Alternative Policies on the Colorado River

Kevin Wheeler, Timothy M. Magee, Terrance Fulp*, Edith Zagona
Center for Advanced Decision Support for Water and Environmental Systems, University of Colorado

Campus Box 421, Boulder, CO 80309-0421, 303-492-3972
*U.S. Bureau of Reclamation

Abstract

The Colorado River has a long history of litigation over a limited water supply. Projected increases in water consumption and recognition of environmental needs will lead to further litigation unless a consensus of interested parties can be reached. Recent developments in computer modeling suggest a way of reaching such a consensus on sustainable policies that could be transferred to other river basins. The United States Bureau of Reclamation (Reclamation) has modeled the Colorado River within a general modeling environment, RiverWare, developed at the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado at Boulder under joint sponsorship by Reclamation and the Tennessee Valley Authority. The Colorado River model includes the existing policy, frequently called the "Law of the River." The structure of RiverWare allows policies to be extended and modified easily by model users. This flexibility in modeling alternative policies, combined with graphical comparison of the results, has led to the evaluation of a wide range of alternative policies by Reclamation, CADSWES, and several environmental groups. Rapid comparison of policy alternatives has led to generating improved alternatives that better balance the multiple uses of the river. Recent studies include:

1) Interim Surplus Guidelines for developing a strategy to decrease California's dependency on surplus Colorado River water;
2) Secretarial Implementation Agreement to analyze the effects of water transfers and potential inadvertent overrun withdraws as proposed in California's Quantification Settlement Agreement and Reclamation's Inadvertent Overrun Policy;
3) Multiple Species Conservation Program, designed to conserve habitat and work toward the recovery of threatened and endangered species, while accommodating future water and power development;
4) The impact on water users of alternative plans for supplying sustainable flows to restore biodiversity in the Colorado River Delta; and
5) The operation of the Flaming Gorge Dam to simulate natural flow patterns and meet minimum flow recommendations and consumptive use demands.

Introduction

During the twentieth century, dams were constructed on the Colorado River. Most of the water in the basin is now diverted for agricultural and municipal uses in the states of Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming and the

United Mexican States (Mexico). Prior to the diversion of water, the Colorado River flowed freely to the Gulf of California. For many years, only California used their full allotment of water and was able to exceed their allotment by diverting the unused apportionment of other Lower Basin states. In recent years, the river has come under considerable pressure. The Lower Basin states are using more of their entitled water with plans to completely use their allotment by 2005. In addition, there has been increased awareness of the environmental needs on the river. Some examples include endangered species throughout the river system, building beach habitat in the Grand Canyon, and potential restoration of the ecosystem in the delta at the northern end of the Gulf of California. The competition between demands on the river would appear to be greater today than ever before.

The potential for competing demands was anticipated long ago. The apportionment of water to the states and Mexico is governed by a collection of documents, known collectively as the *Law of the River*, which dates as far back as 1899 (RECLAMATION, 2000b). The Law of the River includes international treaties, interstate compacts, court decisions and decrees, state and federal statutes and operating criteria. The most notable documents are:

- The Colorado River Compact of 1922, which apportioned water between the Upper and Lower Basins, divided by water flowing through Lee Ferry Arizona;
- The California Seven Party Water Agreement of 1931, which established the relative water rights of water users in California;
- The United States-Mexico Water Treaty of 1944 and its amendments, known as "minutes," related to water quality and water quantity delivered to Mexico;
- The Upper Colorado River Basin Compact of 1948, which apportioned water among the Upper Basin states;
- The Colorado River Storage Project Act of 1956, including construction of Glen Canyon Dam;
- The 1964 U.S. Supreme Court Decree, *Arizona v. California*, which confirmed the Lower Basin apportionment of 4.4 maf for California, 2.8 maf for Arizona, and 0.3 maf for Nevada, and reserved water for Native American consumption;
- The Colorado River Basin Project Act of 1968 which authorized construction of the Central Arizona Project (CAP);
- The Colorado River Basin Salinity Control Act of 1974 which authorized salinity control projects and set salinity standards;
- The Grand Canyon Protection Act of 1992.

In addition, national environmental laws such as the Endangered Species Act, National Environmental Policy Act, and the Clean Water Act have affected the Colorado River. Three U.S. Supreme Court rulings (1964, 1979, and 1984) demonstrate the litigious nature of the Colorado River water users. With growing demands on the river, more legal action would appear inevitable unless the interested parties can reach consensus. While our focus is the Colorado River, we note that water disputes are not unique to the Colorado River; problems of a similar magnitude exist for both the Rio Grande and the Truckee-Carson drainage for example. We believe the process presented here could be applied to other river basins.

Modeling

Computer modeling of river basins has been possible for several decades, but a new generation of modeling tools opens the possibility for using modeling as a mechanism for reaching consensus. In the previous generation of models, policy was embedded in the code and largely inaccessible. Changing the operational logic in the models to conduct policy studies was a large programming task that depended on a small number of highly trained individuals. The Colorado River Simulation System (CRSS) was one such model. While the model was extremely useful, it was difficult to understand how policy was implemented let alone change it because the policy was intertwined with the simulation software.

In the 1990's the logic of the CRSS model was reimplemented as a RiverWare model and is still known as CRSS. RiverWare is a general purpose modeling tool developed at the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado, under joint sponsorship by the U.S. Bureau of Reclamation (Reclamation), and the Tennessee Valley Authority (TVA) (Zagona *et al*., 2001). Within RiverWare, the CRSS policy is visible to the end users and can be readily changed without rewriting and recompiling the simulation software (Fulp et. al., 1999).

In addition, CADSWES and Reclamation have jointly developed a Graphical Policy Analysis Tool (GPAT) that can compare the output from several RiverWare runs that differ only in terms of policy and hydrologic scenarios. With GPAT, a user can interactively compare different facets of policy alternatives. Prior to GPAT, modelers would make an educated guess of what would be of interest to policy makers and prepare graphical comparative figures in advance of a meeting. If any additional analysis were required, the analytical process would be postponed. With GPAT, graphs can typically be prepared interactively to fully explore the modeled policies. Ideally, a new policy could be simulated just as fast, but with existing computer hardware, a CRSS simulation still requires several hours due to the complexities that must be represented to properly simulate the system behavior.

