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:

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

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.

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[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

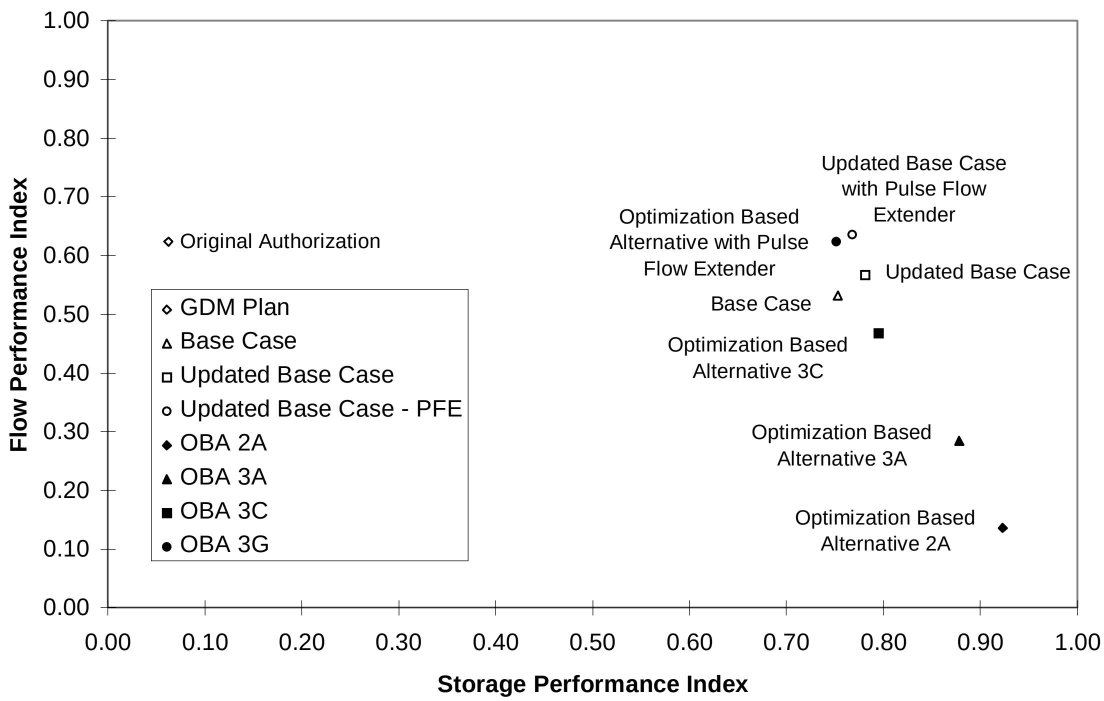

Figure 3.1 Performance Index Comparison for Alternatives Without Draw-Down

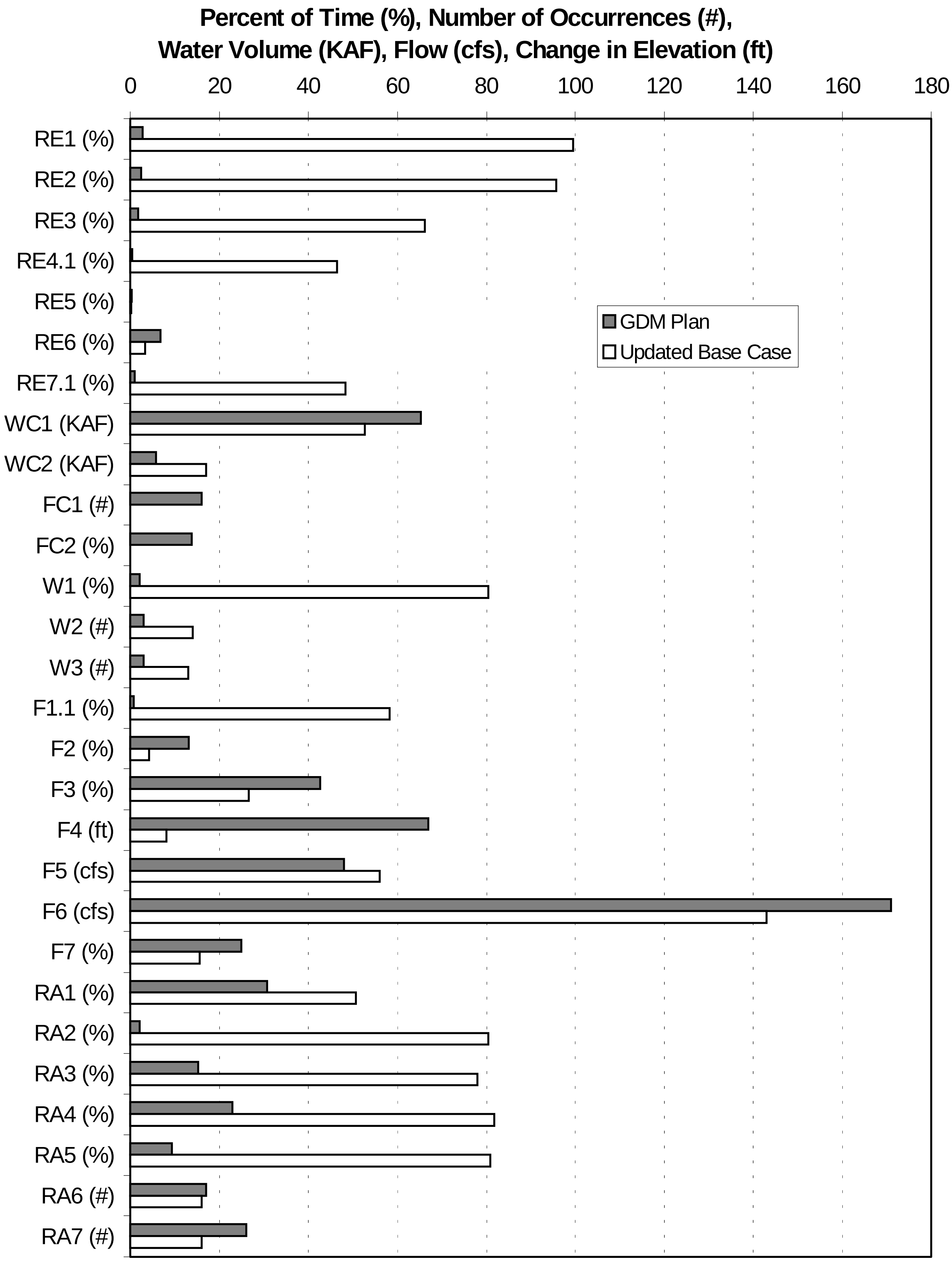

Figure 3.2 Evaluation Criteria: GDM Plan vs Updated Base Case

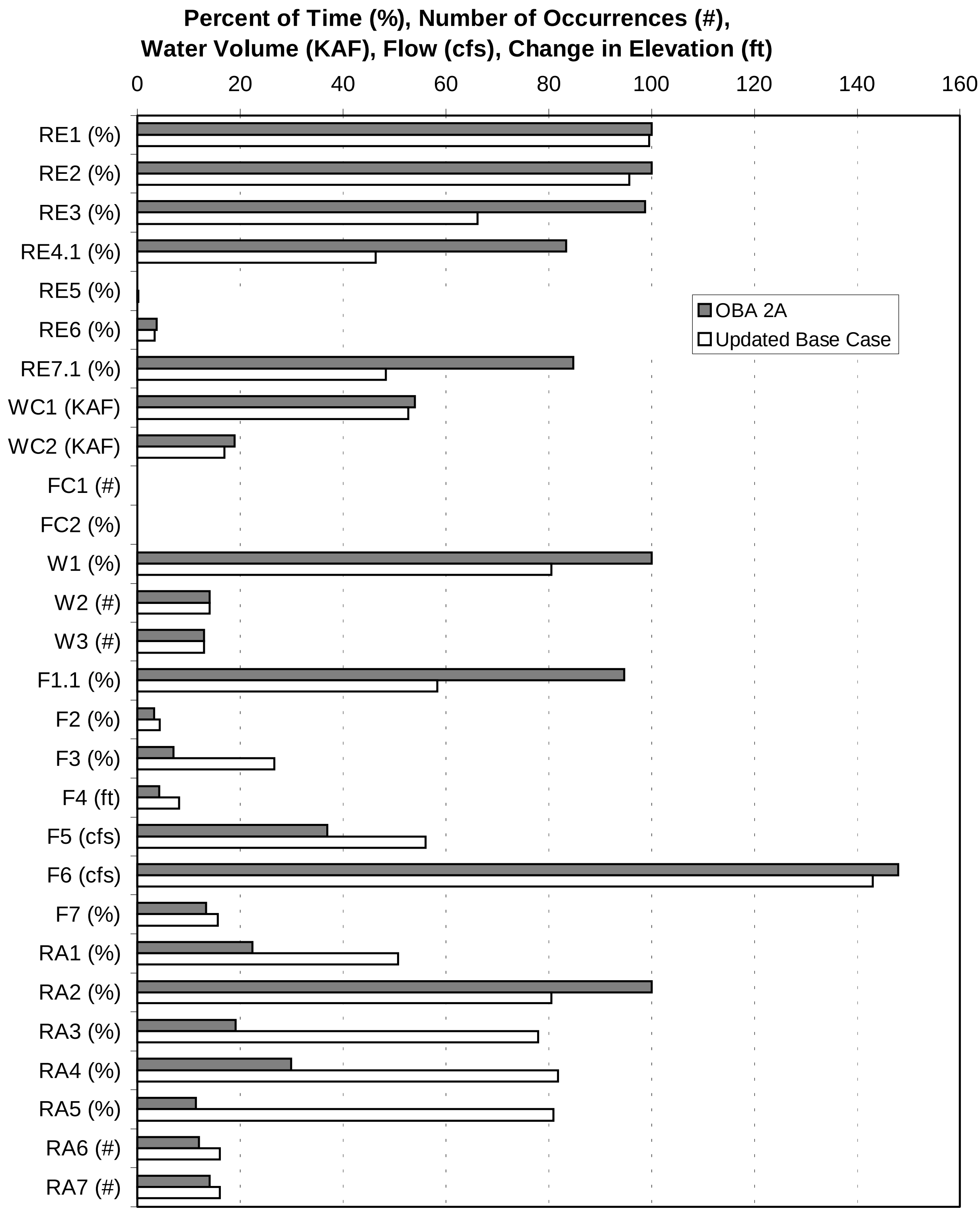

