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Alternatives for Restoring the Colorado River Delta

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ABSTRACT

The ongoing debate over the management, protection, and restoration of the Colorado River Delta near the U.S.-Mexico border can be informed by quantifying the effects of restoring flows to the Delta. The once-vibrant Colorado River Delta was nearly decimated by the construction of dams and diversions in the United States and Mexico. However, flood management, inadvertent releases from upstream reservoirs, and agricultural return flows partially restored the Delta in the 1980s and 1990s. Recent research estimates the Delta's freshwater needs – to sustain native riparian forests and associated wetlands – at 50,000 acre-feet annually (commonly referred to as baseflows), plus occasional flood flows (one in four years) of at least 260,000 acre-feet in May and June. If this need were to be regularly met, what would be the impact on existing water uses? This article documents a collaborative study to examine various alternative scenarios for delivering the estimated minimum freshwater flows needed to sustain the Delta ecosystems. Using the Bureau of Reclamation's Colorado River Simulation System (CRSS) model, this article presents the hydrologic differences of several alternative assured sources of baseflows and flood flows, including system water releases, market-based mechanisms, and various combinations of the two. In addition, we considered one alternative that does not fully meet the minimum requirements during shortage conditions (defined by a low elevation of water in Lake Mead). Alternatives were studied specifically to determine their effects on

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***** The study documented in this article emphasized the use of the identical modeling tool and assumptions used by the Bureau of Reclamation as of November 2005 for long-term planning and evaluation of operational policies. The authors are indebted to and sincerely appreciate the assistance of Dr. Terrance Fulp, Area Manager of Hoover Dam of the Lower Colorado office of the Bureau of Reclamation. This research would not be possible without his expertise of the CRSS model and his contribution to this effort.

Colorado River water storage and deliveries, with particular attention to changes in water available to current consumptive users. On one extreme, making additional system water releases for the Delta from Lake Mead would reduce expected deliveries in Arizona by 2.7 percent, in Nevada by 1.7 percent, and in California by 0.2 percent by the year 2060. In contrast, leasing water from existing uses for the Delta could have a slightly beneficial effect on other existing uses in the United States. This article does not seek to advocate one particular alternative over another, but to provide an understanding of the impacts of these alternatives.

I. INTRODUCTION

The Colorado River Delta (Delta), once one of the world's greatest desert river deltas, remains an important ecological resource despite being dramatically reduced in size because of decreased freshwater flows from the Colorado River (River).[1] Early in the twentieth century, the Colorado was not yet dammed, and snowmelt floods reached the Delta every year in the late spring and summer.[2] As these large floods spread through the Colorado's alluvial deposits, the water slowed and meandered through numerous channels, creating vast wetland and estuarine habitats that totaled 1.5 million acres.[3] While few records document the Delta's historic biological characteristics, a recent paleoecological study suggests that biological productivity in the estuary of the Upper Gulf of California may have been 15 times greater than it is today.[4]

The Delta is located in the arid Sonoran desert at the very southern extent of the Colorado River in the United States and extends south into the Gulf of California in the states of Sonora and Baja California, Mexico (see the map in Figure 1). The Delta today is about one-tenth of its former size, consisting of some 150,000 acres of riparian forest and wetlands, as well as the hydrologically related near-shore marine habitats.[5] While greatly

1. Jennifer Pitt et al., *Two Nations, One River: Managing Ecosystem Conservation in the Colorado River Delta*, 40 NAT. RESOURCES J. 819, 824 (2000).

2. *See* PHILIP L. FRADKIN, A RIVER NO MORE 330 (Alfred A. Knopf, Inc. 1981).

3. *See* Edward P. Glenn et al., *Effects of Water Management on the Wetlands of the Colorado River Delta, Mexico*, 10 CONSERVATION BIOLOGY 1175, 1177 (1996).

4. Michat Kowaleski et al., *Dead Delta's Former Productivity: Two Trillion Shells at the Mouth of the Colorado River*, 28 GEOLOGY 1059, 1062 (2000).

5. For a complete discussion of ecosystem types, see FRANCISCO ZAMORA-ARROYO ET AL., CONSERVATION PRIORITIES IN THE COLORADO RIVER DELTA, MEXICO AND THE UNITED STATES (Sonoran Institute, Environmental Defense, University of Arizona, Pronatura Noroeste Dirección de Conservación Sonora, Centro de Investigación en Alimentación y Desarrollo, and World Wildlife Fund-Gulf of California Program 2005), *available at* http://sonoran.org/ (follow "Reports" hyperlink; then follow "Conservation Priorities in the Colorado River Delta" hyperlink).

reduced from its former extent, the region continues to serve as a key link in the Pacific flyway, harboring endangered species among its migrating birds and year-round residents alike.[6] Although the Delta no longer supports extensive commercial fisheries, it does sustain numerous endangered aquatic species.[7]

The Delta's ecosystems are located downstream from an extensive system of dams and diversion infrastructure that irrigates three million acres of agricultural land and supplies water to more than 25 million domestic users in both the United States and Mexico.[8] These ecosystems are sustained today by what little Colorado River water is yet unclaimed for consumptive use in either country. However, no in-stream flow rights or other assurances exist to guarantee the flow of water that sustains the Delta's ecosystems. The water that sustains the delta arrives there inadvertently and unintentionally, and predictions for the future are dire. Without a water right, projected increases in water use, droughts, and the potential impacts of climate change all jeopardize the delta's future. A model of the Colorado River developed by the U.S. Bureau of Reclamation (Reclamation)[9] predicts a decrease in the frequency and magnitude of flood

6. Several birds found in the delta are listed as endangered in the United States, including the southwest willow flycatcher and the Yuma clapper rail. *See* Endangered and Threatened Wildlife and Plants, Lists, Endangered and Threatened Wildlife, 50 C.F.R. § 17.11 (2005). Additionally, Mexico lists Heerman's gull, the elegant tern, reddish egret, peregrine falcon, the brant, and great blue heron as threatened, in need of special protection, or rare. *See* NORMA Oficial Mexicana NOM-059-ECOL-1994, que determina las especies y subespecies de flora y fauna silvestres terrestres y acuáticas en peligro de extinción, amenazadas, raras y las sujetas a protección especial, y que establece especificaciones para su protección (1994), *available at* http://www.ine.gob.mx/ueajei/publicaciones/gacetas/227/especies.html (last visited Feb. 4, 2008).

7. *See* 50 C.F.R. § 17.11. Other endangered animals, such as the Colorado delta clam, are so rare that recent surveys identified as few as 12 individuals. *See* Kowaleski et al., *supra* note 4, at 1061. Endangered aquatic animals include the vaquita porpoise, the world's smallest and most endangered marine mammal; the totoaba fish; and the desert pupfish. *Id.*

8. DALE PONTIUS ET AL., COLORADO RIVER BASIN STUDY: FINAL REPORT 2 (1997) (report to the Western Water Policy Review Advisory Commission), *available at* http://wwa.colorado.edu/resources/colorado_river/pontius%20colorado.pdf.

9. Reclamation's principal planning model, the Colorado River Simulation System (CRSS), was used in this study. The particular version used to develop a baseline was Reclamation's official model as of November 1, 2005, which incorporates modeling assumptions in the Record of Decision for the Interim Surplus Guidelines 2002, Secretarial Implementation Agreement and several recent modifications made by Reclamation. These modifications include expansion of the period of record to 90 years of reconstructed hydrology (1906-1995), a shortage criteria referred to as 80P1050, which aims to protect Mead's pool elevation of 1050 feet above mean sea level with an 80-percent probability; a Level 2 shortage criteria was also implemented in this version of CRSS (as implemented and described in the 2002 FEIS) and updated initial conditions for reservoir contents.

flows from Lake Mead[10] over the long term, such that the probability of floods sufficient to sustain the Delta will be less than nine percent by 2060. Add the impact of climate change (not reflected in Reclamation's model), and the Delta's future looks even more uncertain.[11]

One of the world's most highly regulated and litigated river systems, the Colorado has been over-allocated for decades.[12] Flood flows (flows inundating the floodplain) reach the Delta only after repeated high water years when runoff from the basin's melting snowpack and rainfall events exceeds the upstream capacity to divert and store water.[13] The erratic flows that reach the Delta are typically the result of inevitable inefficiencies in developed river management,[14] water that Reclamation refers to as "excess flows."[15] Under today's legal and institutional conditions, the Delta receives little, if any, water in normal and dry years. As development of the Colorado continues in the United States, the Delta is expected to receive water less frequently, a condition that—absent affirmative efforts to the contrary—will soon destroy the Delta's remaining aquatic ecosystems.[16]

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10. BUREAU OF RECLAMATION, U.S. DEP'T OF INTERIOR, COLORADO RIVER INTERIM SURPLUS CRITERIA, FINAL ENVIRONMENTAL IMPACT STATEMENT, vol. I, ch. 3, at 3-16-13 (2000), *available at* http://www.usbr.gov/lc/region/g4000/surplus/SURPLUS_FEIS.HTML (last visited Nov. 18, 2007) [hereinafter SURPLUS CRITERIA]; BUREAU OF RECLAMATION, U.S. DEP'T OF INTERIOR, FINAL ENVIRONMENTAL IMPACT STATEMENT, IMPLEMENTATION AGREEMENT, INADVERTENT OVERRUN AND PAYBACK POLICY, AND RELATED FEDERAL ACTIONS, vol. I, ch. 3, at 3.12-13 to 3.12-17 (2002), *available at* http://www.usbr.gov/lc/region/g4000/FEIS/Volume%20I.pdf [hereinafter IMPLEMENTATION AGREEMENT].

11. Niklas S. Christensen et al., *The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin*, 62 CLIMATIC CHANGE 337 (2004). The topic of what the impacts of climate change will be in the region is currently being debated and the authors chose not to delve into this topic during this study to remain consistent with Reclamation's current assumptions. We recognize, however, that studies have indicated that climate change is expected to reduce precipitation in the Colorado River Basin by 14 to 18 percent over the next century.

12. PONTIUS ET AL., *supra* note 8, at 14.

13. Edward P. Glenn et al., *Status of Wetlands Supported by Agricultural Drainage Water in the Colorado River Delta, Mexico*, 34 HORTSCIENCE 39 (1999); DANIEL F. LUECKE ET AL., A DELTA ONCE MORE: RESTORING RIPARIAN AND WETLAND HABITAT IN THE COLORADO RIVER DELTA, iv, 12 (Envtl. Defense Fund 1999), *available at* http://www.environmentaldefense.org/documents/425_delta.pdf; Francisco Zamora-Arroyo et al., *Regeneration of Native Trees in Response to Food Releases from the United States into the Delta of the Colorado River*, 49 J. ARID ENV'TS 49, 62 (2001). The baseflow is needed to maintain backwaters and a wetted soil perimeter in the main stem channel, conditions necessary to sustain the habitat for migratory and resident birds that depend on insects for food. Flood flows are important to restore and maintain riparian vegetation in arid-zone rivers. *Id.*

14. These inefficiencies in Colorado River management include cancelled water orders, river and reservoir maintenance, and seepage from dams.

15. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 3, at 3.12-3.

16. *See* Pitt et al., *supra* note 1, at 821.

In recent years, the Environmental Defense Fund and other non-governmental organizations have advocated dedicated in-stream flows to protect and sustain the Delta.[17] While there is little disagreement that the Delta's aquatic ecosystems need water to survive, the subject of where this water should come from, how it might be secured, and what the effects of doing so will be has emerged as one of the most controversial issues in Colorado River management today. There are two basic methods for securing Colorado River water for the Delta. First, a regulatory change in river management could direct Reclamation to release water from a reservoir on the Colorado and deliver what is known as "system water," water that is not dedicated a priori to a particular water user.[18] An alternative source of water for the Delta is a market transfer, a purchase or lease from willing sellers who would reduce their consumptive use of Colorado River water.[19] However accomplished, any commitment and subsequent release of water for the Delta would have to be allowed to flow past all intervening downstream diversions and into the Delta ecosystems. Although the northernmost reach of the delta is located in the United States, institutional and legal obstacles make implementation of either of these methods for securing dedicated in-stream flows for the Delta challenging at this time. However, the legal framework governing the Colorado, known as the "Law of the River," continues to evolve to meet changing needs and possibly could be changed to restore the Delta.[20]

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17. ASOCIACIÓN ECOLÓGICA DE USARIOS DEL RÍO HARDY-COLORADO, A.C. ET AL., BINATIONAL DECLARATION: THE COLORADO RIVER (2001), http://www.biologicaldiversity.org/swcbd/Programs/watersheds/lcr/binational.pdf. *See* Pitt et al., *supra* note 1. In 2001, 20 non-governmental organizations signed the Binational Declaration for the Colorado River, including Asociación Ecológica de Usarios del Río Hardy-Colorado, A.C.; Center for Biological Diversity; Centro de Derecho Ambiental y Integración Económica de Sur, A.C.; Centro Intercultural de Estudios de Desiertos y Océanos, A.C.; Centro Regional de Estudios Ambientales y Cientificos; Defenders of Wildlife; ECO-SOL Educación y Cultura Ecológica A.C.; Environmental Defense; El Grupo Ecológista Antares, A.C.; Friends of Arizona Rivers; High Country Citizens' Alliance; International Rivers Network; La Sociedad de Historia Natural Niparajá, A.C.; Living Rivers; Pacific Institute for Studies in Development, Environment, and Security; Pro Esteros, Pronatura Peninsula de Baja California; Sierra Club; Colorado River Task Force; Sonoran Institute; and Southwest Rivers. *Id.*

18. Pitt et al., *supra* note 1, at 849-52.

19. We did not model transfers of undeveloped water rights. From a hydrologic perspective, such a transfer would be similar to diverting system water to the Delta. For discussion of market transfers to the Colorado Delta, see *id.* at 856-59.

20. Recent changes to the Law of the River include new federal laws such as the Grand Canyon Protection Act of 1992 and the Interim Surplus Guidelines. Grand Canyon Protection Act of 1992, Pub. L. No. 102-575, 106 Stat. 4669 (1992); BUREAU OF RECLAMATION, U.S. DEP'T OF INTERIOR, COLORADO RIVER INTERIM SURPLUS GUIDELINES: FINAL ENVIRONMENTAL IMPACT STATEMENT (2001) [hereinafter SURPLUS GUIDELINES]. As of this writing, the Bureau of Reclamation has completed a final environmental impact statement for shortages guidelines.

Considerable controversy surrounds any discussions of dedicating water to the Delta. Operation of the Colorado is politically sensitive, and even discussing alternative operations can be contentious. A common qualitative assumption is that promising water for one use (in this case the Delta) can only decrease the water available for other uses. Existing water users suspect that they have nothing to gain, but possibly much to lose, by discussing changes that increase water delivered to others.

Specifically with respect to the Delta, many environmental organizations would prefer to see the United States address the impact of river management on all species downstream from Federal dams, or at least consider habitat on the Colorado River in Mexico as a suitable site for habitat loss mitigation.[21] The United States maintains that its obligations under the Endangered Species Act stop at the Mexican border.[22] However, the United States and Mexico have both acknowledged the importance of the Delta's ecosystems.[23] Outside the legal arena, many institutions and agencies have been exploring how to protect and restore the Delta, including environmental and community organizations,[24] universities and research organizations,[25] and state governments and federal agencies in

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BUREAU OF RECLAMATION, U.S. DEP'T OF INTERIOR, COLORADO RIVER INTERIM GUIDELINES FOR LOWER BASIN SHORTAGES AND COORDINATED OPERATIONS FOR LAKES POWELL AND MEAD: FINAL ENVIRONMENTAL IMPACT STATEMENT (2007), *available at* http://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html.

21. *See* Defenders of Wildlife v. Norton, 257 F. Supp. 2d 53 (D.C. Cir. 2003); Press Release, Defenders of Wildlife, Groups Sue U.S. to Protect Mexican Wetlands and U.S. Endangered Species (June 28, 2000), *available at* http://www.defenders.org/newsroom/press_releases_folder/2000 (scroll down to June press releases); *see also* ASOCIACIÓN ECOLÓGICA DE USARIOS DEL RÍO HARDY-COLORADO, A.C. ET AL., *supra* note 17. Although the court has ruled that the United States is not obligated to manage the Colorado River for endangered species that rely on the river in Mexico, many environmental groups contend that the United States must share with Mexico in the obligation to protect and restore the habitats of the Colorado Delta. *Id.*

22. Letter from Sylvia A. Waggoner, Division Engineer, International Boundary and Water Commission U.S. and Mexico, to Jayne Harkins, Manager, Lower Colorado River Office, U.S. Bureau of Reclamation (Sept. 8, 2000), *reprinted in* SURPLUS CRITERIA, *supra* note 10, vol. III, at B-278–B-280 (stating that "the United States government does not assume any obligation to mitigate for adverse impacts in Mexico").