GPAT has five predefined graph formats that allow analysts to view different slices of data with four dimensions: policy alternatives, hydrologic scenarios, time periods, and measurements (such as reservoir elevations and reach flows). Each view contains a measurement and collapses the other dimensions in some way. For example, GPAT can calculate the mean, standard deviation, and percentiles of a measurement across hydrologic scenarios. Alternatively, GPAT can show the entire probability distribution for a measurement at one point in time. In addition, the graphs from alternative policies can be overlaid or subtracted from each other to show policy differences. Because GPAT runs as an Add-In to Microsoft Excel the graphs and data can easily be shared. The graphs presented in this paper were created with GPAT.

In the remaining sections we will illustrate with examples from different studies how modeling has been used as a tool to assist in compromise among the participating parties. Due to the extensiveness of each study, we won't attempt to discuss any of these in great detail; but for each one we will present the basic conflict, the alternatives under consideration, and the highlights of the modeling analysis – in some cases leading to consideration of new alternatives. We will reference more in depth reports where they exist; although some of these studies are still in progress and reports haven't been issued yet.

The five case studies are:

1) Interim Surplus Guidelines Study – a study of alternatives to gradually decrease California's dependency on water use beyond its apportionment over the next 15 years;
2) Secretarial Implementation Agreement Study – the Interim Surplus Guidelines are contingent on certain stipulations for California, primarily transfer of water from agricultural to municipal use; this study analyzed the effects of water transfers and potential inadvertent overrun withdrawls;
3) Multi-Species Conservation Program Study – analysis of the potential effects of other future water transfers from agricultural uses to municipal and industrial uses;
4) The restoration of the Colorado River Delta – comparing alternative plans for restoring a formerly rich riparian habitat; and
5) The operation of Flaming Gorge Dam – comparing policies that attempt to mimic natural flow patterns and meet minimum flow recommendations and consumptive use demands.

Our discussion of the studies concentrates only on hydrologic comparison of the alternatives. While each study has biological and other implications, the analyses of these implications are dependent upon the hydrologic analysis. We respectfully leave these analyses for other resource specialists.

<u>Case Studies</u>

Interim Surplus Guidelines

Hydrologic modeling often plays a key role in the development, evaluation, and selection of potential alternatives within Environmental Impact Statements (EIS). Reclamation used the Colorado River Simulation System (CRSS) (Reclamation, 1985, Fulp, *et al*., 1999) model in RiverWare and GPAT for the development of an EIS of the Interim Surplus Criteria formally referred to as the Interim Surplus Guidelines in the Record of Decision (Reclamation, 2000b). The purpose of this study was to evaluate the potential environmental effects of alternative proposed management scenarios, which establish specific criteria for the declaration of surplus conditions for the Lower Basin of the Colorado River through 2016. Inherent to this purpose was the reduction of California's dependency upon surplus Colorado River water by this date. This dependency has developed for the past several years due to frequent unused apportionment water causing frequent diversions in excess of the allotted 4.4 maf as declared in *Arizona vs. California* (1964). The intention of the Interim Surplus period was to provide a "soft landing" for California. The Interim Surplus Guidelines analysis was a landmark study for Reclamation by allowing multiple Colorado River stakeholders to have their policy alternatives analyzed within the modeling framework and participate in the analysis through interactive graphical representations of the modeled results.

Under NEPA guidelines, the development of a baseline scenario is required that would represent current operational conditions against which to compare alternative management policies. Historically, the declaration of a surplus is at the discretion of the Secretary of the Interior. The highly uncertain nature of the declaration of surplus conditions led to a scenario termed "70R" that imprecisely replicated the historical pattern, but was necessary for establishing a baseline. The "70R" alternative assumes above average inflows (i.e., the 70th percentile of the historical inflow) into Lake Mead and subtracts out consumptive uses and system losses. If flood control releases would be required under this assumption, then surplus water would be made available to the Lower Basin states. Flood control releases can be required as part of regulations for dam safety, etc., established by the Army Corps of Engineers (Reclamation, 1982).

Both Reclamation and other interested parties developed alternative scenarios. One alternative proposed by Reclamation is a "Flood Control" alternative in which surplus conditions are determined to exist only when flood control releases from Lake Mead are occurring. Another management scenario proposed by Reclamation, termed "Shortage Protection" or "80P" was designed to maintain an amount of water in Lake Mead necessary to provide an normal annual supply of 7.5 maf for the Lower Basin states and 1.5 maf for Mexico, while also assuring with an 80 percent probability that Lake Mead's elevation would stay above the "80P-1083" line through 2050. The 80P-1083 line is defined to be a lower elevation at Lake Mead such that when Lake Mead's elevation is above the 80P1083 line there is an 80 percent probability that the system will avoid shortages before 2050.

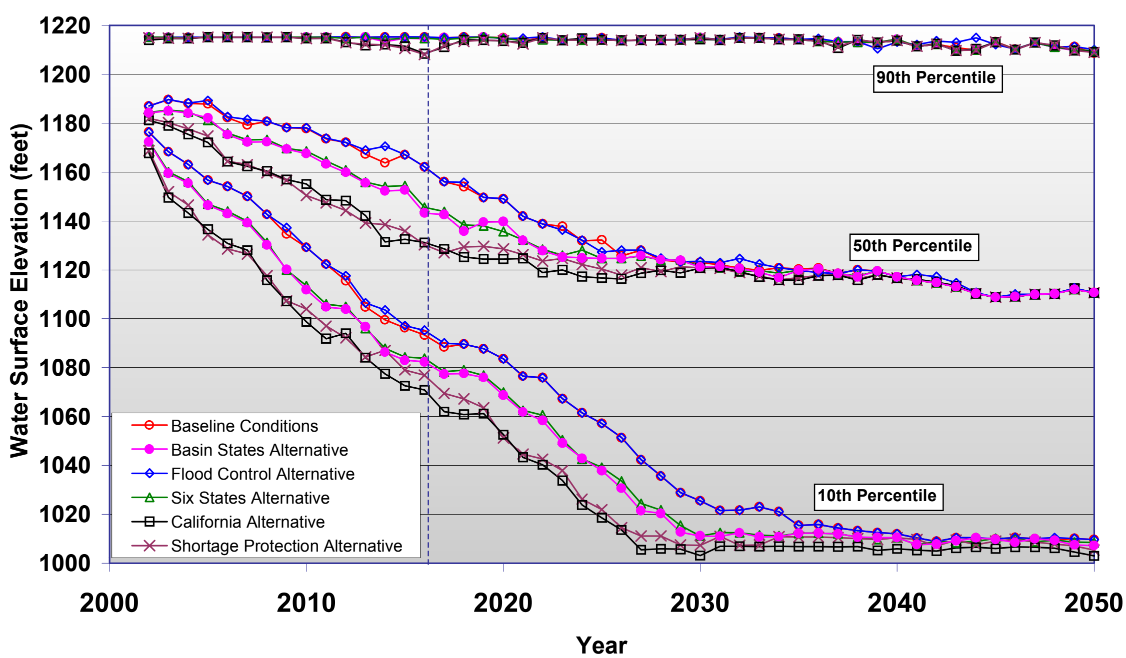
In the Draft EIS, two scenarios submitted by governmental agencies were analyzed. On December 17, 1997, the state of California presented a plan to reduce their dependence on surplus Colorado River water to their normal 4.4 maf per year allocation. The key component of this proposal was a 3-tiered approach that would permit certain levels of surplus water to be declared according to the current elevation of Lake Mead. The elevations that would indicate the current surplus state of the system would change through time until 2016 to reflect the gradually increasing water demand of the Upper Basin states. This plan was later revised in May 2000, and combined with a proposal submitted in October 1999, with the *Key Terms for Quantification Settlement Among the State of California, Imperial Irrigation District, Coachella Valley Water District, and Metropolitan Water District of Southern California* to make the scenario termed the "California Alternative."

