Policy Analysis Using RiverWare: Colorado River Interim Surplus Guidelines

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Abstract
During calendar year 2000, the Secretary of the Department of the Interior (Secretary), acting through the Bureau of Reclamation (Reclamation), considered the adoption of specific interim surplus criteria under which surplus water would be declared in the lower Colorado River Basin during an interim period that would extend through 2016. An Environmental Impact Statement was prepared to discuss the specific alternatives under consideration and to identify the potential environmental effects of implementing such criteria.

Potential hydrologic effects of the alternatives compared to baseline conditions were analyzed using Reclamation's long-term policy model, implemented in RiverWare, a general-purpose river and reservoir modeling framework. Using RiverWare's rule-based simulation option, each alternative was represented in a different rule set and used to direct the particular simulation. Multiple runs were made to quantify the uncertainty with respect to future inflow hydrology. The results were then used to quantify the comparative impacts on various resources, including recreation, fisheries, special-status species, and energy production.

The work culminated in the selection of a preferred alternative and the Record of Decision, which was signed by the Secretary on January 16, 2001.

Introduction
The primary management objectives on the Colorado River include providing flood control, providing water for consumptive use and recreation, enhancing and maintaining ecosystem habitat, recovering and preserving endangered species, and generating hydropower. As in most watersheds, these objectives are often in conflict. As water master of the system, the Secretary of Interior (Secretary) through the Bureau of Reclamation (Reclamation) must find an equitable balance of these objectives. Through a process that includes consideration of the legal and political constraints, utilization of the best technical information, and stakeholder involvement, Reclamation has been successful in finding such balances to date (Fulp, 1999).

The process employed can be viewed as a hierarchical one, beginning with long-term planning and resulting in real-time operating decisions. Our focus for this paper is in long-term planning, where the goal is to assess the future impacts to Colorado River resources of current and proposed operating policies. We are particularly interested in the establishment of interim surplus guidelines for the Lower Basin (below Lake Powell and Glen Canyon Dam to Mexico).

We first present some background information to clarify the need for the guidelines, followed by a brief description of the model used for the study. An overview of the alternatives analyzed and the results follows. Finally, we conclude by summarizing the decision that was made.

Background

The hierarchical decision process employed on the Colorado River is illustrated in Figure 1, where the major activities are depicted in the center, the approximate spatial and time scales for each activity on the left, and the major decisions that are reached for each activity on the right. For long-term planning, the primary decision is the establishment and review of the Long-Range Operating Criteria (Operating Criteria). Since the impacts to the system of current and proposed criteria may occur over many years and have wide-ranging effects, typical planning studies include the entire basin and have horizons on the order of 50 – 60 years.