23. Minutes of the U.S. and Mexican Sections of the International Boundary and Water Commission, Conceptual Framework for U.S.-Mexico Studies for Future Recommendations Concerning the Riparian and Estuarine Ecology of the Limitrophe Section of the Colorado River and its Associated Delta, Minute 306 (Dec. 13, 2000), *available at* http://www.ibwc.state.gov/Files/Minutes/Min306.pdf [hereinafter Minute 306].

24. *See* Pitt et al., *supra* note 1, at 840–41.

25. The list of researchers is extensive, with some of the notable efforts mentioned here. Institutions that have demonstrated a commitment include, in the United States, the University of Arizona (at both the Environmental Research Laboratory and the National Science Foundation funded Research Coordination Network for the Colorado River Delta)

both the United States and Mexico.[26] Rather than wading into the institutional issues, our intent is to assess the implications of delivering Colorado River water to the Delta by examining the effects of various alternatives on existing and proposed consumptive water users. To that end, it is important to quantify the effects of restoring flows to the Delta, thus informing the debate over Delta protection and restoration.

This article documents a collaborative study by the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems, the Environmental Defense Fund, and Reclamation to model various alternative scenarios for delivering the estimated minimum freshwater flows needed to sustain the Delta ecosystems. Recent research estimates the Delta's freshwater needs – to sustain native riparian forests and associated wetlands – at 50,000 acre-feet annually (commonly referred to as baseflows), plus occasional flood flows (one in four years) of at least 260,000 acre-feet in May and June.[27] The authors studied alternatives, based on both system water and market-based mechanisms, that would deliver these flows to the Delta. In addition, we considered one alternative that does not fully meet the minimum requirements during shortage conditions (defined by a low elevation of water in Lake Mead). Alternatives were studied specifically to determine their effects on Colorado River water storage and deliveries, with particular attention to changes in water available to current consumptive users.

The study was conducted to determine the hydrologic impact on water users, reservoir elevations, and river reaches. This assessment of impact is relative to a set of baseline conditions that reflect the current institutional and legal framework used by Reclamation in managing the Colorado, as well as in modeling its future operations. As the baseline scenario for this study, we selected the official Colorado River Simulation System (CRSS) model provided by Reclamation on November 1, 2005 and generally described in the "Proposed Action Alternative" from a recent

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and, in Mexico, the Centro de Investigación Científica y de Educación Superior de Ensenada and the Centro de Investigación en Alimentación y Desarrollo.

26. For interested government agencies, see generally International Boundary and Water Commission, United States-Mexico Colorado River Delta Symposium Proceedings 67-74 (Sept. 11-12, 2001), *available at* http://www.ibwc.state.gov/FAO/CRDS0901/English Symposium.pdf.

27. The baseflow is needed to maintain backwaters and a wetted soil perimeter in the main stem channel, conditions necessary to sustain the habitat for migratory and resident birds that depend on insects for food. Flood flows are important in restoring and maintaining riparian vegetation in arid-zone rivers. Glenn et al., *supra* note 13, at 40; LUECKE ET AL., *supra* note 13, at iv; Zamora et al., *supra* note 13.

Colorado River environmental compliance document.[28] In addition, this baseline includes updates to the model made by Reclamation that include expansion of the period of record to 90 years of reconstructed hydrology (1906–1995); a shortage criteria referred to as 80P1050, which aims to protect Mead's pool elevation of 1050 feet above mean sea level with an 80 percent probability; a Level 2 shortage criteria, which was also implemented in this version of CRSS (as implemented and described in the 2002 Final Environmental Impact Statement); and updated initial conditions for reservoir contents. Thus, the baseline scenario for this study includes the assumed implementation of several pending policies in future river management, not because the authors necessarily endorse the adoption of these policies but, rather, because using them in the model allows comparison of this study's alternatives with modeled scenarios used in Reclamation's decision-making processes. This study neither advocates a particular alternative nor introduces new information on the secondary kinds of impact (e.g., environmental or economic) of the alternatives.

This article is comprised of five sections: (1) the history and ecology of the Delta, (2) the flows to the Delta under the current institutional and legal framework that governs its management, (3) a description of the modeling methodology, (4) an explanation of the alternatives studied, and (5) a hydrologic comparison of the alternatives.

II. THE HISTORY AND ECOLOGY OF THE DELTA

The Colorado originates in the Rocky Mountains of the United States and travels approximately 1400 miles to its mouth at the northern end of the Gulf of California, dropping more than 14,000 feet along its journey (Figure 2). Typical of a river dominated by snowmelt, the Colorado's flow fluctuates significantly over the course of the year, with high flows occurring in late spring and low flows occurring through the fall and winter.[29] In addition to this annual variation, flows vary considerably from year to year and have been recorded to be as low as 5,000,000 acre-feet and in excess of 23,000,000 acre-feet.[30] The Delta historically received nearly all of the Colorado's flows.[31] However, extensive development of Colorado

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28. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 2, at 2.2-1. The alternative is described in detail in the section "Description of the Proposed Action and Alternatives," *id.* at 2-1.

29. PONTIUS ET AL., *supra* note 8, at 6.

30. SURPLUS CRITERIA, *supra* note 10, vol. I, ch. 3, at 3.3-6.

31. Paleo-ecological research suggests that over the long term the Colorado's annual average flow may be as low as 14.3 maf. Connie A. Woodhouse et al., *Updated Streamflow Reconstructions for the Upper Colorado River Basin*, 42 WATER RESOURCES RES., NO. W05415, 2006, at 12.

River water over the course of the twentieth century has disrupted the natural flow regime, and today flows that reach the Delta are considerably smaller and less frequent than they were in the past (see Figure 3).[32] During the construction of the Glen Canyon Dam and the subsequent filling of Lake Powell, the last major reservoir built upstream, the Delta was deprived of floods for a period of 20 years, an imposed drought that devastated its flora and fauna.[33] The Colorado became known in popular literature as "A River No More."[34]

Since the filling of Lake Powell in 1981, occasional years of high precipitation in the Colorado River Basin (Basin) have resulted in periodic floods that once again reach the Delta.[35] Demonstrating resilience, the Delta's ecosystems have begun to thrive again. However, Reclamation's model predicts that these floods will decrease in frequency and magnitude as recently adopted policies are implemented and consumptive use increases upstream due to the development of allocated but previously unused Colorado River water.[36] In addition, the recent drought (2000-2007) significantly reduced the probability of floods reaching the Delta in the near term. While the probability in the next few years that the Delta will flood is essentially zero due to the current low storage contents of Lake Mead and Lake Powell, the probability will gradually increase to around 18 percent by 2016, but will continue a downward trend by 2060 to as little as 11 percent.[37]

The contemporary ecosystems of the Delta have been the subject of increasing study and concern over the past decade, as university researchers and representatives of non-governmental organizations have amassed a substantial amount of information about the Delta's physical and

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32. *See* INT'L BOUNDARY & WATER COMM'N, WESTERN WATER BULLETIN 1960: FLOW OF THE COLORADO RIVER AND OTHER WESTERN BOUNDARY STREAMS AND RELATED DATA 29 (1960); INT'L BOUNDARY & WATER COMM'N, WESTERN WATER BULLETIN 2003: FLOW OF THE COLORADO RIVER AND OTHER WESTERN BOUNDARY STREAMS AND RELATED DATA 32 (2003); U.S. Geological Survey, Geological Survey Water Supply Paper 1313, Compilation of Records of Surface Waters of the United States through September 1950, pt. 9: Colorado River Basin, 709–29 (1954).

33. LUECKE ET AL., *supra* note 13, at 1.

34. *See generally* FRADKIN, *supra* note 2.

35. LUECKE ET AL., *supra* note 13, at 13; MICHAEL J. COHEN & CHRISTINE HENGES-JECK, MISSING WATER: THE USES AND FLOWS OF WATER IN THE COLORADO RIVER DELTA REGION 16–18 (Pacific Inst. 2001).

36. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 3, at 3.12-3.

37. We detected this trend in our analysis, which updates the trend documented using the hydrologic record through 1990 in IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, at 3.12-18.

biological characteristics.[38] The Delta consists of four ecosystem types, sustained by several water sources:

- The riparian ecosystem, the primary focus of this article, is currently comprised of native cottonwoods and willows[39] and provides habitat for resident and migratory birds,[40] including the endangered southwest willow flycatcher.[41] While trees in this forest are most likely sustained by ground water,[42] forest diversity and health are maintained by floods that flush salts from the soils, recharge the ground water, and allow the native trees to regenerate.[43] The native riparian forest in the Delta is a habitat type now very rare in the United States: The Delta's cottonwood willow habitats are more than four times greater in acreage than the sum total of all cottonwood willow habitats found along the lower Colorado River in the United States.[44]
- The Ciénega de Santa Clara (Ciénega) is a large, open-water wetland that presently provides habitat for hundreds of species of birds,[45] including the endangered Yuma clapper rail.[46] In addition, its waters sustain the largest documented population of the endangered desert pupfish.[47] About 110,000 acre-feet per year of brackish agricultural drain water from the Wellton-Mohawk Irrigation and Drainage District in the United States flows into the Ciénega via a canal built to ensure that the brackish water does not drain back into the Colorado. This was

38. *See generally* ZAMORA-ARROYO ET AL., *supra* note 5; "Special Issue: The Lower Colorado River Basin and Delta," 49 J. ARID ENV'TS 1 (2001) (which contains ten original research papers, two literature reviews, and two policy papers).

39. Zamorra-Arroyo et al., *supra* note 13, at 50.

40. Daniel W. Anderson et al., *Migratory Bird Conservation in the Colorado River Delta Region*, *in* MANAGING FOR HEALTHY ECOSYSTEMS (David J. Rapport et al. eds., 2003).

41. Garcia-Hernandez et al., *Willow Flycatcher (*Empidonax traillii*) Surveys in the Colorado River Delta: Implications for Management*, 49 J. ARID ENV'TS 161-70 (2001).

42. Zamora-Arroyo et al., *supra* note 13.

43. *Id.*; Julie C. Stromberg, *Restoration of Riparian Vegetation in the South-western United States: Importance of Flow Regimes and Fluvial Dynamism*, 49 J. ARID ENV'TS 17, 18 (2001).

44. *See* LUECKE ET AL., *supra* note 13, at 24 (citing the calculations found in B.W. Anderson & Robert D. Ohmart, *Vegetation*, *in* INVENTORY AND MONITORING OF WILDLIFE HABITAT 639 (Allen Y. Cooperrider et al. eds., 1986)).

45. Jack M. Payne et al., Ducks Unlimited, Inc., Feasibility Study for the Possible Enhancement of the Colorado Delta Wetlands, Baja California Norte, Mexico 8 (1992); Erik Mellink et al., *Non-Breeding Waterbirds of the Delta of the Río Colorado, Mexico*, 68 J. FIELD ORNITHOLOGY 113, 114 (1997).

46. Osvel Hinojosa-Huerta et al., *Distribution and Abundance of the Yuma Clapper Rail (*Rallus longostris yumanensis*) in the Colorado River Delta, Mexico*, 49 J. ARID ENV'TS 171 (2001).

47. S. Zengel & E.P. Glenn, *Presence of the Endangered Desert Pupfish, (*Cyprinodon macularius, Cyprinidontidae*) in Cienega de Santa Clara, Mexico, Following an Extensive Marsh Dry Down*, 41 SW. NATURALIST 73 (1996).

required by Minute 242 of the 1973 International Boundary and Water Commission, which codified the U.S.-Mexico agreement on a salinity standard for Colorado River deliveries to Mexico.[48] The Ciénega, located in a channel of the pre-development Delta, owes its continued existence to this canal. The water deliveries modeled in this article would not have a direct effect on the Ciénega.

- Brackish wetlands thrive throughout the Delta's midsection, providing important habitat for birds.[49] Vast stands of salt-cedar (a non-native species) and other salt-tolerant wetland plants dominate the Delta's midsection and are sustained primarily by agricultural drainage from the Mexicali and San Luis agricultural valleys, as well as by artesian springs and, in some areas, tidal inflows.[50] While restoring flood flows can be expected to reduce salt-cedar and restore native species, this effect has not been quantified.
- The marine zone of the Delta was once productive at many orders of magnitude greater than today. Studies document a biologically rich estuary that supported billions of clams,[51] a thriving population of the vaquita porpoise—the world's smallest and rarest marine mammal[52]—and the totoaba, a fish that once grew to a length of seven feet.[53] Prior to development on the Colorado, nearly the entire inflow to the Colorado would have been delivered as freshwater flows to the marine zone.[54] The production of shrimp in the upper Gulf of California, still an important local fishery, has been directly correlated to freshwater inflows from the Colorado.[55] However, flows that

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48. Jennifer Pitt et al., *New Water for the Colorado River: Economic and Environmental Considerations for Replacing the Bypass Flow*, 6 DENV. WATER L. REV. 70 (2002).

49. Carlos Valdes-Casillas et al., Information Database and Local Outreach Program for the Restoration of the River Hardy Wetlands, Lower Colorado River Delta, Baja California and Sonora, Mexico 18 (1998).

50. *See* Glenn et al., *supra* note 3.

51. Kowaleski et al., *supra* note 4.

52. *Vaquita* (Phocoena sinus), in MARINE MAMMAL COMMISSION: ANNUAL REPORT TO CONGRESS 1996 (1997) [hereinafter MARINE MAMMAL COMMISSION].

53. C.A. Flanagan & J.R. Hendrickson, *Observations on the Commercial Fishery and Reproductive Biology of the Totoaba,* Cyncoscion Macdonaldi, *in the Northern Gulf of California* 74 FISHERY BULL. 531 (1976) (cited in U.S. BUREAU OF RECLAMATION, DESCRIPTION AND ASSESSMENT OF OPERATIONS, MAINTENANCE, AND SENSITIVE SPECIES OF THE LOWER COLORADO RIVER, BIOLOGICAL ASSESSMENT PREPARED FOR U.S. FISH AND WILDLIFE SERVICE AND LOWER COLORADO RIVER MULTI-SPECIES CONSERVATION PROGRAM, vol. IV, at E3.)

54. LUECKE ET AL., *supra* note 13, at 1.

55. Manuel S. Galindo-Bect et al., *Penaid Shrimp Landings in the Upper Gulf of California in Relation to Colorado River Freshwater Discharge*, 98 FISHERY BULL. 222, 222 (2000).

reach the marine zone today have not been quantified, and little is known about how much water would be needed to sustain viable populations of the vaquita and totoaba, both of which are on the verge of extinction.[56] While studies have documented the importance of freshwater floods to the marine ecosystem in the northern Gulf of California, no one has yet predicted what impact the floods modeled in this article might have on those environments.

In recent years, funding for research in the Delta has increased and now totals some $3 million annually.[57] Under the auspices of Minute 306[58] to the 1944 water treaty,[59] the United States and Mexico agreed to collaborate in studying the Delta's ecosystems.

III. THE LAW OF THE RIVER AND ITS EFFECT ON THE DELTA

Management of the Colorado in the United States is primarily the responsibility of Reclamation, acting on behalf of the Secretary of the Interior (Secretary). Management objectives include, but are not limited to, minimizing flood damages, providing reliable delivery of water for beneficial consumptive use, protecting and enhancing the environmental resources of the basin, generating hydropower, and providing recreational opportunities along the river and reservoir system.[60]

These and other objectives are met within an overall legal framework that is commonly known as the Law of the River.[61] Reclamation has established operational criteria to ensure that the management objectives are met within this legal framework.[62] These criteria range from

56. MARINE MAMMAL COMMISSION, *supra* note 52.

57. Telephone Interview with Karl Flessa, Principal Investigator, Colorado River Delta Research Coordination Network (Dec. 6, 2005).

58. Minute 306, *supra* note 23.

59. Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Feb. 3, 1944, U.S.-MEX., 59 Stat. 1219, 1265.

60. Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968, Pub. L. No. 90-537, § 602, 82 Stat. 900 (1968) (codified at 43 U.S.C. § 1552 (1968)), *available at* http://www.usbr.gov/lc/region/g1000/pdfiles/opcriter.pdf.

61. The numerous compacts, court decisions and decrees; contracts; and regulatory guidelines are collectively known as the Law of the River. This collection of documents governs the apportionment and regulates the use and management of the Colorado River. A collection of the most significant documents comprising the Law of the River is available at http://www.usbr.gov/lc/region/pao/lawofrvr.html.