In response to California's submitted surplus alternative plan, the other six states within the Colorado River basin submitted a similar a three-tiered plan, termed the "Six States Alternative," which would require comparatively higher elevations for Lake Mead to be attained before surplus conditions could be declared. After the Draft EIS was published, graphical analysis of these two competing proposals led to a collaborative effort among the seven states to generate another proposal termed the "Basin States Alternative." This proposal also utilized the same three-tiered elevations as the Six States Alternative for determining surplus conditions, but the quantities made available under each condition were adjusted to better meet California's projected demand. The Basin States Alternative was eventually selected as the preferred alternative in the Record of Decision (ROD).

Another alternative was submitted by a consortium of environmental organizations, led by the Pacific Institute for Studies in Development, Environment and Security, that also contained a multi-tiered approach. The significant difference between this proposal and the previous proposals was a guarantee of 32,000 af of base flow water to reach the Colorado River Delta during years when Lake Mead's elevation exceeds 1120.4 feet and an additional flood pulse of 260,000 af to the delta when Lake Mead's elevation exceeds the 70 percent flood control avoidance (70A1) elevation. This policy alternative was excluded from consideration within the EIS by Reclamation with a declaration that the proposal was beyond the purpose and need for the proposed action (Reclamation, 2000). However, a separate modeling exercise of this alternative was completed and presented to the Pacific Institute on December 14, 2000 (Reclamation, 2000a).

Probabilistic projected values of hydrologic conditions were generated using the Index Sequential Method (ISM) to generate multiple future inflow scenarios (or "traces") using the historical monthly natural flows (Kendall and Dracup, 1991). The period modeled for this study was from January 2002 to December 2050.

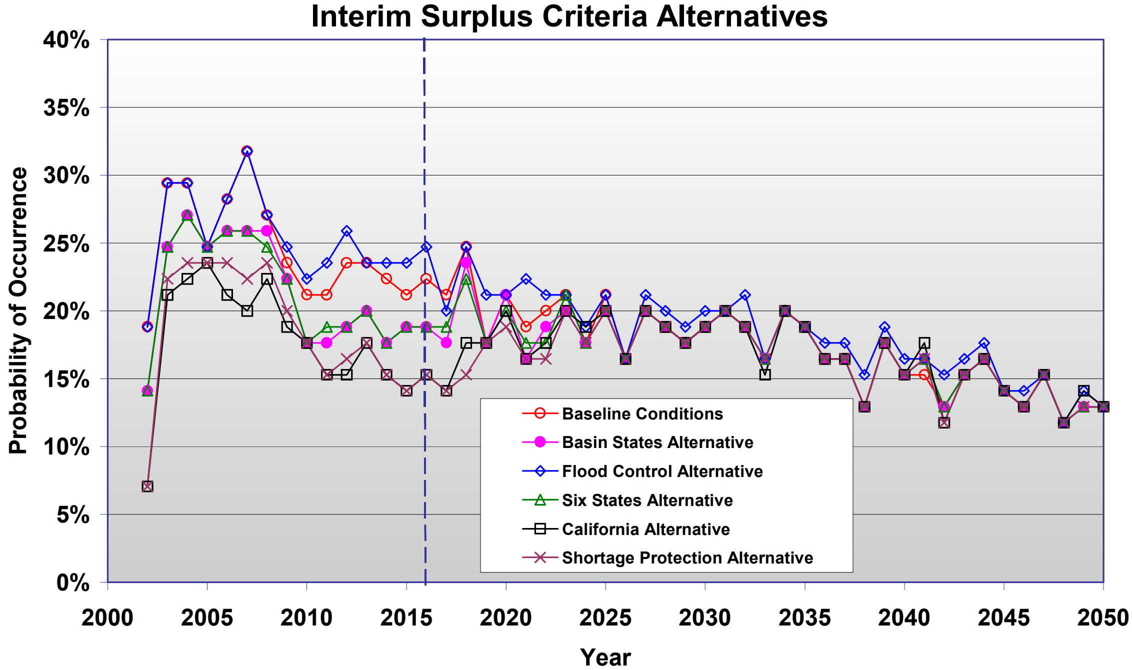
Figure 1: Lake Mead Elevation
Interim Surplus Criteria Alternatives



Modeling results were generated for 85 ISM runs and presented to a variety of stakeholders through a series of meetings, and published in the both the Draft EIS and the Final EIS. Graphs of probabilistic percentiles through the modeled period indicate the differences and similarities between the baseline conditions and the proposed alternatives for a variety of different system variables. Lake Mead holds most of the active storage for the Lower Basin and its elevation is a controlling factor for many of the policies affecting the Lower Basin. Thus, Lake Mead's elevation was a primary indicator of the system impacts of the alternatives in this study.

Figure 1 shows the probabilistic projected reservoir elevations at the end of each year and demonstrates potential comparative impacts on the Lower Basin. At the probabilistic 10th, 50th, and 90th percentiles of the scenarios, clear differences can be seen with the Baseline and Flood Control Alternatives maintaining higher reservoir elevations, and the California and Shortage Protection alternatives resulting in the largest storage declines. While the policy differences between the alternatives end in 2016, meaningful differences in Lake Mead's elevation persist for years until converging in roughly 2040.

