US Army Corps of Engineers
Hydrologic Engineering Center

Technical Considerations for Alamo Lake Operation

April 1998

PR-36

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1998

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Technical Considerations for Alamo Lake Operation

5. FUNDING NUMBERS
U.S. Army Corps of Engineers
Los Angeles District

6. AUTHOR(S)
Ken Kirby-Private Consultant
Michael W. Burnham, Chief, Planning Analysis Division
HEC (Study Oversight and General Direction)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES
US ARMY CORPS OF ENGINEERS
HYDROLOGIC ENGINEERING CENTER (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
PR-36

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Joe Evelyn, Chief, Hydraulics and Hydrology Branch
U.S. Army Corps of Engineers
Los Angeles District, CESPL
P.O. Box 2711
Los Angeles, CA 90053-2325

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
The report represents a technical study regarding operation of Alamo Lake to reduce the conflict between objectives for draw-down for maintenance inspections, protection against inundation of bald eagle nests, and support of down riparian obligate.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release. Distribution of this document is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study evaluates polices for operating Alamo Lake in Arizona for the Los Angeles District Corps of Engineers. The analyses specifically addresses three questions of interest to the District: (1) can Alamo Lake be operated to protect against bald eagle nest inundation and if so, what are the downstream impacts; (2) can different drawn-down schemes for required dam maintenance improve the conflicting conditions; (3) can the operation plan recommended by the Bill Williams River Corridor Technical Committee by improved? Results from a combined approach using an optimization (HEC-PRM) and simulation model of the Alamo system confirmed that the proposed operating rule performs very well. Significant Improvements to operation using a flexible drawn-down scheme instead of a rigid schedule can be obtained. The chance of inundation of eagle nest inundation can be reduced from 18 to 5 percent in a year by a different operation strategy but at a significant impact to other endangered species in the downstream riverine corridor.

14. SUBJECT TERMS
Corps of Engineers, Alamo Lake, endangered species, reservoir operation, optimization and simulation modeling, bald eagle nesting, maintenance draw-down, Bill Williams River Corridor

15. NUMBER OF PAGES
87

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

Technical Considerations for Alamo Lake Operations

April 1998

US Army Corps of Engineers
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX

Table of Contents

Tables

Figures

Preface

This report presents a technical study regarding operation of Alamo Reservoir conducted by the Hydrologic Engineering Center (HEC). The study evaluates various operating strategies designed to reduce conflict between objectives including draw-downs for maintenance inspections, protection against inundation of eagle nests, and support for downstream riparian obligate species.

Kenneth W. Kirby performed the study while under contract with the Hydrologic Engineering Center. Joe Evelyn, Chief, Hydraulics and Hydrologic Branch, Los Angeles District Corps of Engineers provided technical support. Michael Burnham, Chief, Planning Analysis Division, HEC, provided study direction and management. Darryl W. Davis was Director of HEC during the conduct of the study. The Los Angeles District provided data and general guidance for this study.

Executive Summary

Report Summary

This study was conducted as one of several efforts under way by the Los Angeles District of the US Army Corps of Engineers to evaluate policies for operating Alamo Reservoir in Arizona. The Los Angeles District is facing some difficult operational decisions for Alamo Dam. The District recently participated in an interagency cooperative study to address conflicting operational objectives. Results of the cooperative study are outlined in the *Proposed Water Management Plan for Alamo Lake and the Bill Williams River* (BWRCTC 1994). This study addresses questions not resolved during the Bill Williams River Corridor Technical Committee study.

For the past ten years, bald eagles have been nesting around Alamo reservoir. The eagles often nest in snags, (dead trees) near the edge of the reservoir pool. If a large rain event occurs upstream of Alamo Dam, the eagle nests can be inundated by rising reservoir pool levels. The eagles also rely on the reservoir for forage, and the U.S. Fish and Wildlife Service has requested that the reservoir pool level be kept above 1,100 feet elevation to provide adequate forage area. Furthermore, the Bill Williams River downstream of Alamo Dam flows through a National Wildlife Area and supports the last extensive native cottonwood riparian habitat in Arizona. Several species protected by the Endangered Species Act depend on this riparian habitat. The health of the riparian habitat depends heavily upon operation of Alamo dam. This study attempts to provide quantitative estimates of impacts for various objectives caused by different operating strategies.

This work specifically addresses three questions of interest to the Los Angeles District Corps of Engineers:

- Can Alamo reservoir be operated to protect against bald eagle nest inundation, and if so, can impacts on the riparian habitat and other listed species be approximated?
- Can different draw-down schemes for required maintenance improve reservoir performance based on evaluation criteria used in the BWRCTC study?
- Can the operation plan recommended by the Bill Williams River Corridor Technical Committee (BWRCTC) be improved based on results from an HEC-PRM model of Alamo Reservoir system?

The following tasks were performed to address these questions:

- Comparison of results from a combined optimization and simulation modeling approach with results from the operation policy recommended by the BWRCTC.

- Evaluation of a flexible interval draw-down strategy for performing required maintenance inspections of Alamo Dam as compared to the fixed interval draw-down scheme used in the BWRCTC study.
- Development of a probabilistic simulation method to model nesting behavior of bald eagles around Alamo Reservoir.
- Estimation of the likelihood of harassment and inundation for eagle nests based on the BWRCTC proposed operating policy.
- Specification and testing of an operating policy designed to reduce the threat of eagle nest harassment and inundation.
- Estimation and comparison of tradeoffs between operational objectives using probabilistic simulation of the operating policy designed to reduce likelihood of eagle nest inundation.
- Review of the Endangered Species Act (ESA) and related literature to determine what guidance is offered to manage conflict between species protected by the ESA.

Conclusions

1. Results from a combined approach using an optimization (HEC-PRM) and simulation model of the Alamo Reservoir system confirmed that the operating rule proposed by the Bill Williams River Corridor Technical Committee performs very well.

2. The HEC-PRM model results agree with the BWRCTC findings that 1,125 feet is a good target elevation to meet operational objectives.

3. Slight modifications to the BWRCTC rule form can increase the number of pulse flow events (desirable for riparian habitat) over the simulation period.

4. A flexible draw-down scheme that schedules draw-down events based on the condition of the reservoir instead of on a rigid schedule significantly improves reservoir performance according to the evaluation criteria.

5. Based on the historical record of inflows and the physical characteristics of Alamo Reservoir, it is impossible to prevent eagle nest inundation 100% of the time.

6. Probabilistic simulation of eagle nesting behavior shows that if an operating strategy based on the BWRCTC proposed rule is implemented, there exists an 0.18 probability that an eagle nest will be inundated during a year.

7. The chance of eagle nest inundation can be reduced to 5% per year by implementing an operating policy that responds to the nesting behavior of the eagles, but this reduction in inundation risk causes significant reductions in performance for other objectives including protection of other species listed under the Endangered Species Act, and even maintenance of forage area for the bald eagles.

8. Provisions in the Endangered Species Act, such as the federal consultation process and multi species recovery plans provide a legal method for the USACE to help formulate a comprehensive long-term approach to manage conflicting interests between listed species impacted by operation of Alamo Reservoir.

Chapter 1

Introduction

1.1 Summary

This report presents technical study results performed by the Hydrologic Engineering Center for the Los Angeles District US Army Corps of Engineers. The Los Angeles District is currently evaluating possible changes to the operation plan for Alamo Reservoir. During the late 1980's, the agencies responsible for managing resources along the Bill Williams River were in conflict over their individual goals and missions. Many of the issues surrounding the conflict were addressed through an interagency cooperative study performed by the Bill Williams River Corridor Technical Committee (BWRCTC) outlined in the *Proposed Water Management Plan for Alamo Dam and the Bill Williams River* (BWRCTC 1994). However, some of the issues impacting the specification of a new operations plan were not resolved by the BWRCTC. The primary issue not resolved during the BWRCTC study is operation to prevent bald eagle nest inundation. Within recent years, eagle nests have been threatened by rising reservoir pool elevations. These events provoked further disagreement regarding how Alamo reservoir should be operated. Modifying the reservoir operations to prevent inundation during a flood event seemed, at least potentially, to be in conflict with other agreed upon operating strategies, including those for protected species downstream. The Los Angeles District desires to develop a comprehensive long-term strategy to deal with the difficult issue of competition between species protected under the Endangered Species Act. The District felt that an estimate of likely trade-offs between competing objectives for different operating strategies would be extremely helpful to craft a long-term strategy. The District was also interested to see if reservoir performance could be improved by using a different draw-down scheme for required maintenance inspections, and was curious to see how results from a combined optimization / simulation modeling approach would compare to the results obtained by the BWRCTC using only simulation modeling.

Therefore, this study addresses the following questions:

- Can Alamo reservoir be operated to protect against bald eagle nest inundation, and if so, can impacts on the riparian habitat and other listed species be approximated?
- Can different draw-down schemes for required maintenance improve reservoir performance based on evaluation criteria used in the BWRCTC study?
- Can improvements to the operation plan recommended by the Bill Williams River Corridor Technical Committee be made based on results from an HEC-PRM model of the Alamo Reservoir system?

1.2 Study Context

Alamo Lake is a multiple purpose reservoir owned and operated by the U.S. Army Corps of Engineers and is located in Arizona on the Bill Williams River approximately 39 river miles upstream of the confluence with the Colorado River (see Figure 1.1). The reservoir has a maximum capacity of 1,451,300 acre-feet (based on the 1993 storage table) with a gross drainage area of 4,770 square miles of broad desert valleys and irregularly distributed rugged mountain ranges. Steep gradients, impervious soil formations, and fan-shaped runoff patterns tend to produce high peak discharges of relatively short duration. An average annual precipitation of 13 inches over the sparsely vegetated watershed produces a mean annual runoff of 115.4 KAF despite an average annual pan evaporation of 65 inches.

During the late 1980's, agencies responsible for managing the Bill Williams River resources and Alamo Dam and Reservoir faced increasing conflict between their individual missions and perspectives. Much of the disagreement stemmed from how the Corps was operating the water conservation pool at Alamo Lake. In August 1990, believing that a cooperative effort offered the best chance to achieve a comprehensive water management agreement that would best satisfy agency management goals, the agencies instituted an interagency planning team -- the Bill Williams River Corridor Technical Committee. The BWRCTC was charged to develop a comprehensive water resource management plan for the Bill Williams River corridor addressing the following water management objectives (BWRCTC 1994):

- *Flood Control* -- The dam was authorized by Congress to provide flood control for lower Colorado River communities downstream from Parker Dam (Lake Havasu), and protect property along the Bill Williams River corridor. Alamo Dam is operated in conjunction with the U.S. Bureau of Reclamation dams on the Colorado River to reduce flood related damage.
- *Water Conservation and Supply* -- The entire water supply in the Bill Williams River (before reaching Lake Havasu) is entitled solely to Arizona. Bill Williams River flows that reach the Colorado River are allocated according to the "Law of the River" including the U.S. Supreme Court Decree in *Arizona v. California* of March 1964. To date, the Corps has not contracted with a user for water supply storage. The conservation pool has been used only for short-term storage of water, later released to Lake Havasu.
- *Recreation* -- The Arizona Game and Fish Department currently holds water rights for 25,000 acre-feet in the recreation pool. These rights are for fish, wildlife, and recreational purposes. The Arizona State Parks Department operates and maintains boat launching ramps, campgrounds, and appurtenant structures.
- *Fishery* -- Arizona Game and Fish has established a productive lake bass fishery. The productivity of the fishery is negatively affected by fluctuations in lake levels during spawning and growing seasons.
- *Endangered Species* -- Two pair of Southern Bald Eagles, a Federally listed species (recently reclassified as threatened), have nested around Alamo Lake since the early 1980's. In 1988 the U.S. Fish and Wildlife Service requested that the Corps maintain a minimum water surface elevation of 1,100 feet at Alamo Lake to ensure sufficient forage

- area for the eagles. Also, the eagles occasionally nest in tree snags along the periphery of the lake, and reservoir operations have been modified to restrict boater access and prevent nest inundation.
- *Wildlife Habitat* -- The Bill Williams River Corridor includes a National Wildlife Refuge and flows through two designated wilderness areas. The river corridor is home to various neo-tropical migratory birds and several threatened or endangered species. The wildlife habitat depends on the vitality of the riparian habitat.
- *Riparian Habitat* -- The riparian habitat along the Bill Williams River contains the last extensive native cottonwood tree stands in Arizona. The U.S. Fish and Wildlife Service believes that a significant portion of the cottonwood trees have been destroyed due to the pattern of past Alamo Dam releases.

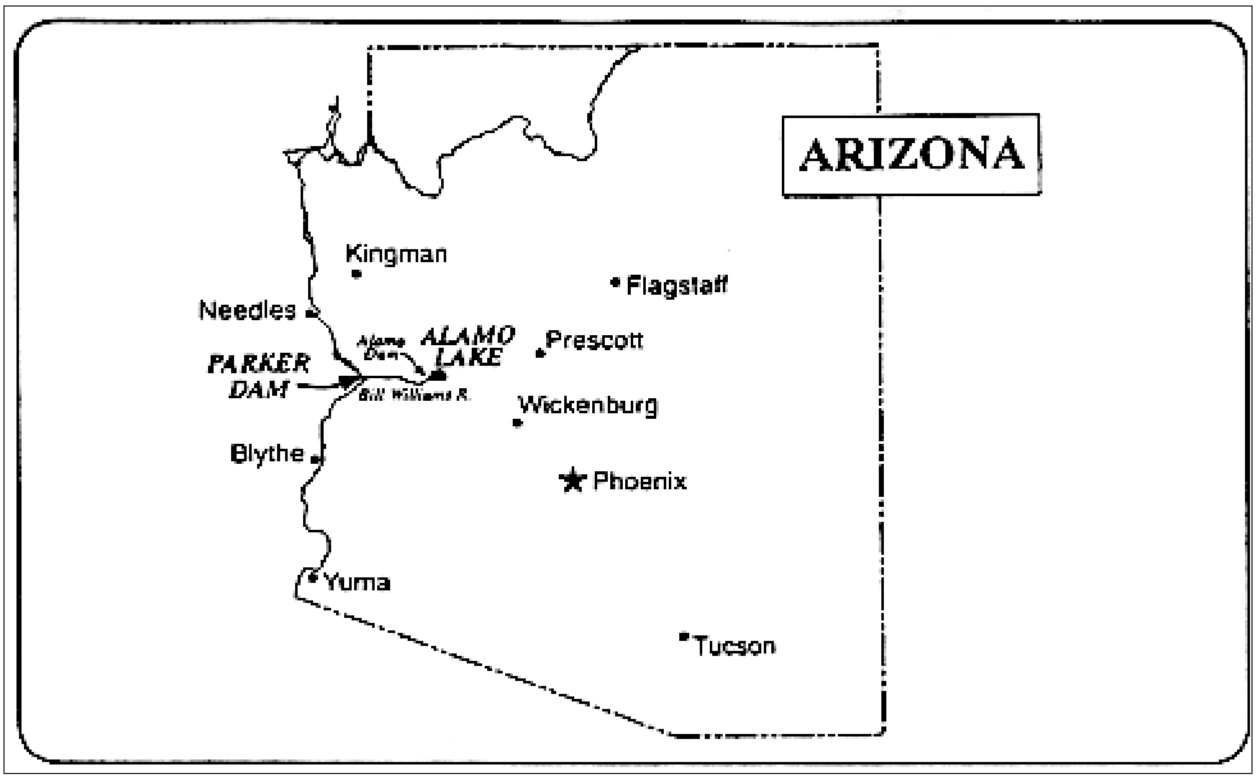

Figure 1.1 Map of Arizona and Alamo Lake (to be provided by Joe Evelyn)

1.3 Organization of Report

This report is divided into seven chapters. Chapter 2 discusses the simulation modeling effort used to conduct this study. The new model developed for this work is verified and compared against the HEC-5 model of the Bill Williams River system used by the BWRCTC. Data analysis techniques and the updated inflow record also are discussed. Chapter 3 presents how the optimization model (HEC-PRM) results are used to infer an alternate operating strategy and the results from this different approach are compared to results from the BWRCTC operating policies. Chapter 4 evaluates alternatives using a flexible interval strategy for maintenance draw-downs of Alamo Reservoir. Chapter 5 addresses the issue of eagle nest inundation, including an approach to model this stochastic behavior and an alternative to try and reduce the threat of nest inundation. Chapter 6 contains a review of the Endangered Species Act and related literature evaluate legal options available to manage competing interests between threatened and endangered species. Chapter 7 presents conclusions drawn from the analysis.

Chapter 2

Simulation Modeling

2.1 Model Development

The Bill Williams River Corridor Technical Committee (BWRCTC) successfully developed and applied an HEC-5 model of the Bill Williams River system to test alternatives during their cooperative analysis. HEC-5 is a flexible and widely used data-driven reservoir model, but is not currently configured to accept operating rules expressed with boolean (i.e. IF - THEN) statements. Analysis of the HEC-PRM model results for Alamo Reservoir indicated that this type of rule form could be promising. Since the Bill Williams River system is relatively simple to model, (one reservoir and a few routed stream reaches), a customized simulation model was developed for the system to allow the use of any operating rule and also to facilitate probabilistic simulation used to study issues regarding eagle nesting, rather than modify HEC-5 to perform this study.

This custom simulation model, referred to as AlamoSim, was configured to represent the Bill Williams River system as shown in Figure 2.1. The model uses a computational approach based on the Euler solution technique for finite difference equations as follows:

Step 1. Estimate the change in storage over a small interval Δt.

Δstorage = Δt * flow

Calculate new value for storages based on this estimate.

$Storage_t = Storage_{t-\Delta t} + \Delta storage$

Step 2. Calculate new values for flows and other calculations in order of evaluation.

Other calculations = f(storages, flows, other calculations)

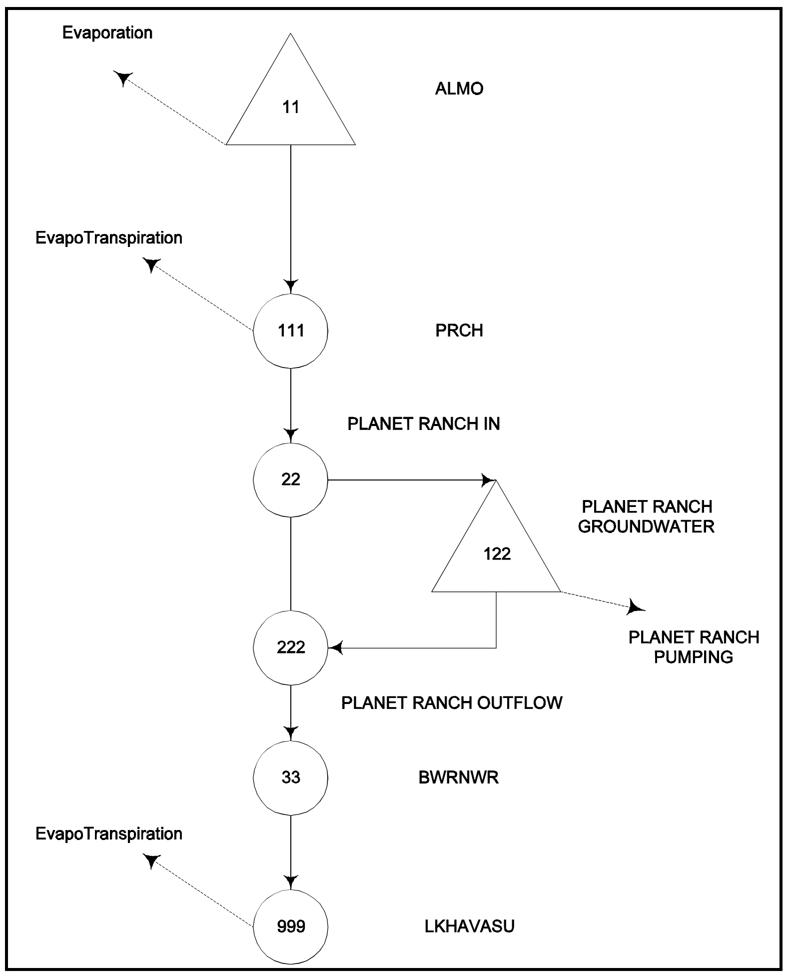

Figure 2.1 System Schematic as Modeled

Flows = f(storages, flows, other calculations)

Step 3. Update simulation time. Stop iteration when Time ≥ simulation stop time.
Time = Time + Δt

The AlamoSim model incorporates features used in the HEC-5 model of the Alamo system that are relevant to this study, including pumping from Planet Ranch, simplified stream and aquifer interactions, and Bill Williams River channel flows. The specifics are outlined in Appendix B.

2.2 Model Comparison

Both the HEC-5 model, (developed by the BWRCTC), and the AlamoSim model are daily simulation models used to evaluate operational alternatives for the Bill Williams River corridor. The models simulate operation of Alamo reservoir for different operating rules based on the historical record of daily inflows (almost 68 years). Performance for each alternative is measured by a set of evaluation criteria (or indicators) for each operating purpose (defined in Table 2.1). The evaluation criteria were identified by the subcommittees involved in the BWRCTC based on how reservoir operation (storage and releases) affects the different operational objectives. The purpose of the AlamoSim model is to evaluate operational strategies and compare their performance to those alternatives simulated with the HEC-5 model. To make meaningful comparisons, the AlamoSim model must be shown to produce results similar to the HEC-5 model given the same inputs. Before comparing model performance, some discussion of data analysis techniques is needed.