62. The term "operating criteria," as used in this article, refers to the Criteria for Coordinated Long-Range Operation of the Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968 (commonly referred to as the Long-Range Operating

providing general guidance for the operation of the system to specifying exactly how a certain objective will be implemented. An important point is that the Law of the River is not static. It has evolved over time and continues to do so, as evidenced by recent legislation and changes to the operating criteria.[63] A complete discussion of the Law of the River and the operating criteria is beyond the scope of this article; the interested reader is directed to the many good summaries and discussions on the subject.[64] Certain aspects, however, are relevant to the study at hand and will briefly be discussed.

Over time, all of the Colorado River water has been allocated (and most researchers believe it has been over-allocated).[65] The Colorado River Compact of 1922 divided the river system into the Upper and Lower Basins at Lee's Ferry, Arizona and apportioned 7.5 million acre-feet (maf) per year to each basin for consumptive use.[66] The United States-Mexico Water Treaty of 1944 further apportioned 1.5 maf to the Republic of Mexico,[67] resulting in a total consumptive use apportionment of 16.5 maf per year basin-wide. With the exception of some federal reserved rights that were quantified in

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Criteria or LROC) and to other criteria used to operate each reservoir within the legislated purposes of each project. The authors will be explicit when referring to the LROC.

63. *See* sources cited in *supra* note 20.

64. *See generally* MILTON N. NATHANSON, UPDATING THE HOOVER DAM DOCUMENTS (1978).

65. Over-allocation of the Colorado River is widely recognized. Sixteen and one-half million acre-feet of water are allocated in the Colorado River Compact and the U.S.-Mexico Treaty, yet this exceeds the average annual inflow into the system of 15.1 million acre-feet (maf) from 1906 through 2003, based on Reclamation's natural or virgin-flow estimates. Bureau of Reclamation, U.S. Dep't of Interior, Reclamation: Managing Water in the West, Response of the System to Various Hydrological and Operational Assumptions, Reclamation Modeling Results (presented at Natural Resources Law Center Conference, Boulder, Col., June 2005), http://wwa.colorado.edu/in_focus/colorado_river/hard_times_conference/Fulp_NRLCpresentation.pdf. Furthermore, a recent paleo-reconstruction of streamflows shows that for the Colorado River the long-term annual mean flow may only be 14.3 million acre-feet. *See* Woodhouse et al., *supra* note 31; *see also* David H. Getches & Charles C. Meyers, *The River of Controversy: Persistent Issues*, *in* NEW COURSES FOR THE COLORADO RIVER: MAJOR ISSUES FOR THE NEXT CENTURY 55–56 (Gary D. Weatherford & F. Lee Brown eds., 1986); David G. Tarboton, *Hydrologic Scenarios for Severe Sustained Drought in the Southwestern United States*, 31 WATER RESOURCES BULL. 803 (1995).

66. The full text of the Colorado River Compact can be found in NATHANSON, *supra* note 64, vol. I, at 4–7. The Compact is also available at http://www.usbr.gov/lc/region/g1000/pdfiles/ucbsnact.pdf.

67. Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Feb. 3, 1944, U.S.-Mex., 59 Stat. 1219, 1265. The Treaty is available at http://www.ibwc.state.gov/Files/1944Treaty.pdf.

Arizona v. California[68] and the subsequent 1964 Decree,[69] the current Law of the River does not allocate water specifically for environmental purposes.[70]

In the absence of dedicated flows, the Delta's ecosystems are currently sustained by water that is not consumptively used in the United States or Mexico. Specifically, water flowing in the mainstem of the Colorado River reaches the Delta today only when flows at Morelos Dam exceed what Mexico diverts into the Central Canal as the result of the following:

- Operational activities. Such activities include water that is ordered for delivery in the United States but subsequently canceled after release, and river and reservoir maintenance that may limit the ability to regulate and store river flows.[71]
- Flooding on the Gila River. Due to the large amount of development on the Gila River throughout Arizona, very little water flows into the confluence with the Colorado in most years. However, local storms do occur, although infrequently, and can result in large floods that reach the Delta, such as the event seen in 1993.[72]
- Flood control releases from Lake Mead. Based on the authorization of the Flood Control Act of 1944, the Army Corps of Engineers and Reclamation established specific criteria for the operation of Lake Mead to meet downstream flood management objectives. These criteria specify under what circumstances Lake Mead will release water in excess of downstream demand.[73] These flood control releases form the basis of the larger, but infrequent, flows currently reaching the Delta.[74]

Although significant quantities of water have occasionally reached the Delta over the past 20 years due to a combination of these causes, flows

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68. 373 U.S. 576 (1963) (guaranteeing in-stream flows for some national parks, monuments, and refuges).

69. Arizona v. California, 376 U.S. 340 (1963).

70. However, several recent changes in the Law of the River do require operational changes for the benefit of the environment. The Grand Canyon Protection Act of 1992 authorized flood releases from Lake Powell to flush sediments through the Grand Canyon, and the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin was developed to protect and improve instream flows, restore habitat, and reduce the adverse effects of non-native fish species. *See* Pitt et al., *supra* note 1, at 833–36.

71. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 3, at 3.12-1.

72. *Id.*

73. U.S. ARMY CORPS OF ENG'RS, WATER CONTROL MANUAL FOR FLOOD CONTROL: HOOVER DAM AND LAKE MEAD, COLORADO RIVER (1982).

74. *See* LUECKE ET AL., *supra* note 13, at 13; Cohen & Henges-Jeck, *supra* note 35.

to the Delta are expected to decline in the future. The causes of this decline include future development within the basin, potential effects of climate change, and proposed changes to the Law of the River and the operating criteria, as described in the remainder of this section.

Upper Colorado River Basin (Upper Basin) development is likely to be a primary cause of declining flows to the Delta. Recent studies published by Reclamation assume that the Upper Basin will develop over time and reach approximately 5.4 maf per year of total deliveries and 6.0 maf per year of total use including evaporative losses by the year 2060.[75] This additional water development in the Upper Basin not only affects the amount of water projected to be in Lake Powell but also, due to certain provisions of the Law of the River, would result in less water in Lake Mead.

Less water in Lake Mead will ultimately decrease the frequency and magnitude of flood releases at Hoover Dam and, thus, of flood flows that reach the Delta. Reclamation's Long-Range Operating Criteria[76] (LROC) established a minimum release of 8.23 maf per year from Lake Powell to the Lower Colorado River Basin (Lower Basin), which effectively meets the requirements of the 1922 Compact.[77] However, as stipulated by the Colorado River Basin Project Act of 1968[78] (CRBPA) and the LROC, additional water (in excess of the minimum) will be released from Lake Powell if necessary to maintain equal amounts of water stored in Lake Mead and Lake Powell. This provision of the Law of the River is known as "equalization" and is predicated on a key condition: Equalization applies only if there is sufficient storage in the Upper Basin to assure future deliveries to the Lower Basin without impairment to future consumptive use in the Upper Basin (known as "602(a) storage").[79] The effect of increasing Upper Basin consumptive use reduces equalization in two ways.

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75. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, app. G, at B-1, Technical Memorandum No. 1, Analysis of River Operations and Water Supply.

76. Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968, Pub. L. No. 90-537, § 602, 82 Stat. 900 (1968) (codified at 43 U.S.C. § 1552 (1968)).

77. In order to allow for Upper Basin development while ensuring that water would be available for development in the Lower Basin, the 1922 Compact required that the Upper Basin would not deplete the flow at Lee Ferry to less than 75 million acre-feet for any period of ten consecutive years. It further anticipated the need to apportion water to Mexico and declared that the burden to supply that water would be borne equally by the two basins. Consequently LROC specifies a minimum objective release from Lake Powell of 8.23 million acre-feet annually. *Supra* note 76, § II(2).

78. 43 U.S.C. § 1552(a)(3)(ii).

79. Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968, Pub. L. No. 90-537, § 602, 82 Stat. 900 (1968) (codified at 43 U.S.C. § 1552 (1968)), as amended by 69 Fed. Reg. 28,945 (May 19, 2004).

First, consumptive use will decrease the inflow to Lake Powell, reducing the volume of "equalized" water and the frequency of equalization. Second, increased consumptive use increases the volume of 602(a) storage in the Upper Basin required to allow equalization. Eventually, equalization releases will not be required, resulting in the minimum release of 8.23 maf per year from Lake Powell to the Lower Basin.[80] In either case, the overall delivery to the Lower Basin will tend to decrease and to approach the minimum annual release, resulting in less water in Lake Mead over time. This will ultimately decrease both the frequency and magnitude of flood flows that reach the Delta.

As previously mentioned, the Law of the River has undergone significant modification in recent years, and modification is likely to continue. The LROC authorizes the Secretary of the Interior to determine that normal, surplus, or shortage conditions exist based on several criteria.[81] When surplus is declared, California is entitled to 50 percent of the surplus, Arizona is entitled to 46 percent, and Nevada is entitled to 4 percent.[82] When all surplus demand in the United States has been satisfied, additional water may be released to Mexico.[83] The adoption of Interim Surplus Guidelines (ISG) in 2001 established specific guidelines (primarily based upon the amount of water in storage in Lake Mead) that are used to determine when these conditions exist for the Lower Basin and how much additional water is available for consumptive use.[84] These guidelines are in effect for an interim period (2002–2016), given that certain stipulations are

80. *See supra* note 76. Changes to equalization rules by the Colorado River basin states are not expected to change this trend. Letter to Gale Norton, Secretary, Department of the Interior, from the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming 2 (Feb. 3, 2006), *available at* http://www.usbr.gov/lc/region/programs/strategies/consultation/Feb06BasinStatesTransmittalLetter.pdf.

81. *Supra* note 76, § III(3).

82. Arizona v. California, 373 U.S. 546 (1963): II(B)2.

83. The U.S.-Mexico Water Treaty allocates 200,000 acre-feet of water to Mexico "in any year in which, as determined by the United States Section, there exists a surplus of waters of the Colorado River in excess of the amount necessary to supply uses in the United States." The Interim Surplus Guidelines do not define surplus for Mexico. Consequently, Mexico receives surplus deliveries only when flood control releases are anticipated. Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Feb. 3, 1944, U.S.-Mex., art. 10(b), 59 Stat. 1219, 1265. SURPLUS CRITERIA, *supra* note 10, vol. III, pt. B, Letter 58, at B-278–80.

84. The Interim Surplus Guidelines went into effect on January 1, 2002, although they were suspended until October 16, 2003, when the Secretary of the Department of the Interior signed the Colorado River Water Delivery Agreement, recognizing the completion of the California parties' Quantification Settlement Agreement. SURPLUS GUIDELINES, *supra* note 20; *see* Dean E. Murphy, *Pact in West Will Send Farms' Water to Cities*, N.Y. TIMES, Oct. 17, 2003, at A1.

met by the state of California, and may be extended.[85] These increased deliveries for consumptive use will tend to reduce the elevation of Lake Mead both during this period and afterward. Thus, the Guidelines will reduce the frequency and magnitude of flood flows that reach the Delta both before and after 2016.[86]

Reclamation is currently considering or refining several additional policies, including the Inadvertent Overrun Policy (IOP), "bypass flow replacement," development of a regulatory reservoir, and shortage criteria for the Colorado River Basin that could potentially further diminish the probability of flows to the Delta. The IOP establishes requirements for payback of inadvertent overuse of Colorado River water by users in the Lower Basin.[87] The proposed implementation of this policy would allow a multi-year payback that will result in less water in Lake Mead,[88] and that would further decrease the probability and magnitude of flood releases.

A "bypass flow replacement" policy may also have an adverse effect on the probability of flood flows to the Delta. Approximately 110,000 acre-feet of brackish agricultural drain water from the Wellton-Mohawk Irrigation and Drainage District in the United States is diverted into the Ciénega de Santa Clara in Mexico annually.[89] The Colorado River Basin Salinity Control Act requires the United States to replace this water in the main stem of the Colorado.[90] The Act further stipulates that this obligation would be temporarily met through conservation savings through the federally funded lining of the Coachella Canal.[91] However, the Act also required the United States to eventually find an alternate replacement flow. Reclamation is currently exploring options for that replacement.[92] Depending upon the methodology implemented, such replacement could

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85. Reclamation is considering extension of the Surplus Guidelines in its determination of shortage criteria. *See supra* note 20.

86. *See* SURPLUS GUIDELINES, *supra* note 20, fig. 3.16.1.

87. Letter from Jennifer Pitt, Senior Resource Analyst, Environmental Defense, et al., to Bruce Ellis, Environmental Program Manager, Phoenix Area Office of the Bureau of Reclamation (Mar. 26, 2002) (commenting on the Draft Environmental Impact Statement on the Implementation Agreement, Inadvertent Overrun and Payback Policy, and Related Federal Actions, published in the Final Environmental Impact Statement). *See* IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 11, at 11-213.

88. *See* IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 3, at 3.1-31.

89. Report from the Secretary of the Interior, to select members of the U.S. Senate Energy, Resource & Appropriations Committees, Modifications to Projects of Title I of the Colorado River Basin Salinity Control Act 11-12 (Feb. 11, 2003) (draft on file with author and the Natural Resources Journal).

90. 43 U.S.C. § 1571(c) (2000).

91. *Id.* § 1572(a) (2000).

92. Bureau of Reclamation, Notice to interested parties, September 22, 2005: Public Process – Methods to recover or replace the bypass flow, including the Yuma Desalting Plant, *available at* http://www.usbr.gov/lc/region/programs/bypass/letter.pdf.

alter the amount of water in Lake Mead and therefore affect the probability of flood control releases.[93]

In the wake of the most severe drought in the historical record of the Colorado River basin (from 2000 to 2007), Reclamation initiated a public process to determine "management strategies under low reservoir conditions,"[94] in which a wide range of projects and policies are considered. Of note, the Drop 2 storage reservoir, proposed to be built along the All American Canal, would store, and release for consumptive use in the United States, water that today flows to Mexico as "non-storable flows."[95] If this reservoir is built in the absence of dedicated flows to the Delta, it is sure to deprive the Delta of water that sustains its ecosystems. Environmental Defense Fund collaborated with several other NGOs to develop a proposal called "Conservation Before Shortage."[96] This proposal includes mechanisms to increase water in storage at Lake Mead as well as to allow the creation of dedicated flows to the delta. Reclamation has included "Conservation Before Shortage" as an alternative analyzed in its shortage policy development process.[97]

Reclamation will also consider a broad array of policies regarding reservoir operations and water distribution when system storage is low. The CRBPA requires that consumptive use by the Central Arizona Project (CAP) be limited during shortage to assure the availability of 4.4 maf to California. Thus, Arizona will be significantly affected by the frequency and magnitude of shortages. The Secretary has never declared a shortage for the Lower Basin,[98] but with the recent decline in accumulated storage in the system and the resulting increased risk of future shortages in the Lower Basin,

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93. Pitt et al., *supra* note 48, at 68–86.

94. Colorado River Reservoir Operations: Development of Lower Basin Shortage Guidelines and Coordinated Management Strategies for Lake Powell and Lake Mead Under Low Reservoir Conditions, 70 Fed. Reg. 57,322 (Sept. 30, 2005).

95. *See generally* BUREAU OF RECLAMATION, U.S. DEP'T OF INTERIOR, LOWER COLORADO RIVER DROP 2 STORAGE RESERVOIR PROJECT: FINAL ENVIRONMENTAL ASSESSMENT (2007), *available at* http://www.usbr.gov/lc/yuma/environmental_docs/Drop_2/finalea/fea1.pdf. Reclamation defines non-storable flows as "any water exceeding user demand that arrives at Imperial Dam and cannot be sent to another user, sent to storage, or delivered as part of scheduled deliveries to Mexico [and] is inadvertently delivered to Mexico in excess of Treaty obligations." *Id.* at ES-2.

96. *See* Defenders of Wildlife et al., Conservation Before Shortage II: Proposal for Colorado 2 River Operations (July 7, 2006), *available at* http://www.usbr.gov/lc/region/programs/strategies/alternatives/CBS2.pdf.

97. *See* BUREAU OF RECLAMATION, U.S. DEP'T OF INTERIOR, COLORADO RIVER INTERIM GUIDELINES FOR LOWER BASIN SHORTAGES AND COORDINATING OPERATIONS FOR LAKE POWELL AND LAKE MEAD, DRAFT ENVIRONMENTAL IMPACT STATEMENT app. K (2007), *available at* http://www.usbr.gov/lc/region/programs/strategies/draftEIS/index.html.

98. BUREAU OF RECLAMATION, ANNUAL REPORT AND OPERATING PLAN FOR THE COLORADO RIVER SYSTEM RESERVOIRS (annually 1971 et seq.).

