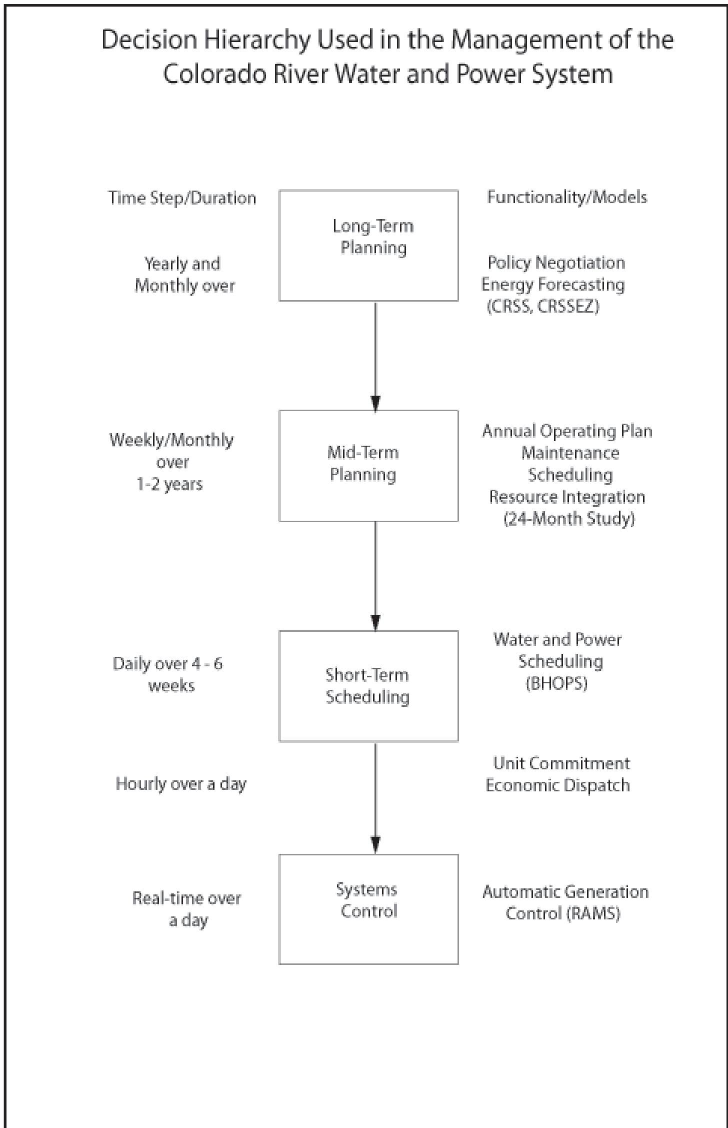

Figure 2: Schematic of the Bureau of Reclamation planning process from days to decadal scale, linked to general operational and planning decisions. (from Zagona et al, 2001).

improving hydropower planning, and anticipating recreation opportunities or obstacles.

Moving forward

Reservoir management is a water resources issue that is sensitive to climate at decadal scales, and has potential responses to minimize adverse affects or take advantage of opportunities. Decadal-scale information in several related areas listed below would be highly useful for reservoir managers and planners. As a bottom line need, reservoir managers would like to improve estimates of inflows, and thus storage, for "look-ahead" horizons out to about 20 years (including the upcoming decade), to 2026 (the horizon of the interim guidelines, Bureau of Reclamation, 2007b), and beyond 20 years in order to better anticipate and mitigate potential shortages. Inflow estimates on longer time scales require temperature and precipitation projections to drive hydrologic models. Although decadal (e.g. 10-year) averages of temperature and precipitation would be of some use, longer interannual outlooks than the 13-month CPC outlooks would be more useful than decadal averages in evaluating the risk of with interannual-to-decadal runs of wet and dry years.

This decadal-scale information could impact decisions by providing information on the risk of wet and dry periods that could then be used to either qualitatively hedge management decisions, or could be used as described above in a combination of qualitative and quantitative analysis.

Other useful information includes:

- Potential shifts of extreme events from the base period of the recent record (e.g. 1950-1999), because even relatively small shifts in average climate can substantially change the risk of extreme events (as described in IPCC, 2007).
- Climate conditions of interest include interannual-to-decadal wet or dry periods, persistence of current long-term drought conditions especially in the Upper Basin where most of the supply originates, and above average temperatures (even in the absence of skillful information about precipitation).
- Longer-term outlooks of temperature, even multiyear averages, may be useful because temperature alone is important in driving runoff anomalies (Hoerling and Eischeid, 2006).
- Temperature outlooks are also of interest because temperature influences demand as evapotranspiration increases. Evaporative losses from reservoirs and conveyances also increase with temperature, and are a small but significant factor in operations.
- Qualitative scenarios for climate in the planning horizon (e.g. within the next 10-20 years, depending on the planning study purpose), and the potential to rule out or consider other scenarios less likely.

Finally, it should be noted that Reclamation managers and planners recognize that there are uncertainties inherent in General Circulation Models used in projections of climate, as well as in relating these projections to hydrologic projections for operations (Bureau of Reclamation, 2007a). They recognize that specific forecasts on long time horizons are not likely to be available in the long term. Two ways of incorporating climate information are to use quantitative sensitivity analyses on operations response to projected climate predictands, and planning studies might involve a "qualitative discussion" of interannual-to-decadal variability within a given study's time horizon, especially if the role of the climate of the next 20 years is critical to the planning purpose. Qualitative analysis of projections might be complemented by a quantitative sensitivity study based on paleoclimate and instrumental data (Bureau of Reclamation, 2007a).

Decadal climate outlooks also potentially have a role in managing water in the context of changing climate, i.e., water adaptation strategies. Identifying usable products on the decadal timescales will require continuing interaction with these and other user communities. Pathways for this interaction include the NOAA-funded Regional Integrated Science and Assessment programs (RISAs; of which Western Water Assessment is one), which worked with Reclamation on the Climate Technical Workgroup. The RISAs are actively engaged with users across water and other sectors. These projects use a variety of mechanisms to elicit and understand user needs, by focusing on the users' decision processes and key issues, including drought, hydropower, multi-purpose reservoir management.

More work needs to be done to both to identify the potentially predictable aspects of decadal climate (the red line in Figure 1), and to identify the types of information that would be useful, and how to translate predictands such as temperature and precipitation into user-oriented hydrologic projections and drought outlooks. More work is also needed on methodologies for incorporating information qualitatively and quantitatively in planning studies. However, these efforts are likely to pay off in useable decadal-scale information that can impact water management decisions and reduce the risks of decadal variability to society.

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