Table 2.1 BWRCTC Alternative Evaluation Criteria Definitions

Criteria	Description
Riparian Criteria	
RA1	Percent of time stream-flows at Refuge >= 18 cfs
RA2	Percent of time Alamo water surface elevation (WSE) between 1,100 and 1,171.3 feet
RA3	Percent of time Alamo Dam releases >= 25 cfs in November through January
RA4	Percent of time Alamo Dam releases >= 40 cfs in February through April and in October
RA5	Percent of time Alamo Dam releases >= 50 cfs in May through September
RA6	Total number of occurrences that Alamo Dam releases >= 1,000 cfs seven or more consecutive days in November through February
RA7	Total number of occurrences that Alamo Dam releases >= 1,000 cfs seven or more consecutive days in March through October

Criteria	Description
Fisheries Criteria	
F1	Percent of time WSE between 1,110 and 1,125 feet
F2	Percent of time in March 15 through May 31 WSE fluctuates more than 2 inches per day **
F3	Percent of time in March 15 through May 31 WSE fluctuates more than 0.5 inches per day **
F4	Maximum WSE drop in feet in June through September for the period of record **
F5	Average daily release during June through September
F6	Average daily release during October through May
F7	Percent of time stream-flows at Refuge >= 25 cfs
Wildlife Criteria	
W1	Percent of time WSE at or above 1,100 feet
W2	Number of times during the year that WSE > 1,135 feet two or more consecutive days
W3	Number of times from December 1 through June 30 that WSE > 1,135 feet two or more consecutive days
Recreation Criteria	
RE1	Percent of time WSE >= 1,090 feet
RE2	Percent of time WSE >= 1,094 feet
RE3	Percent of time WSE >= 1,108 feet
RE4	Percent of time WSE between 1,115 and 1,125 feet
RE5	Percent of time WSE between 1,144 and 1,154 feet
RE6	Percent of time outflow is between 300 and 7,000 cfs
RE7	Percent of time in March through May WSE between 1,115 and 1,125 feet
Water Conservation Criteria	
WC1	Average annual delivery of water in acre-feet to lower Colorado River (Lake Havasu)
WC2	Average annual Alamo Reservoir evaporation in acre-feet for period **
Flood Control Criteria	
FC1	Number of days WSE > 1,171.3 feet during period of record **
FC2	Maximum percent of flood control space used during period of record **
**	Note: Gray cells indicate that lower values are preferred

Data Analysis Techniques

Several data analysis techniques were used in this study to compare performance between operational alternatives. The BWRCTC compared alternatives simulated with HEC-5 using evaluation criteria identified by the technical subcommittees. Values for these criteria were computed by the Los Angeles District for each alternative using a post-processing program on a UNIX workstation. For this study, the Los Angeles District's post-processing program was modified to run on a personal computer and used to calculate evaluation criteria values for alternatives modeled with AlamoSim.

Since the BWRCTC evaluation criteria are based on discrete numbers, they potentially can convey misleading information. Extra care should be used with criteria based on a range of values such as RE4, RE7, and F1. For instance, when computing the value for RE4 (% of time WSE between 1,115 and 1,125 feet), water surface elevations very near 1,125 (e.g. 1,125.01) are not counted. Using discrete performance indicators alone can sometimes suggest misleading conclusions. When testing AlamoSim, values for RE4, RE7, and F1 for the AlamoSim Base Case were computed to be between 7% and 12% lower than for the HEC-5 Base Case. This apparent difference in performance is shown in Figure 2.2 (see RE4, RE7, and F1). These evaluation criteria differences resulted from slight numerical variations in water surface elevations that do not translate to real performance differences. When the three evaluation criteria are modified slightly to include an upper bound of 1,125.1 (instead of 1,125.0) the results are much closer between the AlamoSim and HEC-5 Base Case. The right side of Figure 2.2 shows values for the modified evaluation criteria labeled RE4.1, RE7.1, and F1.1.

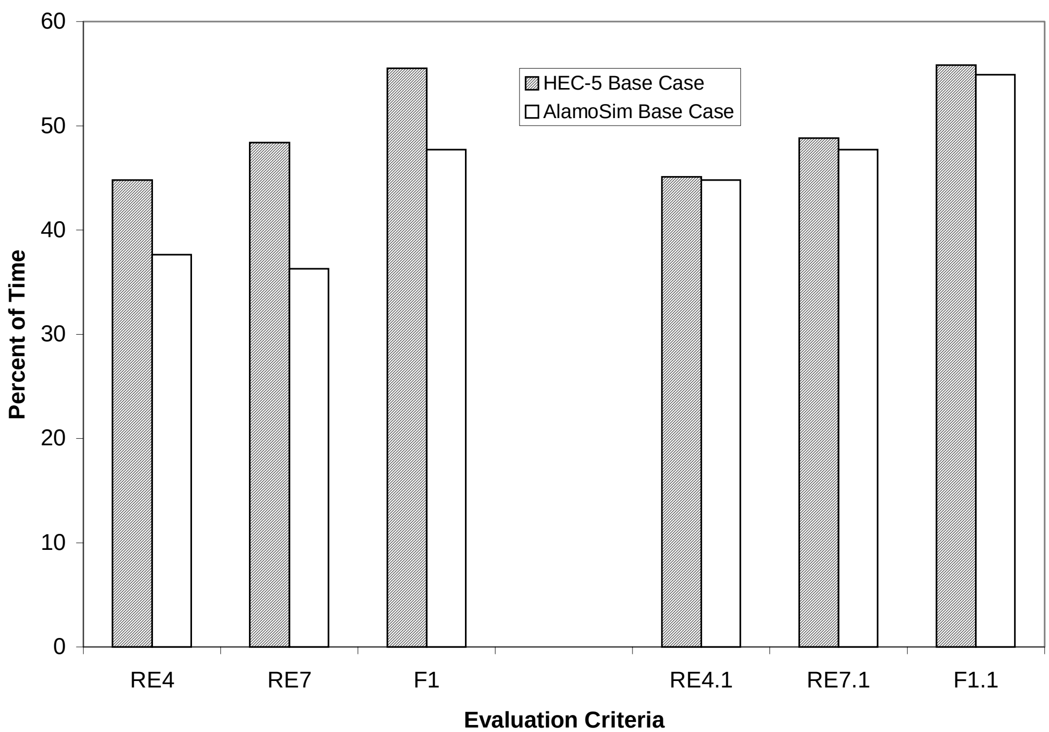

Figure 2.2 Differences in Evaluation Criteria Due to Discrete Performance Indicators

Hazards of discrete performance indicators can be offset by augmenting the indicators with continuous probability distributions. For this study, an additional post-processing program was written to compute exceedance probabilities for storage, elevation, and flow. Plots of the exceedance curves complement the evaluation criteria summary tables by offering a more complete picture of performance values.

Another useful data analysis tool is time series plots of storage, elevation, or release. These plots are important to show operational differences between alternatives that can not be conveyed through discrete or probabilistic performance indicators.

Validating AlamoSim

To demonstrate that AlamoSim can be used to test new alternatives and make direct comparisons with the HEC-5 results, a simple alternative tested in the BWRCTC was selected to simulate with AlamoSim. The alternative chosen for comparison was A1125WOD. This alternative represents the BWRCTC's recommended operating plan with no maintenance draw-downs. This alternative allowed direct comparison of the basic operating plan and the stream-flow routing routines without having to duplicate the draw-down plan tested in HEC-5. If the results from the two models simulating the same conditions are the suitably close, then it is assumed that AlamoSim can be used to test new alternatives. The AlamoSim results can be directly compared to previous results from the HEC-5 model.

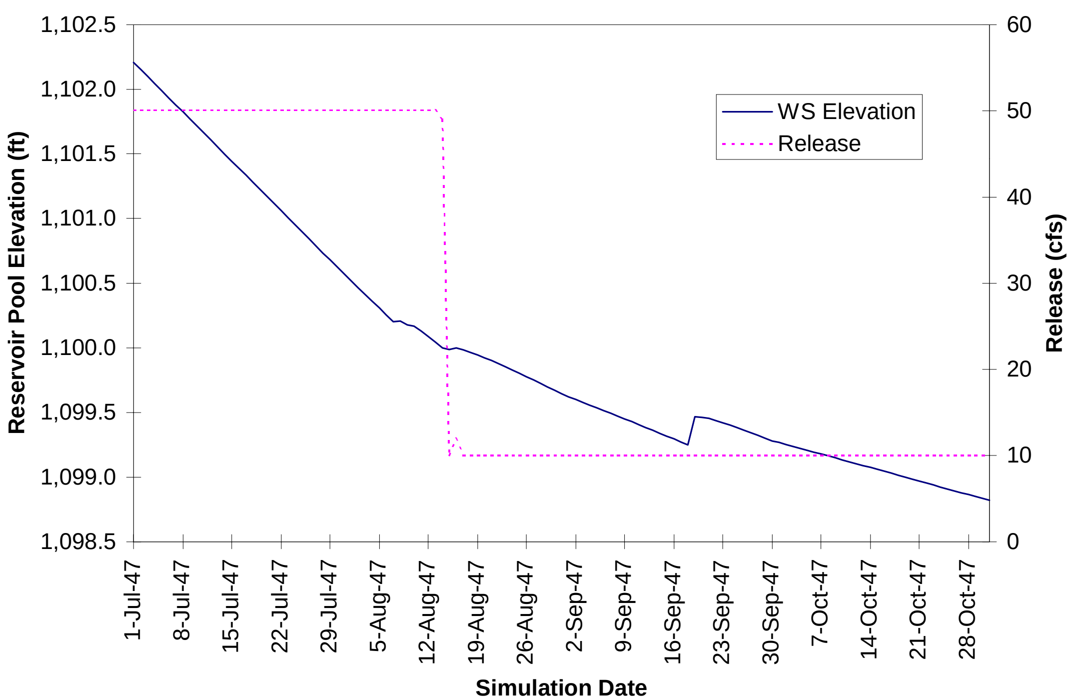

Figure 2.3 Release Compared to Elevation for HEC-5 Base Case

While comparing the two models, an apparent discrepancy was found between the operation rule input into HEC-5 and the model output. According to the recommended operating plan presented in the *Proposed Water Management Plan* (BWRCTC 1994), when the Alamo water surface elevation is between 1,070 and 1,100 feet, releases should be 10, 15, or 25 cfs depending on the date. When the lake elevation drops below 1,070 feet, the release should be 10 cfs. The elevation and release results from the HEC-5 Base Case (A1125WOD) indicate that the model is not working in this manner. Results indicate that HEC-5 releases 10 cfs at all times when the reservoir water surface is below 1,100 feet, regardless of the date. Figure 2.3 shows that when the water surface elevation drops below 1,100 feet, the release drops from 50 cfs to 10 cfs in August. According to the recommended operating plan, the release should be 25 cfs in August and 15 cfs starting October 1. The AlamoSim Base Case operating plan was modified to reflect actual results of the HEC-5 model. (This is not a new plan, merely a correction to reflect actual results from the Alamo model in HEC-5.) Table 2.2 shows the corrected operating rule used in the AlamoSim Base Case to compare with the HEC-5 Base Case.

Table 2.2 Revised BWRCTC Recommended Operating Plan

Reservoir Pool Elevation (ft)	**Release (cfs)**
1265	(Top of Dam)
1,235	(Top of flood control pool; Spillway Crest)
1,148.4	7,000
1,132	6,621 - 7,000
1,131	6,000
1,130	5,000
1,129	4,000
1,128	3,000
1,127	2,000
1,126	1,000
1,125	Transition up to 1,000

Releases for Lower Reservoir Pool Elevation By Season

Elev	**Oct 1 - Oct 31**	**Nov 1 - Jan 31**	**Feb 1 - Mar 31**	**May 1 - Sep 30**
1,100	40 cfs	25 cfs	40 cfs	50 cfs
1,070	10 cfs*	10 cfs	10 cfs**	10 cfs**
990	10 cfs	10 cfs	10 cfs	10 cfs

* Recommended Operating Plan specifies 15 cfs
** Recommended Operating Plan specifies 25 cfs

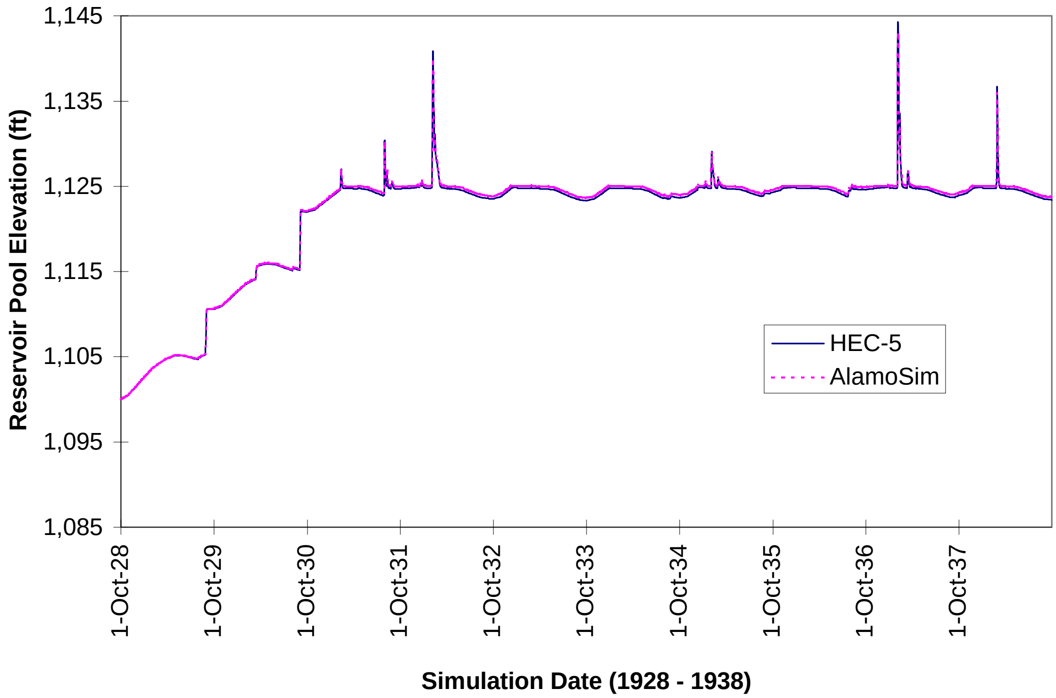

Figure 2.4 Elevation Time Series for HEC-5 and AlamoSim Base Case (1928-38)

Figure 2.4 shows the first ten years of reservoir pool elevation results for the HEC-5 (A1125WOD) and AlamoSim Base Case. The elevation results are very similar, with AlamoSim operating at a slightly higher elevation in some cases. The difference is usually within two to three inches, and does not increase over the simulation period. Figure 2.5 is a plot of the Alamo reservoir water surface elevation exceedance probabilities for the two models. The curves are almost identical traces. The horizontal axis represents the percent of days during the simulation period that an elevation (represented on the vertical axis) is exceeded. For instance, according to Figure 2.5 the water surface elevation is at or above 1,115 feet approximately 49% of the days for both alternatives and at or above 1,125 feet approximately 5% of the days. From these two percentages we can estimate the percent of days the elevation is between 1,115 and 1,125 feet (Evaluation Criteria RE4) to be 44%. (Compare this value to that for RE4 and RE4.1 in Table 2.3.) The water surface elevation time series plots and exceedance curves demonstrate that the AlamoSim and HEC-5 models produce nearly identical results when simulating the same operating rules and input data.

Finally, the evaluation criteria from the Los Angeles District's post processor were used to compare the models. Table 2.3 contains a summary of the evaluation criteria values for the HEC-5 Base Case (A1125WOD) and the AlamoSim Base Case. The evaluation criteria results are very similar except for RE4, RE7, and F1. RE4 values for the two models suggests that

AlamoSim keeps the water surface elevation of Alamo reservoir between 1,115 and 1,125 feet 7.2 % less than HEC-5. (See Figure 2.2.) However, the time series and exceedance probabilities shown above do not support this difference. This variance in the evaluation criteria values illustrates the potential hazard of using discrete performance indicators alone as mentioned above. AlamoSim results near 1,125 were often just over 1,125 (e.g. 1,125.02 ft) and HEC-5 results near 1,125 were often just below 1,125 (e.g. 1,124.95 ft). These slight differences in elevation do not represent significant differences in actual reservoir operation, but they cause the evaluation criteria values to suggest apparent differences. New evaluation criteria for RE4, RE7, and F1 were computed using an upper range of 1125.1 ft to account for the slight differences between how the two models operate near the 1,125 ft. water surface elevation. With the new evaluation criteria, (designated RE4.1, RE7.1, and F1.1), all of the evaluation criteria except RA7 match within 1.9 percent.

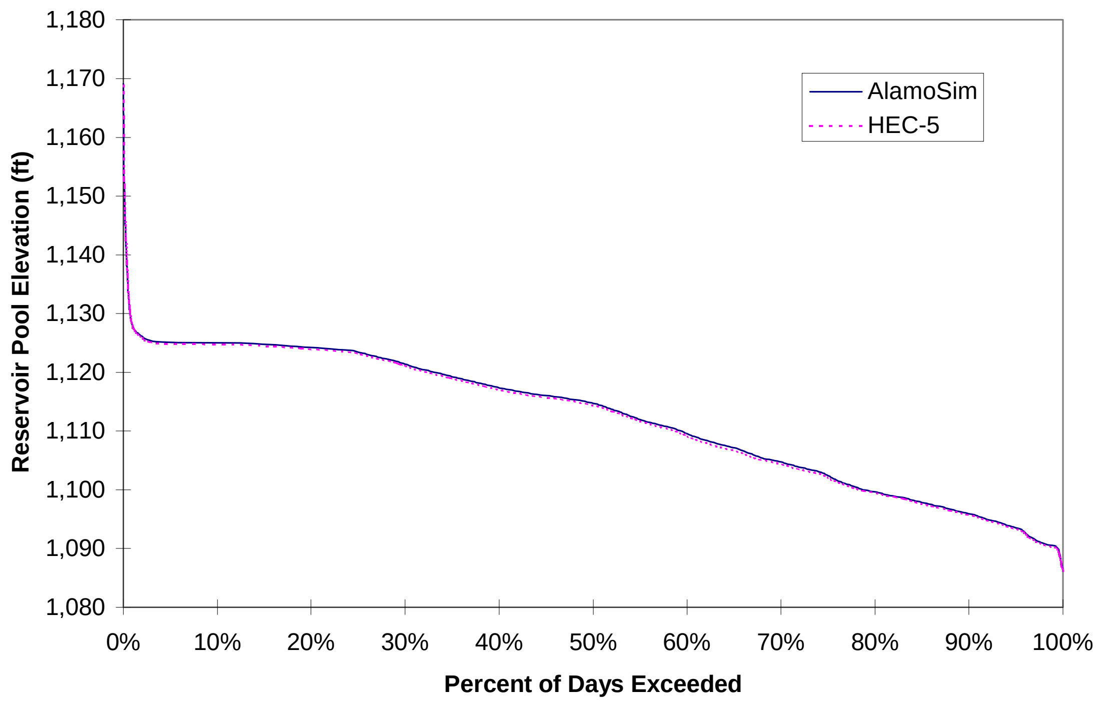

Figure 2.5 Elevation Exceedance Probabilities for HEC-5 and AlamoSim Base Case

The time series plots, elevation exceedance curves, and evaluation criteria for the two different models demonstrate that the AlamoSim model simulates the operation of Alamo Reservoir very similarly to the HEC-5 model for the same operating rules. Based on this comparison, variations of the operation of Alamo reservoir will be tested using AlamoSim and direct comparisons made to HEC-5 simulation results.

2.3 Updated Hydrologic Record

The Los Angeles District supplied a revised hydrologic record of daily inflows to Alamo reservoir. The new record includes corrections to the previous record and extends the record from 31 December 1993 to 29 August 1996. Five missing values were found in the updated record. These missing values were edited as shown in Appendix C. The revised record is used as the standard period of record for all of the new alternatives evaluated. Since the new record will impact simulation results, the rule used in the AlamoSim Base Case alternative was simulated with the new hydrologic record to quantify the differences between the revised record and the previous record. This new base condition is called the "Updated Base Case".

The elevation results for the Updated Base Case and Base Case are the same until the spring of 1970. Figure 2.6 is a plot of reservoir water surface elevation for the two alternatives from 1928 to 1996. The revised hydrology causes a slightly higher water surface elevation for much of the simulation period between February 1970 and December 1993. Elevation exceedance probabilities are plotted in Figure 2.7 confirming that the Updated Base Case maintains slightly higher elevations more frequently when water surface elevation is below 1,120 feet.

Table 2.3 Evaluation Criteria Values for HEC-5 and AlamoSim Base Case

	HEC-5	AlamoSim		HEC-5	AlamoSim
Criteria			**Criteria**		
Min WSE (ft)	1,086.2	1,086.5	W2 (#)	13	13
Mean WSE (ft)	1,111.9	1,112.2	W3 (#)	12	12
Max WSE (ft)	1,170.0	1,169.1	F1 (%)	55.5	47.7
RE1 (%)	99.3	99.5	F1.1 (%)	55.8	54.9
RE2 (%)	93.6	94.0	F2 (%)	4.6	4.5
RE3 (%)	61.8	62.9	F3 (%)	30.6	30.2
RE4 (%)	44.8	37.6	F4 (ft)	9.0	8.4
RE4.1 (%)	45.1	44.8	F5 (cfs)	55	56
RE5 (%)	0.2	0.2	F6 (cfs)	142	142
RE6 (%)	3.2	3.3	F7 (%)	14.4	15.5
RE7 (%)	48.4	36.3	RA1 (%)	49.5	47.6
RE7.1 (%)	48.8	47.7	RA2 (%)	78.2	78.7
WC1 (af)	51,490	51,709	RA3 (%)	75.6	75.9
WC2 (af)	16,804	16,652	RA4 (%)	79.8	80.2
FC1 (#)	0	0	RA5 (%)	78.3	79
FC2 (%)	0.0	0.0	RA6 (#)	15	15
W1 (%)	78.2	78.7	RA7 (#)	16	15

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

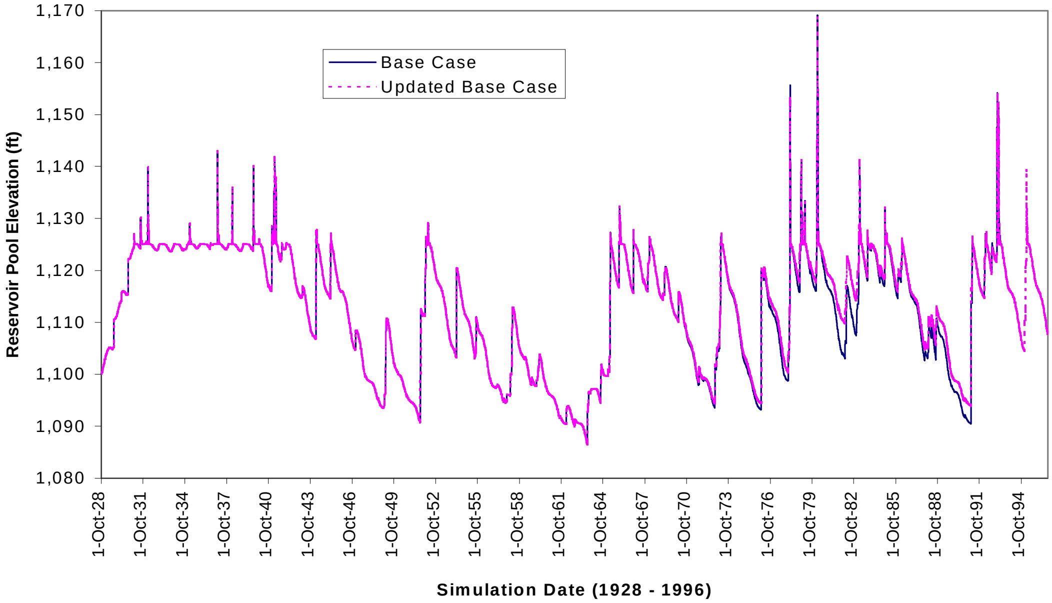

Figure 2.6 Elevation Time Series: Base Case vs Updated Base Case (1928 - 1996)

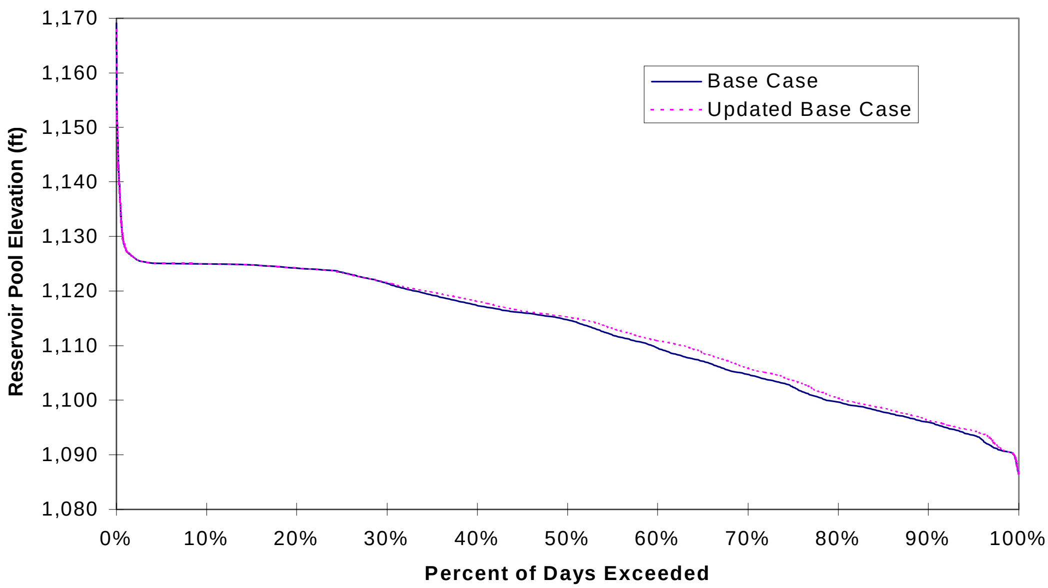

Figure 2.7 Elevation Exceedance Probabilities: Base Case vs Updated Base Case

Table 2.4 presents the evaluation criteria values for the Base Case and Updated Base Case. Figure 2.8 presents the summary data from Table 2.4 in graphical form. The alternative with the updated hydrology (Updated Base Case) does as well or better than the Base Case for all criteria except for W2, W3, and WC2. The Updated Base Case has slightly more evaporation because the reservoir storage is slightly higher over time than in the Base Case. These differences in operation are due solely to the updated hydrology. The operating rules were not changed between these alternatives.