Reclamation's process is expected to result in substantive changes in river management. Changing the shortage guidelines could affect the probability of surplus, normal, and shortage conditions and, thereby, change the probability of flows to the Delta.

In summary, the ecosystems' need for both consistent baseflows and for periodic flood flows will not be met in the future without some policy for enabling and assuring such deliveries. Any such policy will likely require changes in the Law of the River and even modest changes will almost certainly face political and legal challenges. The goal of this article is neither to postulate nor to analyze those potential challenges but, rather, to present the hydrologic differences of some alternative sources of baseflows and flood flows and to show what potential effects may result from such assurances, thereby facilitating future discussion.

IV. DESCRIPTION OF THE MODELING METHODOLOGY

The effects of changing policies on the Colorado are seldom transparent—even ones as apparently straightforward as increasing flows to the Delta—because of the interaction of policies. While those familiar with the Colorado may be able to predict if a particular operational policy change will tend to be beneficial or harmful to a particular use, the magnitude of the benefit or harm and the effects on other uses remain difficult to predict without simulating the change. Several factors contribute to this prediction difficulty:

1. Stochastic (i.e., random or at least unpredictable) variations in hydrology can mitigate or intensify the effects of changes.
2. Because some reservoirs have multi-year storage capacity, changes in operating policy may not affect consumptive uses for many years.
3. The operating rules are complex and act on the system as a whole; changes in one location may or may not affect water availability and losses in other locations.

For these reasons, simulation modeling is necessary to quantify the anticipated effects of alternative operations.

The established planning model for the Colorado River is the Colorado River Simulation System (CRSS). CRSS was developed in the early 1980s by Reclamation and was recently re-implemented in the RiverWare modeling system.[99] The model is used by Reclamation and other

99. T. Fulp et al., *Decision Support for Watershed and River System Management Applications on the Colorado River*, *in* HYDRO'S FUTURE: TECHNOLOGY, MARKETS, AND POLICY: PROCEEDINGS OF THE WATERPOWER '99 CONFERENCE (Peggy A. Brookshier ed., Am Soc. of Civil Engrs. 1999); Edith A. Zagona et al., *RiverWare: A Generalized Tool for Complex Reservoir System Modeling*, 37 J. AM. WATER RESOURCES ASS'N 913-29 (2001).

interested parties, both for operations planning and to analyze policy alternatives—for example, for environmental compliance studies.[100] The Basin has accepted the CRSS model, and most Colorado River stakeholders are familiar with CRSS analysis.

The main features of CRSS include:

1. The main hydrologic flows and storage of the Upper and Lower Basins are modeled: 11 reservoirs, over 300 diversions, consumptive use, evaporation, bank storage in reservoirs, and river reach losses.
2. Simulation is done at a monthly time step. A monthly time step tracks the overall movement of water and is an appropriate scale for modeling the Law of the River.[101] The period of analysis for this study is December 2005[102] through December 2060.
3. Reservoir releases and diversion schedules are determined during simulation runs by "rules" that represent the Law of the River and Reclamation operating rules. These rules are input data in the form of logical statements; the policies can be modified to compare the hydrologic outcome (flows and reservoir levels) of alternative rules.[103]
4. The uncertainty in future hydrologic inflows is quantified by running the model multiple times, each with a different time series of hydrologic inflows (known as a "hydrologic trace") based on the historic record of inflows. The distribution of the outcomes of the multiple runs provides a probability distribution of results.[104]

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100. *See, e.g.*, SURPLUS CRITERIA, *supra* note 10; IMPLEMENTATION AGREEMENT, *supra* note 10.

101. One of the model's limitations is that the monthly time step obscures many of the effects that occur on a smaller time scale, such as power generation, minimum flows, peak flows, flow duration, etc.

102. Initial reservoir elevations for December 2005 are taken from projections made in the 24-month study published in August 2005. BUREAU OF RECLAMATION, LOWER COLORADO REGION, MOST PROBABLE WATER SUPPLY (2005) (on file with author and the Natural Resources Journal).

103. *See, e.g.*, Zagona et al., *supra* note 99.

104. The hydrologic traces are produced using an Index Sequential Method, which currently incorporates 90 years (1906 to 1995) of historical hydrologic data about the River. Each trace is a sample from the historical record, using a different year as the starting point. When a sequence reaches the end of the historical record, it is continued by returning to the start of the record. Another limitation of the model is that the historical hydrology used does not include the most extreme known events for the River. In particular, the fossil records of the Delta indicate severe sustained droughts far in excess of droughts in the last 90 years.

Although much of the Law of the River is clearly defined, several significant aspects of river operations are not legally required but must be assumed to simulate the future operation of the Colorado. For this study, just as we chose to use an accepted model for the Basin (CRSS), we also chose to use Reclamation's November 2005 assumptions about future operating criteria. Although the majority of these assumptions were published in Reclamation's 2002 study,[105] these assumptions continuously evolve to reflect available data, the current state of the system, and the anticipated operation of the Colorado.[106] However, small changes in the assumptions since the previous Reclamation study will probably not significantly change the relative results of this study because the changes apply to both the baseline scenario and the alternatives. In the remainder of this section, we discuss some of these assumptions in more detail: the transfer of water from agricultural to municipal use within California, the Inadvertent Overrun and Payback Policy (IOP), bypass flow replacement, and assumptions with respect to shortage criteria.

As part of an overall plan to reduce California's dependence upon surplus Colorado River water, several California water agencies have signed a Quantification Settlement Agreement (QSA) that codifies conservation measures and transfers of water from agricultural uses to municipal and industrial uses within southern California.[107] Once the QSA and appropriate environmental compliance documents were signed, the Secretary of the Interior modified the amount and location of Colorado River water deliveries in California in accordance with the final QSA via a final "Colorado River Water Delivery Agreement: Federal Quantification Settlement Agreement."[108] Our study used the same modeling assumptions with regard to these transfers as were used in Reclamation's final Secretarial Implementation Agreement (SIA) Environmental Impact Statement.[109]

105. Reclamation's most recently published study is the FINAL ENVIRONMENTAL IMPACT STATEMENT, IMPLEMENTATION AGREEMENT, INADVERTENT OVERRUN AND PAYBACK POLICY, AND RELATED FEDERAL ACTIONS. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, ch. 3, at 3.12-13 to 3.12-17.

106. For example, we expect shortage guidelines to be developed by the end of 2007.

107. Quantification Settlement Agreement by and among Imperial Irrigation District, a California irrigation district; the Metropolitan Water District of Southern California, a California metropolitan water district; and the Coachella Valley Water District, a California county water district, Oct. 10, 2003, *available at* http://www.crss.water.ca.gov/docs/crqsa/Parts/QSA_SC.pdf.

108. Colorado River Water Delivery Agreement: Federal Quantification Settlement Agreement, Oct. 16, 2003, *available at* http://www.usbr.gov/lc/region/g4000/crwda/crwda.pdf.

109. *See* IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, app. G, at 2-6. The amount of water transferred increases until the year 2026 when it reaches 388,200 acre-feet per year. *Id.*

Reclamation recently completed adoption of an inadvertent overrun and payback policy (IOP).[110] Reclamation's analysis concludes that the average cumulative water deficit in Lake Mead in any given year due to inadvertent overruns is estimated to be 66 kaf.[111] The effects of such a deficit on the probabilities and magnitudes of flows reaching the Delta are not currently modeled in this study so as to remain identical to Reclamation's current methodology.[112]

Finally, our model includes a two-tiered shortage assumption published by Reclamation in the ISG Environmental Impact Statement (EIS).[113] Under the first tier, Colorado River water deliveries to the CAP are limited to one million acre-feet per year when there exists less than an 80 percent probability of protecting the Lake Mead minimum power pool (elevation 1083 feet) in the future.[114] After the publishing of the ISG EIS, Reclamation adapted these shortage criteria to protect a pool elevation of 1050, which is believed to more accurately reflect the minimum power production elevation.[115] Furthermore, Colorado River water deliveries to the Southern Nevada Water Authority (SNWA) are also reduced by four percent of the total reductions imposed on the CAP.[116] Under the second tier, the water available to CAP and SNWA is further reduced to maintain the elevation of Lake Mead for effective delivery to SNWA (1000 feet).[117] Colorado River water deliveries to California and Mexico are reduced below their normal allocations only if the CAP deliveries are eliminated and

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110. Colorado River Water Delivery Agreement—Implementation Agreement, Inadvertent Overrun and Payback Policy, and Related Federal Actions, Colorado River, Arizona, California and Nevada, 69 Fed. Reg. 12,202 (Mar. 15, 2004).

111. The projected average overrun may in fact underestimate actual overruns and impacts to flows in the delta. Reclamation also states that a maximum overrun in any one year would be as high as 331 kaf. *See* IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, ch. 3, at 3.12-13. In addition, Reclamation granted a late-year supplemental surplus of 200 kaf to California in 2002 because agricultural water users would run out of their allocated water before the end of the year. *See* Letter from Gale Norton, Secretary of the Interior, to Gray Davis, Governor of California (Nov. 22, 2002), *available at* http://www.usbr.gov/lc/region/g4000/2002suppaop.pdf.

112. For previous Reclamation modeling of IOP, see IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, app. C, at 31. This has been removed from the current version of Reclamation's model.

113. *See* SURPLUS CRITERIA, *supra* note 10, vol. I, ch. 3, at 3.12-3.

114. *Id.* vol. II, attachment J, at J-13 to J-14.

115. This modified shortage assumption, titled 80P1050, is described in IMPLEMENTATION AGREEMENT, *supra* note 10, vol. I, app, G, at 2-7. Reclamation intends to use this assumption as the baseline for the forthcoming Shortage Criteria. Interview with Terry Fulp, Area Manager, Hoover Dam, U.S. Bureau of Reclamation, in Boulder, CO (Mar. 6, 2006).

116. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, ch. 3, at 3.12-13 to 3.12-17

117. SURPLUS CRITERIA, *supra* note 10, vol. 1, ch. 3, at 3.3-12.

additional reductions are necessary to keep the surface of Lake Mead above 1000 feet.[118]

V. EXPLANATION OF THE ALTERNATIVE OPERATIONAL SCENARIOS

For this study we defined four alternative operations ("System Release," "Banking," Mexico Baseflow," and "Mexico Partial Baseflow") that successfully deliver water to the Delta in accordance with the quantity and timing that have been estimated to meet the Delta's minimum ecological needs. In addition we also defined one alternative titled "Shortage" that aims at the same goal but does not meet the Delta's minimum ecological needs during times of shortage. For the most part, the alternatives vary according to the source of the water that would remain in-stream for the Delta and the policies that would have to be adopted to implement them.

In this study, we distinguish between two sources of water that could be delivered to the Delta: system releases and water transfers. System releases in the United States are additional system water released by Reclamation from Lake Mead for the purpose of creating assured in-stream flows for the Delta. Although in-stream flows are generally not considered to constitute a consumptive use of water, existing water users will perceive dedicated downstream flows, with no storage facilities below them, as equivalent to a "new" consumptive use. In contrast, this study defines water transfers originating in the United States or Mexico as waters purchased or leased by some entity from an existing consumptive use and thus as a reallocation of water that does not create a "new" demand for water.

For the purposes of this study we further assume that, however accomplished, any commitment and subsequent release of water for the Delta would be allowed to flow in full past all intervening downstream diversions and reservoirs in the United States and Mexico and into the Delta ecosystems. Fulfilling this assumption would require an international agreement between the United States and Mexico, which would likely take the form of a Minute to the 1944 Treaty.[119]

The baseline operating policy in this study originates from the Action Alternative scenario of the EIS for the Secretarial Implementation

118. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, app. G, at 2-5. While this is consistent with the Law of the River, shortage criteria have not yet been adopted for the Lower Basin.

119. PITT ET AL., *supra* note 1, at 842–49.

Agreement, Inadvertent Overrun Policy and Related Federal Actions[120] and adapted by Reclamation to reflect current modeling assumptions (as described in the Modeling Methodology section). This baseline set of operating policies represents the most plausible combination of existing policies and published assumptions about future operations to which to compare new alternatives for supplying water to the Delta.

There are large numbers of possible sources of water for the Delta and an unlimited number of combinations that could be modeled. We chose five alternatives to illustrate a plausible range of possibilities. To facilitate comparison of each alternative to the baseline scenario and to each other, each alternative is defined as the baseline policy, changed only to add a method of supplying water to the Delta. The alternatives presented are as follows:

1. The "System Release" alternative models regulatory releases that consist of a baseflow of 50,000 acre-feet annually, plus a simulated spring flood flow of 260,000 acre-feet released from Lake Mead in May and June at least once every four years.[121]
2. The "Banking" alternative models the purchase or lease water for the Delta on an annual basis, which is stored as needed in Lake Mead and released for the Delta on the same schedule as in alternative 1.[122] In this alternative, 113,664 acre-feet are purchased or leased annually from either Mexican water users or United States water users in the Lower Basin who are impacted neither by surplus declarations nor by shortage

120. The Action Alternative scenario of the SIA EIS assumes compliance with all aspects of the Law of the River, including the Basin States Interim Surplus Guidelines as selected by the Record of Decision, the benchmarks set forth for California in the ROD, and federal approval for the Quantification Settlement Agreement (QSA), and incorporation of an Inadvertent Overrun Policy for analyzing the effects downstream of Lake Mead.

121. Due to the monthly time-step limitation of the CRSS model, the flood flow is designed to occur over a two-month period in which a total of 263,014 acre-feet would be released. In this two-month period, water is released for 39 days at 3500 to 7000 feet^3/sec (260,000 acre-feet), and the remaining 22 days the rate of water delivery to the Delta returns to baseflow conditions at 70 feet^3/sec (3,014 acre-feet). Simulated spring flood events are triggered from May through the beginning of June and are required only if a sufficient flood control release has not occurred during the prior 40 months. We selected this interval to assure that a simulated spring flood would be released only if the Delta had not benefited from a sufficient flood control release since the month of January, three years prior, guaranteeing the occurrence of exactly one sufficient flood flow every four calendar years. Floods occur more frequently only when Reclamation implements multiple flood control releases.

122. Off-stream banking in the Lower Basin is allowed under current guidelines, and banking in Lake Mead has recently been proposed by the Colorado River basin states. *See supra* note 80. This alternative assumes banking will be allowed and that banked water would be treated as system water for purposes of declaring surplus and shortage conditions.

conditions. This quantity of water is the average annual volume required for providing both the 50,000 acre-feet baseflow and the 260,000 acre-feet simulated spring flood flow once every four years.[123] In the event that a flood control release meets the requirements for a Delta flood flow, the "bank" is emptied.[124] In the event of a flood control release smaller than the minimum flood required for the delta, banked water may be used to supplement the flood flow.[125]

3. The "Mexico Baseflow" models a bi-national commitment to the Delta and requires contributions to in-stream flows from both the United States and Mexico. This alternative requires the United States to contribute system releases for flood flows (260,000 acre-feet) approximately once every four years and requires Mexico to contribute the baseflows of 50,000 acre-feet annually (from its annual Treaty allocation of 1.5 million acre-feet). This alternative exemplifies both how the United States and Mexico might share in the contribution of water for in-stream flows to the Delta.
4. The alternative titled "Mexico Partial Baseflow" is another example of how the United States and Mexico can share in providing water to the Delta—in this case with a contribution of 30 percent of the 50,000 acre-feet baseflow from Mexico and the remaining 70 percent from U.S. system releases. In addition, the United States would use system releases to supply flood flows every four years. In the event of a smaller flood control release, Mexico would supplement the flood flow.[126] This

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123. Water is purchased or leased at the beginning of each calendar year and stored in (or not released from) Lake Mead. Any unused portion of the purchase is carried into subsequent years (banked) for utilization in the next required flood event. We require a sufficient volume of water in the "bank" to allow a simulated spring flood event before any water is released.

124. Water reaches the Delta due to flood control events of at least 263,014 acre-feet over any two consecutive months. In this event, after baseflows were released, the volume of banked water would be set at zero for the remainder of the calendar year.

125. A flood control release is made that results in a volume of water reaching the Delta that is insufficient (less than 263,014 acre-feet over two months) to be considered an adequate flood event, and there is sufficient banked water to supplement the flood control event so that it could result in delivery to the Delta of 263,014 acre-feet over two months. In this event, banked water would be released from Lake Mead. This would allow floodplain inundation to occur occasionally at intervals shorter than four years by maximizing the water released from existing flood control regulation without directly impacting any other user of the system.