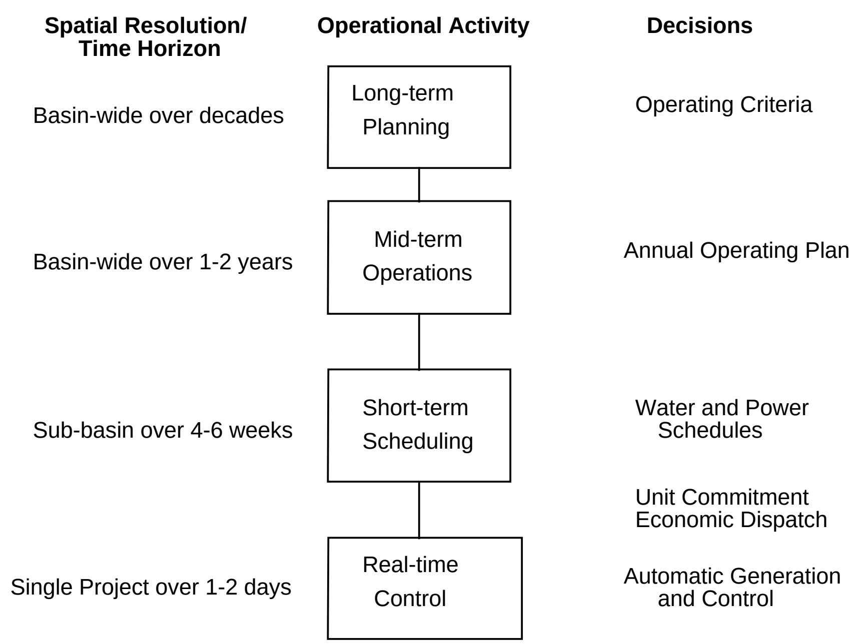

Figure 1. Decision hierarchy used on the Colorado River.

As specified by the Colorado River Basin Project Act of 1968 (Act), the Operating Criteria were first established in 1970 and are reviewed formally at least every five years. These reviews are conducted with the involvement of representatives of federal agencies, the seven Basin States, Indian Tribes, the general public including representatives of the academic and scientific communities, environmental organizations, the recreation industry and contractors for the purchase of federal power. Furthermore, the Secretary may modify the Operating Criteria from time to time in accordance with the Act.

Although previous reviews did not result in any changes to the Operating Criteria, recent pressures on the system resulted in the need for the Secretary to clearly define under what circumstances surplus water would be make available to the Lower Division states (California, Arizona, and Nevada). As defined in the Operating Criteria, “surplus is … water which can be used to meet consumptive use demands in the three Lower Division States in excess of 7,500,000 acre-feet annually” (Nathanson, 1978). Although the Operating Criteria gave the Secretary several factors to consider when determining if surplus water is available, there was not a prescribed methodology or guidelines to follow.

Prior to 1996, the lack of prescribed guidelines was not an issue. Although California has been diverting more than its normal 4.4 million acre-feet (maf) apportionment for many years, they utilized unused apportionments of other Lower Division states that were made available by the Secretary and the total consumptive use was at or below 7.5 maf. Since 1996, however, as the other states approached their normal apportionments, California has also relied on surplus water made available by the Secretary by considering factors including, but not limited to, those found in the Operating Criteria. These factors included end-of-year system storage, potential runoff conditions, projected water demands of the Basin States and the Secretary’s discretion in addressing year-to-year issues.

As a result of this actual operating experience and to afford an increased level of predictability of surplus water for planning purposes, the Secretary determined that there was a need for more specific surplus guidelines to assist in the annual decision making during an interim period. The interim period was chosen for 15 years to allow California time to fully implement its plan to reduce reliance on surplus deliveries. An Environmental Impact Statement (EIS) was prepared pursuant to the National Environmental Policy Act of 1969 (NEPA). The EIS addresses the formulation and evaluation of specific interim surplus criteria and identifies the potential environmental effects of implementing such criteria (Reclamation, 2000). The alternatives addressed were those determined to meet the purpose and need for the federal action and represented a broad range of the most reasonable alternatives.

The Policy Model

Long-term policy and planning studies on the Colorado River have typically used model results from the Colorado River Simulation System (CRSS), a Fortran-based modeling system, developed in the 1980's. CRSS originally ran on a Cyber mainframe computer, but was ported to run on both personal computers and Unix Workstations in 1994. CRSS modeled twelve major reservoirs and some 115 diversion points throughout the Upper and Lower basins on a monthly time step. A major drawback of CRSS was that the operating policies or rules were “hardwired” into the modeling code, making modification of those policies difficult.

In 1994, Reclamation began a collaborative research and development program with the University of Colorado and the Tennessee Valley Authority with the goal of developing a general-purpose modeling tool that could be used for both operations and planning on any river basin. This modeling tool, known as RiverWare, is now being used by the Upper and Lower Colorado Regions for both planning and monthly operations (Fulp, 1999). A major advantage of RiverWare is that the operational policies or rules are no longer "hardwired" into the modeling code (Zagona, et al, 2001). The user expresses and prioritizes the rules through the RiverWare graphical user interface, and RiverWare then interprets the rules when the model is run. Multiple rule sets can be run with the same model and this provides the capability for efficient "what-if" analysis with respect to different policies.