Figure 3.3 Evaluation Criteria: OBA 2A vs Updated Base Case

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).

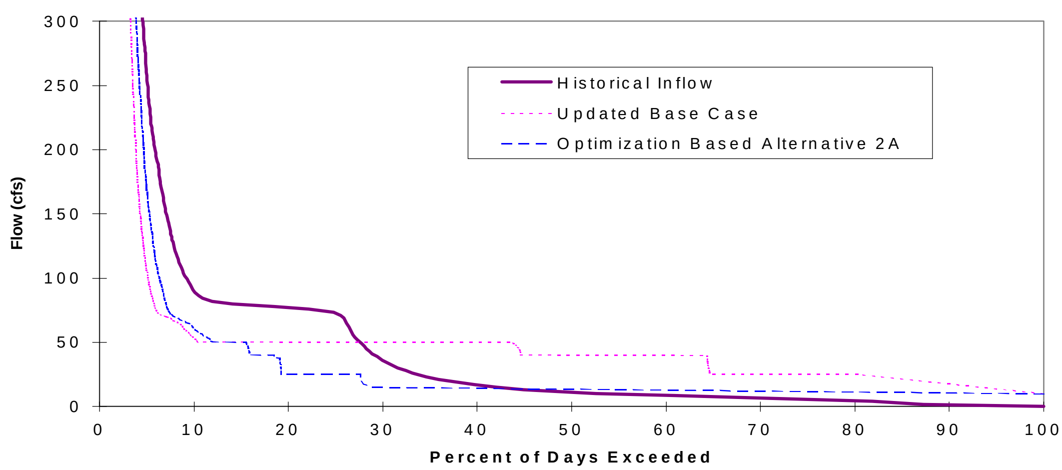

Figure 3.4 Flow Exceedance Probabilities (Below 300 cfs)

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.