126. This alternative also requires Mexico to supplement any U.S. flood control releases that are predicted to occur in a quantity too small to meet the Delta's minimum ecological needs (in other words, a flood control spill of less than 263,014 acre-feet over two months) with up to 200,000 acre-feet of surplus water that typically is allocated as surplus flows to Mexico.

distribution of contributions from the United States and Mexico (87 percent and 13 percent, respectively) closely reflects the current allocation of Colorado River water between these countries (90 percent and 10 percent).

5. Although it does not fully satisfy the Delta's minimum ecological needs, we defined one alternative titled "Shortage" that uses U.S. system releases to provide the necessary baseflow and flood flows during years with normal or surplus conditions but that reduces flows to the Delta during shortage conditions. During shortages, flows to the Delta are reduced in proportion to the reduction imposed on the Central Arizona Project.[127] Since this alternative does not deliver sufficient water to meet the published hydrologic needs to restore the Delta ecosystems, the authors do not endorse it as a viable alternative.

Four of our five alternatives meet the minimum flows required to restore the Delta's riparian habitat. One alternative presented fails to meet the necessary flow requirements but allowed the authors to explore the flexibility of the modeling process and to examine the incremental effects on existing water users. Each alternative incorporates one or several mechanisms for acquiring water to be delivered to the Delta for restoration. Two alternatives depend solely on additional system releases of system water but provide different flow regimes to the Delta. One alternative acquires all necessary water through market-based transfers of water from consumptive uses. It is important to note that, from a hydrologic perspective, while water might be acquired from any number of sources and transferred to in-stream flows for the Delta, the model results are not significantly sensitive to the source. Finally, two alternatives use a combination of additional system releases and market-based transfers to satisfy the recommended flow requirements.

VI. HYDROLOGIC COMPARISON OF ALTERNATIVES

The simulations generated 660 months of data, including reservoir storage, water available for consumptive uses, and flows to the Delta for each combination of the six policies and the 90 different hydrologic inflow scenarios. Thus, policy comparisons require statistical analysis to highlight the similarities and differences in these outputs. Previously, CADSWES and

127. The baseflows are reduced on the same schedule as CAP. In addition, the frequency of flood flows released for the Delta is increased in the same proportion as the reductions imposed on CAP. For example, if, due to shortage conditions, CAP receives only half of the water originally requested, the baseflow to the Delta would be reduced to 25,000 acre-feet per year and flood flows would be released every eight years.

Reclamation developed the Graphical Policy Analysis Tool (GPAT) to graph statistics based on RiverWare results.[128] The GPAT software can generate such statistics as the mean, minimum, and maximum values throughout time and probability distribution functions, as well as more complex statistical analyses of the outputs. We used GPAT extensively to generate a wide variety of graphs and tables for the modeled alternatives. This section presents the highlights of those results.[129] The following discussion of the comparison of the model outputs of the alternatives is divided into three parts: (1) general system-level effects, (2) water available for consumptive use at a state level, and (3) flows to the Delta.

A. System Effects

Reservoir storage volume and elevation at Lake Mead and Lake Powell are common and useful measures of the system effects of policy alternatives.[130] The lakes' relatively large active storage capacity gives an indication of the overall system storage.[131] In addition, the existing operating policy uses reservoir storage volume and elevation of Lake Mead in several ways to determine the quantity of water deliveries to Lower Basin water users. Similarly, the existing operating policy uses the storage volume and elevation at both Lake Mead and Lake Powell to set Lake Powell's releases.[132]

Under the baseline scenario, as well as those of all of our alternatives, the model predicts a substantial decline in storage content due to increased demands as a result of Upper Basin development and over-allocation of water in the system.[133] Although a partial recovery from the recent drought is expected to immediately increase the storage contents of

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128. Getting Started with the Graphical Policy Analysis Tool, CADSWES, University of Colorado (2002), http://cadswes.colorado.edu/users/RiverWare/Releases/GettingStartedWithGPAT.pdf.

129. The reader should take note of the extents of the axes in each graph. Often the axes do not include the zero value to demonstrate the differences between policies, which would be hard to detect otherwise.

130. *See, e.g.*, Analysis of River Operations and Water Supply Technical Memorandum No. 1, *in* IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, app. G, at 3-6, 3-16.

131. Maximum storage at Lake Mead is 27.3 million acre-feet; maximum storage at Lake Powell is 24.3 million acre-feet. *See* Bureau of Reclamation, U.S. Dep't of Interior, Boulder Canyon Project—Hoover Dam, Arizona and Nevada, www.usbr.gov/dataweb/html/bcphoover.html, and Bureau of Reclamation, U.S. Dep't of Interior, Upper Colorado Region, Water Resources Group, Upper Colorado River Drainage Basin, www.usbr.gov/uc/water/basin/tc_cr.html.

132. For a discussion of rules that determine releases from Lake Powell, see SURPLUS CRITERIA, *supra* note 10, vol. II, attachment J, at J 4-10.

133. *See supra* note 65.

the reservoirs, the effects from the assumed future demands are expected to dominate the system and result in overall reduced storage contents. For example, even in the baseline scenario, the average volume of storage in Lake Mead is expected to decrease to 51 percent of the total storage capacity by 2060, representing an 11.9 percent decrease relative to initial contents. Figure 4 illustrates the predicted mean reservoir storage of Lake Mead under the baseline scenario and all modeled alternatives. The effect of the alternatives on Lake Mead is small by comparison—at most 2.2 percent less volume is predicted in Lake Mead in any one year through the period of study and 1.3 percent by 2060. The most notable differences between the baseline scenario and any of the alternatives occur by 2014, when the System Release alternative decreases storage in Lake Mead by 539,000 acre-feet, or 2.1 percent of total capacity. The System Release alternative creates a "new demand" for Colorado River water by requiring regulatory releases for the total amount of water required to restore the Delta and therefore results in the greatest impact on the reservoirs. The Mexico baseflow, Mexico Partial, and Shortage alternatives fall between the Baseline and System Release alternatives.[134] The Banking scenario has no negative impacts on the predicted storage in Lake Mead.

The projected storage conditions of Lake Powell are a function of the initial conditions of the reservoir, the effect of the policies on Lake Mead and the increased development in the upper basin. Following the extreme drought in the Upper Colorado River Basin during 2000 to 2004, the dominant expected trend until 2025 is the gradual recovery of the storage of Lake Powell.[135] As the volume of Lake Powell increases, the probability of the upper basin exceeding the 602(a) storage value increases, resulting in more frequent equalization releases from Lake Powell to Lake Mead. During years in which equalization releases are made, any policies that reduce the storage in Lake Mead also reduce the storage in Lake Powell. However, in later years the projected increase in Upper Basin consumptive use will significantly decrease the average 602(a) storage in the Upper Basin reservoirs and thereby frequently remove a prerequisite for "equalization." In the absence of "equalization," the releases from Lake Powell are not affected by reduced storage in Lake Mead. Figure 5 shows that the storage in Lake Powell is projected under all alternatives to increase through 2026

134. The Banking alternative is similar to the baseline. The alternatives in decreasing order of Lake Mead's storage are baseline, Banking, Mexico Baseflow, Shortage, Mexico Partial Baseflow, and System Release alternatives.

135. This predicted recovery, as illustrated in Figure 5, has begun to occur since the initial conditions for the model were selected for January 2006. As of June 25, 2007, Lake Powell has recovered to 12.9 million acre-feet. Data for historical reservoir conditions can be found at Bureau of Reclamation, U.S. Dep't of Interior, Upper Colorado Region Reservoir Operations, http://www.usbr.gov/uc/crsp/GetSiteInfo.

by 34 percent relative to current contents, to about 16.2 million acre-feet (which is 66.6 percent of full capacity). Following 2026, Lake Powell begins a decreasing trend through 2060, when storage is projected to decline to 15.3 million acre-feet. From 2040 to 2060, when equalization applies infrequently, the alternatives converge to virtually identical values of expected storage for Lake Powell. The predicted average volumes stored in Lake Powell for the Mexico baseflow, Mexico Partial, and Shortage alternatives fall between the baseline scenario and System Release alternative. As for Lake Mead, the Banking alternative shows no negative impacts on the storage contents of Lake Powell. Because the alternatives do not differ above Lake Powell and because the operation of the other Upper Basin reservoirs are independent of the storage in Lake Powell and below, there are no resulting differences between any of the alternatives above Lake Powell.[136]

The General Status of the System: The Probability of Surplus and Shortage

Another measure of difference between alternatives is the probability that either a system surplus or shortage will be declared. These declarations change the allowed consumptive use for the Lower Basin. As Table 1 shows, the probability of a surplus declaration in any given year varies little between the baseline scenario and all alternatives. The largest differences are predicted in 2015 and in the years immediately preceding and following.[137] While the probability of a surplus under the baseline scenario and the Banking alternative is 47 percent in 2015, the probability for the other alternatives is 42 to 43 percent. This effect is relatively minor compared to the overall trend from nearly 100 percent surplus in 2006, declining to 11 to 14 percent by 2060 for all alternatives. The high probability of surplus declarations in early years is due to the present condition of Lake Mead and the implementation of Interim Surplus Guidelines (which are slated to expire in 2016). The low probability of surplus in later years is due to projected increased water consumption by Upper Basin and the reversion to a more conservative policy for surplus declarations.

136. SURPLUS CRITERIA, *supra* note 10, vol. I, ch. 3, at 3.2-1.

137. The timing of this maximal difference is an example of occasional simulation results that are difficult to predict due to the interaction of rules and the probabilistic nature of the analysis. However, if the results were easy to predict, simulation would be unnecessary. One possible explanation in this case is that the accumulation of delta flows increases the differences with time while the increasing diversion of water in the Upper Basin tends to mask the differences over time. In addition, the end of the Interim Surplus Criteria in 2016 could be masking the differences.

TABLE 1: PROBABILITY OF SURPLUS

	Baseline	Banking	System Release	Mexico Partial Baseflow	Mexico Baseflow	Shortage
2006	100%	100%	100%	100%	100%	100%
2010	49%	49%	48%	48%	48%	48%
2015	47%	47%	42%	42%	43%	42%
2020	21%	21%	20%	20%	20%	20%
2025	21%	21%	20%	20%	21%	20%
2030	22%	22%	22%	22%	22%	22%
2035	20%	20%	19%	19%	19%	19%
2040	20%	20%	18%	18%	19%	18%
2045	19%	20%	17%	17%	18%	17%
2050	17%	18%	16%	16%	16%	16%
2055	16%	16%	14%	14%	16%	14%
2060	13%	14%	11%	13%	14%	12%

Table 2 shows the probability of shortages under the baseline scenario and all alternatives. The increase in probability of shortages for the baseline scenario and all alternatives over time, from zero percent in 2005 to approximately 60 percent in 2060, results from the same factors that cause the decreased probability of surplus declarations. Again, relative to this overall trend, the alternatives differ little. The largest differences are again in 2015: a 34 percent probability of shortage for the baseline scenario and 36 percent for the Banking alternative and a 39 percent probability for the System Release and Shortage alternatives. The differences are due to the increased demands on "system" water in these alternatives.

TABLE 2: PROBABILITY OF SHORTAGES

	Baseline	Banking	System Release	Mexico Partial Baseflow	Mexico Baseflow	Shortage
2006	0%	0%	0%	0%	0%	0%
2010	8%	8%	10%	9%	9%	10%
2015	34%	36%	39%	39%	38%	39%
2020	44%	44%	47%	47%	47%	47%
2025	46%	46%	48%	48%	48%	48%
2030	49%	48%	51%	51%	51%	50%
2035	51%	51%	51%	51%	51%	51%
2040	51%	51%	52%	52%	52%	52%
2045	53%	52%	54%	54%	53%	54%
2050	57%	57%	57%	57%	57%	57%
2055	57%	57%	59%	59%	59%	59%
2060	60%	59%	62%	62%	61%	62%

The System Release alternative models the dedication of water for the Delta through regulatory releases and therefore adds an additional consumptive use—albeit small in comparison to existing consumptive uses—to the system. In contrast, the Banking alternative acquires the total amount of water necessary to restore the Delta through market-based transfers of water from existing consumptive uses, in effect re-allocating water that is already being used. Consequently, the Banking alternative has a minimal impact upon the system and actually *increases* the average storage in the two major reservoirs because when banked water is stored in Lake Mead, reservoir elevations are increased. In fact, the Banking alternative actually increases the probability of surplus conditions being declared (up to 6.7 percent in 2007) and decreases the probability of shortage conditions being declared (up to 2.2 percent various years). Table 3 indicates the decade-averaged, annual increased probability of surplus conditions; decreased probability of shortage conditions; and increased delivery to the Lower Basin due to allowed banking for the Delta in Lake Mead.[138]

TABLE 3: AVERAGE CHANGE IN SURPLUS, SHORTAGE AND TOTAL DIVERSIONS DUE TO LOWER BASIN BANKING

	Increased Surplus Probability	Decreased Shortage Probability	Average Annual Increased Diversions (acre-feet)		
			California	Nevada	Arizona
2006-2009	2.2%	0.0%	6106	53	0
2010-2019	0.2%	-0.4%	1380	145	3091
2020-2029	0.6%	-0.1%	3425	704	5975
2030-2039	0.1%	0.0%	1820	336	1899
2040-2049	0.1%	-0.2%	1067	561	5277
2050-2059	0.4%	-0.1%	2323	873	4925

The Mexico Baseflow and the Mexico Partial Baseflow alternatives do not rely exclusively on regulatory releases from the United States and result in smaller demands on the system. Thus, their effect on surplus and shortage lies between the baseline scenario and the System Release alternative.

138. The decadal averages are necessary to show the overall trend of increased surpluses and decreased shortages with the Banking alternative. Select years can be misleading because of the multi-stage surplus and shortage assumptions that Reclamation uses. For example, a level 2 shortage declared in one year decreases the probability that any shortage will be called in the following year.

B. Consumptive Use Effects

Our primary focus in this study is to determine, assuming different alternatives, the potential impact on existing water users of providing restorative flows to the Delta. The declaration of surplus conditions as described by the Interim Surplus Guidelines[139] and the flood control regulations as dictated by the Army Corps of Engineers[140] determine, respectively, the amount of surplus water that states may acquire and the criteria for flood control releases. Reclamation modeled its assumptions about the distribution of water during shortage conditions, which, as of November 2005, reflected a slight modification of the shortage policy assumptions published in the Interim Surplus Guidelines Final Environmental Impact Statement.[141] It should be noted that these shortage criteria are not formally defined in the Law of the River and were created primarily as a modeling assumption based on prior appropriations.

One measure of the impact of the alternatives on consumptive uses is the projected delivery to each state. This measure is sensitive to the effects of the alternatives on the probability of both surplus and shortage.

Figure 6 shows projected deliveries to California under the baseline scenario and for several alternatives considered.[142] Under the baseline scenario, California's average delivery increases from 4,580,000 acre-feet in 2006 to 4,690,000 in 2015 as reservoir storage is projected to recover, and then drops to 4,500,000 acre-feet by 2060 as the probability of surplus declines. The average delivery to California remains above the "normal" allocation of 4.4 million acre-feet because both the probability and magnitude of surpluses are greater than the shortages that affect California. The differences between the baseline scenario and all alternatives are small compared to this overall trend over time. After an initial difference of 56,900 acre feet occurs between the baseline and System Release alternative due to the current stressed state of the system, a maximum difference of 31,800 acre-feet occurs between these scenarios in any given year. These differences are predominantly due to reduced surplus water and, to a smaller extent, increased shortages.

Similarly, Figure 7 shows that expected deliveries to Nevada are roughly 313,000 acre-feet for all years under the baseline scenario and all alternatives. The differences between the baseline scenario and all

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139. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, app. G.

140. U.S. ARMY CORPS OF ENG'RS, *supra* note 73.

141. IMPLEMENTATION AGREEMENT, *supra* note 10, vol. 1, app. G.

142. The Mexico Baseflow, Mexico Partial Baseflow, and Shortage alternatives have been removed from the graph to improve readability because they overlap the other alternatives. The Mexico Partial Baseflow and Shortage Alternatives fall between the Mexico Baseflow and the System Release alternatives.

alternatives are very small in volume over time: at most 7,192 acre-feet in a year. However, as a fraction of Nevada's delivery, this reduction is significant.