Reclamation replaced the original CRSS model with a new model implemented in RiverWare in 1996. The new model has the same spatial and temporal resolution, uses the same basic input data (hydrology and consumptive use schedules), and uses the same physical process algorithms as the original CRSS. A rule set was also developed to mimic the policies contained in the original model. Comparison runs were made between the original CRSS and the new model and rule set, with typical differences of less than 0.5% (Fulp, et al, 1999). The second phase of the program to replace CRSS consists of examining the rules extracted from CRSS and developing new rule sets that better reflect current operational policy, as well as rules to represent and test new policies. This phase is on-going.

Hydrologic Uncertainty

The model was used to simulate the future state of the Colorado River system on a monthly basis, in terms of reservoir levels, releases from the dams, hydroelectric energy generation, flows at various points along the system and diversions to and return flows from various water users. The input data for the model included the monthly tributary inflows, various physical process parameters (such as the evaporation rates for each reservoir) and the diversion and depletion schedules for entities in the Basin States and Mexico. The common and specific operating criteria were also input for each alternative being studied.

Despite the differences in the operating criteria for the baseline conditions and each surplus alternative, the future state of the Colorado River system (i.e., water levels at Lake Mead and Lake Powell) is most sensitive to the future inflows. Observations over the period of historical record (1906–present) show that inflow into the system has been highly variable from year to year (Figure 2). Predictions of the future inflows, particularly for long-range studies, are highly uncertain. Although the model does not predict future inflows, it can be used to analyze a range of possible future inflows and to quantify the probability of particular events (i.e., lake levels being below or above certain levels).

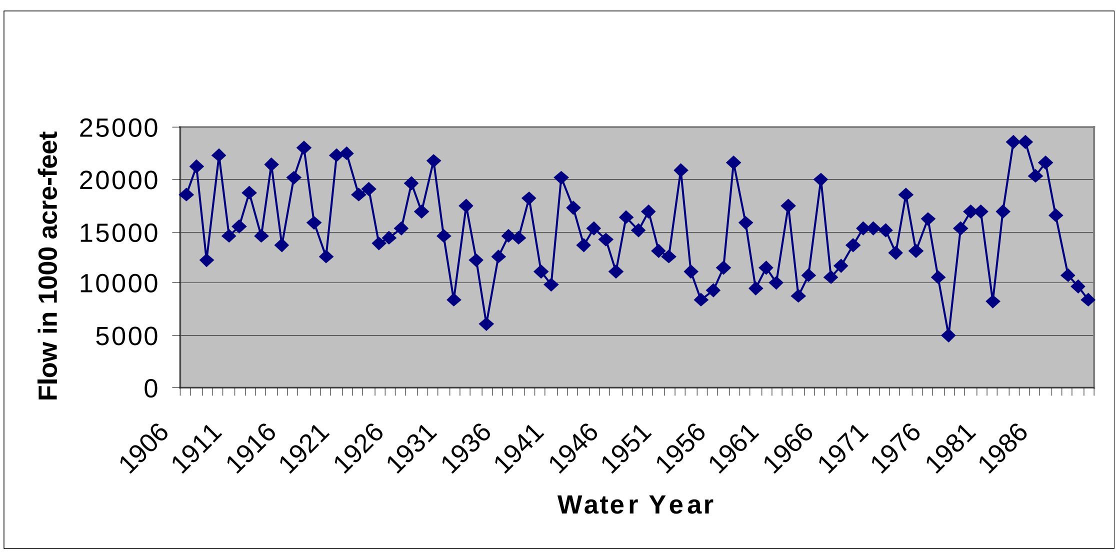

Figure 2. Historical natural flow at Lee's Ferry, Arizona.