Table 2.4 Evaluation Criteria Values for Base Case vs Updated Base Case

	Base Case	Updated Base		Base Case	Updated Base
Criteria			**Criteria**		
Min WSE (ft)	1,086.5	1,086.5	W2 (#)	13	14
Mean WSE (ft)	1,112.2	1,112.8	W3 (#)	12	13
Max WSE (ft)	1,169.1	1,168.7	F1 (%)	47.7	51.3
RE1 (%)	99.5	99.5	F1.1 (%)	54.9	58.3
RE2 (%)	94.0	95.7	F2 (%)	4.5	4.3
RE3 (%)	62.9	66.2	F3 (%)	30.2	26.6
RE4 (%)	37.6	39.3	F4 (ft)	8.4	8.1
RE4.1 (%)	44.8	46.4	F5 (cfs)	56	56
RE5 (%)	0.2	0.2	F6 (cfs)	142	143
RE6 (%)	3.3	3.3	F7 (%)	15.5	15.6
RE7 (%)	36.3	37.0	RA1 (%)	47.6	50.7
RE7.1 (%)	47.7	48.3	RA2 (%)	78.7	80.5
WC1 (af)	51,709	52,689	RA3 (%)	75.9	78.0
WC2 (af)	16,652	16,997	RA4 (%)	80.2	81.8
FC1 (#)	0	0	RA5 (%)	79	80.9
FC2 (%)	0.0	0.0	RA6 (%)	15	16
W1 (%)	78.7	80.5	RA7 (%)	15	16

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

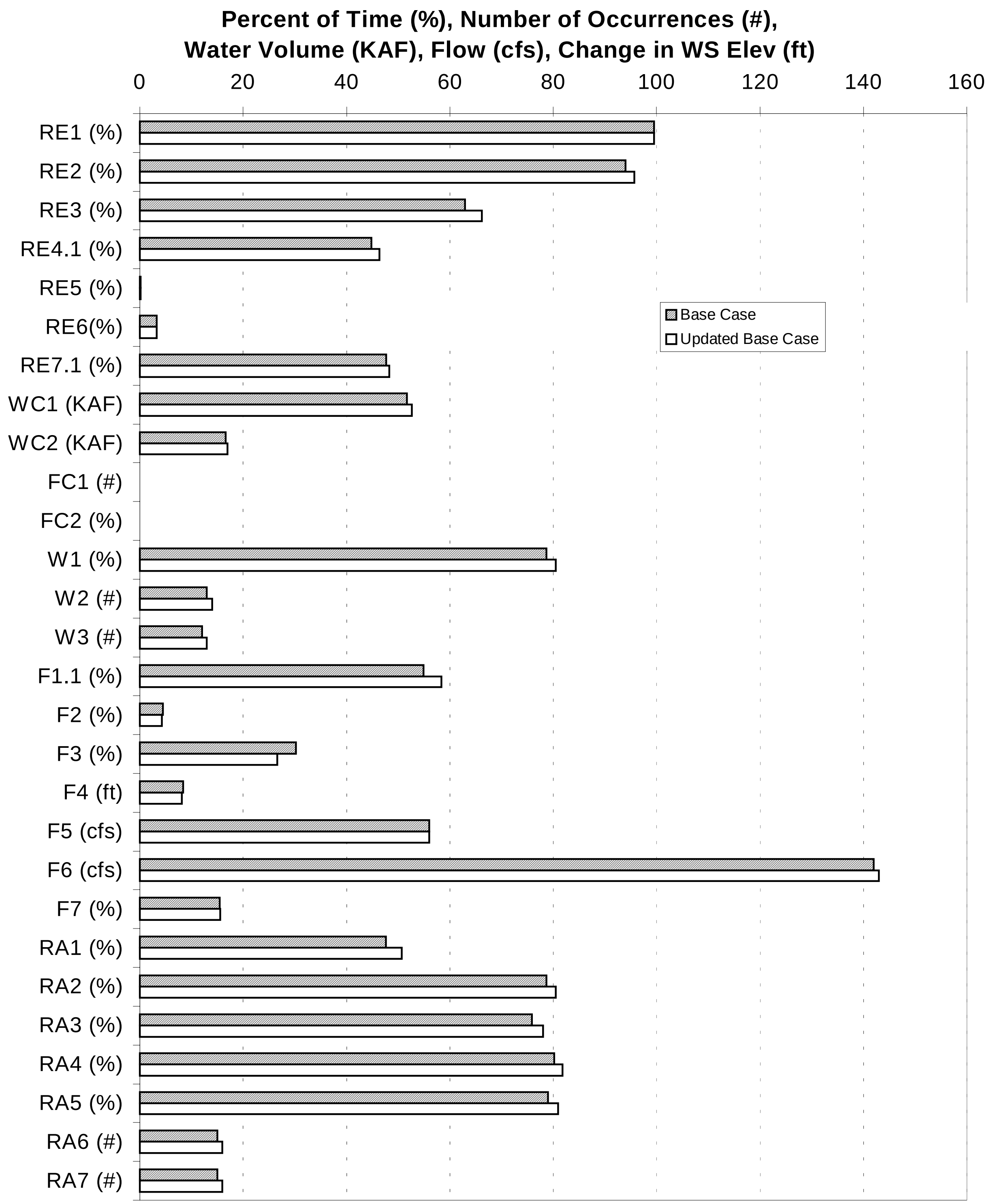

Figure 2.8 Evaluation Criteria: Base Case vs Updated Base Case

Chapter 3

Testing Alternatives Based on HEC-PRM Results

3.1 Prescriptive Model

This phase of the study sought to use information generated from the optimization model (HEC-PRM) of Alamo reservoir based on monthly operations. As discussed in *Resolving Conflict Over Reservoir Operation: A Role for Optimization and Simulation Modeling* (USACE 1998), a prescriptive model of the Alamo Reservoir system was set up according to objectives specified by the BWRCTC subcommittees. Model results were scrutinized to learn about system operation resulting from a prescriptive modeling approach. These insights were tested using simulation to compare results with the alternatives tested by the BWRCTC (1994).

The optimization results for the monthly model suggested trying to maintain a constant water surface elevation in Alamo Reservoir near 1,125 feet in each month of the year. This "target" elevation is the same elevation that the BWRCTC recommended based on their simulation studies.

The optimization data was analyzed to look for possible correlations between release decisions and current storage, release, and inflow. There was almost no correlation between the prescribed releases and the current storage at a monthly time step, but there was significant correlation between prescribed releases and current inflow, supporting an operation that tried to maintain a constant storage. This finding suggested that a operation rule based on storage and inflow may perform better than a rule based on storage alone.

3.2 Optimization Based Alternatives

From the optimization results, a form of release rule was proposed based on a target storage (or elevation) that varied by date. The release decision is a function of deviation from the target storage, date, and current inflow. The first alternative using this new rule form was called OBA 2A, (for Optimization Based Alternative 2A), and the storage target values were based on storage percentiles from the optimization results. Several variations of this rule form were tested. A sample of the release rules are detailed in Appendix D.

3.3 Performance Indexing

Evaluating performance based on the 28 evaluation criteria defined by the BWRCTC can be cumbersome when considering numerous alternatives. To help visualize tradeoffs between alternatives, storage and flow based performance indexes were defined as a simple visual indicator of overall performance. These indexes represent all of the evaluation criteria in a simple two dimensional form, based on whether the criteria are storage or flow related (see Table 3.1). These indexes can be plotted for each alternative to get a quick indication of their performance relative to one another.

Table 3.1 Storage and Flow Performance Index Components

Evaluation Criteria in Storage Index		Evaluation Criteria in Flow Index	
RE1	Percent of time WSE at or above 1090'	RE6	Percent of time outflow is between 300 and 7,000 cfs
RE2	Percent of time WSE at or above 1094'	WC1	Average annual delivery of water to LCR (Lake Havasu)
RE3	Percent of time WSE at or above 1108'	WC2	Average annual evaporation in acre feet for period
RE4.1	Percent of time WSE between 1115' and 1125.1'	F5	Average daily release during June thru Sept
RE5	Percent of time WSE between 1144' and 1154'	F6	Average daily release during October thru May
RE7.1	Percent of time in March thru May WSE between 1115' and 1125'	F7	Percent of time stream-flows at BW Refuge equal or exceed 25 cfs
FC1	Number of days WSE above 1171.3' during period of record	RA1	Percent of time stream-flows at BW Refuge equal or exceed 18 cfs
FC2	Maximum percent of flood control space used during period of record.	RA3	Percent of time Alamo releases >= 25 cfs in Nov. thru Jan.
W1	Percent of time WSE at or above 1100'	RA4	Percent of time Alamo releases >= 40 cfs in Feb. thru Apr. & Oct.
W2	Number of times during the year that WSE exceeds elevation 1135' two or more consecutive days	RA5	Percent of time Alamo Releases >= 50 cfs in May thru Sep.
W3	Number of times from 1 December through 30 June that WSE exceeds elevation 1135' two or more consecutive days	RA6	Total number of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov. thru Feb.
F1*	Percent of time WSE between 1110' and 1125.1'	RA7	Total number of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar. thru Oct.
F2	Percent of time in March thru May WSE fluctuates more than 2" per day		
F3	Percent of time in March 15 thru May WSE fluctuates more than 0.5" per day		
F4	Maximum WSE drop, in feet, in June thru Sept. for the period of record		
RA2	Percent of time WSE between 1100' and 1171.3'		

The performance indexes are computed using a series of simple steps. For each evaluation criteria:

- select the best and worst value for each evaluation criteria (from among the alternatives being compared)

- set the best value of the evaluation criteria to a scaled value of one (1) for that evaluation criteria
- set the worst value of the evaluation criteria to a scaled value of zero (0) for that evaluation criteria
- for evaluation criteria values between the best and worst, set their scaled values between zero and one using the simple linear transformation:

$$0 \leq \frac{Z - Z^*}{Z^* - Z_*} \leq 1$$

Where Z^* is the best criteria value and Z_* is the worst.

Once all of the individual evaluation criteria values have been scaled for the alternatives being considered:

- compute the Storage Performance Index value by averaging the individual scaled values for the evaluation criteria designated as part of the Storage Performance Index (see Table 3.1)
- compute the Flow Performance Index value by averaging the individual scaled values for the evaluation criteria designated as part of the Flow Performance Index (see Table 3.1)

This approach assumes:

1. All criteria are equally important
2. Utility is a linear function of the criterion value

For example, the best value (among the alternatives being compared) for evaluation criteria F5 [1] would be scaled to one and the worst value for F5 would be scaled to zero. The remaining values for F5 are scaled between zero and one, according to how they compare to the best and worst values. The storage and flow index values are computed by averaging the scaled values for all components in the index. If one alternative had the best values for all evaluation criteria among the alternatives being considered, it would have index values of (1,1) and would plot at the upper right-hand corner.

What information do the performance indexes offer? How can the results be interpreted? The performance indexes provide a quick visual indication of how alternatives compare relative to one another for all evaluation criteria. The way the performance indexes are computed assumes that all evaluation criteria are equally important in determining the merit of each alternative. This may or may not be an adequate representation, depending on the perspective of the interested party evaluating different alternative performances.

---

[1] F5 = Avg. daily release for June - Sept. and is part of the Flow Performance Index

Given the assumptions regarding equally important consideration of all evaluation criteria, the alternatives that plot further up and to the right of the other alternatives perform better overall. The plotting position of the alternatives performance indexes should be viewed as an *ordinal* comparison, meaning that alternatives plotting further up and to the right satisfy the collective evaluation criteria better than alternatives that plot lower and to the left, but the plotting position does not provide quantitative information regarding the difference in performance. The "raw" values of the evaluation criteria should be used to make judgements regarding how much better one alternative performs than another, since the assumption of linear utility may not hold.

3.4 Comparing Alternative Performance

Multiple alternatives were considered and analyzed in this study. Table 3.2 provides a brief description of the alternatives compared in this section. These operating plans are presented in more detail in Appendix D. Evaluation criteria values for a sample of alternatives are shown in Table 3.3. The storage and flow performance index values for selected alternatives are plotted in Figure 3.1, with the Storage Performance Index along the horizontal axis and the Flow Performance Index along the vertical axis.

Table 3.2 Description of Alternative Operating Plans

Alternative	Description
GDM Plan	Originally authorized operating plan from the General Design Memorandum (represents current operation)
Base Case	The alternative used to compare AlamoSim results to HEC-5 results as discussed in Chapter 2. Based on BWRCTC alternative A1125WOD
Updated Base Case	The Base Case with the updated hydrologic record
Updated Base Case - PFE	The Updated Base Case with an additional component referred to as a "Pulse Flow Extender" (PFE). The PFE extends flows greater than or equal to 1,000 cfs for at least seven consecutive days if they occur during January through May.
OBA 2A	Operating rule based on analysis of HEC-PRM results that sets releases to maintain a target storage level. The release decision is based on deviation from target storage and the inflow
OBA 3A	Similar to OBA 2A except allows more deviation below target storage before reducing releases
OBA 3C	Similar to OBA 3A except allows even more deviation before target storage before reducing releases, and uses a less aggressive release scheme when the reservoir is below target storage but is rising
OBA 3G	A simplified version of OBA 3A allowing even more deviation below target storage before reducing releases and has the PFE component described above

Table 3.3 Evaluation Criteria Values Summary

	Alternative				
Criteria	GDM Plan	Updated Base Case	OBA 2A	OBA 3G	Updated Base Case - PFE
RE1 (%)	2.8	99.5	100.0	99.5	99.5
RE2 (%)	2.4	95.7	100.0	95.3	95.4
RE3 (%)	1.8	66.2	98.7	65.7	65.8
RE4.1 (%)	0.4	46.4	83.4	47.6	45.9
RE5 (%)	0.3	0.2	0.1	0.1	0.2
RE6 (%)	6.7	3.3	3.7	2.7	3.3
RE7.1 (%)	0.9	48.3	84.8	51.6	48.7
WC1 (af)	65,327	52,689	53,954	52,802	52,728
WC2 (af)	5,857	16,997	18,876	16,949	16,971
FC1 (#)	16	0	0	0	0
FC2 (%)	13.8	0.0	0.0	0.0	0.0
W1 (%)	2.1	80.5	100.0	80.4	80.4
W2 (#)	3	14	14	13	14
W3 (#)	3	13	13	12	13
F1.1 (%)	0.7	58.3	94.7	59.4	57.7
F2 (%)	13.1	4.3	3.2	3.2	4.5
F3 (%)	42.6	26.6	7.0	25.1	26.7
F4 (ft)	67	8.1	4.2	8.1	8.1
F5 (cfs)	48	56	37.0	56.0	56.0
F6 (cfs)	171	143	148	144.0	144.0
F7 (%)	24.9	15.6	13.4	14.8	15.5
RA1 (%)	30.7	50.7	22.4	49.5	50.4
RA2 (%)	2.1	80.5	100.0	80.4	80.4
RA3 (%)	15.2	78.0	19.1	78.0	78.0
RA4 (%)	22.9	81.8	29.9	81.7	81.8
RA5 (%)	9.3	80.9	11.3	80.6	80.6
RA6 (%)	17	16	12	22	22
RA7 (%)	26	16	14	23	22

Note: Gray cells indicate that lower values are preferred.

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

Results from BWRCTC study alternatives, namely the GDM Plan (representing the original General Design Memorandum authorized reservoir operation) (BWRCTC 1994) and the Base Case, were included in the comparison to serve as a reference for the new alternatives. As shown in Figure 3.1, the GDM plan has the worst storage performance index value. This result suggests that the GDM plan has the worst performance on several of the individual storage related evaluation criteria, but says nothing about how different the performance is between the best and worst evaluation criteria values. The evaluation criteria values can be compared to determine how different the performance levels are between the GDM Plan and other alternatives.

Figure 3.2 compares the evaluation criteria values for the GDM Plan and the Updated Base Case. Figure 3.2 shows that the GDM Plan's performance for recreation objectives is dismal compared to the Updated Base Case. The GDM Plan performs much worse for five of the seven recreation evaluation criteria and only slightly better for one (RE6). Similar results are seen for fisheries and riparian objectives. The only objectives for which the GDM Plan performs better is water conservation, and for W2 and W3 (indication of high water levels potentially harmful to eagle nesting).

The first optimization based alternative, OBA 2A, has the best storage performance index value, but the worst flow index value. The performance index values suggests that the optimization based rule form is very successful at satisfying evaluation criteria related to storage, but not very effective in satisfying flow related evaluation criteria. Figure 3.3 confirms that OBA