Figure 2: Probability of excess flows to delta greater than 250,000 Acre-feet Interim Surplus Criteria Alternatives



The interest in the riparian habitat of the Colorado River delta required that the impacts of each scenario upon the water flowing to the delta (termed "excess flows") be evaluated and considered for each alternative. Under current policy, water flows to the delta under the following circumstances:

1) due to operational activities upstream of Morelos Dam,
2) flooding in the Gila River, or
3) flood control releases on the main stem from Lake Mead.

CRSS does not model either 1) or 2) since they are due to infrequent and uncertain events. However, water resulting from 3) can be modeled. The probabilities of annual flows to the delta exceeding 250,000 and 1,000,000 af were determined and published. Figure 2 shows the probability of annual flows exceeding 250,000 af. A clear distinction can be made between the policies that restrict surplus declarations to higher Lake Mead elevations (e.g., Flood Control, Baseline) resulting in increased frequencies of delta flows versus policies that tend to make more frequent surplus releases and less flows to the delta (e.g., Shortage Protection Alternative, California Alternative).

In summary, while the EIS did not include all proposed alternatives, the modeling environment did provide a comparative framework from which the "Basin States Alternative" emerged, and this alternative became the preferred alternative for the Record of Decision of the Interim Surplus Guidelines in January 2001.

Secretarial Implementation Agreement

Following the Interim Surplus Guidelines EIS and the subsequent Record of Decision, the method by which California would reduce its use of surplus Colorado River water was outlined in the Quantification Settlement Agreement (QSA). This agreement consists of the contractual arrangements negotiated between the major California diverters. The Secretary of the Interior has developed an implementation agreement that would implement the QSA. Reclamation has modeled an Implementation Agreement (IA) alternative, the worst case scenario of QSA with regard to river flows below Parker Dam. A federal EIS is currently in the process of being developed to ascertain the environmental impacts of several federal actions including the IA, the adoption of an Inadvertent Overrun and Payback Policy (IOP), and other related federal actions (Reclamation, 2002).

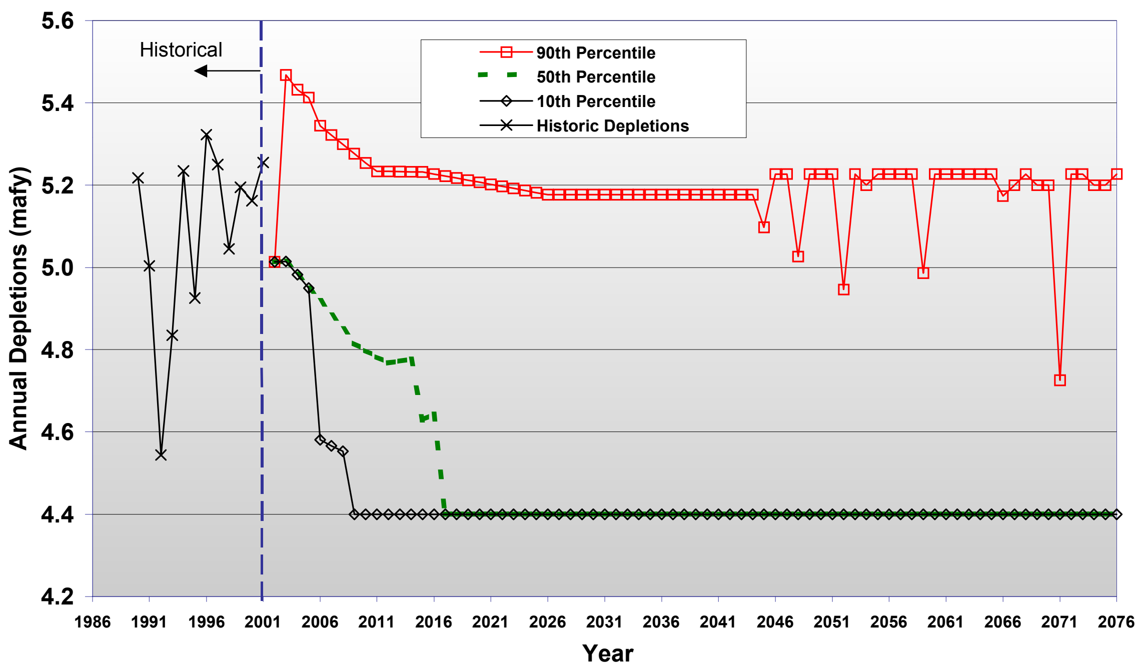
The primary goal of the QSA is to provide additional water to the municipal and industrial sector through transfers of higher priority agricultural water. If certain benchmarks specified in the Interim Surplus Guidelines Record of Decision are not met, the Interim Surplus Guidelines will be likely replaced by a policy that declares a surplus only when the 70R trigger elevation is exceeded, significantly reducing the probability of a surplus. The QSA involves the agreement to transfer water from the major agricultural diverters, the Imperial Irrigation District (IID), to municipal and industrial uses in the Metropolitan Water District of Southern California (MWD) and the San Diego County Water Authority (SDCWA), as well as the Coachella Valley Water District (CVWD), for a period of 75 years. These transfers are intended to maximize the collective utilization value of the normal allotment of California water by allowing the water reductions to occur in the agricultural sectors where the unit value of water is significantly lower. One effect of the transfers is that greater amounts of water would be diverted higher in the river system, from Parker Dam instead of Imperial Dam. The hydrologic impacts that were studied include: flow in intermediate reaches, the reservoir elevations, deliveries to the Lower Basin States, and the delivery of water to the riparian habitat of the Colorado River Delta.

The goal of developing an Inadvertent Overrun and Payback Policy (IOP) is a response to the situation in which water users unintentionally divert more water then they are legally allowed due to a number of reasons. These reasons include scheduling errors that are common in large scale agricultural diversion projects which may occur as a result of inaccurate measuring mechanisms, difficulty in determining unmeasured return flows, etc.

The modeling framework that was used for the Interim Surplus Guidelines has also been implemented for the SIA EIS. To date, the Draft EIS (DEIS) has been completed and the Final EIS is in production. The DEIS included two scenarios to be analyzed. The baseline "No Action" scenario assumes California will meet the benchmarks set by the Interim Surplus Guidelines Record of Decision by gradually reducing demand at MWD. No transfers of water are assumed to take place under this baseline scenario except prior existing agreements.