Several methods are available for ascertaining the range of possible future inflows. On the Colorado River, a particular technique (called the Indexed Sequential Method) has been used since the early 1980s and involves a series of simulations, each applying a different future inflow scenario (Ouarda, *et al.*, 1997). Each future inflow scenario is generated from the historical natural flow record by "cycling" through that record. For example, the first simulation assumes that the inflows for 2002 through 2050 will be the 1906 through 1954 record, the second simulation assumes the inflows for 2002 through 2050 will be the 1907 through 1955 record, and so on. As the method progresses, the historical record is assumed to "wrap-around" (i.e., after 1990, the record reverts back to 1906), yielding a possible 85 different inflow scenarios. The result of the Indexed Sequential Method is a set of 85 separate simulations (referred to as "traces") for each operating criterion that is analyzed. This enables an evaluation of the respective criteria over a broad range of possible future hydrologic conditions using standard statistical techniques.

Analysis of Model Output

The model generates data on a monthly time step for some 300 points (or nodes) on the river system. Furthermore, through the use of the Indexed Sequential Method, the model generates 85 possible outcomes for each node for each month over the time period 2002 through 2050. These very large data sets are generated for each surplus alternative and baseline conditions and can be visualized as three-dimensional data "cubes" with the axes of time, space (or node) and trace (or outcome for each future hydrology). The data are typically aggregated to reduce the volume of data and to facilitate comparing the alternatives to baseline conditions and to each other. The type of aggregation varies depending upon the needs of the particular resource analysis. The post-processing techniques used for the EIS fall into two basic categories: those that aggregate in time, space or both, and those that aggregate the 85 possible outcomes.

For aggregation in time and space, simple techniques are employed. For example, deliveries of Colorado River water to all California diversion nodes in the model are summed to produce the total delivery to the state for each calendar year. Similarly, lake elevations may be chosen on an annual basis (i.e., end of December) to show long-term lake level trends as opposed to short-term fluctuations. Since the interim criteria period is 2002 through 2016, some analyses may suggest aggregating over that period of time and comparing the aggregation over the remaining years (2017 through 2050).

Once the appropriate temporal and spatial aggregation is chosen, standard statistical techniques are used to analyze the 85 possible outcomes for a fixed time. Statistics that may be generated include the mean and standard deviation. However, the most common technique simply ranks the outcomes at each time (from highest to lowest) and uses the ranked outcomes to compute other statistics of interest. For example, if end-of-calendar year Lake Mead elevations are ranked for each year, the median outcome for a given year is the elevation for which half of the values are below and half are above (the median value or the 50th percentile value). Similarly, the elevation for which 10 percent of the values are less than or equal to, is the 10th percentile outcome.

Policy Alternatives Analyzed

At the initiation of the NEPA process, Reclamation began a public scoping process, which included a series of public meetings in 1999. The purpose of these meetings was to inform interested parties of the consideration being given to the development of interim surplus criteria, to show options and proposals developed up to that time, and to solicit public and agency comments and suggestions regarding the formulation and evaluation of alternatives. From these meetings and subsequent written comments, a No Action Alternative and five action alternatives were chosen for analysis in the EIS. We present the No Action Alternative and three of the action alternatives as examples.

No Action Alternative

As required by NEPA, a No Action alternative must be considered during the environmental review process and is used as a "baseline" against which to compare other alternatives. Since the existing process of surplus determination included the Secretary's discretion to consider year-to-year issues, it was not possible to describe that process mathematically to the model. Consequently, Reclamation selected a specific operating strategy that was representative of recent operational decisions for use as a baseline condition (termed "70R").

The 70R baseline strategy is a spill avoidance strategy. It involves assuming a 70-percentile inflow into the system, subtracting out the consumptive uses and system losses, and checking the results to see if all of the water could be stored or if flood control releases would be required. If flood control releases would be required, additional water is made available to the Lower Basin states beyond 7.5 maf. The notation 70R refers to the specific inflow where 70 percent of the historical natural runoff is less than this value (17.4 maf) for the Colorado River basin at Lee Ferry.