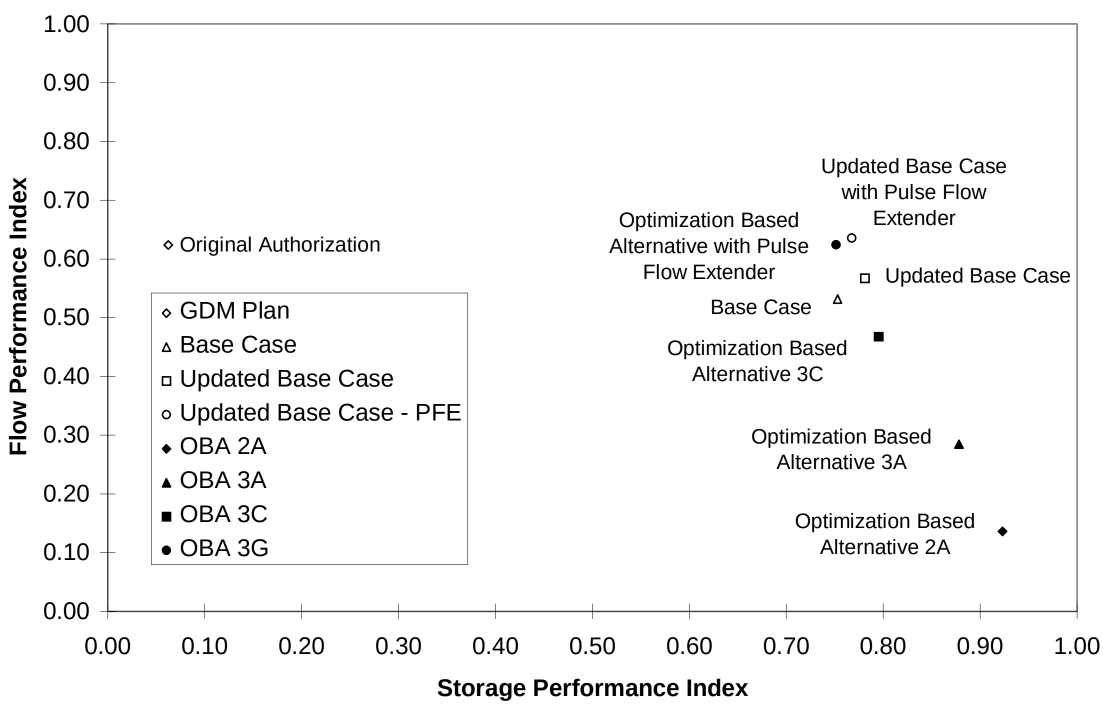

Figure 3.1 Performance Index Comparison for Alternatives Without Draw-Down

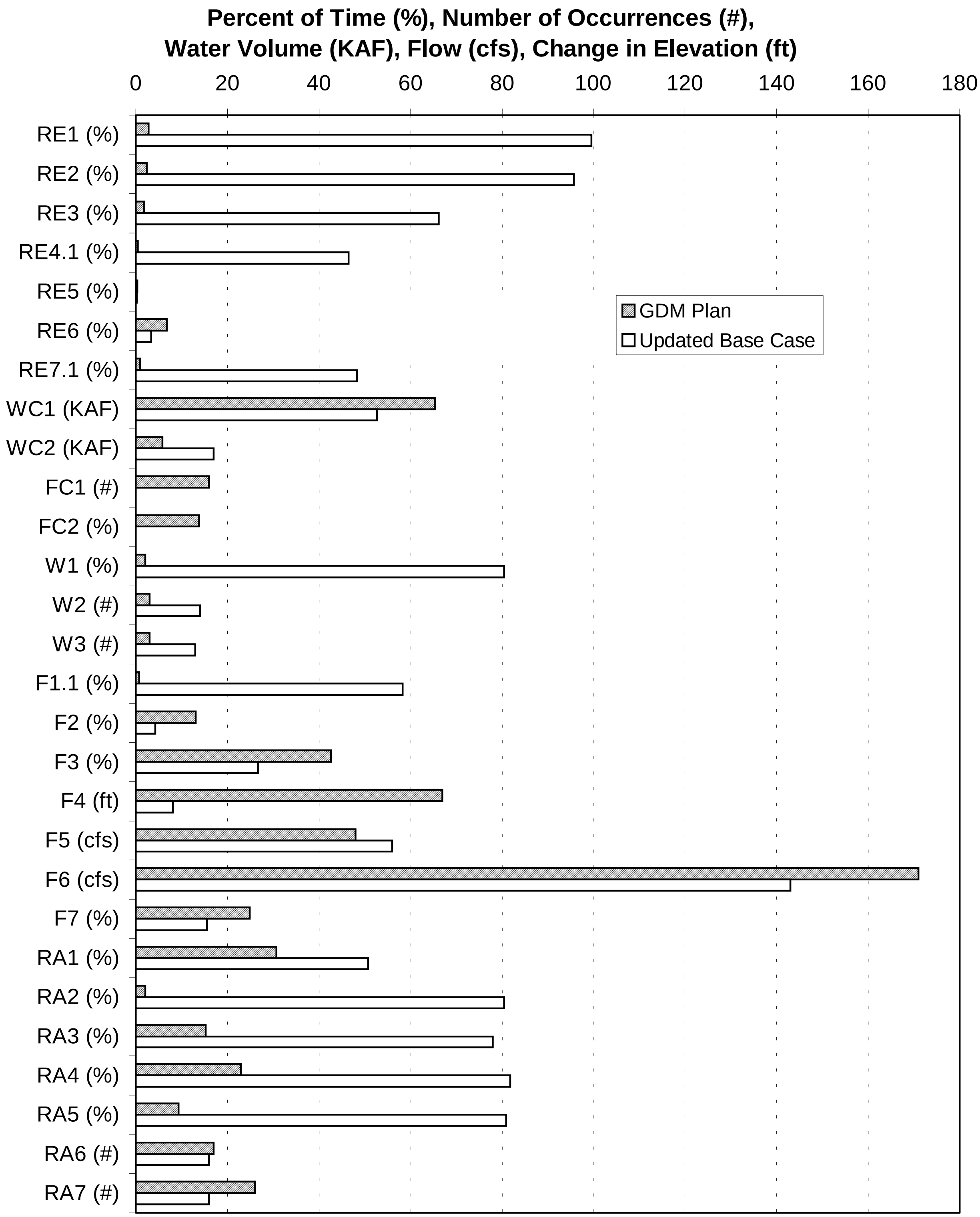

Figure 3.2 Evaluation Criteria: GDM Plan vs Updated Base Case

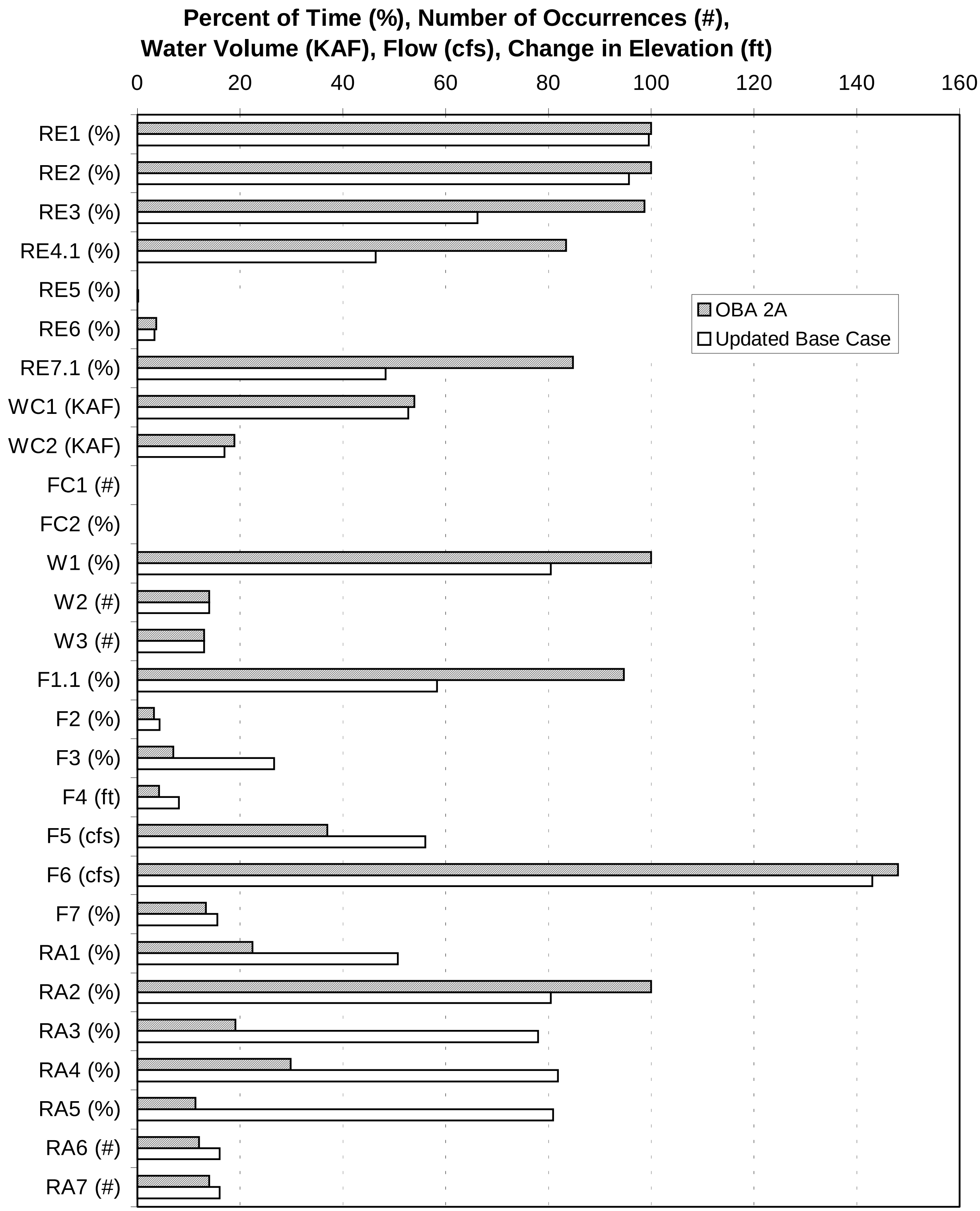

Figure 3.3 Evaluation Criteria: OBA 2A vs Updated Base Case

2A performs very well for storage related objectives, and poorly for flow related objectives. Figure 3.3 shows that the recreation objectives are met significantly better by OBA 2A than by the Updated Base Case. RE3, RE4.1, and RE7.1 each show over 50% improvement. The optimization based alternative 2A performs about the same for water conservation and slightly better for wildlife. The fishery criteria that affect lake fishery are satisfied significantly better by OBA 2A. However, OBA 2A performs significantly worse for flow related criteria important to stream fishery and riparian objectives.

These results indicate that an operation policy focused on maintaining a constant lake level near 1,125 feet to benefit recreation, wildlife, and lake fishery, often does not meet the relatively steady and constant flows desired for riparian restoration. Although the optimization based alternative 2A does not meet the flow related criteria for the riparian objective as well as the Updated Base Case, in some sense the releases under the OBA 2A plan more closely resemble the natural flow pattern. Figure 3.4 compares exceedance probabilities for releases from Alamo Dam (from 0 to 300 cfs) to historical inflows. Notice that the OBA 2A flow exceedance probability curve resembles the exceedance curve of natural inflows more closely than that of the Updated Base Case.

The optimization based rule form was modified repeatedly to relax emphasis on maintaining constant storage and thus improve flow related performance. This was done by successively increasing the range of allowable variation below the target storage before reducing releases and relaxing the release scheme designed to reduce storage levels above the target level used to when the reservoir level was below target and rising. Results from OBA 3A and OBA 3C indicate how the tradeoff progressed. OBA 3C shows improvement in flow related performance with a decrease in storage related performance. However, the Updated Base Case has a better flow performance index value than any of the alternatives yet tested using the optimization based rule (OBA 2A, OBA3A, and OBA3C on Figure 3.1).

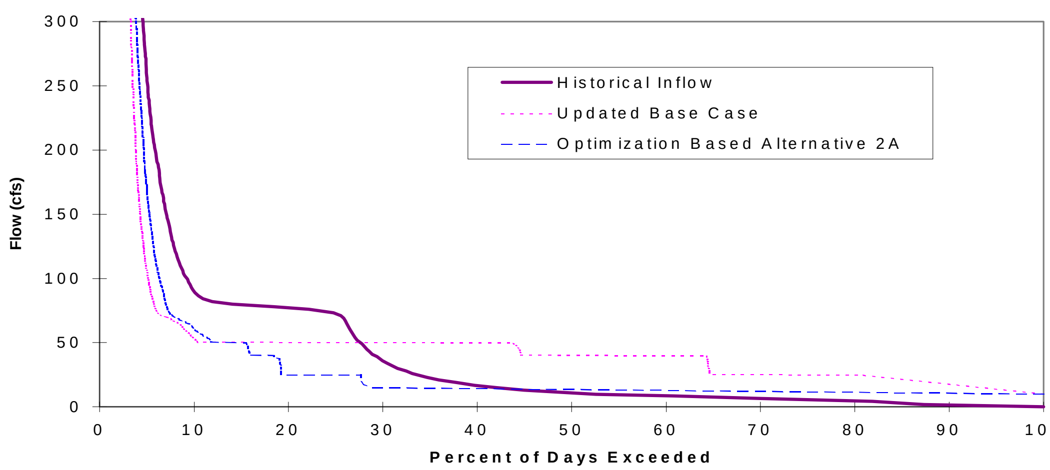

Figure 3.4 Flow Exceedance Probabilities (Below 300 cfs)

Analysis of the different alternatives showed that the frequency of spring flushing flows of at least seven days duration (evaluation criteria RA6 and RA7) could probably be increased without large impacts on storage related criteria. A new condition was added to the optimization based rule form that would check for releases greater than or equal to 1,000 cfs and when they occurred during January through May, maintain releases of 1,000 cfs or more for at least seven consecutive days. This addition to the rule is referred to as a "pulse flow extender" and was tested in OBA 3G. This modification improved the flow performance index value with a decrease in the storage performance index as shown in Figure 3.1.

The optimization based rule used in OBA 3G had been simplified and changed to improve flow based performance to the point that it is very similar to the rule recommended by the BWRCTC except for the "pulse flow extender". Noting this similarity, a new version of the Updated Base Case was created by adding the "pulse flow extender" rule (referred to as Updated Base Case - PFE). The Updated Base Case - PFE produced the best performance indicator values among all of the alternatives considered, and was very close to the optimization based alternative with the pulse flow extender (OBA 3G). According to Table 3.2, the evaluation criteria values for the Updated Base Case with the Pulse Flow Extender rule are almost identical to the Updated Base Case evaluation criteria values, except for the total number of occurrences that Alamo releases equal or exceed 1,000 cfs seven or more days (RA6 and RA7). Figure 3.5 shows the significant improvement in RA6 and RA7 caused by the pulse flow extender rule. Figure 3.5 illustrates that the Updated Base Case with the pulse flow extender and the optimization based alternative with the pulse flow extender (OBA 3G) perform essentially the same with regard to evaluation criteria values. The optimization based alternative performs slightly better on storage related criteria and the Updated Base Case - PFE performs slightly better on flow related criteria.

a. 3.5 Observations

Results from the HEC-PRM model of Alamo Reservoir suggested ways to improve the storage related criteria significantly as evidenced in OBA 2A and OBA 3A. However, due to simplifications required to use HEC-PRM (monthly model based on a network flow algorithm), some of the flow based criteria were not adequately represented in the prescribed operations. The optimization results strongly supported the target elevation of 1,125 feet recommended by the BWRCTC.

The independent modeling exercise, based on a combination of optimization and simulation modeling, confirms that the BWRCTC recommended rule is an efficient one in terms of balancing tradeoffs between storage and flow related criteria. Given the assumption that all of the evaluation criteria are equally important, no alternatives were found to be clearly superior to the BWRCTC recommended rule. Slight improvement in overall performance was gained by an incremental adjustment to the rule that takes advantage of opportunities to extend pulse flows over 1,000 cfs when they occur in the Spring.

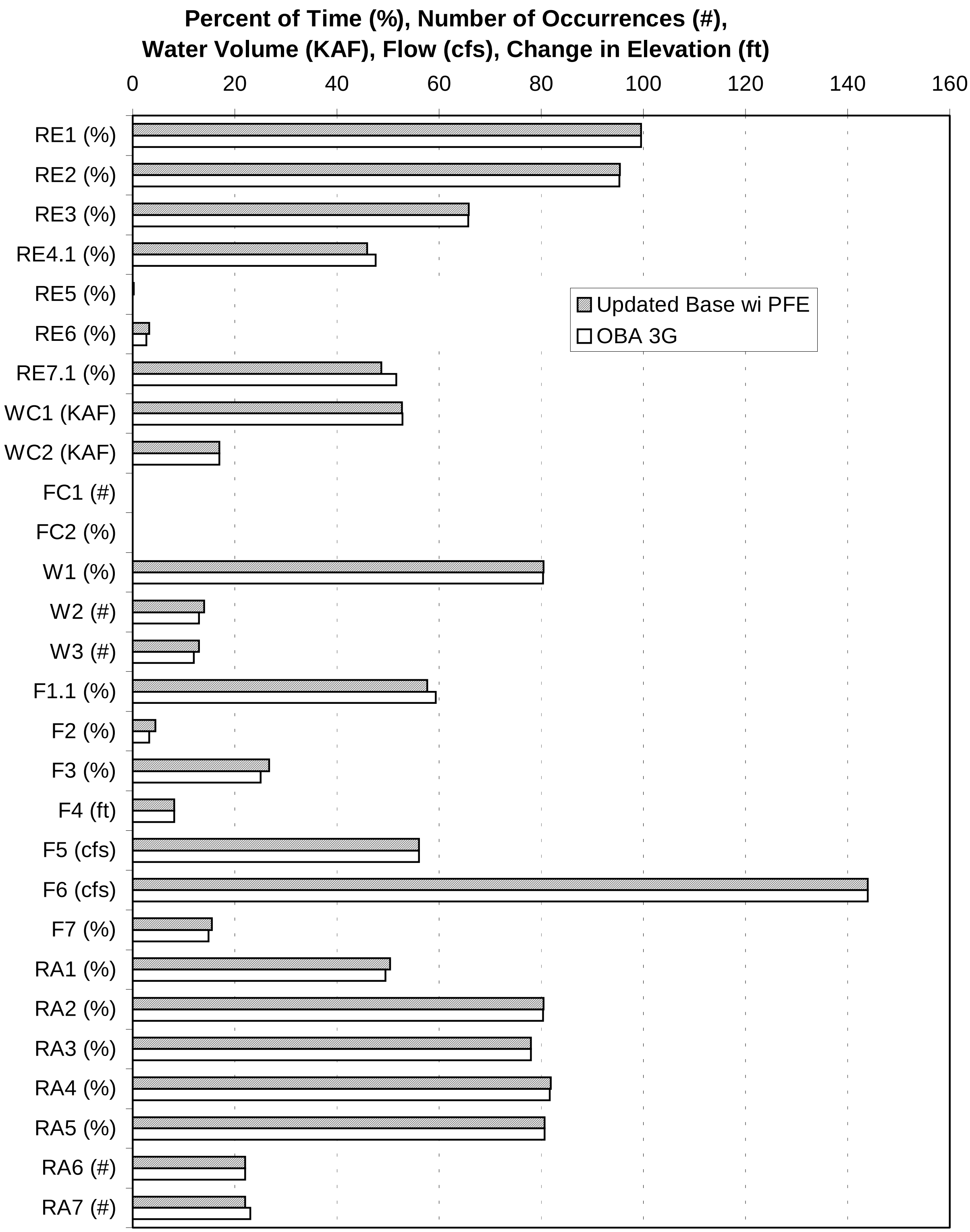

Figure 3.5 Evaluation Criteria: OBA 3G vs Updated Base Case with Pulse Flow Extender

Chapter 4

Testing Maintenance Draw-Down Alternatives

4.1 Draw-Downs for Dam Maintenance

Up to this point in the study, all model runs were made without considering the need to draw down the reservoir periodically to allow maintenance inspections. The remaining alternatives implement a draw-down scheme that lowers the water surface elevation to 1,100 feet to allow inspection and/or maintenance of Alamo Dam's outlet works. The BWRCTC tested alternatives for draw-down based on a fixed interval such as five, ten, or fifteen years. The draw-down scheme tested in the HEC-5 models started gradually lowering the water surface target in June, eventually reaching 1,100 feet in October or November to allow inspection and/or maintenance. The draw-down of the lake to 1,100 feet causes negative impacts on the evaluation criteria values. Based on the variability of inflows evident in the hydrologic record, a more flexible draw-down interval may have less negative impact on the evaluation criteria.

4.2 Proposed Flexible Draw-Down Strategy

For testing purposes, an assumption was made that would allow inspections to take place every three to eight years with a goal to achieve an average frequency of five years. Decisions for draw-down are tied to actual lake conditions and the time since the last inspection. Two different draw-down events are described: low-level draw-down and forced draw-down. If the water surface elevation is low following the historical rainy-season, then that year is a natural candidate for draw-down because storage in the lake is already low and the draw-down would have minimal incremental impact. If, however, an inspection has not been made for the last seven years, a draw-down will be made in the eighth year regardless of lake level.

The following strategy was used:

If the number of years since last inspection is >2 and < 8 then check for a low storage level in September.
If water surface elevation <= 1,105 feet between September 1 and September 15 then check average frequency of inspections updated for an inspection this year.
If average period between inspections updated for this year is > 4.8 then implement low level draw-down release rule.

Else if the number of years since last inspection is = 8 then implement forced draw-down release rule.

Details for the low level draw-down release rule and the forced draw-down release rule are presented in Appendix E. The forced draw-down release rule tries to utilize any surplus water to make the largest spring season pulse flow possible in April. The proposed draw-down scheme was tested for two different operating rules: Updated Base Condition - PFE and OBA 3G. The Updated Base Condition - PFE represents the BWRCTC recommended rule modified to sustain pulse flows greater than 1,000 cfs for at least 7 days, and OBA 3G represents the rule based on the optimization results.

4.3 Performance Improvements

The flexible interval draw-down release rule performs better than the fixed interval rule on many of the criteria. As expected, the alternatives with draw-down perform worse on many of the storage related criteria than the same alternatives without draw-down. Table 4.1 is a summary of the evaluation criteria values for the HEC-5 Base Case alternative with regular five year draw-downs (BWRCTC A1125D05) and the Updated Base Case - PFE and OBA 3G alternatives with and without draw-down. The performance index values in Figure 4.1 show that the flexible draw-down strategy performs better than the fixed interval draw-down on both storage and flow related evaluation criteria overall. Figure 4.2 compares evaluation criteria values for the HEC-5 Base with 5 year draw-down and the Updated Base Case - PFE with flexible draw-down. Figure 4.2 shows that the flexible draw-down performs better for recreation and shows a split for wildlife. The flexible draw-down alternative does better for lake fishery objectives, especially for F4 (maximum water surface drop, in feet, June through September). Results for stream fishery objectives are split between the alternatives. Figure 4.2 shows that the flexible draw-down strategy performs markedly better for riparian objectives, especially on pulse flows (RA6 and RA7).

The reservoir pool elevation time series for the HEC-5 Base with 5 year draw-down (A1125D05) and the Updated Base Case - PFE with flexible draw-down are compared in Figure 4.3. Eleven draw-downs were performed using the flexible draw-down strategy for an average period between draw-downs of 5.6 years. Table 4.2 contains a summary of the draw-down events for the Updated Base Case - PFE with flexible draw-down. The purpose of testing a flexible draw-down interval was to try and reduce the negative impacts of draw-down associated with the variable desert hydrology. If the water level in the reservoir can be used to help decide when to perform the draw-downs, overall reservoir performance should be improved. The evaluation criteria values discussed above confirm this is true, and the time series comparisons illustrate how this takes place. Conditions during 1968 to 1978 (Figure 4.3) dramatically show how scheduling draw-downs according to reservoir condition can provide benefits. Under the flexible draw-down strategy, almost ten years of extended periods of low storage levels experienced using the 5 year draw-down interval are avoided by not drawing down the reservoir at the beginning of drought periods.

Furthermore, under the flexible draw-down strategy, if a low storage level does not occur within the maximum allowable time between inspections, the water in the reservoir that must be

Table 4.1 Impacts from Draw-Down on Evaluation Criteria

	Alternative				
Criteria	HEC-5 Base Case with 5 yr Draw-Down	Updated Base - PFE without Draw-Down	Updated Base - PFE with Flex Draw-Down	OBA 3G without Draw-Down	OBA 3G with Flex Draw-Down
RE1 (%)	96.7	99.5	99.6	99.5	99.6
RE2 (%)	90.5	95.4	95.2	95.3	94.6
RE3 (%)	49.0	65.8	60.0	65.7	58.8
RE4.1 (%)	34.9	45.9	40.6	47.6	42.1
RE5 (%)	0.2	0.2	0.2	0.1	0.1
RE6 (%)	4.7	3.3	3.4	2.7	3.0
RE7.1 (%)	41.0	48.7	43.0	51.6	45.7
WC1 (af)	53,463	52,728	53,129	52,802	53,241
WC2 (af)	15,844	16,971	16,622	16,949	16,576
FC1 (#)	0	0	0	0	0
FC2 (%)	0.0	0.0	0.0	0.0	0.0
W1 (%)	69.2	80.4	77.8	80.4	77.5
W2 (#)	11	14	13	13	12
W3 (#)	11	13	12	12	11
F1.1 (%)	43.9	57.7	51.9	59.4	53.2
F2 (%)	4.6	4.5	5.4	3.2	4.2
F3 (%)	27.1	26.7	27.6	25.1	25.8
F4 (ft)	20.0	8.1	9.4	8.1	11.0
F5 (cfs)	72.0	56.0	58.0	56.0	59.0
F6 (cfs)	137.0	144.0	143.0	144.0	143.0
F7 (%)	19.0	15.5	15.9	14.8	15.2
RA1 (%)	51.3	50.4	49.6	49.5	48.7
RA2 (%)	69.5	80.4	77.8	80.4	77.5
RA3 (%)	59.6	78.0	73.3	78.0	73.1
RA4 (%)	70.3	81.8	79.6	81.7	79.4
RA5 (%)	61.2	80.6	78.7	80.6	78.1
RA6 (%)	12	22	21	22	21
RA7 (%)	16	22	25	23	26

Note: Gray cells indicate that lower values are preferred.