The IA alternative, which would provide federal approval for the QSA, models the negotiated allocation of water among California's participating agencies. This scenario models proposed water transfers resulting in the reduction of flows between Parker and Imperial Dams of up to 338 kafy. In addition, the IA alternative also incorporates an Inadvertent Overrun Policy (IOP). The Preferred Alternative includes a set of criteria specifying that overruns cannot exceed 10% of a users normal allotment, and repayment of debt to the system would be required within 3 years under normal conditions. Because the IOP is transient in nature, it was not modeled explicitly in the RiverWare model, except to analyze the effect on excess flows.

Figure 3: California Depletions
Proposed Alternative of the Impementation Agreement



The hydrologic analysis is only one part of the study, but serves as a key component that provides estimates of water availability for the components of the system for each alternative. Hydraulic floodplain analysis and biological habitat studies utilize these data to differentiate the potential impacts of each alternative.

Figure 3 demonstrates the probabilistic reduction of California's dependency on surplus Colorado River water under the Proposed Action of the Implementation Agreement.

Lower Colorado Multi-Species Conservation Program

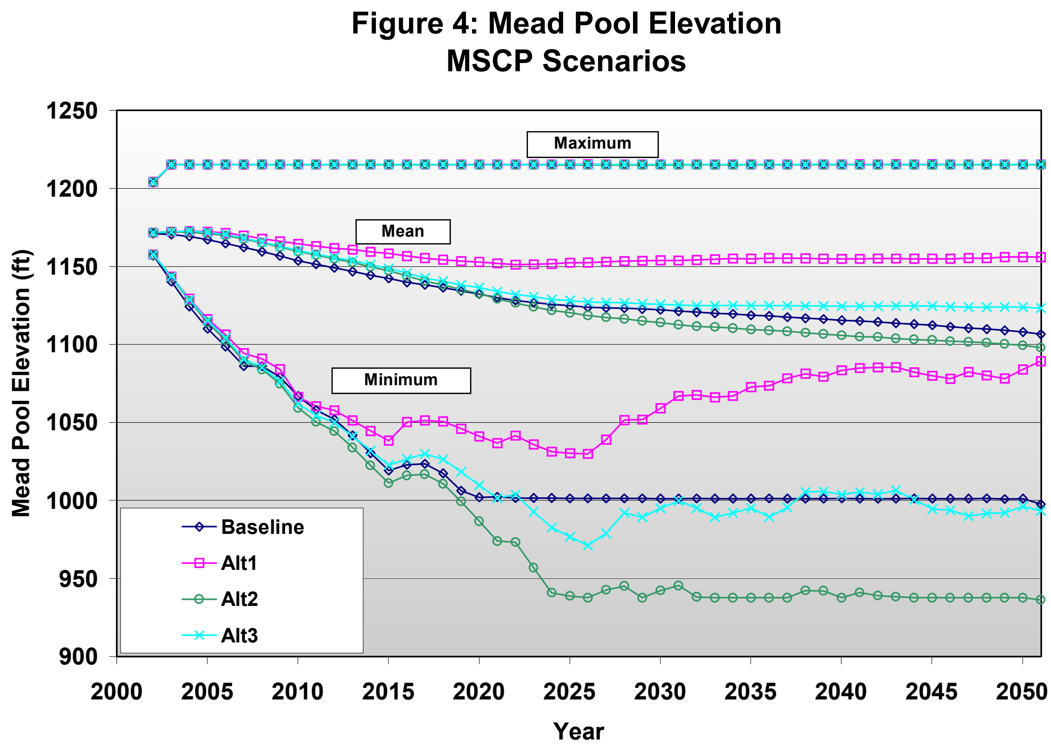
The Lower Colorado Multi-Species Conservation Program is a partnership of state, Federal, tribal, and other public and private stakeholders with an interest in the management of the water and related resources of the Lower Basin of the Colorado River. The program is still in the preliminary stages and negotiations are on going. The goals are stated as:

1) "Conserve habitat and work toward the recovery of included (covered) species within the 100-year flood plain of the Lower Colorado River, pursuant the ESA, and attempt to reduce the likelihood of additional species under the ESA;
2) Accommodate current water diversions and power production and optimize opportunities for future water and power development, to the extent consistent with the law; and
3) Provide the basis for taking incidental authorizations pursuant to the Federal ESA and California ESA." (Reclamation, 1999)

The participatory involvement that the RiverWare modeling process has contributed to the MSCP program includes the simulation of increased transfers from agricultural uses to other uses of up to 1.574 mafy. Methods for achieving transfer amounts in addition to those considered in the SIA are thus far hypothetical. They include maximizing currently proposed transfers, reductions of consumptive use from agricultural diverters proportional to their current use, maximizing current capacities of municipal and industrial diversion structures, and isolating federal water for reallocation to various uses. A variety of alternatives have been explored within the RiverWare modeling environment, yet at this time, none have been formally proposed. Figure 4 demonstrates percentiles of Lake Mead elevations for four scenarios that have been examined during the MSCP studies including:

1) Baseline is essentially equivalent to the SIA Implementation Alternative;
2) Alt1 allows full transfers of up to 1.574 mafy, but withholds 600 kafy of this water in Lake Mead for future unspecified uses;
3) Alt 2 allows full transfers of up to 1.574 mafy like Alt1, but withdraws the 600 kafy directly from Lake Mead to reflect that all of the water will likely not remain in Lake Mead; and
4) Alt 3 allows full transfers of up to 1.574 mafy like Alt1, but redistributes the 600 kafy downstream of Lake Mead.

The MSCP study demonstrates how RiverWare and GPAT can be used for experimentation and making adjustments to a scenario prior to suggesting a formal alternative.