Under the CRBPA, the Central Arizona Project has a junior water priority,[143] and its diversion is assumed to be the first to have reductions imposed during shortage conditions. Under the baseline scenario, Arizona is expected to receive less than its 2,800,000 acre-feet apportionment after 2009 because projected increases in Upper Basin development in an over-allocated system result in frequent shortages. Figure 8 illustrates the effects of the Banking and System Release alternatives on average deliveries to the state of Arizona. The additional losses that Arizona would face under the System Release alternative increase with time in proportion to the declining Lake Mead elevation. In contrast to California's and Nevada's expected deliveries, Arizona's expected deliveries vary significantly under the different alternatives. For example, by 2060 the expected deliveries are 2,467,000 acre-feet under the baseline scenario, 2,480,000 acre-feet under the Banking alternative, and 2,399,000 acre-feet under the System Release alternative.[144]

While Mexico contributes flows to the Delta under two alternatives, the only additional effect of the alternatives on deliveries to Mexico is a slight reduction in the frequency of surplus deliveries. Figure 9 illustrates the average annual Treaty deliveries for consumptive use purposes in Mexico under the baseline scenario, System Release, Mexico Baseflow, and Mexico Partial Baseflow alternatives. While the deliveries under the baseline scenario and System Release alternative are very similar, the average consumptive use under the Mexico Baseflow and Mexico Partial Baseflow alternatives is reduced by 50,000 acre-feet and 15,000 acre-feet respectively.[145]

Table 4 shows the impact on water users of implementing the System Release alternative as compared to the baseline scenario. The last column of Table 4 shows the total reduction in, or "burden" to, Lower Basin deliveries under the System Release alternative. The distribution of the burden within the Lower Basin under the System Release alternative appears to vary over time because of the projected eventual shift in conditions to shortages and differences between surplus and shortage policies. In the early years, when the reduction of total deliveries is relatively small (19.1 kaf/yr on average from 2006 to 2009), California's

143. 43 U.S.C. § 1521(b) (2007).

144. Once again, several alternatives have been omitted for clarity. The Mexico Baseflow, Mexico Partial Baseflow, and Shortage alternatives are between the Banking and the System Release alternatives.

145. We have adjusted the scale of this graph to make the relatively small differences visible.

share of the burden is large (98 percent). Because the System Release alternative would impact surplus declarations under the Interim Surplus Guidelines, and because California benefits the most from surplus through 2016, this alternative disproportionately affects California's delivery in the near future. In later years, the projected difference between total deliveries increases significantly and is attributed to an increase in shortages. Arizona's deliveries are disproportionately affected by shortages due to the state's lower priority diversion rights during shortages, and Arizona bears a greater share of the total burden (as much as 82 percent on average from 2050-2059). Regarding Nevada and Mexico, each accounts for six percent or less of the total difference in deliveries.

TABLE 4: REDUCTION IN DELIVERY AND PERCENTAGE OF TOTAL REDUCTION DUE TO THE SYSTEM RELEASE ALTERNATIVE[146]

	ARIZONA		CALIFORNIA		NEVADA		MEXICO		TOTAL	
	KAF	% TOTAL	KAF	% TOTAL	KAF	% TOTAL	KAF	% TOTAL	KAF	% TOTAL
2006-2009	0.1	0.5%	18.7	98.3%	0.2	1.2%	0.0	0.1%	19.1	100%
2010-2019	34.6	66.5%	13.8	26.5%	2.4	4.6%	1.2	2.4%	52.1	100%
2020-2029	50.1	75.9%	10.5	15.9%	3.5	5.3%	1.9	2.8%	66.0	100%
2030-2039	50.7	79.6%	7.8	12.2%	3.5	5.5%	1.7	2.7%	63.7	100%
2040-2049	50.0	77.0%	8.9	13.6%	3.8	5.9%	2.2	3.4%	64.9	100%
2050-2059	75.1	82.5%	8.4	9.2%	5.0	5.5%	2.6	2.8%	91.0	100%

Part of the reason that Arizona and California appear to take much of the burden (compared to that of Nevada and Mexico) for supplying system water to the Delta is that their normal deliveries are relatively large in comparison. Table 5 displays the reductions as a percentage of each state's baseline delivery. This demonstrates the effect of the System Release alternative on the water users of each state. Deliveries of water to California from 2050 to 2059 would, on average, be 0.2 percent less under the System Release alternative than they would be under the baseline scenario. Deliveries of water to Arizona and Nevada from 2050 to 2059 would, on

146. This table documents decadal averages that represent the general trend of decreased impact of the system release alternative on surplus water and increased importance of shortages. Due to the periodicity of delivering the 260,000 acre-feet flood flows to the Delta every four years, a regular sampling of years does not properly demonstrate this trend.

average, be 2.7 percent and 1.7 percent less under the System Release alternative than they would be under the baseline scenario, and deliveries to Mexico would be minimally impacted. Thus, Arizona and Nevada water users would make the largest percentage reductions, with Arizona's almost twice as large as Nevada's.

TABLE 5: PERCENTAGE REDUCTIONS IN DELIVERY DUE TO THE SYSTEM RELEASE ALTERNATIVE				
	Arizona	California	Nevada	Mexico
2006-2009	0.0%	0.4%	0.1%	0.0%
2010-2019	1.2%	0.3%	0.8%	0.1%
2020-2029	1.8%	0.2%	1.2%	0.1%
2030-2039	1.8%	0.2%	1.2%	0.1%
2040-2049	1.8%	0.2%	1.3%	0.1%
2050-2059	2.7%	0.2%	1.7%	0.2%

C. Flows to the Delta

By design, all of the alternatives except the baseline scenario and Shortage alternative fully meet the Delta's estimated minimum ecological requirements. The Shortage alternative is designed to minimize the impact of flows to the Delta on existing water users during shortage conditions by reducing the baseflows required to the Delta and by decreasing the frequency of simulated spring flood events. Although this alternative does not fully meet the needs of the Delta,[147] it does provide increased flows to the Delta in almost all hydrologic scenarios.

Figure 10 indicates the probability that flows of any magnitude will reach the Delta under the baseline scenario, System Release, and Shortage alternatives. While the baseline scenario predicts only a 20-percent probability of getting water to the Delta in early years, decreasing to a 10-percent probability of getting water to the Delta by 2060,[148] the System Release alternative guarantees that some water will reach the Delta under all hydrologic scenarios, as would the three other alternatives for delta flows (Banking, Mexico Baseflow, and Mexico Partial Baseflow). In comparison, the results from the Shortage alternative also indicate that a high probability exists that at least some water reaches the Delta during the period of study. Figure 10 illustrates that although the magnitude of flows to the Delta differs between the System Release and Shortage alternative, the Shortage alternative will result in only a slightly lower probability that

147. *See* Glenn et al., *supra* note 13, at 19; LUECKE ET AL., *supra* note 13, at iv.

148. Under the baseline, virtually any flow that reaches the Delta will be in excess of 260,000 acre-feet because these flows are the result of flood control events.

the Delta will go completely dry relative to the System Release alternative. These infrequent events would occur after 2025 only under the most extreme, extended drought conditions.[149] While the Delta is seldom expected to go dry under the Shortage alternative, there is, overall, a 54 percent probability that the 50,000 acre-feet baseflow would not be attained in at least one year between 2006 and 2060, with more of the risk concentrated in later years.

From an ecological perspective, the number of years since the last flood plain inundation is a key measure of habitat viability in riparian areas.[150] Figure 11 shows the cumulative distribution function for the number of years since the last 260,000 acre-feet flood event for the Delta. The cumulative distribution function shown here includes probabilities at each month during the years of the study (2006-2060). By design, under the System Release, Banking, Mexico Baseflow, and Mexico Partial Baseflow alternatives, 260,000 acre-foot flood flows occur regularly—at least once every four years.[151] In the baseline scenario, there is a 50 percent probability that 260,000 acre-foot flood flows will not occur for an interval of more than 12.4 years, a 33 percent probability that there will not be an event for more than 19.3 years, and a 15 percent probability that there will not be an event for more than 33.6 years.[152] The Shortage alternative is predicted to provide a 98 percent probability that a 260,000 acre-feet flood event at least once every ten years, even during extended shortage conditions. In addition, Figure 11 shows that the optimal four-year interval between sufficient flood flows is expected to be achieved 84 percent of the time in this scenario.

While Figure 11 illustrates the probability of long periods without flood plain inundation, it also obscures the timing of these periods. Additional examination of the model results shows that dry periods are far more likely to occur in later years, as consumptive uses of Colorado River water are projected to increase over time.

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149. In reality, there is some non-zero probability that the Shortage alternative will not supply flow in each year. However, this probability is too small for this study to accurately measure.

150. Stromberg, *supra* note 43, at 17-19.

151. Durations greater than four years appear at the far right of the cumulative distribution function for the System Release and Banking alternatives. These are a result of the initial historical conditions at the beginning of the period of study, and in the case of the Banking alternative, the initial period required to accumulate sufficient water banked to make a flood release. Under normal operation, the maximum period without a flood in both these scenarios is four years.

152. This study did not use enough years to draw any conclusion about the specific probability of periods longer than 60 years. However, even 60 years without water would devastate the ecology of the Delta.

VII. DISCUSSION

Although the altered hydrology of the Colorado has substantially degraded the Delta, this unique region provides important habitat for several species that are endangered in northwestern Mexico and in the desert southwest of the United States. This degradation is a result of the extensive development that has occurred during the twentieth century. In recent years, the Delta's ecosystems have been partially restored by flood control flows. However, these flows are inadvertent and unintentional, and they are threatened with virtual elimination as consumptive use of water upstream increases.[153] Under the baseline scenario, Reclamation's CRSS model projects that development in the Upper Basin over the next 60 years will decrease the probability of floods that reach the Delta to 11 percent by 2060.

The dedication of Colorado River water to the Delta could be implemented through regulatory changes in river management, through market-based acquisition of water from existing consumptive water uses, or through any combination of these two basic options. The hydrologic impact on the system varies according to the degree to which these methods are used. In this study, four of the five alternatives meet the same goal: supplying an annual 50,000 acre-feet of baseflow to the Delta and at least one flood flow of 260,000 acre-feet every four years. Because these flows represent less than one percent of the average annual runoff in the Basin,[154] the effects on reservoir storage are minimal compared to the trends identified in the baseline scenario: average storage in Lake Mead will decrease to 51 percent of capacity and average storage in Lake Powell will recover from the present low but decline to 62.9 percent of its total capacity by 2060. By this date, the probability of surplus conditions will decrease to 13 percent and the probability of shortage conditions will increase to 60 percent.

A. System Release

In the System Release alternative, the entire volume of water is acquired through releases from Hoover Dam, without the acquisition of any water that is consumptively used, demonstrating the effect of adding an additional demand onto the already over-allocated River. The impacts of taking additional water out of the Colorado under the System Release alternative are varied and complex. The United States' river management policies may allow for the delivery of "surplus" water to Lower Basin

153. *See* Pitt et al., *supra* note 1, at 821.
154. *See supra* note 65.

consumptive users over the 15-year life of the recently adopted Interim Surplus Guidelines, as might the policy that is expected to be used once they expire. The effects of this additional demand on the system would initially draw Lake Mead levels lower (539,000 acre-feet, or 2.1 percent of total capacity by 2014), and this average difference in storage would persist throughout the period of study, causing a maximum 5.6 percent reduced probability of surplus. Beyond this initial period, occurrences of surplus deliveries under the baseline scenario, as well as of all of our alternatives, become less likely and have essentially identical probabilities in all alternatives. Although Reclamation initiated a process to define shortage criteria under the Long Range Operating Criteria for the Colorado River, we used Reclamation's November 2005 assumptions of its CRSS model projecting how shortages would be implemented under existing rules. Using additional water to protect the Delta mildly accelerates the onset of shortages: On average, a given probability of shortage occurs 3.3 years sooner during the time period from 2016 to 2060. Thus, compared to the overall trend, the System Release alternative has a relatively small effect on the Lower Basin, which is largely masked by the greater magnitude of assumed future development in the Upper Basin.

This model demonstrates that with regulatory releases of water for the Delta the average consumptive use of Colorado River water by California would decrease by 0.4 percent at most. However, Arizona's average consumptive use would decrease by 2.7 percent, and Nevada's average consumptive use would decrease by 1.7 percent, with most of the decrease occurring during shortage conditions. Although this effect is notable, it is also clear that shortage conditions will dominate the system under any alternative, including the baseline scenario, and that Arizona will likely receive significantly less than its allocated 2,800,000 acre-feet under baseline scenario due to the over-allocation of water resources in the basin.

B. Lower Basin Banking

In contrast, the Banking alternative relies strictly on a purchase or lease of water from existing water users. This market-based alternative not only has no negative effects on other water users but also increases reservoir elevations and, therefore, provides a small net improvement to the water users who benefit from surplus conditions or those users who are potentially affected adversely by shortage.

C. Mexico Alternatives

The Mexico Baseflow and Mexico Partial Baseflow alternatives endeavor to simulate a bi-national commitment to restoration of the Delta by supplying the necessary water via a combination of regulatory releases from the United States and either regulatory releases or market-based transactions in Mexico. In both of these alternatives, we decreased the consumptive use of Colorado River water in Mexico in order to provide either a portion or all of the required baseflow necessary for sustaining Delta ecosystems. Because Mexico has no facilities for Colorado River water storage, the alternatives do not define whether contributions from Mexico are due to policy changes or to market-based transactions. However, this is of little consequence from a hydrologic perspective. In any event, both alternatives assume that the United States would use regulatory releases to provide the 260,000 acre-feet flood flows at least once every four years.

These two alternatives require the United States to make regulatory releases in quantities smaller than those in the System Release alternative and, therefore, the hydrologic impact of both alternatives falls between the System Release alternative and the Banking alternative with the Mexico Partial Baseflow alternative closer to the System Release alternative. Lake Mead elevations would decline slightly, and Arizona would be subject to shortages more often than in the baseline scenario but less often than in the System Release alternative. Again, these effects are dwarfed by the general decline in water storage predicted to occur in the baseline scenario due to over-allocation, causing a high probability of shortages in the future.

D. Shortage Alternative

Like the System Release alternative, the Shortage alternative assumes that all water delivered to the Delta is provided by U.S. regulatory releases. In the Shortage alternative, however, the flows that are required to restore and sustain the Delta would be compromised under shortage conditions, which are predicted to occur with over a 49 percent probability by 2030 and a 60 percent probability by 2060.

Significantly, the Shortage alternative would not deliver sufficient water to sustain the Delta during these critical dry conditions. However, the magnitude of the total shortages to existing water users in the Shortage alternative are on average 21 kaf less compared to the System Release alternative after 2017, yet the frequencies of occurrence are essentially the same. In addition, in all but a few extreme drought conditions, this alternative keeps some water flowing to the Delta and allows no more than 16 years from ever occurring without providing the Delta with a sufficient flood event of greater than 260,000 acre-feet and an 98 percent probability of achieving these flows within a ten-year period. Although this duration without a flood event may be devastating for the Delta's ecosystem, this is significant improvement compared to the baseline, which has a 75 percent chance of a 25-year period occurring without a flood event. In essence, while the shortage alternative does not provide sufficient flows to the Delta during critically dry conditions, this alternative demonstrates the potential to consider other alternatives.

E. Future Studies

This study analyzes several alternatives for providing water to the Delta and the kinds of impacts these alternatives have on existing consumptive water users. These alternatives represent specific policies from a continuum of possible policies. There are innumerable sources of water for the Delta, and additional policies could use any combination of sources. Shortage policies could vary in terms of when they are triggered, what baseflow levels are, and how frequent flood events occur. RiverWare and GPAT analysis can help define the impact of any proposed policy. Clearly, the over-allocation of the system and multiple institutional hurdles make a challenging political climate in which to make any changes: Modeling allows stakeholders to analyze a range of possibilities and to investigate additional alternatives for protecting and restoring the Delta.

For many reasons, contemplating changes in Colorado River management is difficult: the basin is vast and the hydrologic system is complex. Much of the legal management framework was established in the first half of the last century, and more than 30 million people already depend on the Colorado for domestic supply. However, management of the Colorado has evolved considerably over time and must remain dynamic in order to meet the needs of an ever-growing population that has ever-changing needs and values.

With storage capacity of greater than 58,000,000 acre-feet along the main stem of the Colorado, the existing reservoirs can store more than four times the Colorado's average annual flow. For this reason alone, dedicating water to the Delta is much more an institutional challenge than it is a technical challenge. Whether to protect and restore the Delta is, in the end, a choice for society to make.