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

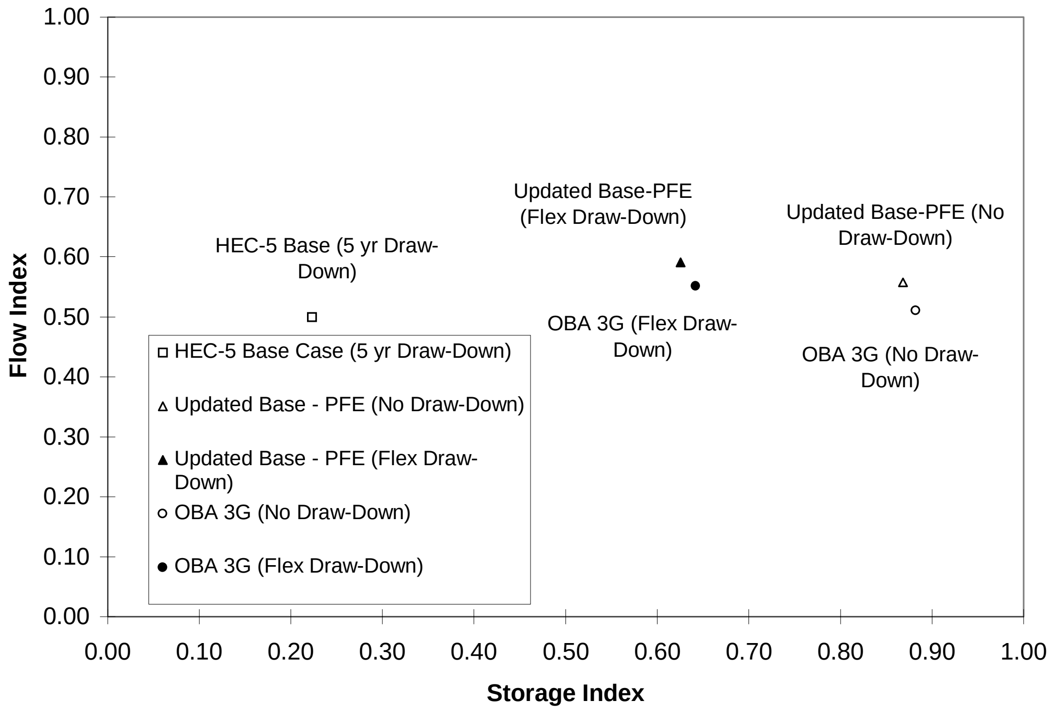

Figure 4.1 Performance Indexes for Alternatives with Draw-Down

evacuated is scheduled to provide spring flushing flows deemed to be important to long term vitality of the riparian corridor (BWRCTC 1994). Figure 4.4 shows releases during 1935 (one of the four years in which a forced draw-down was performed under the flexible draw-down strategy). Since a draw-down had not been performed within the last eight years of the simulation, the model forces a draw-down in 1935 even though the reservoir level is not low. Since there is surplus water, the model calculates how much water is available and makes a spring flushing flow release according to the guidelines in the *Proposed Water Management Plan* (BWRCTC 1994), retaining enough water to make desired releases from April to November. (See Appendix E for details.)

Comparing exceedance probabilities for reservoir pool elevation and Alamo Dam releases also show that the flexible draw-down scheme provides significant benefits. Figure 4.5 has exceedance curves for reservoir pool elevations for the fixed five year draw-down and the flexible draw-down strategy. At the 90% exceedance the water surface elevation for the five year interval alternative is 1,094 feet (meaning that the reservoir pool elevation is at or above 1,094 feet 90 percent of the days simulated). The flexible draw-down plan exceeds 1,096 feet 90% of the time, two feet higher than the fixed draw-down interval. Also, note that the fixed draw-down interval is below 1,100 feet 27% of the days simulated, and the flexible draw-down alternative is below 1,100 feet only 21% of the days simulated. This means that the flexible draw-down alternative is able to keep reservoir levels above the minimum level requested for bald eagle forage purposes (BWRCTC 1994) 6% more often (about 4 years more). At the 50% exceedance

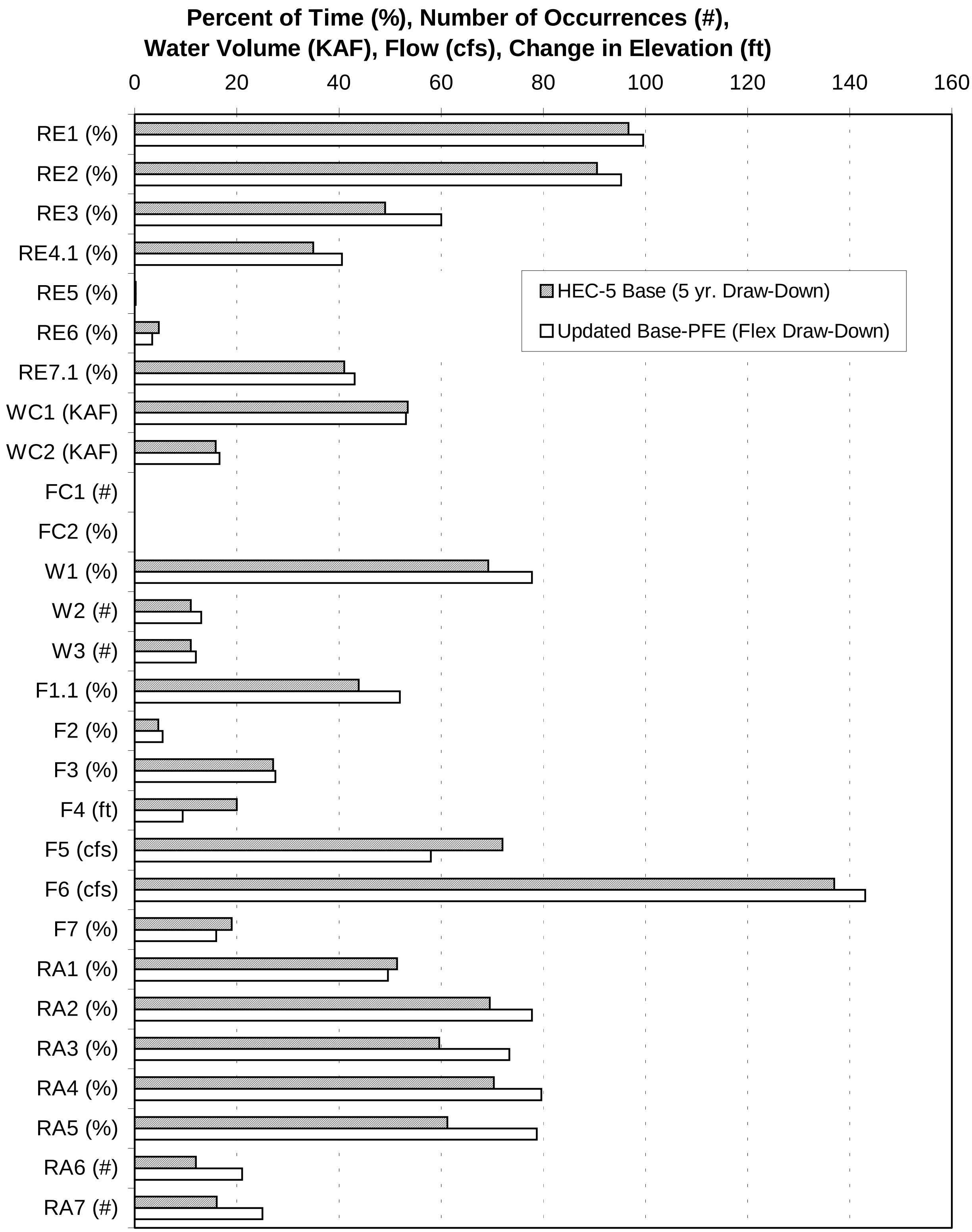

Figure 4.2 Evaluation Criteria: 5 Year vs Flexible Draw-Down

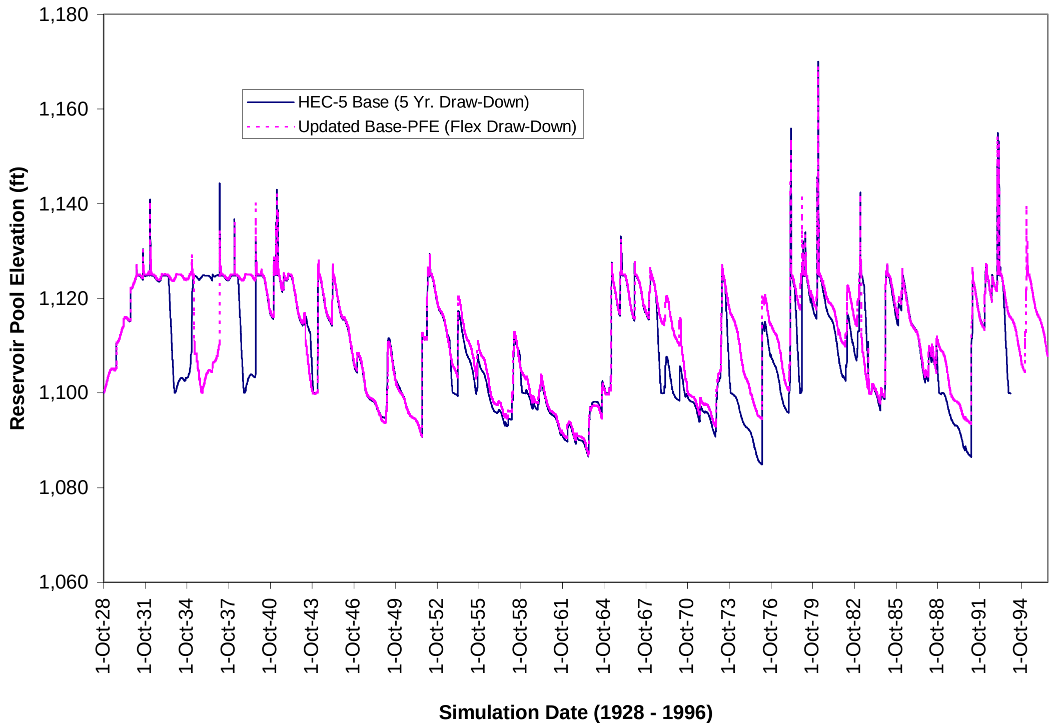

Figure 4.3 Reservoir Pool Elevation Time Series: 5 Yr. vs Flexible Draw-Down

Table 4.2 Summary of Draw-Downs for Updated Base Case-PFE (Flexible Draw-Down)

Draw-Down Type	Year	Number of Years Between Draw-Downs
Forced	1935	8
Forced	1943	8
Low level	1947	4
Low level	1950	3
Low level	1956	6
Low level	1959	3
Low level	1962	3
Forced	1970	8
Low level	1975	5
Forced	1983	8
Low level	1989	6

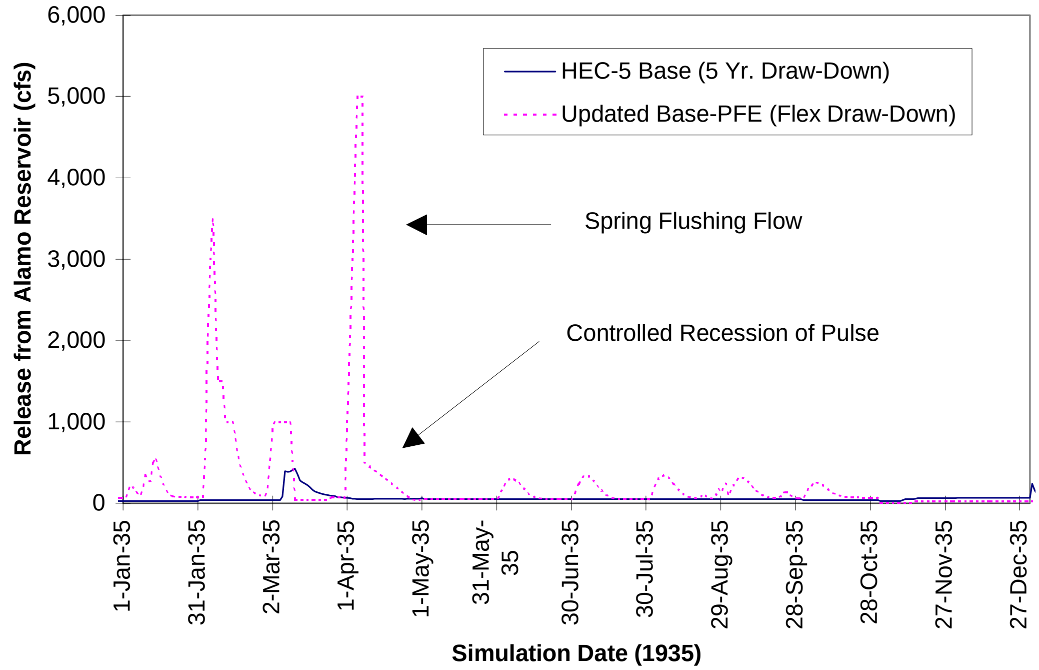

Figure 4.4 Spring Pulse Flow Resulting from Forced Draw-Down

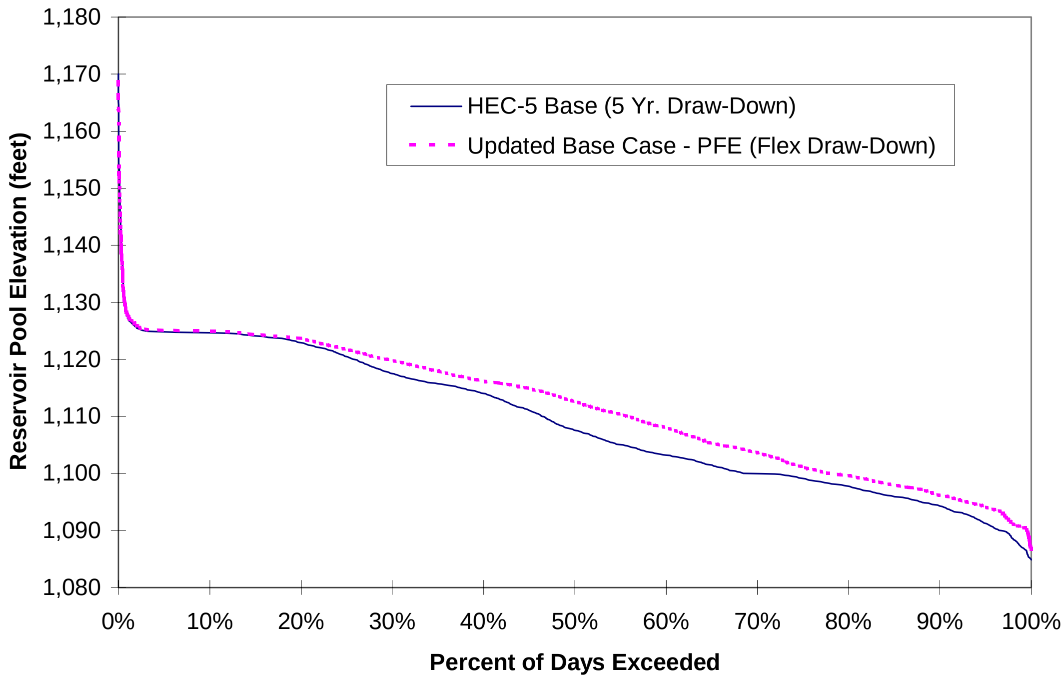

Figure 4.5 Elevation Exceedance Probabilities: 5 Year vs Flex Draw-Down

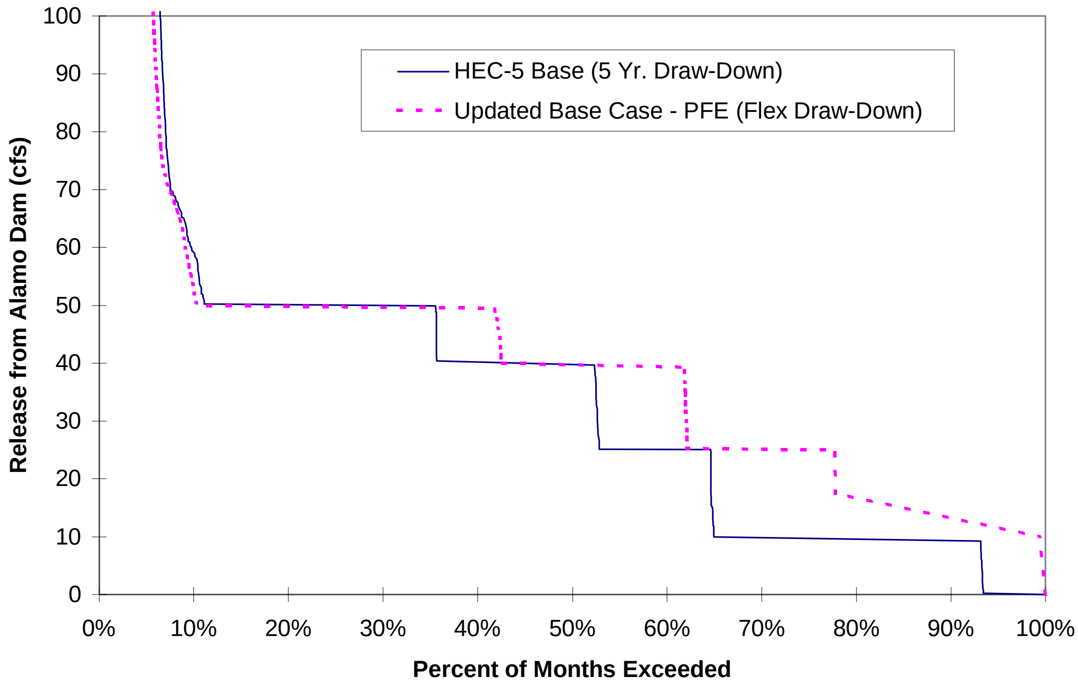

Figure 4.6 Release (< 100 cfs) Exceedance Probabilities: 5 Year vs Flex Draw-Down

level, the flexible draw-down scheme is at 1,113 feet and the fixed draw-down alternative is at 1,107 feet, six feet lower than the flexible draw-down alternative.

Exceedance probabilities for releases from Alamo Dam also help demonstrate the benefits of the flexible draw-down approach. Figure 4.6 compares the probability of exceeding releases below 100 cfs for the two draw-down alternatives. Note that under both alternatives, releases are below 100 cfs over 95% of the time. In general, the flexible draw-down strategy does significantly better maintaining desired flows for riparian objectives. The flexible draw-down alternative makes releases of 25 cfs or higher 78% of the time and 50 cfs 42% of the time whereas the fixed draw-down alternative can only meet or exceed these releases 65% and 36% of the time respectively.

The exceedance curves for releases below 25 cfs also are quite different. Statistics for releases below 25 cfs are not included in any of the evaluation criteria, but are likely to be important in comparing operational strategies. Observe that the flexible draw-down alternative is able to make releases at or above 10 cfs over 99 % of the time as compared to only 65 % of the time for the fixed draw-down alternative. The exceedance curves also suggest that the fixed interval draw-down makes no release (0 cfs) about 7% of the days whereas the flexible draw-down alternative makes no release less than 1% of the time. This large difference in the amount of time when no water is released from Alamo Dam between the alternatives appears to be due largely to the way draw-downs are implemented in the BWRCTC HEC-5 Alamo model. In the

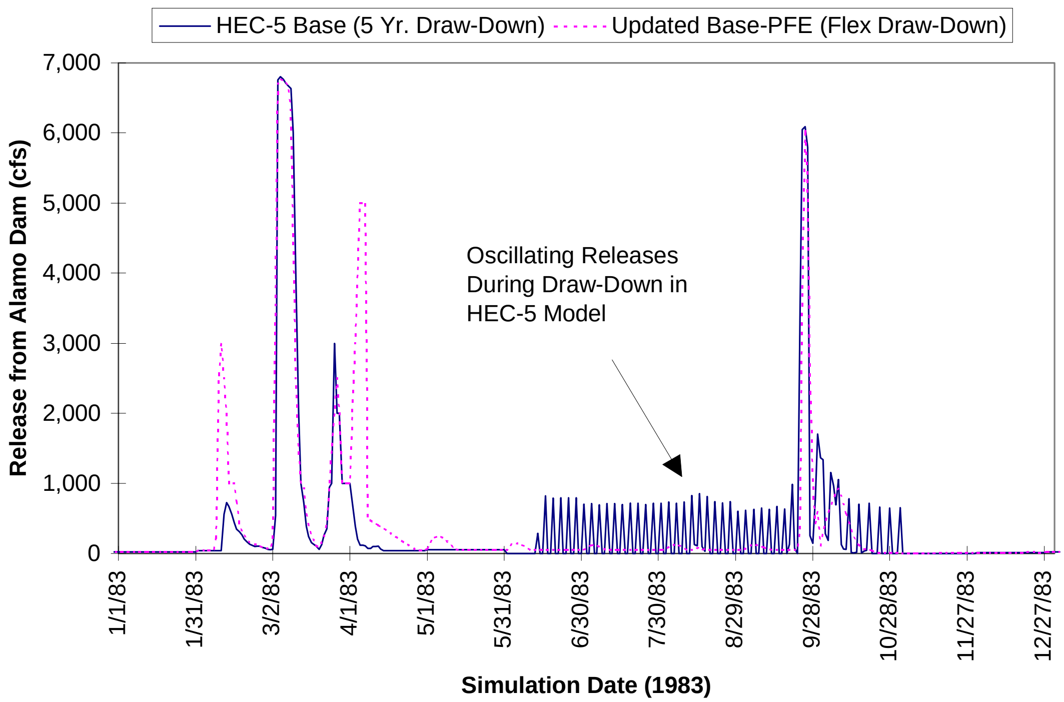

Figure 4.7 Oscillating Releases in HEC-5 Model During Draw-Down

HEC-5 model, draw-downs are made every five years. The draw-down is made over about five months, and during these five months the releases oscillate between values of 100 to 800 cfs for one day often followed by releases of 0 cfs for two or three days. Figure 4.7 illustrates this pattern for the HEC-5 draw-down event in 1983. This oscillation between relatively high releases and no release skews the release statistics and complicates direct comparison between the two different models. (This could be corrected by modifying the input configuration of the Alamo model in HEC-5.)