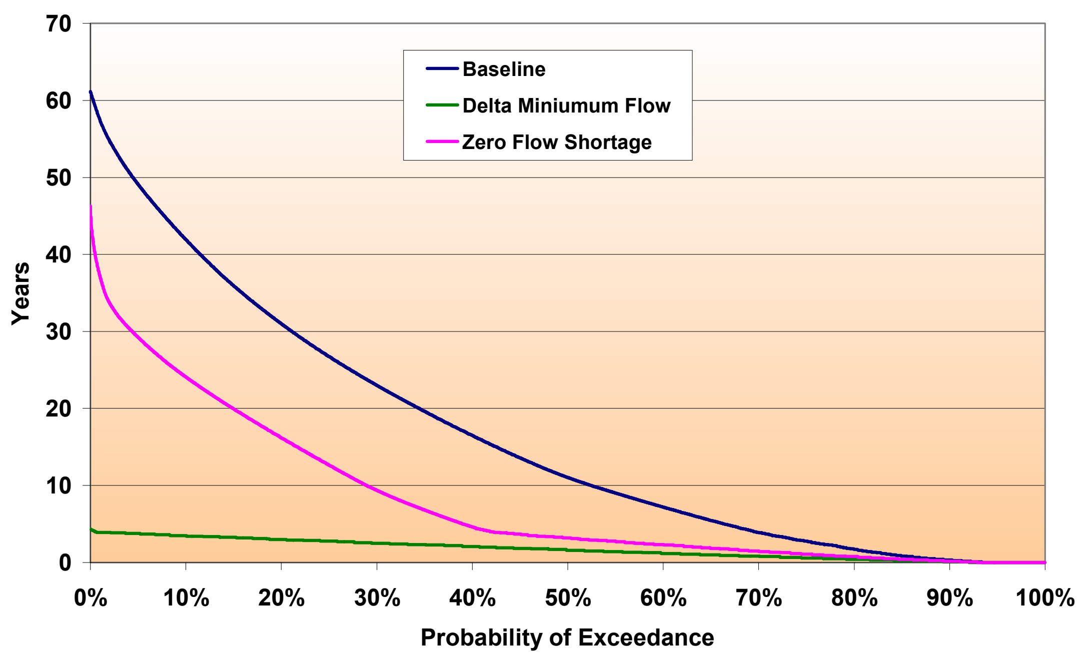
Delta Flows

Although the alternative submitted by the Pacific Institute and other environmental organizations for the Interim Surplus Guidelines EIS was not considered, a significant interest in the restoration of the Colorado Delta remains. Environmental Defense is currently taking a proactive role by collaborating with CADSWES and Reclamation in exploring potential alternatives for providing water for habitat restoration. While flows currently reach the delta through flood control releases from Lake Mead, the water does not always arrive at the delta when it would be most useful to restore and sustain the habitat of the delta. This research analyzes the impact on existing water users of improving the flows to the delta. Starting with the CRSS model of the Colorado River, a baseline analysis and several alternatives have been examined that provide flows to the delta under various hydraulic conditions. Academic researchers believe the necessary conditions to adequately restore habitat is to provide a guaranteed 50 kafy for base flows and a 260 kaf simulated spring flood flow at least once every four years (Luecke *et al.*, 1999). The following scenarios have been created, but research has not been completed:

- One scenario, termed "Delta Minimum Flow" examined the impacts of using system water to meet these flows. The simulated spring flood flow would occur in the months of May and June when flood control releases of sufficient magnitude has not occurred within the past 4 years. Because system water is being used the short-term effect on other water users is negligible. However, in the long term using system water increases the probability of shortages and decreases the probability of surpluses.

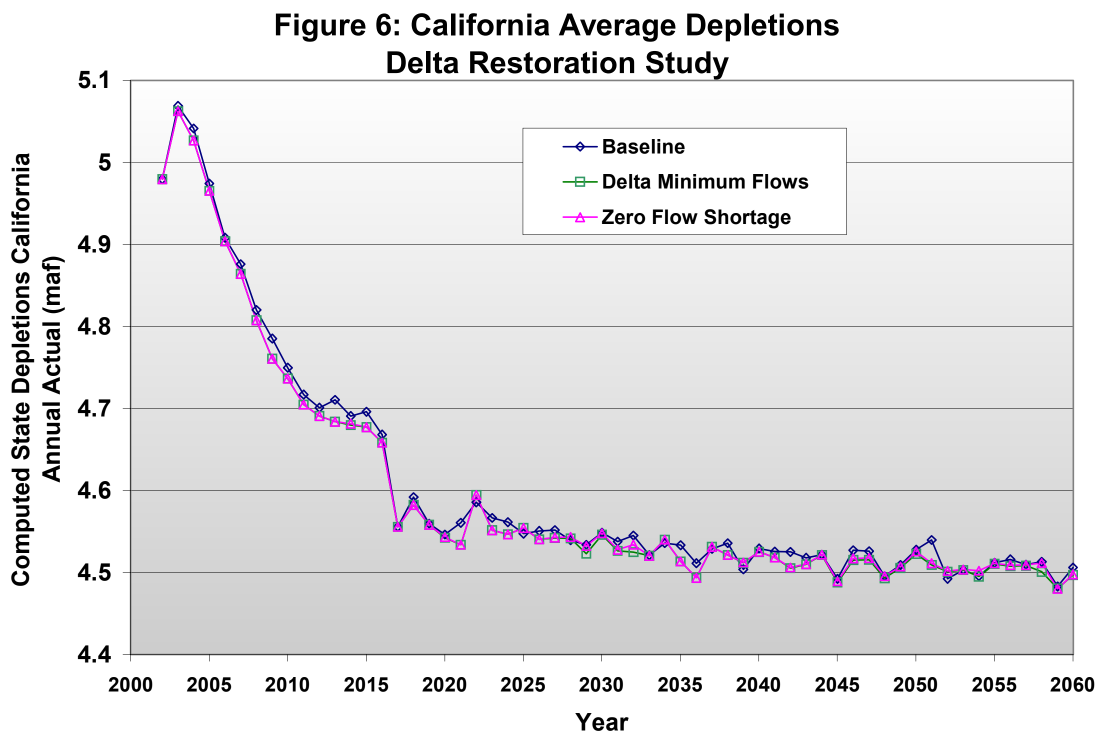
- One variation of the "Delta Minimum Flow" scenario involves eliminating delta flows under shortage conditions. This scenario is titled "Zero Flow Shortage." While this scenario is clearly worse for the delta, it reduces the sacrifice made by existing water users and represents a potential compromise solution.
- Another compromise solution involves reducing flows to the delta proportional to the reduction of Arizona during shortage conditions. In addition, simulated spring flood releases of 260 kaf would be made when Lake Mead's elevation exceeded the 70R level. This scenario is titled "Reduced Flow Shortage." This scenario creates surplus, normal, and shortage conditions for the delta that mimic those for the existing water users and is more akin to the Pacific Institute proposal.
- Another variation of the "Delta Minimum Flow" scenario, termed "Lower Basin Bank," includes purchasing or leasing water from various Lower Basin users and banking the water in Lake Mead to be made available for base flows and simulated spring flood flows. When flood control releases are released from Lake Mead but are insufficient to meet the 260 kaf required for delta flood plain inundation, "supplementary" water is released from the banked water if sufficient banked water is available. Under this alternative, the water is obviously coming from the water seller/lessor and the need for analysis is minimal.