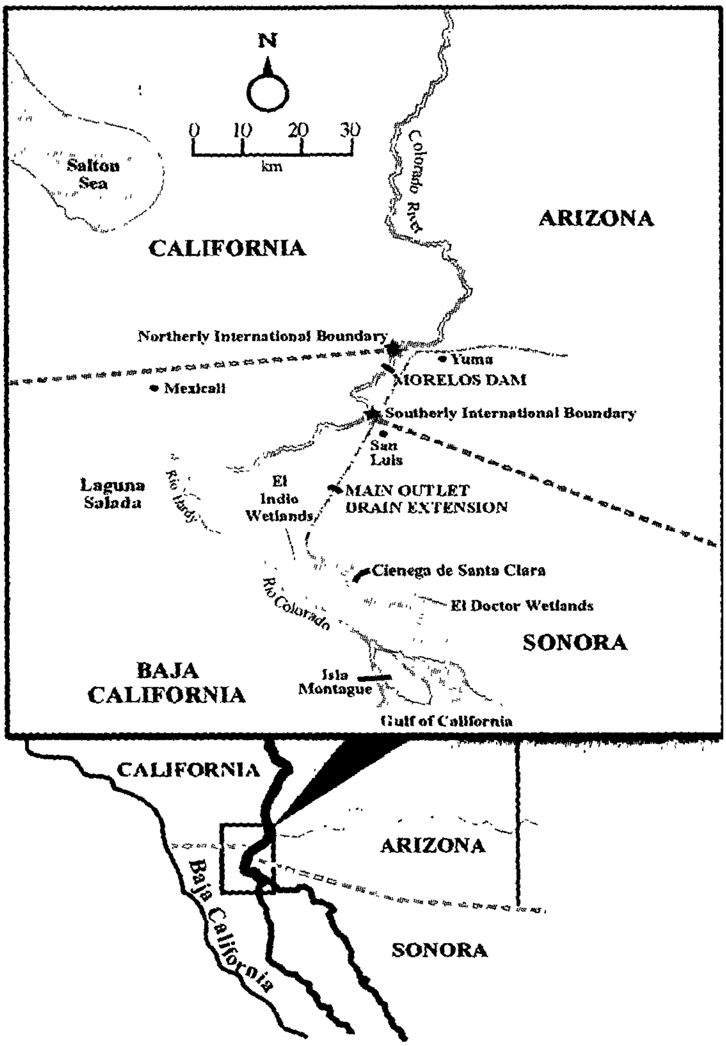


Figure 1. The Colorado River Delta

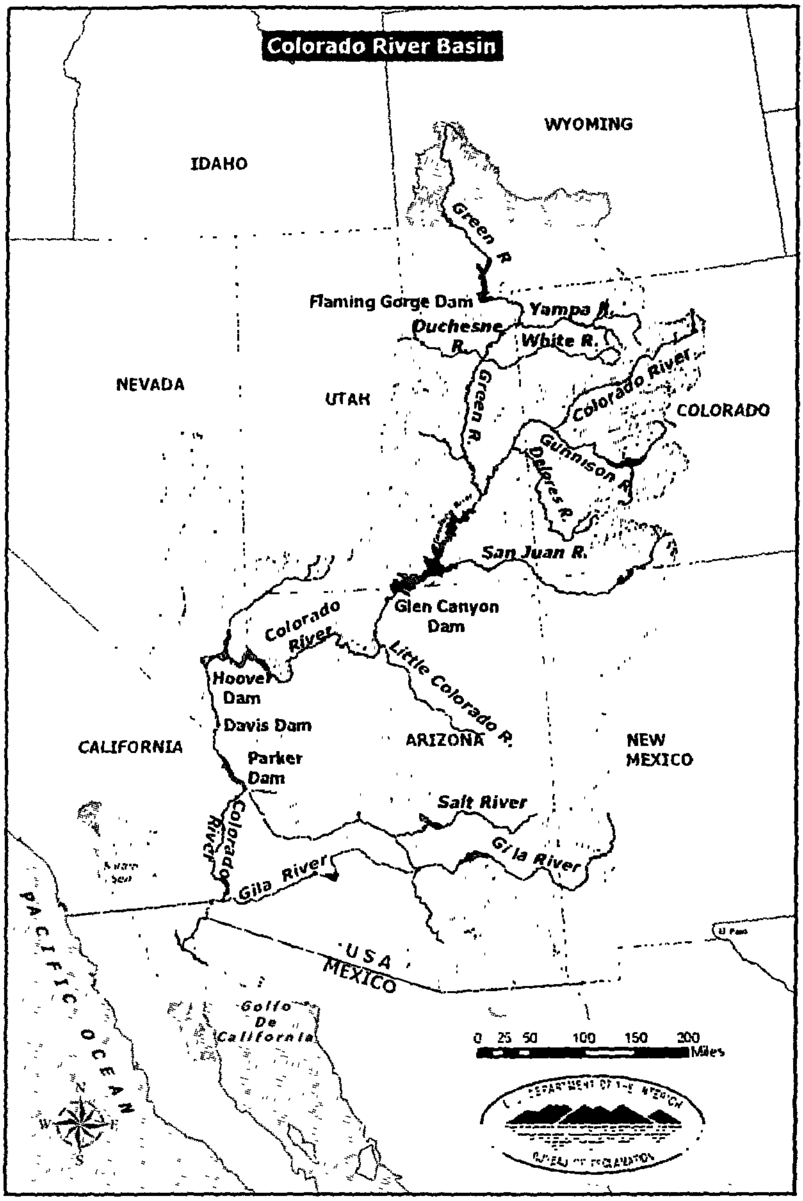
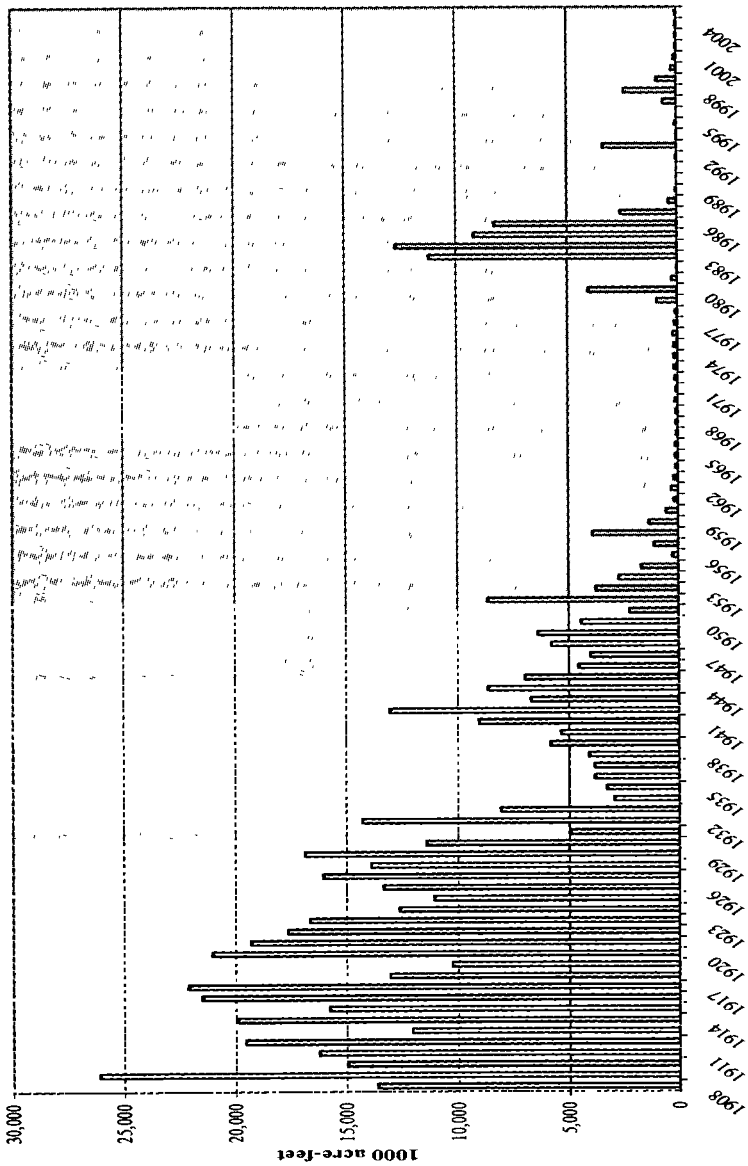


Figure 2. The Colorado River Basin



Sources. International Boundary and Water Commission, "Western Water Bulletin Flow of the Colorado River and Other Western Boundary Streams and Related Data" (annual), http://www.ibwc.state.gov/wad/ddqsibco.htm; and US Geological Survey. 1954 Compilation of Records of Surface Waters of the United States through September 1950 Part 9. Colorado River Basin. Geological Survey Water-Supply Paper 1313. (pp 709-729).