This unusual release pattern for the draw-down alternatives simulated with HEC-5 also may cause misleading values for some of the flow based evaluation criteria values. For instance, RE6 (Percent of time outflow is between 300 and 7,000 cfs) would likely have a higher value for alternatives simulated with the HEC-5 model due to the pattern of high flows (600 to 800 cfs) followed by 0 cfs flows. Figure 4.2 and Table 4.1 show that the HEC-5 modeled alternative does have the highest value for RE6. Figure 4.8 shows that flows between 100 and 800 cfs do occur more frequently in the HEC-5 modeled alternative. However, if the time series of releases are compared between the two models, flows in this range occur primarily during the HEC-5 draw-down events.

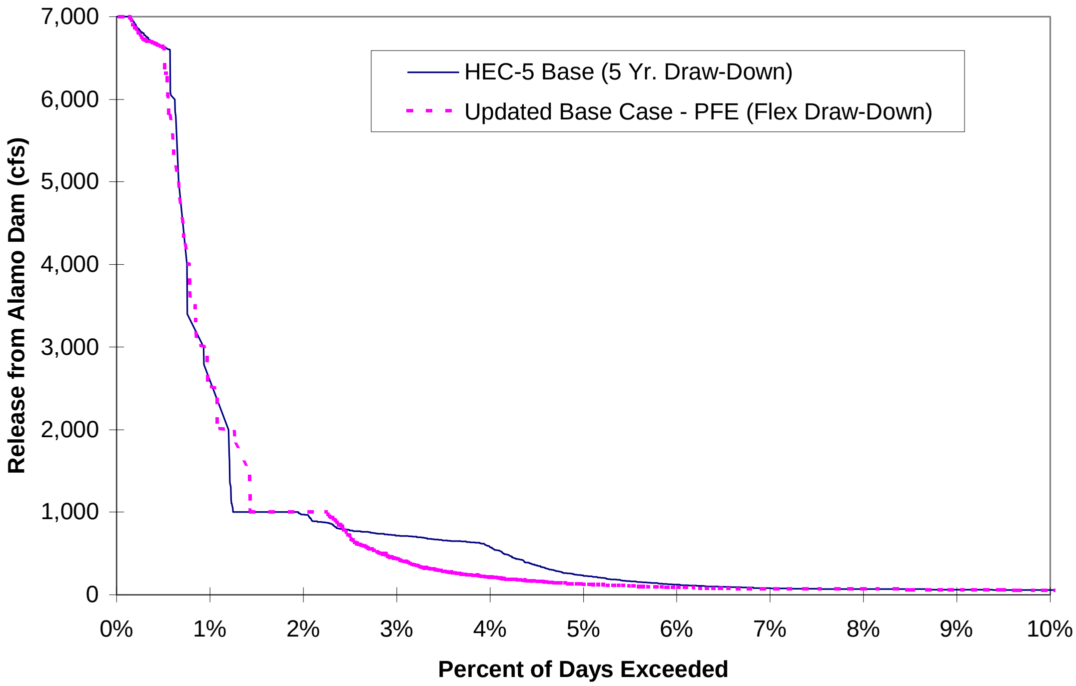

Figure 4.8 Release Exceedance Probabilities (0-10%): 5 Year vs Flex Draw-Down

Chapter 5

Bald Eagle Nest Protection

5.1 History of Eagles at Alamo Reservoir

Bald eagles have been observed nesting near Alamo Reservoir since December 1986. Two pair of eagles have been returning each year. One pair, called the Alamo eagles, have nested on a tree snag within the reservoir seven out of the nine years between 1988 and 1996. Another pair, called the Ive's Wash eagles, have nested on a snag within the reservoir two out of ten years between 1987 and 1996. The other eight years, the Ive's Wash eagles have nested on a cliff below Alamo Dam. When the eagles nest in a snag within the area of the reservoir, the nest is in danger of inundation due to rising reservoir levels. Also, if the water level rises a few feet up the base of the tree, boaters approaching the nest can be considered harassment under the Endangered Species Act. The eagles typically build their nests in the fall (October to December) after the dry summer months when the lake tends to be low. Historically, when the eagles have selected a snag, the reservoir water surface has been at the base of the tree or lower.

The problem of nest inundation was not addressed specifically during the BWRCTC study for the *Proposed Water Management Plan* (1994). This study evaluates strategic operation policies to reduce or prevent bald eagle nest inundation and harassment. The resulting impacts on the other interests, including other federally listed species dependant on the riparian corridor downstream are approximated.

5.2 Modeling Eagle Nesting

According to data provided by Greg Beatty, Acting Nonpasserine Birds Program Manager, Arizona Game and Fish Department, the nest sites chosen between 1987 and 1996 were between elevations 1,135 and 1,138 feet. Data for one of the nests shows that the base of the nest is approximately 22 feet above the ground. This means that the base of the tree is somewhere between 1,113 and 1,116 feet. According to Mr. Beatty, the eagles built a nest at the beginning of the 1997 breeding season in a willow snag, five to ten feet lower than previous nests, and about 200 feet west of the previous nest sites. There are numerous snags around the lake, and the exact elevations of possible nesting sites is not known.

In order to simulate the interaction of eagle nesting and reservoir operation, several assumptions were made:

- The Alamo eagles have a 0.778 probability of using a nesting site within the reservoir, based on historical pattern of 7 out of 9 years.

- The Ive’s Wash eagles have a 0.20 probability of using a nesting site within the reservoir, based on historical pattern of 2 out of 10 years.
- Both pairs of eagles could nest within the reservoir in any given year.
- Eagles can choose a nesting site elevation between 1,125 feet and 1,138 feet based on available snags.
- Both pairs of eagles will choose their nesting site and the elevation will be known by November 1 of each year.
- Eagles will not build a nest closer than fifteen feet to the surface of the water surface on November 1. (This means the valid nesting elevation range will be reduced if the reservoir water surface is above 1,110 feet.)
- Harassment occurs, due to boat accessibility, at water surface elevation 1,115 feet.
- Eagle young normally fledge by late May, but often remain in the nest through July.

The AlamoSim model includes a probabilistic simulation component that simulates the nesting location of each eagle pair on November 1 based on the above frequencies. This simulation approach consists of using a statistical sampling technique to represent stochastic inputs, and applying these inputs to a model to determine the resulting outputs. This approach is often referred to as Monte Carlo simulation (Hillier and Lieberman 1995). If either of the eagles are simulated to nest within the reservoir, a nest elevation is selected from the available nesting site range. The available nesting site range is represented as a uniform distribution between 1,125 and 1,138 feet, modified by the reservoir water surface elevation. For example, if the water surface elevation is 1,112.5 feet on November 1, the available nesting site range would be 1,127.5 to 1,138 feet. (The lower range is determined by adding 15 feet to the water surface elevation of 1,112.5 feet.) Using this technique, if the reservoir is high enough on November 1, there could be no available nesting sites on the reservoir for that year.

An additional post processing routine was developed to quantify impacts on the eagle nests. The eagle data post processor summarizes the nest elevations for each year a nest is within the reservoir, the number of days the water surface elevation exceeds 1,115 feet when a nest is within the reservoir (representing a nuisance), the number of days the water surface elevation is within 5 feet of the nest, and the number of days the water surface elevation equals or exceeds the elevation of the nest. The post processor also keeps track of the number of inundation events. An inundation event occurs if the reservoir pool elevation reaches the nest elevation during the nesting season. Once a nest is inundated, it is assumed to be abandoned. Under these assumptions there can never be more than two inundation events in a given year, (a maximum of one per nest per year). All of this data is computed for the period November to July and December to May.

5.3 Considering the Threat of Inundation

The probability of the eagles being affected by rising lake levels is subject to the elevation at which the eagles nest, the storage of the reservoir at the beginning of the nesting season, the inflows during the nesting season, the operating strategy, and the physical constraints on release capacity. To evaluate possible operating strategies to try and prevent negative impacts to eagle nesting due to rising lake levels, some tests were done to characterize the possibility of protection.

Four of the largest flood events from the historical record of daily inflows were used to determine roughly the largest net increase in storage that would occur based on inflow and release capacity. The following events were used:

Start Date	*End Date*	*Maximum Increase in Storage (acre-ft)*
12/01/1940	5/31/1941	58,700
1/1/1978	4/30/1978	146,600
1/10/1980	3/31/1980	202,900
1/1/1993	3/22/1993	115,500

One of the events (1980) would cause water levels to encroach well into the range of nesting elevations *even if the reservoir were completely empty* at the beginning of the floods and maximum releases were made during the floods. This simple analysis demonstrates that the eagle nests can not be protected 100 % of the time without structural modifications to the dam outlet works.

Another analysis was done to gain a better understanding of possible maximum reservoir levels between November 1 and July 31. AlamoSim was modified to simulate operation using optimization based alternative 3G (OBA 3G) from November 1 to July 31, starting over each year from a specified storage level. Results from this analysis show the maximum reservoir levels that would occur when starting from a given reservoir pool level on November 1 and operating according to alternative OBA 3G. Simulations were run for November 1 starting elevations of 1100, 1105, 1110, 1115, and 1120 feet. Figure 5.1 shows the traces of reservoir pool elevations between November 1 and July 31 for the 68 years of inflow with a starting pool elevation of 1,100 feet. Figure 5.2 shows the 68 traces for a starting pool elevation of 1,120 feet. Note that under both starting conditions there are numerous peaks that reach or exceed the potential nesting elevations. Information contained in these multiple event traces was summarized by computing the maximum reservoir pool elevation exceedance probabilities for the different starting elevations. Figure 5.3 contains curves that describe the probability (X) that the maximum reservoir elevation between November 1 and July 31 for a single year will not exceed some value (Y) given a starting elevation of 1100, 1105, 1110, 1115 or 1120 feet. These curves provide the following types of information:

> If the reservoir pool elevation in Alamo this November 1 is 1,100 feet, there is a 0.75 probability that the reservoir pool elevation will not exceed 1,125 feet before July 31, and a 0.93 probability that it will not exceed 1,138 feet. Or conversely,

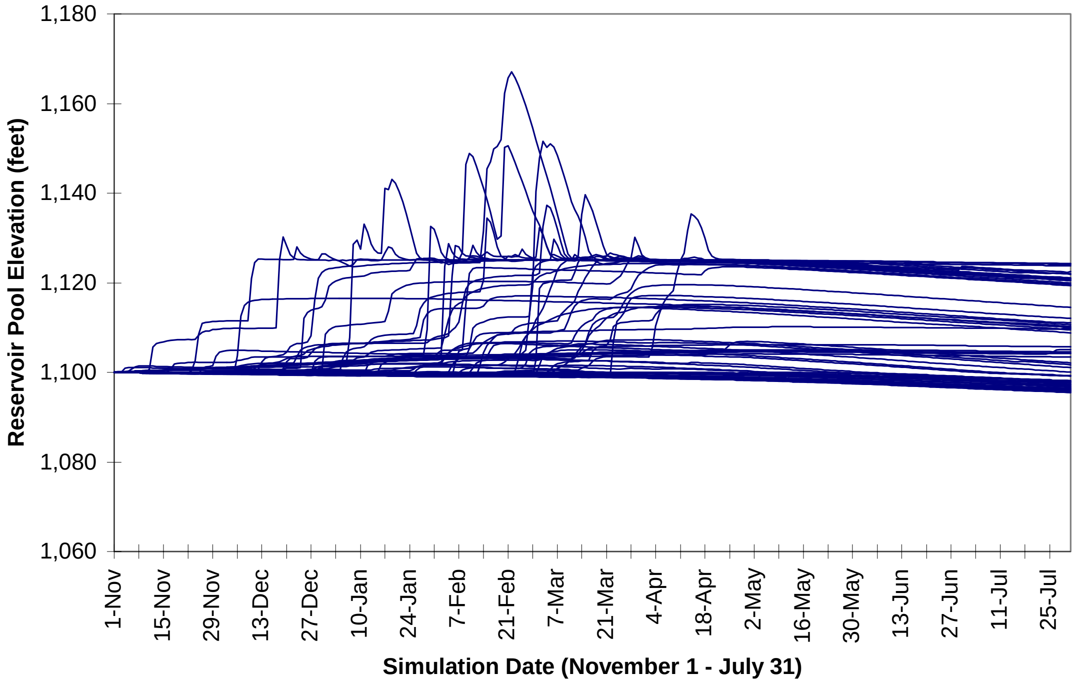

Figure 5.1 Possible Reservoir Pool Elevations Under OBA 3G Starting From 1,100 feet on November 1

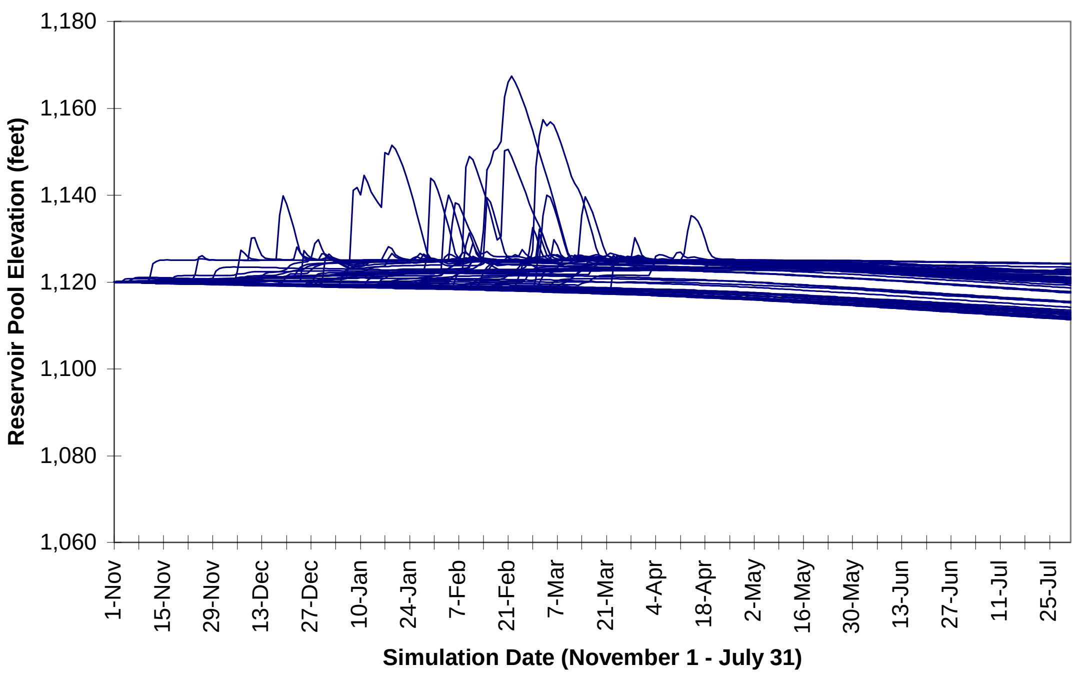

Figure 5.2 Possible Reservoir Pool Elevations Under OBA 3G Starting From 1,120 feet on November 1

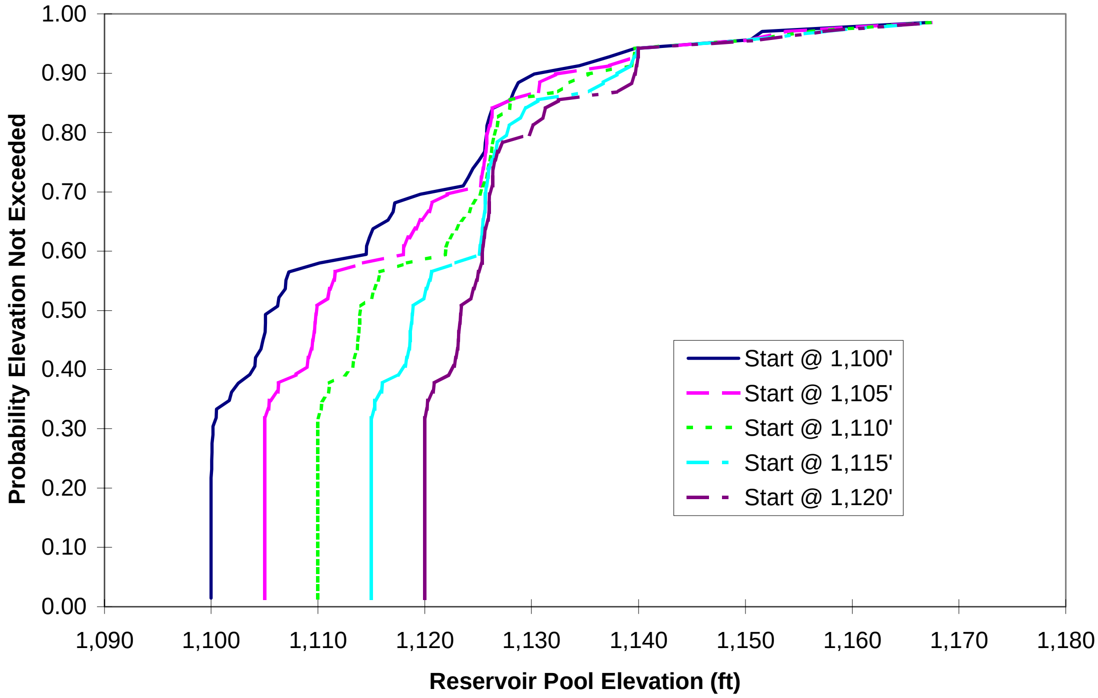

Figure 5.3 Probability of Maximum Reservoir Pool During November through July for Alternative OBA 3G for Different Starting Elevations on November 1

there is a 25% chance that the elevation will exceed 1,125 feet and a 7% chance that it will exceed 1,138 feet between November 1 and July 31.

If the reservoir pool elevation is 1,120 feet on this November 1 , there is a 0.57 probability that the reservoir pool elevation will not exceed 1,125 feet before July 31, and a 0.87 probability that it will not exceed 1,138 feet. This means that if the reservoir level is at 1,120 feet on November 1 and an eagle nest is occupied then there is at least a 13% chance that it will be inundated if no preventative measures are taken.

This position analysis (Hirsch 1978) of possible maximum reservoir pool elevations given different starting elevations demonstrates that a significant flood threat exists any time a nest is occupied within elevations of 1,125 feet and 1,138 feet.

5.4 Negative Impacts on Eagles from Previously Proposed Policies

To approximate the impact on eagle nesting caused by water surface elevations in Alamo reservoir, two previously discussed operating alternatives (Updated Base Case - PFE WD and OBA 3G WD) were tested with the eagle nesting component in the model active. AlamoSim

Table 5.1 Impacts on Eagle Nesting Updated Base Case - PFE WD vs OBA 3G WD

	Alternative	
Criteria	OBA 3G WD	Updated Base Case - PFE WD
IN1	10	12.2
IN2	14.7	18.0
EG1	37.3	37.0
EG2	7.82	8.24
EG3	2.10	2.24
EG4	0.55	0.81
EG5	0.14	0.23
EG6	37.6	37.3
EG7	9.2	9.8
EG8	2.4	2.7
EG9	0.83	1.2
EG10	0.20	0.34
# of Simulations	200	200

IN1 - Number of nests flooded at least once in a year
IN2 - Probability of inundation event occurring in any year (%)
EG1 - Percent of days WSE >= 1,115 during Nov thru Jul (Harassment)
EG2 - Percent of days WSE within 5 feet of Alamo eagle nest during Nov thru Jul
EG3 - Percent of days WSE within 5 feet of Ive's Wash eagle nest during Nov thru Jul
EG4 - Percent of days WSE >= elevation of Alamo eagle nest during Nov thru Jul
EG5 - Percent of days WSE >= elevation of Ive's Wash eagle nest during Nov thru Jul
EG6 - Percent of days WSE >= 1,115 during Dec thru May (Harassment)
EG7 - Percent of days WSE within 5 feet of Alamo eagle nest during Dec thru May
EG8 - Percent of days WSE within 5 feet of Ive's Wash eagle nest during Dec thru May
EG9 - Percent of days WSE >= elevation of Alamo eagle nest during Dec thru May
EG10 - Percent of days WSE >= elevation of Ive's Wash eagle nest during Dec thru May

was run as before on a daily time step between October 1, 1928 to August 29, 1996, except instead of running the simulation once, it was run at least 200 times. The reservoir operation was exactly the same for every simulation, but the eagle nesting elevations could change during each year of each simulation. By running the simulation many times and averaging the results, an approximation of impacts on eagle nesting is made assuming inflows in the near future are similar to those observed over the past sixty eight years.

Evaluation criteria proposed to measure the impacts on the eagle nesting is shown in Table 5.1. The Optimization Based Alternative with flexible draw-down (OBA 3G WD) caused an average of 10 inundation events over sixty eight years of operation. Therefore the probability that a nest will be inundated in any given year is 0.147 when operating according to this operational policy. The Updated Base Case - PFE with flexible draw-down (Updated Base Case - PFE WD) resulted in an average of 12 inundation events over sixty eight years of operation and a 0.181 probability that a nest may be inundated in any year. Also, for both alternatives, the water level is high enough to allow harassment for around 37% of the days during November through July.

If the reservoir is operated according to one of the two alternatives proposed earlier, (including a version of the BWRCTC recommended policy), an eagle nest is likely to be inundated on average every 6 or 7 years and water levels are expected to be high enough to allow harassment from boaters 37% of the time. Figure 5.4 shows the occurrence of harassment and encroachment for both the Alamo and Ive's Wash eagles during November through July according to the two alternatives tested.

5.5 Operating to Reduce the Likelihood of Nest Inundation

Since the analysis discussed above showed that eagle nest inundation could not be prevented 100% of the time, an operating policy was devised to try and achieve a 95% protection rate against eagle nest inundation. The rule form is similar to the other Optimization Based Rule forms discussed earlier. Details for the protection rule are in Appendix F. The simulation for protecting eagle nests against inundation in AlamoSim depends on the probabilistic simulation of the eagle nesting events. If one or two eagle nests are simulated to be active within the reservoir, then the eagles are said to be vulnerable. If the eagles are vulnerable, then the operational policy is switched from the "normal" policy to the protection rule. If the protection rule is invoked, it remains active from November 1 to July 31. The main difference between the protection rule and the "normal" rule is the storage target. If an eagle nest is inhabited, then the storage target is set to 101,000 acre-feet (1,107.3 feet elevation) as opposed to 160,977 acre-feet (1,125 feet elevation) used in the "normal" operation. This lower storage target is necessary to provide storage space in the reservoir to contain flood events while trying to reduce the chance of inundation to 5% or less.