Figure 5: Cumulative Distribution Function - Length of time since a 260 kaf flood event for the Colorado Delta



- A variation of the "Lower Basin Bank" scenario that purchases or leases 30% of the 50 kafy required for sustained base flows from Mexico and uses system water for the remaining 70% of the base flow. In addition, water from simulated spring flood releases would also come out of system water. If there is a flood control event planned that will be insufficient to meet the needs of the 260 kaf required for flood plain inundation, supplemental water will be used from the additional water Mexico receives during flood control events. This scenario is termed "Mexico Purchase."

Figure 5 demonstrates the cumulative distribution function of the length of time since a 260 kaf event has occurred for the baseline condition, the "Delta Minimum Flow" scenario and the "Zero Flow Shortage" scenario. Clearly, under the baseline conditions, the delta on average waits many years more for a 260 kaf event. Even the policy that eliminates flows to the delta only during shortage years has significant periods without a 260 kaf event. Figures 6 and 7 show the average California and Arizona depletions respectively under the alternatives.

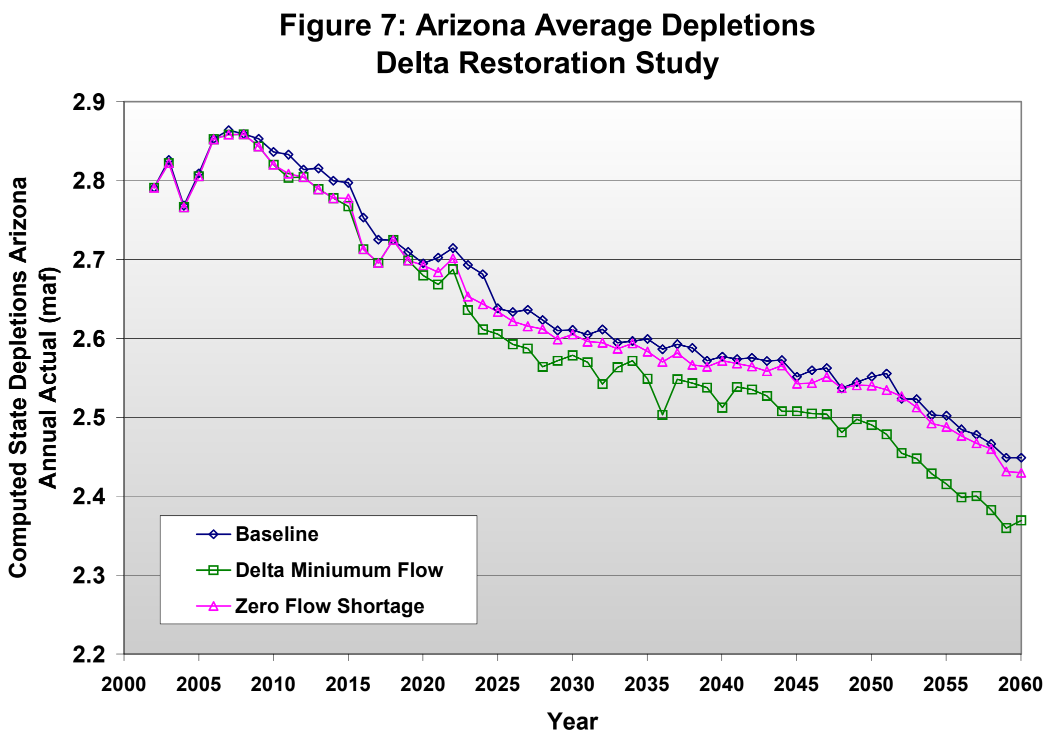


Notice that California's average depletion drops considerably under any scenario and that Arizona's depletions are quite different between the Delta Minimum Flow and baseline scenarios, while the Zero Flow Shortage scenario is fairly close to the baseline scenario. More in depth study of individual years reveals that in the early years most of the reduction in Arizona's expected depletions would be due to a likely reduction in surplus water. However, by 2060, most of the reduction in Arizona's expected depletions is due to a likely increase in shortages.

In 2060, the Delta Minimum Flow alternative is expected to reduce Arizona depletions by 3.2% with far smaller percentages for the other Lower Basin states and Mexico, and no effect in the Upper Basin. The total depletion of the Lower Basin States and Mexico is reduced. The breakdown of the total depletion reduction is as follows.

Arizona	82%
California	10%
Nevada	5%
Mexico	3%

These flows do not exactly match the increase in delta flows. This is expected to a certain degree because of other possible changes such as reservoir evaporation. These are preliminary results, and while they seem to be qualitatively correct, the authors urge caution in their use until the study is completed and the final results are published.



Flaming Gorge

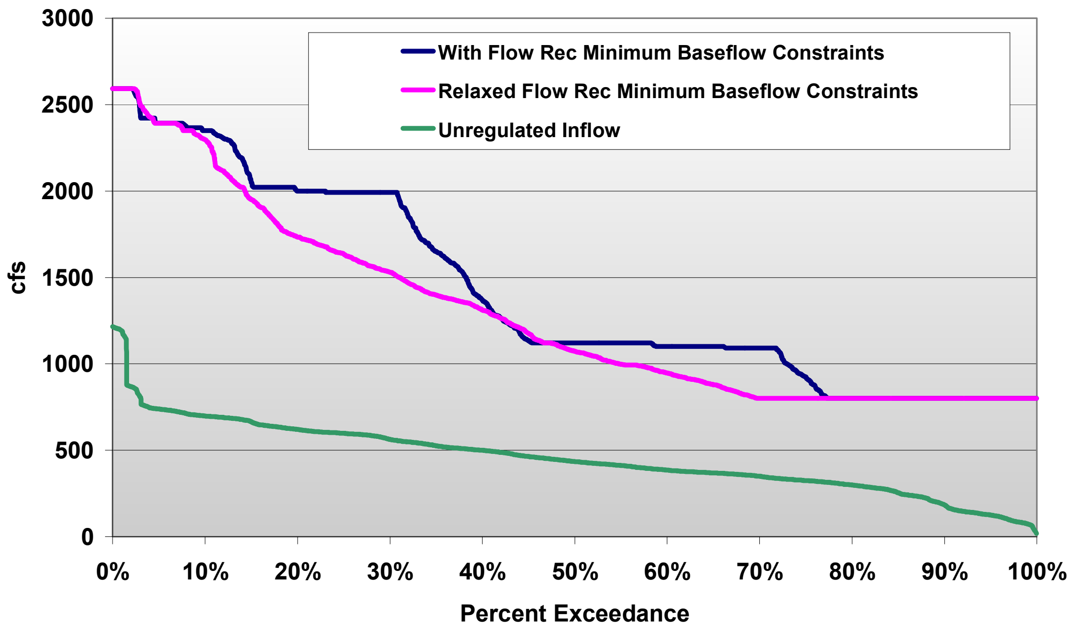
Another Environmental Impact Statement in the Colorado River basin concerns possible changes in the operation of Flaming Gorge Dam on the Green River. The natural flow of the Green River prior to dam development had a significant peak flow during spring run off with substantially lower flows during the rest of the year. Under operations based on the 1992 Biological Opinion (USFWS, 1992), a significant portion of the spring peak is captured and released throughout the base flow months, resulting in a substantially unnatural system. A study conducted by several agencies and led by the Fish and Wildlife Service (FWS) (Muth *et al*., 2000) suggested reoperating the dam with larger flows in spring and lower flows during the rest of the year. These flow recommendations specify the frequency and magnitude of flows required to improve habitat for a variety of endangered species found within the affected reaches. In October 2001, the Upper Colorado Region of Reclamation published preliminary results of a