Basin States Alternative

The Basin States Alternative specifies ranges of Lake Mead water surface elevations to be used for determining the availability of surplus water. The elevation ranges (or tiers) are coupled with specific uses of the water in such a way that, if Lake Mead's surface elevation were to decline, the amount of surplus water would be reduced. Three distinct tiers were identified, defined by elevations 1125 feet msl, 1145 feet msl, and at the elevation represented by the 70R strategy.

Flood Control Alternative

Under the Flood Control Alternative, a surplus condition is determined to exist when flood control releases from Lake Mead are occurring or projected to occur in the subsequent year. The method of determining need for flood control releases is based on flood control regulations published by the Los Angeles District of the Corps and the Field Working Agreement between the Corps and Reclamation. A surplus is determined when the Corps flood control regulations require releases from Lake Mead in excess of downstream demand.

Shortage Protection Alternative

The Shortage Protection Alternative is based on maintaining an amount of water in Lake Mead necessary to provide a normal supply of water to the Lower Division states and Mexico, plus storage sufficient to provide an 80 percent probability of avoiding future shortages over the next 50 years. This amount of storage varies over time as development in the Upper Basin increases. The storage required is determined through a separate ("off-line") model study and is then represented as a set of elevations over time (called “triggers”). At Lake Mead elevations above the surplus trigger, surplus conditions would be determined to be in effect and surplus water would be available for use in the Lower Division states. Below the trigger elevation, surplus water would not be made available.

Comparison of Alternatives

As previously noted, the model is used to generate probabilistic estimates of the effects of each alternative on the hydrologic state of the system (lake elevations, water supply, river flows, etc.). Based on these hydrologic results, the effects on various other resources (recreation, fisheries, special-status species, energy, etc.) are analyzed. We show examples of the hydrologic estimates and refer the reader to the EIS for the specific resource analyses.

Under the baseline conditions, the water surface elevation of Lake Mead is projected to fluctuate between full level and decreasingly lower levels during the period of analysis (2002 to 2050). Figure 3 illustrates the range of water levels (end of December) by three lines, labeled 90th Percentile, 50th Percentile and 10th Percentile.