Two eagle protection alternatives were studied by adding the eagle protection rule component to the best two alternatives analyzed previously, (now referred to as Updated Base Case - PFE WD EP and OBA 3G WD EP, where EP indicates eagle protection). Under the Updated Base Case - PFE WD EP, if no eagle nests are vulnerable, then the alternative uses the same operating policy as used in Updated Base Case - PFE WD. If an eagle nest is vulnerable, then the eagle protection rule described above becomes the controlling operating policy. Again, the daily simulation for the period of record was run at least 200 times, with probabilistic simulation of eagle nesting each year. The results were monitored after each fifty runs to

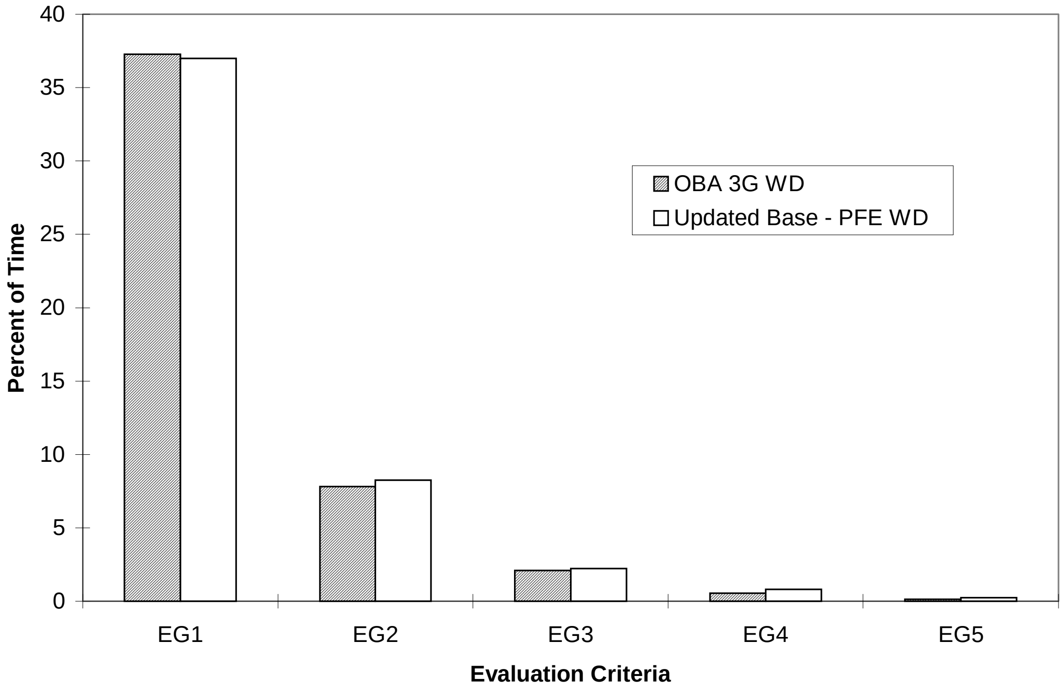

Figure 5.4 Evaluation Criteria for Alternatives without Protection

determine when the model outputs were stable. Table 5.2 contains the estimated impacts to the eagles under the two protection-oriented operating policies. Both alternatives were able to achieve slightly better than 95% protection against inundation events — 9% to 13% better than protection policy. The frequency of conditions deemed to allow harassment is reduced from 37% without protection to less than 1% with protection. The protection strategies reduce, but do not eliminate negative impacts on the eagles' nesting. However, these improvements for the eagles' nesting come at a price of reduced performance for other objectives.

5.6 Performance Trade-offs

As shown above, the operational strategies tested to reduce negative impacts on bald eagle nesting were successful. The frequency of inundation was reduced from 18% per year to 5% per year -- a 72% reduction. Unfortunately, this change in operation also caused a significant decrease in performance for other objectives. Table 5.3 presents a summary of evaluation criteriavalues for the Updated Base Case - PFE WD and the OBA 3G alternatives with and without eagle nest protection. The performance index values shown in Figure 5.6 suggest that the alternatives with and without eagle nest protection. The performance index values shown in Figure 5.6 suggest that the alternatives with eagle protection perform worse overall for storage related criteria, and better overall for flow related criteria.

Table 5.2 Impacts on Eagle Nesting when Protecting Against Inundation

	Alternative	
Criteria	OBA 3G WD with Protection	Updated Base Case - PFE WD with Protection
IN1	3.2	3.3
IN2	4.7	4.9
EG1	0.6	0.7
EG2	0.30	0.30
EG3	0.07	0.08
EG4	0.21	0.20
EG5	0.05	0.06
EG6	0.9	0.9
EG7	0.4	0.4
EG8	0.1	0.1
EG9	0.31	0.30
EG10	0.07	0.09
# of Simulations	200	200

IN1 - Number of nests flooded at least once in a year
IN2 - Probability of inundation event occurring in any year (%)
EG1 - Percent of days WSE >= 1,115 during Nov thru Jul (Harassment)
EG2 - Percent of days WSE within 5 feet of Alamo eagle nest during Nov thru Jul
EG3 - Percent of days WSE within 5 feet of Ive's Wash eagle nest during Nov thru Jul
EG4 - Percent of days WSE >= elevation of Alamo eagle nest during Nov thru Jul
EG5 - Percent of days WSE >= elevation of Ive's Wash eagle nest during Nov thru Jul
EG6 - Percent of days WSE >= 1,115 during Dec thru May (Harassment)
EG7 - Percent of days WSE within 5 feet of Alamo eagle nest during Dec thru May
EG8 - Percent of days WSE within 5 feet of Ive's Wash eagle nest during Dec thru May
EG9 - Percent of days WSE >= elevation of Alamo eagle nest during Dec thru May
EG10 - Percent of days WSE >= elevation of Ive's Wash eagle nest during Dec thru May

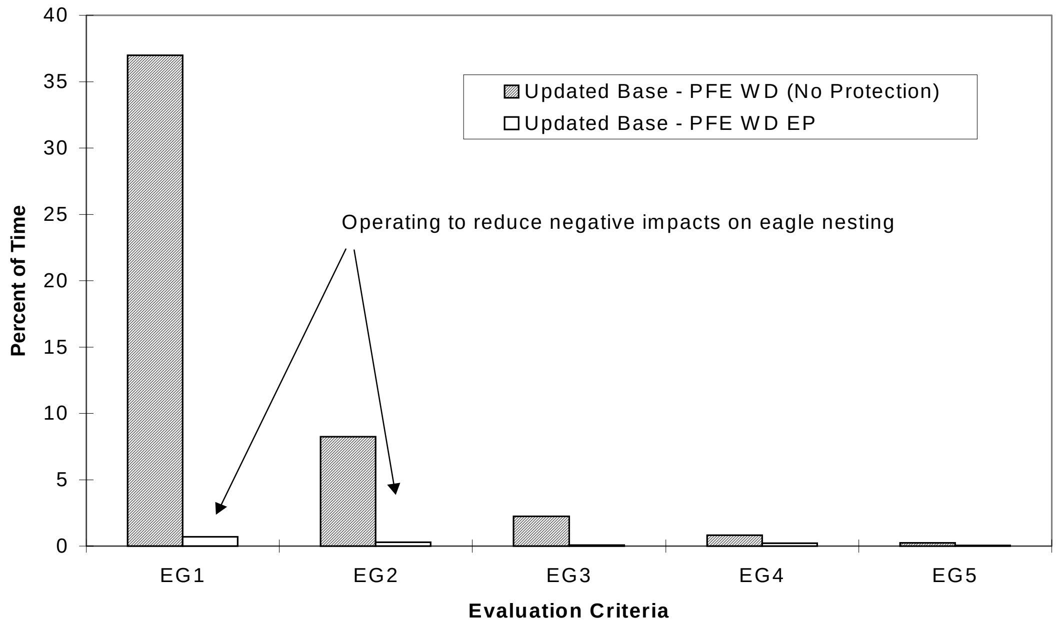

Figure 5.5 Eagle Evaluation Criteria: No Protection vs Eagle Nest Protection

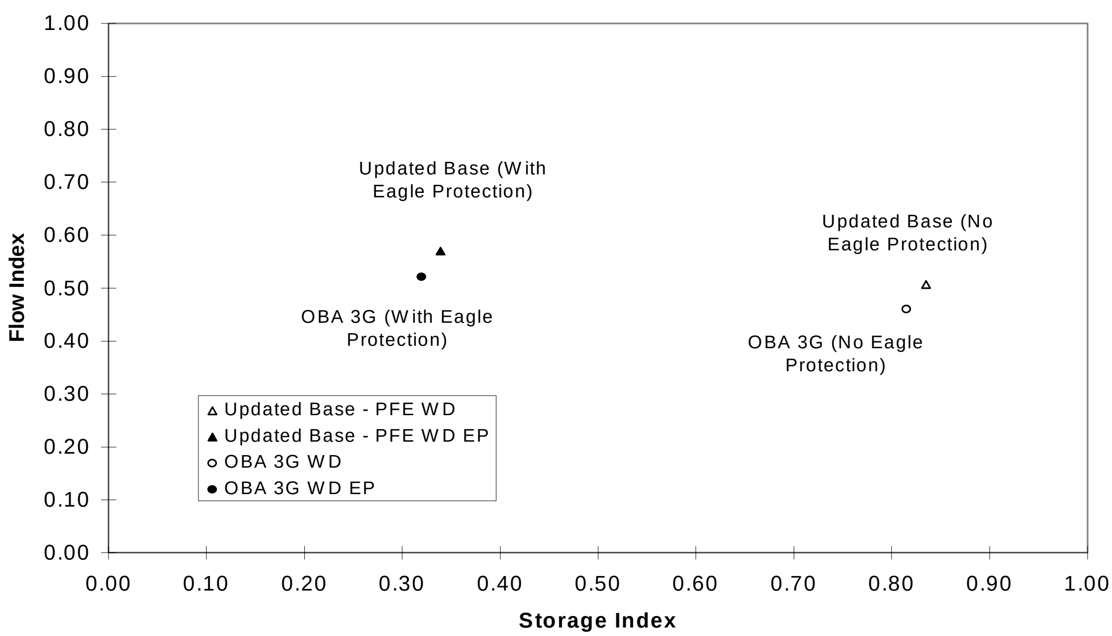

Figure 5.6 Performance Index Values for Alternatives With and Without Eagle Protection

Figure 5.7 offers a direct comparison of evaluation criteria values for the Updated Base Case (including the pulse flow extender and flexible draw-down rules) without eagle protection and with eagle protection. The recreation evaluation criteria values are much worse for the alternative designed to protect eagle nesting as shown in Figure 5.7. The largest recreation related decline occurs for RE3 (percent of time WSE at or above 1,108 feet), going from 60% to only 10% -- an 83% reduction in performance. The eagle protection policy does slightly better for water conservation evaluation criteria with an 8% increase in the average annual delivery to Lake Havasu and a 14% reduction in average annual evaporation from Alamo.

Results for the fishery evaluation criteria are mixed. For instance, the F2 criteria (a measure of lake fluctuation during spawning and growing season) value for the policy with eagle protection is 35% better than the policy without eagle protection, but the value for F1.1 (a measure of how frequently the water level is within a desirable zone in the lake to support spawning and growing) is 84% lower for the protection alternative.

The eagle nest protection policy is designed to reduce the threat to the eagles' welfare posed by the reservoir, but ironically this threat exists because the reservoir is such an attractive site to nest and raise young. The reservoir serves as the primary forage area for the eagles that nest in the basin. In a 1988 letter to the Corps, the U.S. Fish and Wildlife Service requested that Alamo Lake not be drawn down below 1,100 feet to ensure adequate forage area for the two pairs of eagles nesting near the reservoir (BWRCTC 1994). While helping the eagles by reducing the threat of harassment and nest inundation, the protection alternatives also harm the eagles by causing the lake level to drop below 1,100 feet elevation much more often. Figure 5.7 shows that W1, the percent of time the WSE is greater than or equal to 1100 feet, decreases from 78% (with no nest protection) to 53% (with nest protection). Under the scenarios tested, the risk of flooding a nest in a year can be reduced from 18% to 5%, but at a cost of 25% more days that the forage area is below a level deemed adequate.

Operating to protect against eagle nest inundation would also impact other listed species dependant on the riparian corridor. Figure 5.7 shows large decreases in performance for several of the riparian evaluation criteria. Five of the criteria values (RA1 - RA5) are between 27% to 43% lower under the eagle nest protection policy.

These results illustrate one of the most challenging aspects about managing Alamo Reservoir. If the reservoir is managed to try and reduce harassment and nest inundation for the bald eagles, then other listed species are impacted in a negative way. In fact, even the bald eagles are impacted negatively due to more frequent low lake levels.

Table 5.3 Evaluation Criteria Summary: With and Without Eagle Protection

	Without Protection		With Protection	
Criteria	Updated Base-PFE WD	OBA 3G WD	Updated Base-PFE WD EP	OBA 3G WD EP
RE1 (%)	99.6	99.6	98.3	98.4
RE2 (%)	95.2	94.6	89.7	89.8
RE3 (%)	60.0	58.8	10.2	10.0
RE4.1 (%)	40.6	42.1	5.3	5.4
RE5 (%)	0.2	0.1	0.1	0.0
RE6 (%)	3.4	3.0	3.5	3.4
RE7.1 (%)	43.0	45.7	5.7	5.9
WC1 (af)	53,129	53,241	57,328	57,330
WC2 (af)	16,622	16,576	14,229	14,224
FC1 (#)	0	0	0	0
FC2 (%)	0.0	0.0	0.0	0.0
W1 (%)	77.8	77.5	53.4	53.6
W2 (#)	13	12	5.9	5.6
W3 (#)	12	11	5.9	5.6
F1.1 (%)	51.9	53.2	7.9	8.0
F2 (%)	5.4	4.2	3.5	3.3
F3 (%)	27.6	25.8	23.6	23.3
F4 (ft)	9.4	11.0	7.8	7.8
F5 (cfs)	58.0	59.0	40.9	41.1
F6 (cfs)	143.0	143.0	157.5	157.5
F7 (%)	15.9	15.2	17.3	17.3
RA1 (%)	49.6	48.7	35.4	35.4
RA2 (%)	77.8	77.5	53.4	53.6
RA3 (%)	73.3	73.1	41.6	41.8
RA4 (%)	79.6	79.4	56.1	56.4
RA5 (%)	78.7	78.1	57.7	57.9
RA6 (%)	21	21	23.6	24.1
RA7 (%)	25	26	26.7	25.7

Note: Gray cells indicate that lower values are preferred.

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

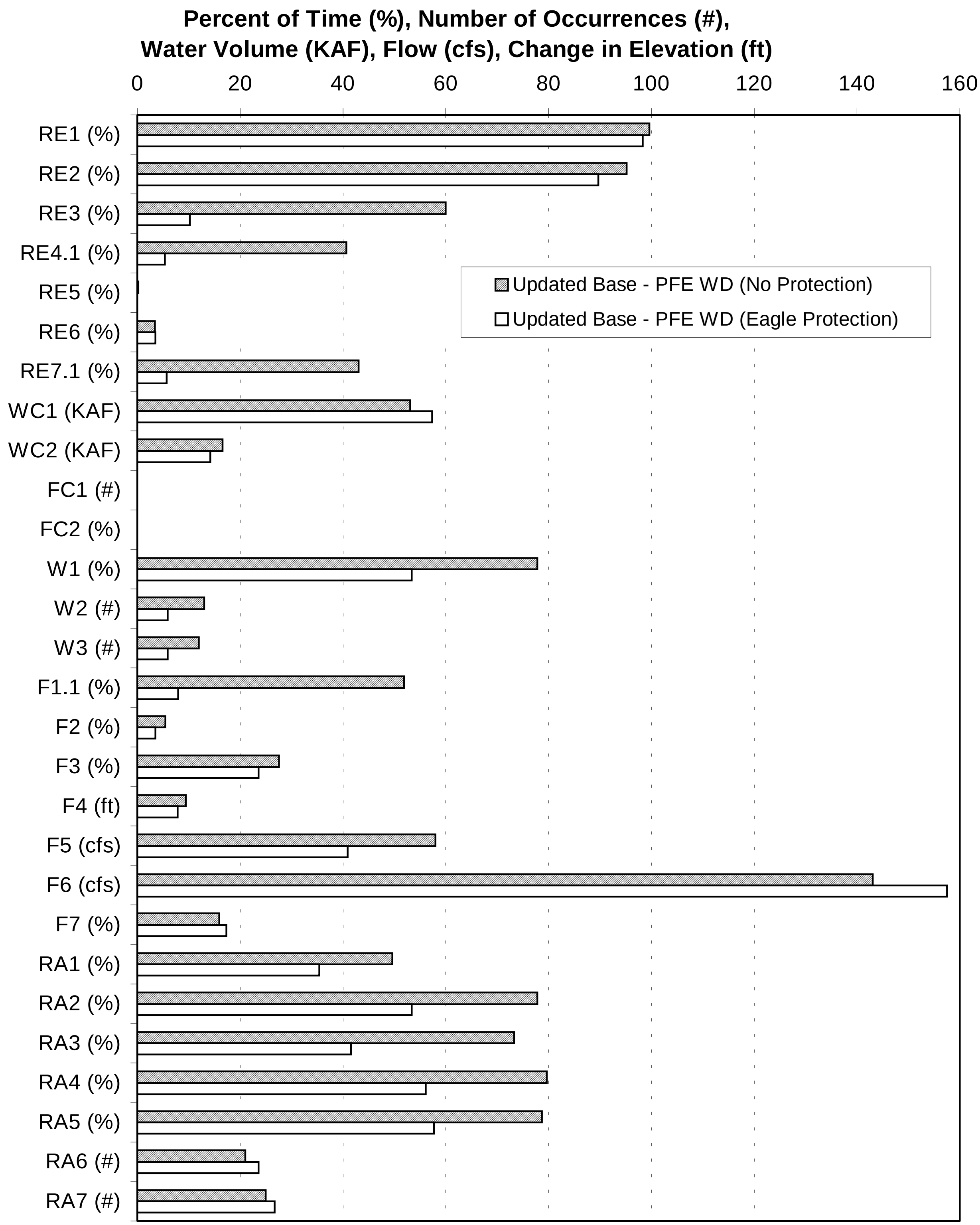

Figure 5.7 Evaluation Criteria: Eagle Nest Protection vs No Eagle Nest Protection

Chapter 6

Legal Options: Managing Conflict Between Listed Species

6.1 Background

Dealing with conflicting demands for water from a reservoir system is nothing new for reservoir managers. However the rising number of species protected by the Endangered Species Act (ESA) of 1973 (ESA, 1988) impacted by reservoir operation makes the balancing process even more complicated. Historically, the ESA elevates the needs of listed species to the highest priority when balancing tradeoffs between conflicting demands. Unfortunately, the ESA does not include clear direction on how to balance conflicting needs between listed species. Since different interest groups may be supporting different endangered or threatened species, this problem can be particularly troublesome for reservoir managers to address. This chapter presents ideas that possibly could help resolve conflicts between different listed (or candidate) species under the following assumptions:

- the reservoir manager is interested and committed to adjust reservoir operation as possible to help resolve conflict arising from different public and/or private interests
- the requirements and intent of the current Endangered Species Act provisions will be upheld (i.e., reservoir managers will seek to conserve and promote recovery of endangered and threatened species)
- relevant state and local laws regarding Endangered Species will be followed.

This section is not intended to address the effectiveness of the current ESA or comment on the various debates in Congress over the reauthorization of the ESA. However, potential changes in the ESA legislation could impact the specifics of this approach. Also, since states have differing laws surrounding environmental protection, state laws are not addressed in this chapter but would need to be for actual implementation of this approach in a particular region.

6.2 Endangered Species Act Provisions

The Endangered Species Act embodies a legal conviction to preserve and recover species (and the ecosystems on which they depend) in danger of extinction (ESA, 1988; § 1531(a)). In response to concern over modern extinction rates, Congress put powerful regulatory tools in the ESA that place species preservation above almost all other interests (Smith, et al., 1993). The act designates two categories of classification warranting different levels of attention. A species is listed as "endangered" -- thus deserving of the most stringent ESA protection measures -- when it is "in danger of extinction throughout all or a significant portion of its range" (ESA, 1988; §

1532(6)). A species is listed as "threatened" if the species is likely to become endangered within the "foreseeable future" (ESA, 1988; § 1532 (20)). Final authority for listing a species lies with either the Secretary of the Interior or Secretary of Commerce. The Interior's Fish and Wildlife Service (USFWS) is charged with the bulk of the duties under the ESA (Smith, et al., 1993). The legislation states that listing determinations must be based solely on evidence from the "best scientific and commercial data available" (ESA, 1988; § 1533 (b)(1)(a)). The act also requires the Secretary to designate "critical habitat" for the species concurrent with listing that define geographic areas "essential to the conservation of the species and ... which may require special management considerations or protection" (ESA, 1988; § 1532 (5)(A)). (Although according to Smith, et al. (1993), the USFWS had only designated critical habitat for 16 percent of the listed species as of 1991.) Section 4 of the ESA also directs the Secretary to develop "recovery plans" for listed species that identify measures (and their costs) to promote recovery and criteria to determine when they have recovered sufficiently to be removed from the list.

Upon official listing, the ESA offers multiple levels of protection. Section 9 of the ESA states that no person (including private and government individuals and agencies) may "take" any endangered species, where "take" is defined "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" (ESA, 1988; § 1532 (19)). In Palila v. Hawaii Department of Land and Natural Resources in 1988, "take" was interpreted to include "habitat destruction that prevents the recovery of a species." Section 9 also forbids actions that "maliciously damage or destroy" endangered plants on federal lands and prohibits commerce or possession of any kind for all listed species. Threatened species do not receive protection from taking automatically, but the Secretary can apply any portion or all of Section 9 as required for their conservation and recovery (Smith, et al., 1993).

Federal agencies are charged to further the purposes of the ESA in Section 7. Before performing an action that may affect a listed species or its critical habitat, the agency must consult with the Secretary and provide a "biological assessment" of the potential impacts resulting from the proposed action. The Secretary has authority to require the agency to adjust its proposed actions to mitigate the action's negative consequences. The Secretary also can grant a permit authorizing the agency to take a specified number of the listed species, as long as the taking is consistent with the agreed upon conservation actions. This consultation and permitted taking provides one mechanism within the ESA for federal reservoir managers to handle conflicting demands between listed species. (State and private parties may also obtain take permits via a "habitat conservation plan" (HCP) under Section 10 (ESA, 1988; § 1539 (a)).)