RiverWare model (Clayton and Gilmore, 2001a; Clayton and Gilmore 2001b) developed to measure the system impacts of meeting these flow recommendations for the Green River. Upon preparation of a DEIS for changing the operation of Flaming Gorge Dam, The Nature Conservancy, U.S National Park Service, and Environmental Defense became involved and, together with CADSWES and Reclamation, studied alternative operational scenarios with the goal of a more natural operation on the Green River.

One of the major differences in the policies was the level of the minimum flow requirements during the period of August through February. Slight lowering of these requirements allowed significantly more water to be made available for spring runoff releases. Figure 8 demonstrates flow duration curves for the Flaming Gorge releases during the base flow month of December for:

1) the minimum base flow requirements as specified by the FWS alternative,
2) with the flow recommendation constraints relaxed, and
3) unregulated inflows into Flaming Gorge.

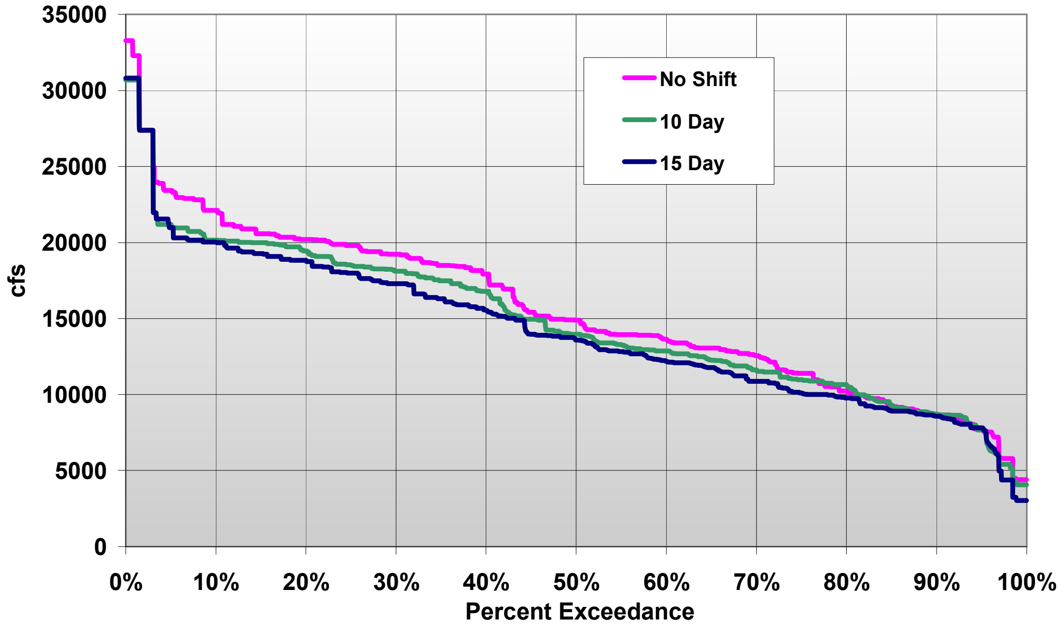
Figure 8: Flow Duration Curves for Flaming Gorge Release December



Another concern of The Nature Conservancy was Reclamation's assumption that the initiation of spring releases from Flaming Gorge Dam is to coincide with peak flows on the Yampa River tributary. This assumption was made to meet the minimum required flow recommendations downstream of the Green-Yampa confluence while minimizing the bypass of power generation capacity for Flaming Gorge Dam. However, this disregarded the natural hydrologic pattern with the Green River peaking an average of 17 days after the Yampa River, effectively extending the duration of the peak below the confluence. Two scenarios were studied that offset the peak of the Green River by 10 and 15 days after the Yampa River peak and are titled 10-Day and 15-Day respectively. Figure 9 shows the affect on the frequency of meeting the critical 18,600 cfs flow recommendation over a 14 day duration for the reach below the Green-Yampa River confluence.

The insights made into the Flaming Gorge model functionality have increased the understanding of all parties involved, including the Reclamation, Fish and Wildlife Service, the National Park Service.

Figure 9: Maximum 14 Day Flow Duration Curves Below Green-Yampa Confluence



Conclusion

The recent experience of modeling alternative policies on the Colorado River offers hope of a less litigious process for reaching compromise on the operation of river basins. The examples we cite indicate the potential to involve more parties in policy analysis and create new alternatives with win-win potential. Flexible modeling and analysis has assisted in:

- generating other alternatives,
- illustrating the effect of alternatives on Lake Mead elevations, and
- showing the environmental impacts of river management policies.

Clearly, advances in modeling technology have made it possible to explore more alternatives and in more depth.

Just as importantly, the case studies indicate how more accessible modeling tools have made it possible for a wider range of participation in exploring options. In these case studies, additional government agencies as well as environmental organizations were able to take an active role in proposing and analyzing alternative policies.

The history of litigation on the Colorado River because of competing water demands is not unique. For example, within the United States the use of water in both the Rio Grande and the Truckee-Carson drainage are similarly contentious. Performing similar analysis of policy alternatives on these basins would be aided by the fact that these basins are already modeled in RiverWare and the results can easily be exported to GPAT. Furthermore, performing this kind of analysis is not limited to river basins in the United States or even using these particular modeling tools.

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