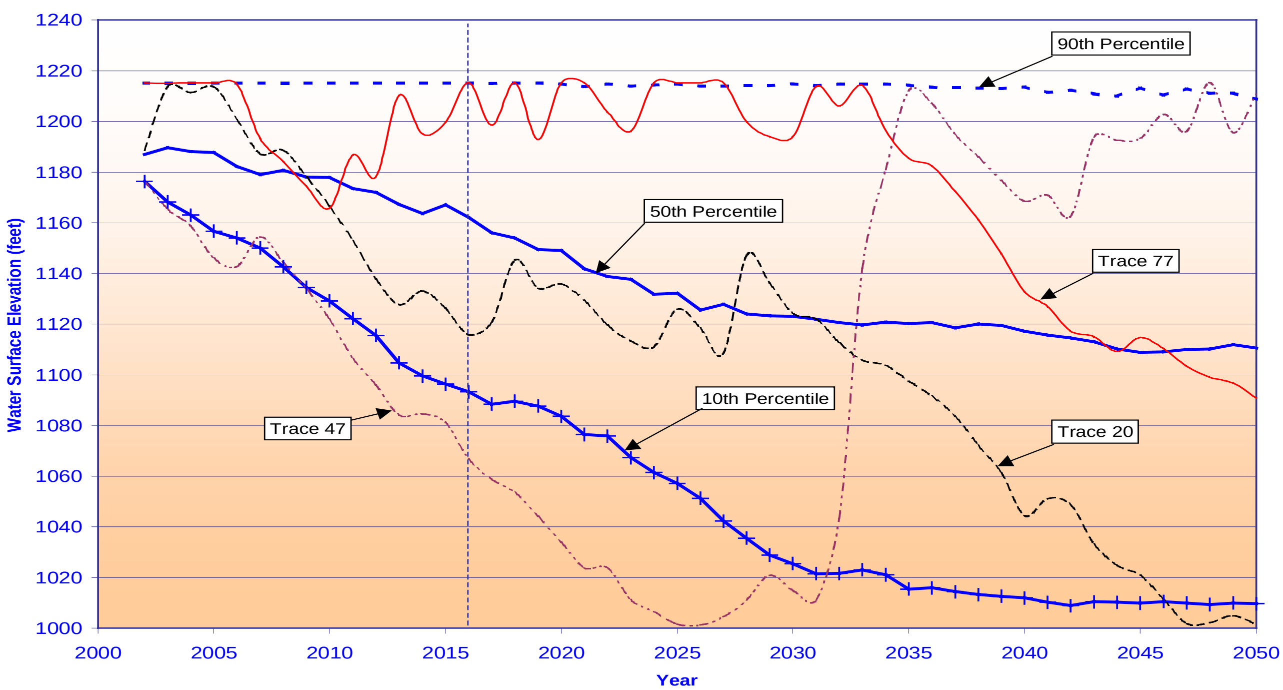

Figure 3. Lake Mead End-of-December Water Elevations Under Baseline Conditions for the 90th, 50th and 10th Percentile Values and Representative Traces

Three distinct traces are added to Figure 3 to illustrate what was actually simulated under the various traces and respective hydrologic sequences and to highlight that the 90th, 50th and 10th percentile lines do not represent actual traces, but rather the ranking of the data from the 85 traces for the conditions modeled. The three traces illustrate the variability among the different traces and that the reservoir levels could temporarily decline below the 10th percentile line. The 90th and 10th percentile lines bracket the range where 80 percent of future Lake Mead water levels simulated for the baseline conditions occur. The highs and lows shown on the three traces would likely be temporary conditions. The reservoir level would tend to fluctuate through multi-year periods of above average and below average inflows. Neither the timing of water level variations between the highs and the lows, nor the length of time the water level would remain high or low can be predicted. These events would depend on the future variation in basin runoff conditions.

Figure 4 presents a comparison of the 90th, 50th and 10th percentile lines obtained for the baseline conditions to those obtained for the surplus alternatives. This figure is best used for comparing the relative differences in the general lake level trends that result from the simulation of the baseline conditions and surplus alternatives. As shown, the Flood Control Alternative is the alternative that could potentially result in the highest Lake Mead water levels. The California Alternative is the alternative that could potentially result in the lowest water levels. The water levels observed under the Shortage Protection Alternative are similar to those of the California Alternative with some years slightly lower. The baseline conditions yield slightly lower levels than the Flood Control Alternative, but the differences are very small. The results obtained under the Six States and Basin States alternatives are similar and fall between the Flood Control and Shortage Protection alternatives.