Although Sections 7 and 10 provide mechanisms to handle special cases through the federal consultation process and the habitat conservation plan, these mechanisms do not directly address how to "balance" (or prioritize) conflicting demands between competing listed species. Perhaps the most direct mention of prioritizing between species is found in Section 7 with regard to recovery plans. The act directs the Secretary to "give priority to those endangered species or threatened species, without regard to taxonomic classification, that are most likely to benefit from such plans, particularly those species that are, or may be, in conflict with construction or other forms of economic activity" when deciding how to allocate resources for recovery plans (ESA, 1988; § 1533 (f)(1)(A)). While this section does not directly address the issue of conflict between species, it seems to indicate that the intent of the law is to provide the most benefit to listed species as possible with a finite set of resources. Furthermore, ecosystem preservation is a basic intent of the ESA, which seeks to “provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved” (ESA, 1988; § 1531 (b)). Smith, et al. (1993) and others advocate the use of a more holistic approach that gives priority to integrated, multi species recovery plans and habitat conservation plans (HCPs) for listed and candidate (petitioned for consideration by the Secretary but not yet processed) species that offer the most potential benefit in a given ecological community. This multi species approach for addressing conflicts between species can be carried out legally under the existing ESA if a cooperative partnership is formed with the USFWS and other involved parties. One example of where this type of partnership has been tried is discussed by Volkman (1992) along the Columbia River System.

6.3 Bill Williams River System Conflict

The operation of Alamo Reservoir located on the Bill Williams River in western Arizona directly impacts the welfare of several listed species (BWRCTC 1994). The Bill Williams River contains the last extensive native riparian habitat in the lower Colorado River area. The lake and riparian forest support several listed species including the bald eagle and riparian obligates such as the southwestern willow flycatcher.

The riparian obligate species depend on the health of the riparian habitat, and the habitat is dependant upon Alamo Reservoir operation. The Wildlife Subcommittee of the Bill Williams River Corridor Technical Committee (BWRCTC) has recommended a flow regime to maintain and enhance the existing riparian environment (BWRCTC 1994). In simple terms, the desired flow regime defines minimum release quantities that vary seasonally to sustain existing trees and also advocates intermittent high flow “pulses” to emulate natural high flows produced by flood events prior to construction of Alamo Dam. The “pulse” flows are thought to be necessary for recruitment and long term viability of the riparian vegetation.

The bald eagles are affected more by the reservoir than the riparian habitat downstream. In 1988, the U.S. Fish and Wildlife Service (USFWS) issued a letter to the U.S. Army Corps of Engineers (USACE) recommending that the lake level be kept above 1,100 ft to maintain sufficient forage area for the bald eagles under the provisions of the National Environmental Protection Act (NEPA) and ESA. Another consideration is the location of eagle nesting each year. If the bald eagles establish their seasonal nest in a snag over the lake the nest can be in danger of inundation from rising reservoir levels. Nest inundation can be considered a taking under ESA since the USACE has some control over reservoir level.

Therefore, a long term conflict exists between the riparian obligate species and the bald eagles. In fact, a conflict exists in protecting the eagles -- protecting the eagle nests against inundation actually reduces the time the lake is above 1,100 feet (to provide adequate forage area for the eagles). Prescriptive and simulation model results have demonstrated that the requested flow regime for riparian habitat can be met more often if the reservoir level is kept higher than historical levels. This is reasonable since long periods of drought can occur in the desert region where Alamo Reservoir is located. If the reservoir is operated to maintain a low level, the desired minimum flows for the riparian habitat frequently can not be met during periods of drought. Chapter 5 shows that if the USACE operates to try and prevent inundation of an eagle nest, the ability to meet long term riparian habitat needs (and thus other listed species' needs) is significantly reduced.

In the strictest since, the USACE actions could be said to constitute a taking for either case. Inundation of the eagle nest could be interpreted as a taking (if other alternatives have not been established under the ESA Section 7 federal consultation process). If the reservoir is operated to protect the eagle nests, the riparian habitat's long term viability could be impaired comprising a taking for the riparian obligate species related to their habitat. As discussed before, consultation between the USFWS and the USACE (responsible for operation of Alamo Dam) and other related parties can produce a legally valid plan for resolving this conflict. The BWRCTC has described the likely interaction between reservoir operation parameters and species' response according to the best available data (BWRCTC 1994). Chapter 5 demonstrates a technique using probabilistic simulation to estimate the tradeoffs for different operating policies such as protection against nest inundation.

6.4 Long-term Management Options

Managing competing demands between endangered species is a challenging task that requires cooperation between several disciplines and agencies. Although the ESA does not explicitly address how to balance competing demands between listed species, Sections 7 and 10 provide mechanisms reservoir managers can use to satisfy the act's intents and requirements. Specifically by utilizing the ESA's federal consultation process and through developing a multi species recovery plan. The modeling methods presented in this report can serve as useful tools in determining how to best operate a reservoir system within a multi species recovery plan that focuses on the health of an ecological community.

Chapter 7

Conclusions

This study addressed three questions of interest to the Los Angeles District regarding re-operation of Alamo Reservoir. These questions were:

- Can Alamo reservoir be operated to protect against bald eagle nest inundation, and if so, can impacts on the riparian habitat and other listed species be approximated?
- Can different draw-down schemes for required maintenance improve reservoir performance based on evaluation criteria used in the BWRCTC study?
- Can improvements to the operation plan recommended by the Bill Williams River Corridor Technical Committee be made based on results from an HEC-PRM model of the Alamo Reservoir system?

Addressing these questions led to the following conclusions:

1. Results from a combined approach using an optimization (HEC-PRM) and simulation model of the Alamo Reservoir system confirmed that the operating rule proposed by the Bill Williams River Corridor Technical Committee performs very well.

2. The HEC-PRM model results agree with the BWRCTC findings that 1,125 feet is a good target elevation to meet operational objectives.

3. Slight modifications to the BWRCTC rule form can increase the number of pulse flow events (desirable for riparian habitat) over the simulation period.

4. A flexible draw-down scheme that schedules draw-down events based on the condition of the reservoir instead of on a rigid schedule significantly improves reservoir performance according to the evaluation criteria.

5. Based on the historical record of inflows and the physical characteristics of Alamo Reservoir, it is impossible to prevent eagle nest inundation 100% of the time without structural modifications to the outlet works.

6. Probabilistic simulation of eagle nesting behavior shows that if a modified version of the BWRCTC proposed rule is implemented, there exists an 0.18 probability that an eagle nest will be inundated during a year.

7. The chance of eagle nest inundation can be reduced to 5% per year by implementing an operating policy that responds to the nesting behavior of the eagles, but this reduction in inundation risk causes significant reductions in

performance for other objectives including protecting other species listed under the Endangered Species Act, and even maintenance of forage area for the bald eagles.

8. Provisions in the Endangered Species Act, such as the federal consultation process and multi species recovery plans provide a legal method for the USACE to help formulate a comprehensive long-term approach to manage conflicting interests between listed species impacted by operation of Alamo Reservoir.

Appendix A

References

Bill Williams River Corridor Technical Committee (1994). *Proposed Water Management Plan For Alamo Lake and the Bill Williams River*, Final Report and Recommendations of the Bill Williams River Corridor Technical Committee, Technical Committee Coordinator: Eric Swanson, Arizona Game and Fish Department, Phoenix, AZ, November.

Endangered Species Act (1988). 16 U.S.C. §§ 1531-1544.

Hillier, S. and Lieberman, G. (1995). *Introduction to Operations Research, Sixth Edition*, McGraw-Hill, New York, Chapter 21.

Hirsch, R.M. (1978), "Risk Analysis for a Water-Supply System - Occoquan Reservoir, Fairfax and Prince William Counties, Virginia," *Open-File Report 78-452*, U.S. Geological Survey, Reston, VA.

National Environmental Protection Act (1970). 42 U.S.C. §4321 et. seq.

Smith, Andrew et. al. (1993). "The Endangered Species Act at Twenty: An Analytical Survey of Federal Endangered Species Protection," *Natural Resources Journal*, Fall, V33 N4:1027-1075.

U.S. Army Corps of Engineers (1998). *Resolving Conflict Over Reservoir Operation: A Role for Optimization and Simulation Modeling*, Hydrologic Engineering Center, Davis, CA.

Volkman, John (1992). "Making Room in the Ark: The Endangered Species Act and the Columbia River Basin," *Environment*, May, V34 N4:18-20, 37-43.

Appendix B

AlamoSim Model Configuration

The Bill Williams River system modeled includes pumping from Planet Ranch, simplified stream and aquifer interactions, and channel flows. The following tables present details extracted from the HEC-5 model and used in the AlamoSim model.

Table B1: Evaporation Rates for Alamo Reservoir (Inches / Month) over Area

Month	Jan	Feb	Mar	Apr	Ma y	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(in/mo)	1.70	2.08	3.68	5.55	7.42	9.69	9.43	8.52	6.35	4.35	2.42	1.5

Table B2: Alamo Reservoir Physical Characteristics

Storage Capacity (ac-ft)	Outlet Capacity (cfs)	Surface Elevation (feet)	Surface Area (acres)
0	0	990	0
1,282	3,515	1,030	170
8,168	4,314	1,050	542
24,372	4,974	1,070	1,151
38,058	5,274	1,080	1,596
56,619	5,571	1,090	2,139
80,411	5,834	1,100	2,600
108,699	6,095	1,110	3,086
142,224	6,351	1,120	3,606
179,730	6,594	1,130	4,075
221,453	6,732	1,140	4,574
260,399	7,000	1,148	5,063
321,716	7,000	1,160	5,881
386,931	7,000	1,171	6,743
445,866	7,000	1,180	7,519
521,170	7,000	1,190	8,488

Storage Capacity (ac-ft)	Outlet Capacity (cfs)	Surface Elevation (feet)	Surface Area (acres)
605,774	7,000	1,200	9,436
700,080	7,000	1,210	10,390
809,220	7,000	1,220	11,520
930,210	7,000	1,230	12,740
995,300	7,000	1,235	13,300
1,063,500	11,295	1,240	14,000
1,209,100	24,603	1,250	15,200
1,367,400	51,934	1,260	16,500
1,451,300	65,197	1,265	17,100

Table B3: Muskingum Routing Parameters for Stream Reaches

Upstream End	Downstream End	Subreaches	Routing Coef. (X)	Travel Time (K)
ALMO	PRCH	2	0.15	14.5 hrs
BWRNWR	LKHAVASU	2	0.1	13.5 hrs

Table B4: Monthly Diversions Along Stream (cfs)

Month	ET from PRCH	ET from LKHAVASU	Pumping from PLANET RANCH GROUNDWATER
Jan	2.90	5.27	0.217
Feb	3.55	6.45	0.217
Mar	6.27	11.41	13.429
Apr	9.46	17.21	28.21
May	12.65	23.01	42.25
Jun	16.52	30.05	42.25
Jul	16.08	29.24	42.25
Aug	14.53	26.42	42.25
Sep	10.83	19.69	21.19
Oct	7.42	13.49	14.08
Nov	4.13	7.50	0.217
Dec	2.65	4.65	0.217

Table B5: Dry Bed Infiltration to Planet Ranch Aquifer

Flow in Stream (cfs) at PLANET RANCH IN	Flow to Aquifer (cfs) PLANET RANCH GROUNDWATER
0	0
296	236
466	425
1360	638
3200	1010

Table B6: Planet Ranch Groundwater Physical Characteristics

Storage Capacity (ac-ft)	Release Capacity (cfs)	Ground Water Elevation (feet)
1	20	463
365,800	20	563
368,458	103	564
371,116	333	565
373,774	669	566
376,432	1,106	567
379,090	1,643	568
381,748	2,279	569
384,406	3,018	570
387,064	3,862	571
501,146	87,750	600

Table B7: Elevation Discharge Relation for Aquifer

Groundwater Table Elevation (ft)	Channel Capacity (cfs)	Interpolate
463	0.01	Yes
550	9	Yes
555	12	Yes
560	15	Yes
563	19	Yes
600	87,750	No

Appendix C

Hydrologic Record Missing Values

Five missing values (-901) were found in the updated hydrologic record supplied by the Los Angeles District. The following values were inserted into the record based on the values surrounding the missing data.

Date	Value in Record	Changed to
July 1, 1981	-901	0.0
July 2, 1981	-901	0.0
August 30, 1983	-901	5.0
August 31, 1983	-901	5.0
August 31, 1984	-901	28.0

Appendix D

Release Rules

Optimization Based Alternative (OBA) 2A

A simulation rule based on HEC-PRM results for all interests weighted equally. The rule was designed to set releases to maintain a target storage level. The release decision is based on a deviation from the target storage and the inflow. The rule can be written as:

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage Deviation	>= 0	Maximum of: Good Release, 0.95 * Net Inflow, or 0.90 * Storage Deviation
ElseIf Storage Deviation	>= -500	Maximum of: Good Release, or 0.95 * (Net Inflow + Storage Deviation)
ElseIf Storage Deviation	> Dry Deviation	Maximum of: Mid Release, or 0.95 * (Net Inflow + Storage Deviation)
Else		Maximum of: Low Release, or 0.95 * (Net Inflow + Storage Deviation)

Where:

Storage Deviation = Current Storage - Target Storage
Net Inflow = Inflow - Evaporation

Month	Target Storage (KAF)	Dry Deviation (KAF)	Good Release (cfs)	Mid Release (cfs)	Low Release (cfs)
Jan	158.1	-9.1	25	10	10
Feb	159.4	-7.0	40	25	10
Mar	160.3	-0.4	40	25	10
Apr	159.4	-1.7	40	25	10
May	156.7	-2.2	40	25	10
Jun	156.1	-2.5	50	25	10
Jul	157.0	-3.8	50	25	10
Aug	156.1	-5.4	50	25	10
Sep	155.2	-5.3	50	25	10
Oct	155.2	-6.5	40	15	10
Nov	154.5	-7.5	25	10	10
Dec	156.7	-12.7	25	10	10

Optimization Based Alternative (OBA) 3A

OBA 2A modified to relax emphasis on maintaining target storage. (Changes from OBA 2A are underlined.) The rule can be written as:

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage Deviation	>= 0	Maximum of: Good Release, 0.95 * Net Inflow, or 0.90 * Storage Deviation
ElseIf Storage Deviation	>= -1,500	Maximum of: Good Release, 0.85 * Net Inflow, or 0.95 * (Net Inflow + Storage Deviation)
ElseIf Storage Deviation	> Dry Deviation	Maximum of: Mid Release, 0.50 * Net Inflow, or 0.95 * (Net Inflow + Storage Deviation)
Else		Maximum of: Low Release, or 0.95 * (Net Inflow + Storage Deviation)

Where:

Storage Deviation = Current Storage - Target Storage
Net Inflow = Inflow - Evaporation
Dry Deviation = -31,000

Month	Target Storage (KAF)	Good Release (cfs)	Mid Release (cfs)	Low Release (cfs)
Jan	158.1	25	10	10
Feb	159.4	40	25	10
Mar	160.3	40	25	10
Apr	159.4	40	25	10
May	156.7	40	25	10
Jun	156.1	50	25	10
Jul	157.0	50	25	10
Aug	156.1	50	25	10
Sep	155.2	50	25	10
Oct	155.2	40	15	10
Nov	154.5	25	10	10
Dec	156.7	25	10	10

Optimization Based Alternative (OBA) 3C

OBA 3A modified to relax emphasis on maintaining target storage. (Changes from OBA 3A are underlined.) The rule can be written as:

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage Deviation	>= 0	Maximum of: Good Release, 0.50 * Net Inflow, or 0.10 * Storage Deviation
ElseIf Storage Deviation	>= -40,000	Maximum of: Good Release, 0.50 * Net Inflow, or 0.10 * (Net Inflow + Storage Deviation)
ElseIf Storage Deviation	> Dry Deviation	Maximum of: Mid Release, 0.50 * Net Inflow, or 0.10 * (Net Inflow + Storage Deviation)
Else		Maximum of: Low Release, or 0.10 * (Net Inflow + Storage Deviation)

Where:

Storage Deviation = Current Storage - Target Storage
Net Inflow = Inflow - Evaporation
Dry Deviation = -50,000

Month	Target Storage (KAF)	Good Release (cfs)	Mid Release (cfs)	Low Release (cfs)
Jan	158.1	25	10	10
Feb	159.4	40	25	10
Mar	160.3	40	25	10
Apr	159.4	40	25	10
May	156.7	40	25	10
Jun	156.1	50	25	10
Jul	157.0	50	25	10
Aug	156.1	50	25	10
Sep	155.2	50	25	10
Oct	155.2	40	15	10
Nov	154.5	25	10	10
Dec	156.7	25	10	10

Optimization Based Alternative (OBA) 3G

A simplified form of OBA 3A modified to relax emphasis on maintaining target storage. (Changes from OBA 3A are underlined.) An additional component was added so that if a release greater than or equal to 1,000 cfs was made in January through May, the release would be kept at or above 1,000 cfs for at least seven consecutive days. This new component is referred to as a "Pulse Flow Extender" (PFE). The rule can be written as:

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage Deviation	>= 0	Maximum of: Good Release, 0.95 * Net Inflow, or 0.90 * (<u>Net Inflow +</u> Storage Deviation)
ElseIf Storage Deviation	>= <u>-80,566</u>	Maximum of: Good Release, or 0.95 * (Net Inflow + Storage Deviation)
Else		Maximum of: Low Release, or 0.95 * (Net Inflow + Storage Deviation)

Where:

Storage Deviation = Current Storage - Target Storage
Net Inflow = Inflow - Evaporation
<u>Target Storage</u> = 160,977

Month	Good Release (cfs)	Mid Release (cfs)	Low Release (cfs)
Jan	25	10	10
Feb	40	25	10
Mar	40	25	10
Apr	40	25	10
May	40	25	10
Jun	50	25	10
Jul	50	25	10
Aug	50	25	10
Sep	50	25	10
Oct	40	15	10
Nov	25	10	10
Dec	25	10	10

Pulse Flows are sustained by:

```
IF Release > 1,000 cfs THEN
    IF Month > 0 and < 6
        Maintain Release >= 1,000 cfs for at least 7 days
    ENDIF
ENDIF
```

Appendix E

Draw-Down Release Rules

Low Level Draw-Down Release Rule

The target storage for September and October are set to provide enough water for base flows. If the storage is higher than the target storage for that month, releases are made to try and meet the target storage by the end of the month. No releases are made from November 1 to November 14.

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage	> Target Storage	Maximum of: Good Release, or Storage Deviation * (Current Day / 31)
ElseIf Storage	>= 80,411 (1,100 ft)	Good Release
Else		Low Release

Where:

Storage Deviation = Current Storage - Target Storage

Month	Target Storage (acre-feet)	Good Release (cfs)	Low Release (cfs)
Sep	83,911 (1,101.2 ft)	50	10
Oct	80,411 (1,100 ft)	40	10
Nov 1 - 14	80,411	0	0

Forced Draw-Down Release Rule

This release rule is implemented eight years have passed since the last outlet tunnel inspection. The rule is implemented in the Spring to try and release any surplus water as a spring flushing flow with an extended recession as outlined in the *Proposed Water Management Plan For Alamo Lake and the Bill Williams River,* (BWRCTC, 1994). Determining the amount of surplus water is based on a target elevation of 1106 feet at the end of April to provide about 17,800 acre-feet of water make base flow releases until November.

The rule is implemented as follows:

- Determine amount of surplus on April 1.

  Surplus = Storage - 109, 611

- If Surplus > 0 then set a pulse flow strategy.

Condition	Criteria	Pulse Flow Characteristics
If Surplus	> 75,000 ac-ft	Peak Flow = 7,000 cfs; Recession Length = 20 days
ElseIf Surplus	> 50,000 ac-ft	Peak Flow = 5,000 cfs; Recession Length = 20 days
ElseIf Surplus	> 30,000 ac-ft	Peak Flow = 4,000 cfs; Recession Length = 20 days
ElseIf Surplus	> 5,000 ac-ft	Peak Flow = 1,000 cfs; Recession Length = 6 days
Else		No pulse release

- The pulse releases are made starting at 1,000 cfs and increasing by 1,000 cfs per day until the peak is reached.
- The peak release is maintained for as many days as possible according to the available surplus allowing for the volume required for the recession, (always releasing at least 1,000 cfs for at least seven days).
- The recession releases decrease from 500 cfs to 45 cfs over the recession length.

After pulse release make releases as follows. If storage is greater than the target storage for a given month, releases are made to try to meet the target storage by the end of the month.

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage	> Target Storage	Maximum of: Good Release, or Storage Deviation * (Current Day / 31)
ElseIf Storage	>= 80,411 ac-ft (1,100 ft)	Good Release
Else		Low Release

Where:

Storage Deviation = Current Storage - Target Storage
and

Month	Target Storage (acre-feet)	Good Release (cfs)	Low Release (cfs)
Apr	109,611	40	10
May	104,611	50	10
Jun	99,211	50	10
Jul	93,811	50	10
Aug	88,411	50	10
Sep	83,911	50	10
Oct	80,411	40	10

Appendix F

Eagle Nest Protection Rule

The following rule is used between November 1 and July 31 if an eagle nest is vulnerable (at least one active nest over the reservoir). The rule can be written as:

Storage Condition	Criteria	Release (Subject to Release Capacity)
If Storage Deviation	>= 0	Maximum of: Good Release, 0.95 * Net Inflow, or 0.90 * (Net Inflow + Storage Deviation)
ElseIf Storage Deviation	>= 80,411 - Storage Target *(Storage between Storage Target and 1,100 ft elevation)*	Maximum of: Good Release, or 0.90 * (Net Inflow + Storage Deviation)
ElseIf Storage Deviation	>= 24,372 - Storage Target *(Storage between 1,100 ft and 1,070 ft elevation)*	Maximum of: Low Release, or 0.50 * (Net Inflow + Storage Deviation)
Else	*(Below 1,070 ft)*	Maximum of: 0 cfs, or 0.50 * (Net Inflow + Storage Deviation)

Where:

Storage Deviation = Current Storage - Target Storage
Net Inflow = Inflow - Evaporation
Target Storage = 101,000 (1,107.3 feet elevation)

Month	Good Release (cfs)	Mid Release (cfs)	Low Release (cfs)
Jan	25	10	10
Feb	40	25	10
Mar	40	25	10
Apr	40	25	10
May	50	25	10
Jun	50	25	10
Jul	50	25	10
Aug	50	25	10
Sep	50	25	10
Oct	40	15	10
Nov	25	10	10
Dec	25	10	10

Pulse Flows are sustained by:

```
IF Release > 1,000 cfs THEN
    IF Month > 0 and < 6
        Maintain Release >= 1,000 cfs for at least 7 days
    ENDIF
ENDIF
```