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.

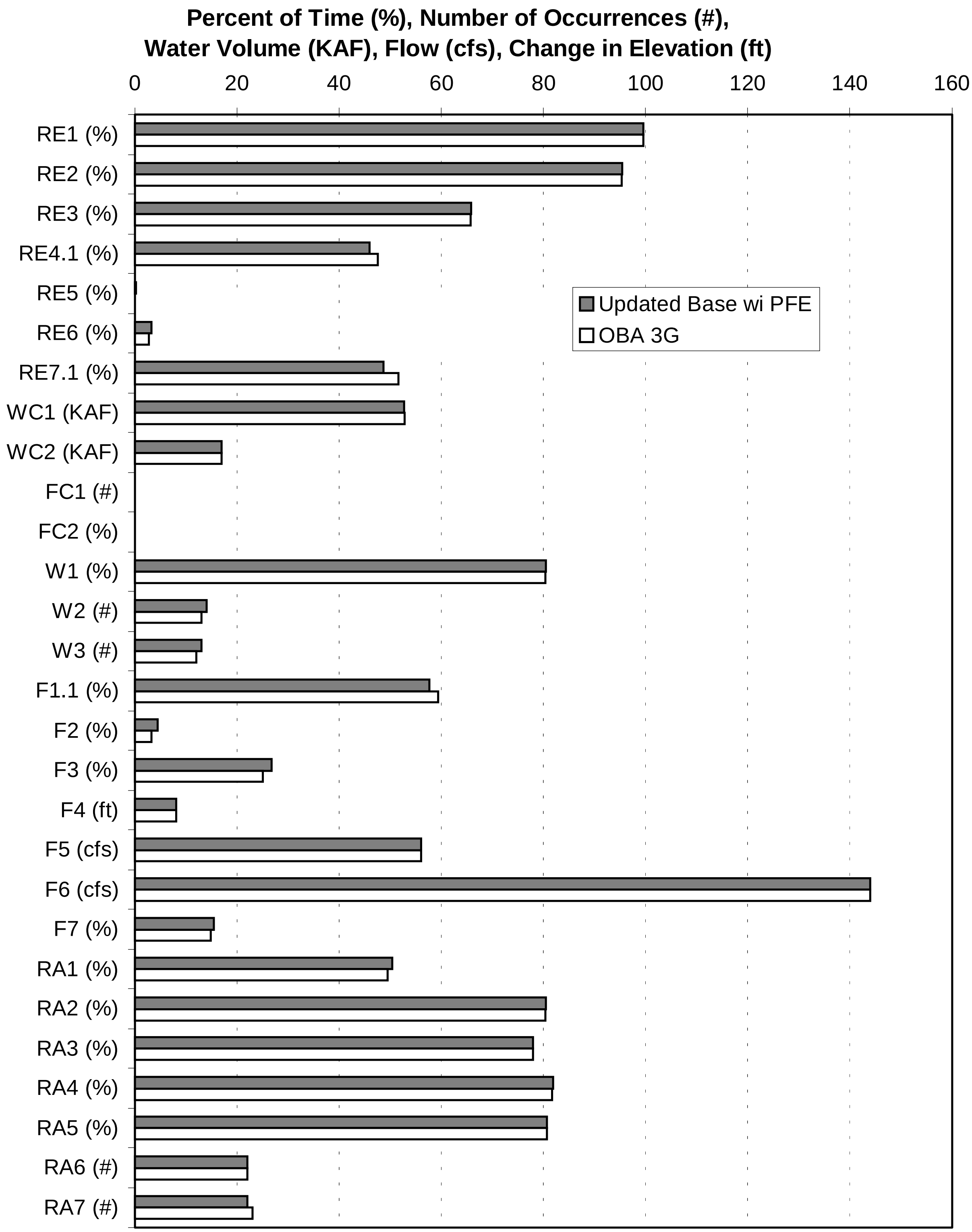

Figure 3.5 Evaluation Criteria: OBA 3G vs Updated Base Case with Pulse Flow Extender