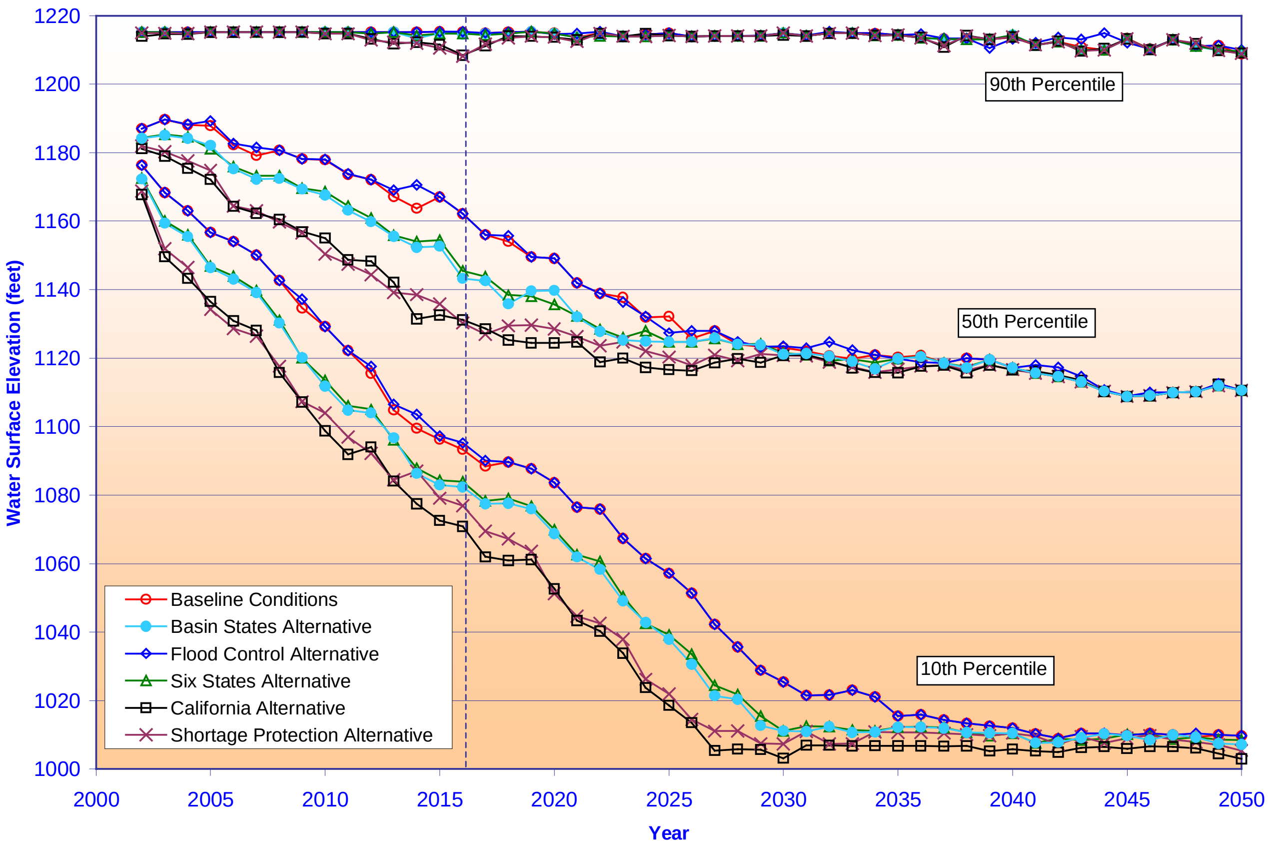

Figure 4. Lake Mead End-of-December Water Elevations
Comparison of Surplus Alternatives and Baseline Conditions 90th, 50th and 10th Percentile

Similar hydrologic analyses were made for Lake Powell water levels, river flows between Lake Powell (Glen Canyon Dam) and Lake Mead, and river flows in reaches below Lake Mead to Mexico.

Of particular environmental interest is the potential impacts of interim surplus criteria on flows to the Gulf of California (Sea of Cortez). These flows (termed excess flows to Mexico) are almost entirely due to flood control releases originating at Hoover Dam. As mentioned previously, these flood control releases are dictated by the flood control criteria established for Lake Mead and Hoover Dam and are dependent upon hydrologic conditions.

Figure 5 presents a comparison of the frequency of occurrence of future delivery of excess flows to Mexico observed under the surplus alternatives to those of baseline conditions. The frequency of occurrence is compiled by counting the number of modeled traces for each year that have excess flows and dividing by the total number of traces. As illustrated in the figure, with the exception of the Flood Control Alternative, the excess flows to Mexico occur less frequently under the surplus alternatives when compared to baseline, during the interim surplus criteria period (2002 to 2016). These differences decrease to negligible amounts after 2027. The low frequency of occurrence in excess flows under the baseline conditions in the first year (2002) can be attributable to the relatively low reservoir starting conditions (approximately 33 feet below full content level at Lake Mead). The differences between the baseline and surplus alternatives, with the exception of the Flood Control Alternative, can be attributed to more frequent surplus deliveries which tend to lower Lake Mead reservoir levels. With lower reservoir levels, the frequency of flood control events (which are the primary source of the excess flows) is decreased.