Figure 3. Colorado River Flow Below All Major Dams and Diversions 1908-2005

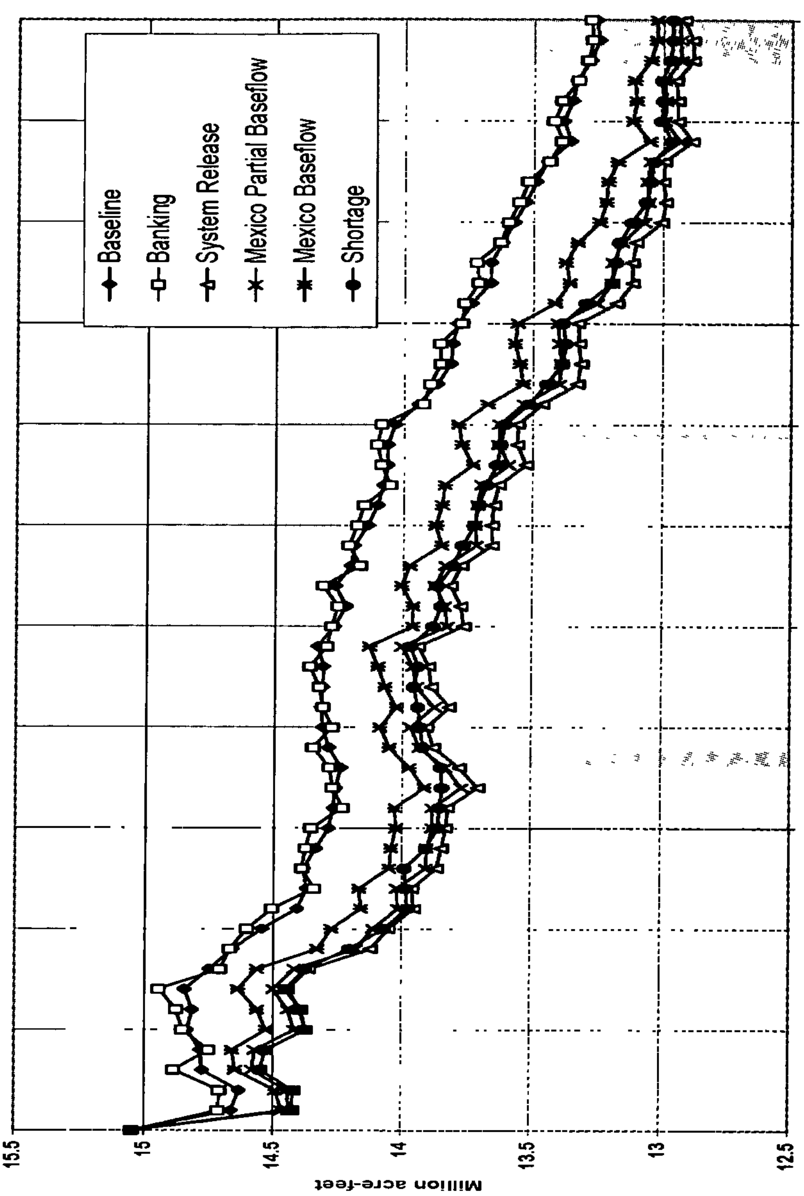


Figure 4. Average Lake Mead Storage

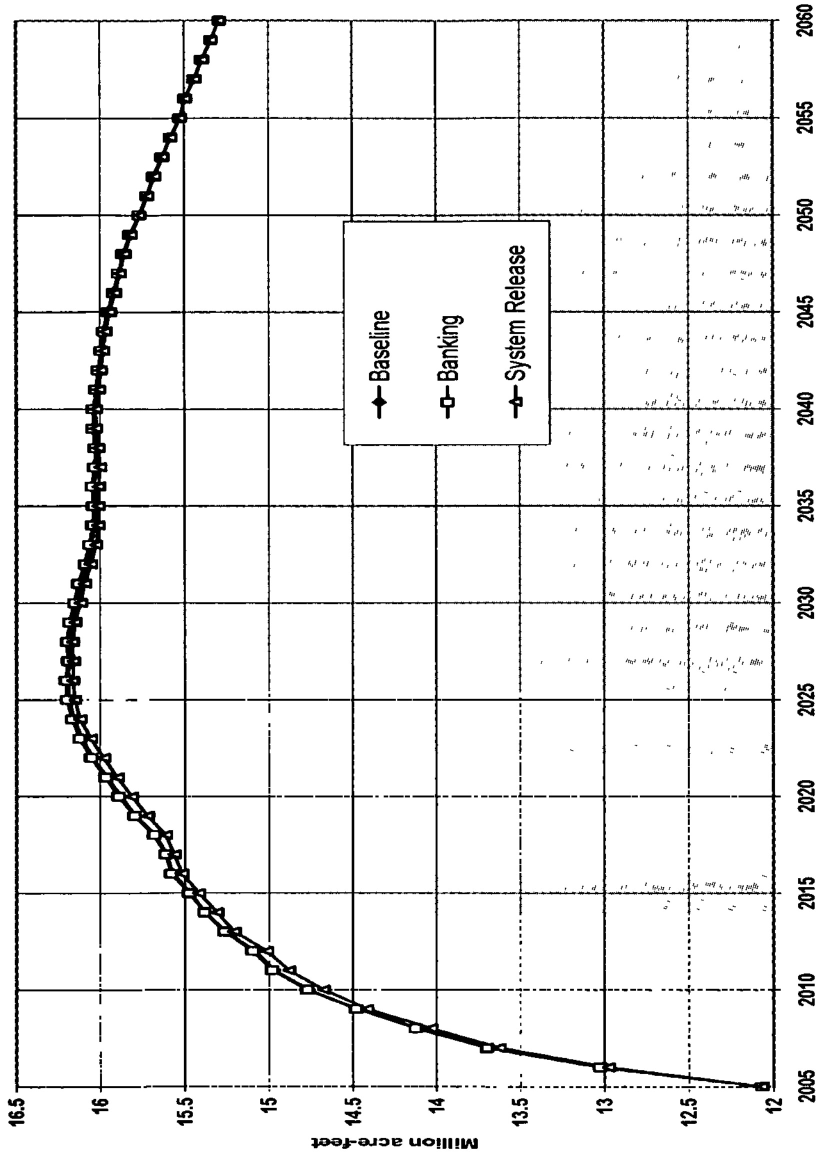


Figure 5. Average Lake Powell Storage

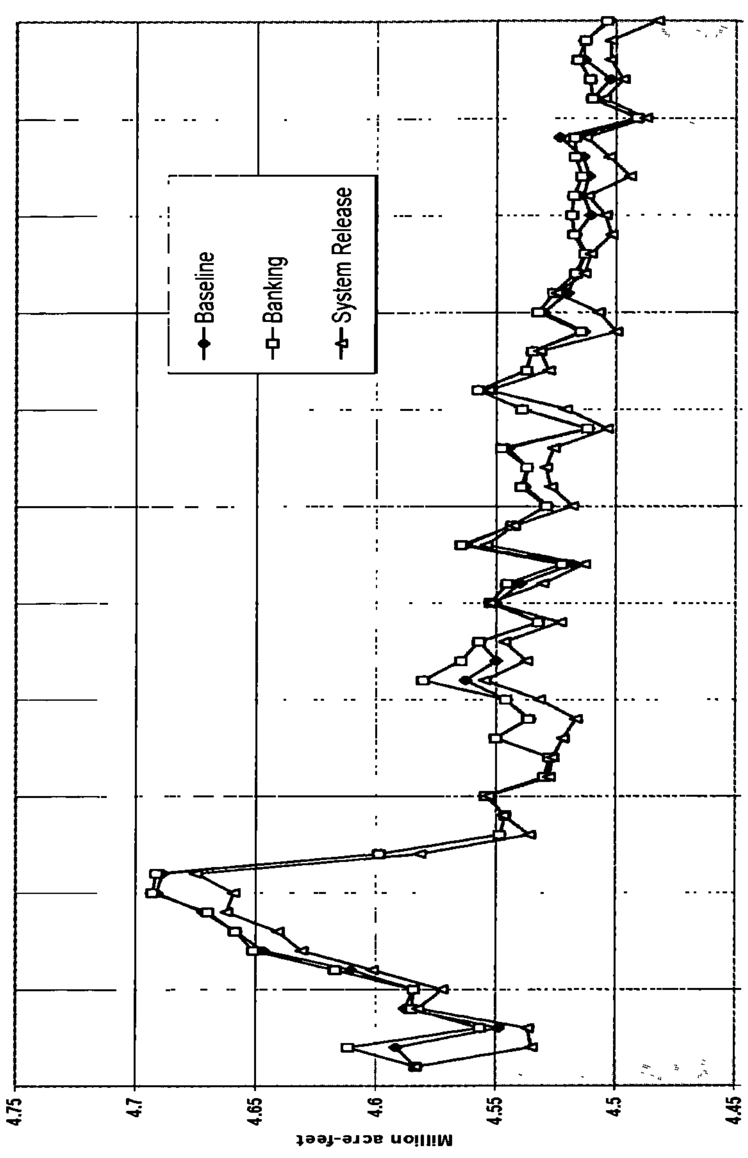


Figure 6. Average Annual California Depletions

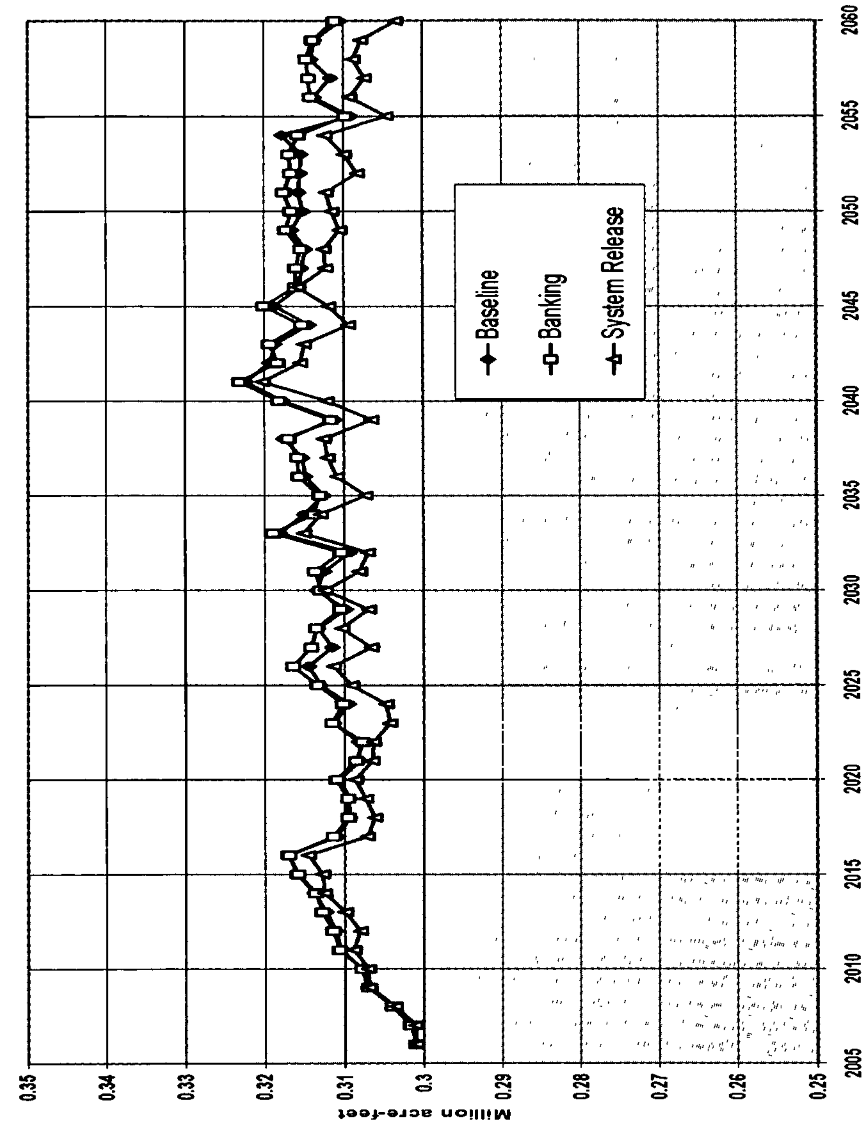


Figure 7. Average Annual Nevada Depletions

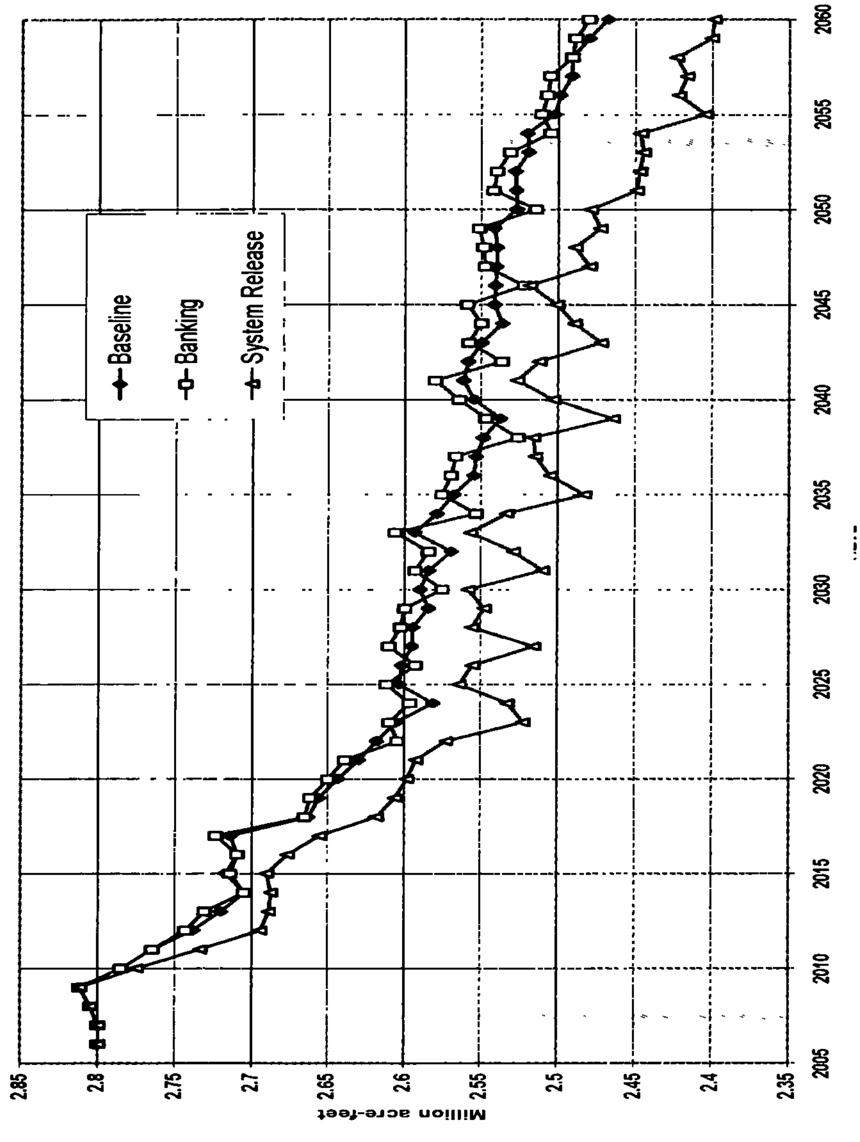


Figure 8. Average Annual Arizona Depletions

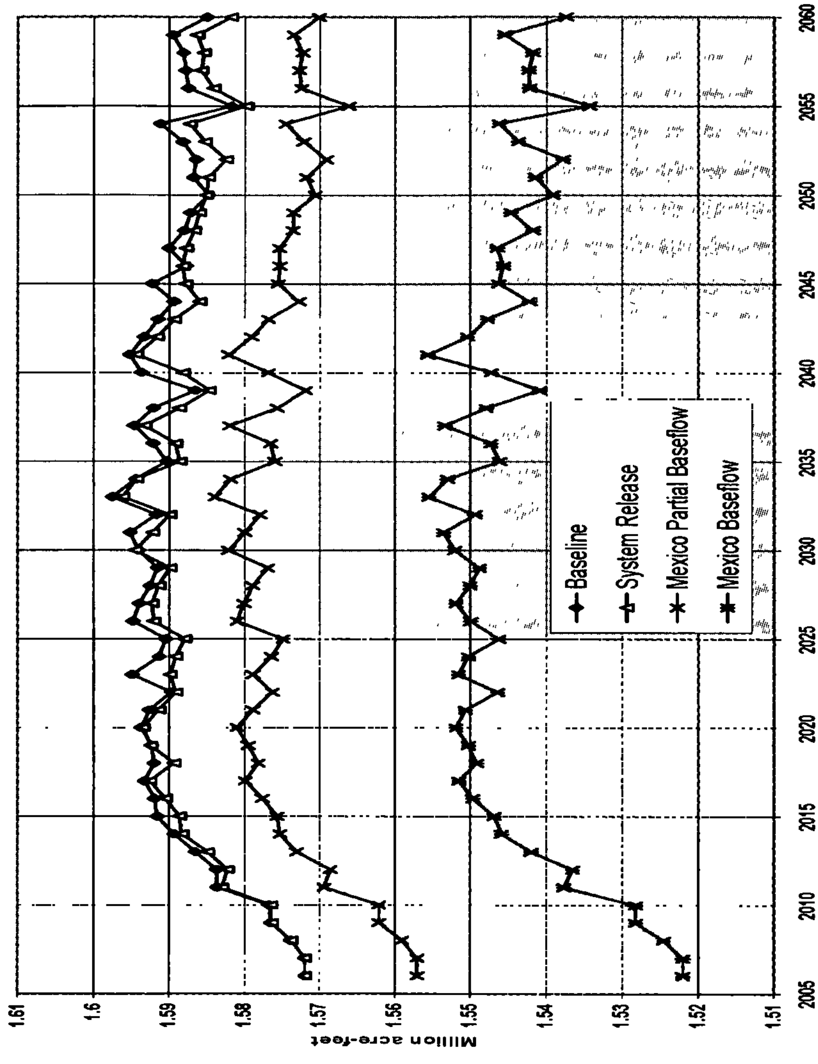


Figure 9. Average Annual Mexico Depletions

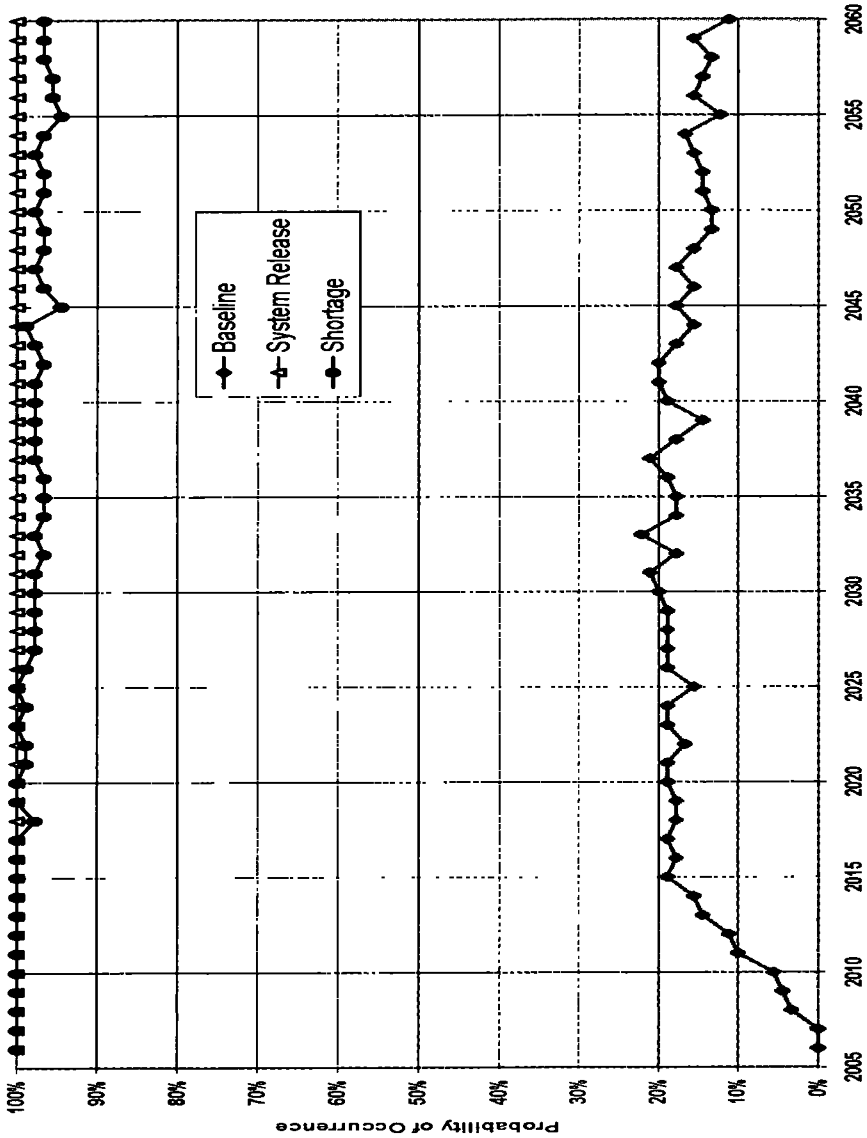


Figure 10. Probability of Any Flow Reaching the Colorado River Delta

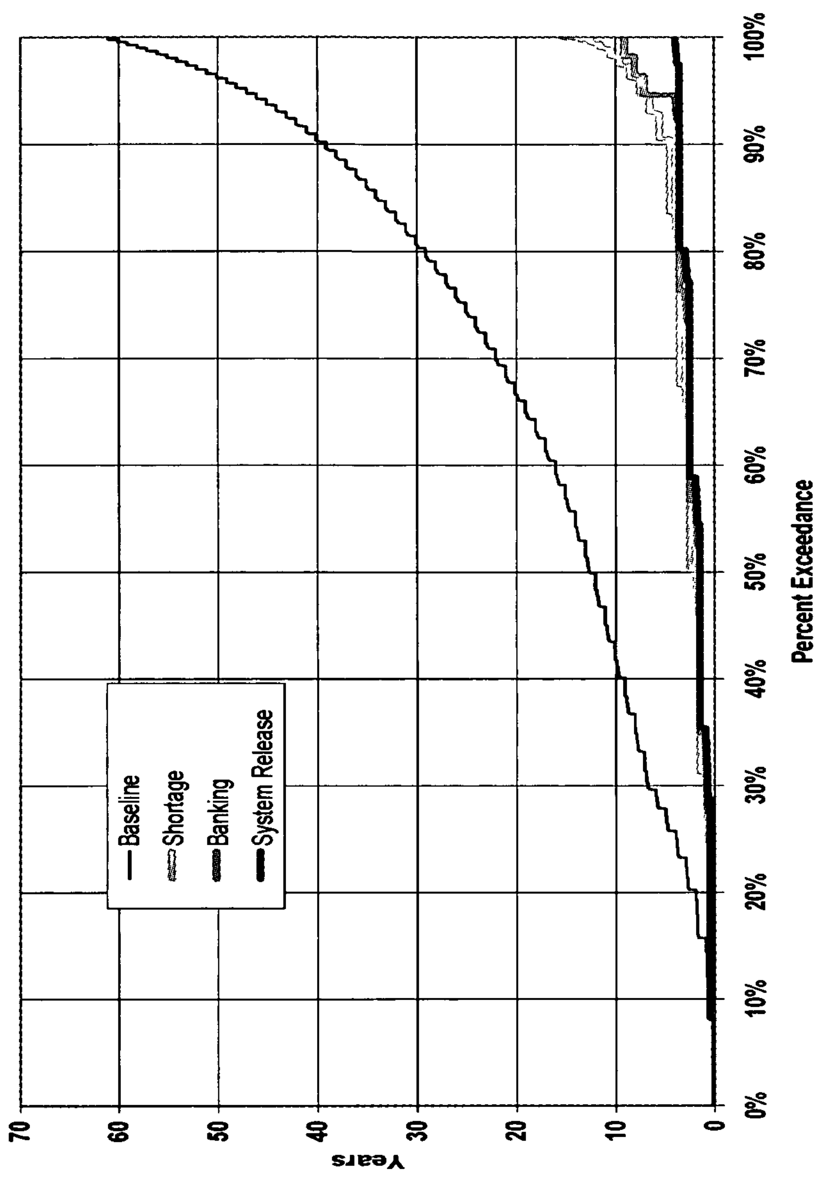


Figure 11. Cumulative Distribution Function for the Number of Years Since the Last 260,000 Acre-foot Flood Event