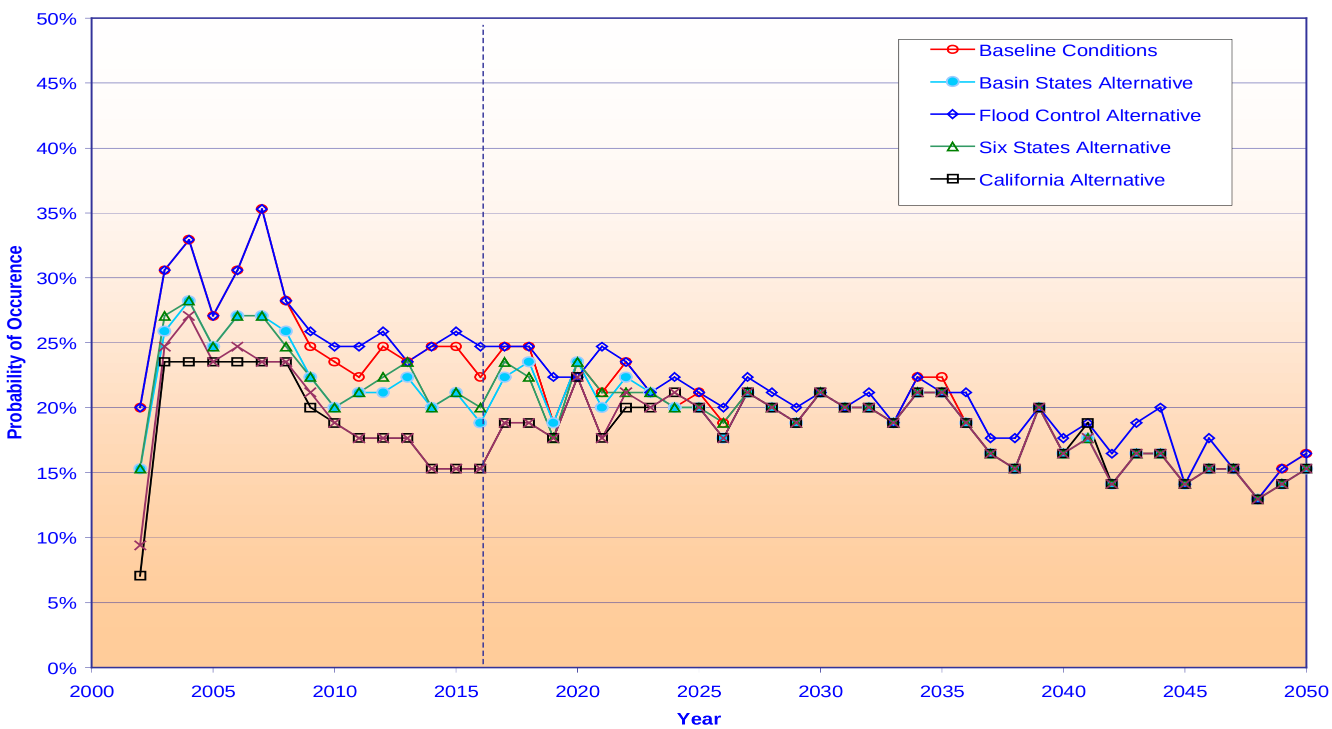

Figure 5. Probability of Occurrence of Excess Flows to Mexico
Comparison of Surplus Alternatives to Baseline Conditions

Selection of a Preferred Alternative and the Record of Decision

Based on the analyses presented in the EIS, Reclamation determined that the Basin States Alternative best met all aspects of the purpose and need for the action and consequently, selected that alternative as its preferred alternative. Based on this recommendation and subsequent preparation of a Record of Decision (ROD), the Secretary signed the ROD in San Diego, California on January 16, 2001.

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