Table 9. Generalized Alamo Dam release schedule. Based on target elevations for alternative operating plans.

**If current lake elevation ≤ TARGET ELEVATION then:**

| | Alamo Dam Releases (cfs) | | | |
|---|---|---|---|---|
| Lake Elevation (ft, msl) | Oct | Nov-Jan | Feb-Apr | May-Sept |
| 990-1070 | 10 | 10 | 10 | 10 |
| 1070-1100 | 15 | 10 | 25 | 25 |
| 1100 to TARGET ELEV. | 40 | 25 | 40 | 50 |

**If current lake elevation > TARGET ELEVATION then:**

| Lake Elevation (ft, msl) | Alamo Dam Releases (cfs) |
|---|---|
| TARGET ELEVATION + 1 ft | 1,000 |
| TARGET ELEVATION + 2 ft | 2,000 |
| TARGET ELEVATION + 3 ft | 3,000 |
| TARGET ELEVATION + 4 ft | 4,000 |
| TARGET ELEVATION + 5 ft | 5,000 |
| TARGET ELEVATION + 6 ft | 6,000 |
| TARGET ELEVATION + 7 ft | 7,000 (or outlet capacity) |
| Up to 1235 feet (spillway crest) | 7,000 |
| From 1235-1265 feet (top of dam) | over 7,000 (uncontrolled spillway flow) |

# IV. EVALUATION OF ALTERNATIVE RESERVOIR OPERATION PLANS

## A. EVALUATION TOOLS: HEC-5 MODEL

The principal water management evaluation tool used in the Technical Committee study was the Corps of Engineers' HEC-5 "Simulation of Flood Control and Conservation Systems" computer program. HEC-5 simulates river flow and reservoir system operation on a continuous basis using observed flow records as input. The hydrologic model provides trends analysis and probability based on historic records, which permits prediction of possible future water management outcomes.

The following sections describe the HEC-5 program, how it was used to evaluate alternative reservoir operation plans, and the inputs to the program model used for the Technical Committee study.

## 1. GENERAL DESCRIPTION

The HEC-5 program is used to evaluate the operation of dams and reservoirs. The program accomplishes the task by modeling the sequential operation of a reservoir/river system over a designated time period. The time period can range from a few hours to historical periods of any length.

To completely model a reservoir/river system, HEC-5 requires the following input parameters:

**Inflows:** Inflows include all flows into each of the system's reservoirs and flows in the system's unregulated streams at regular time intervals (e.g., hourly, daily, or monthly); they are usually in the units of cubic feet per second (cfs).

**Dam and Reservoir Characteristics:** The characteristics of the dams and reservoirs include elevation/storage and elevation/area relationships, dam outlet works elevation/discharge relationships, and dam spillway elevation/discharge relationships.

**Reservoir Evaporation:** Monthly evaporation values, expressed in inches, for each reservoir are used by HEC-5 to compute reservoir evaporation.

**Reservoir Storage Allocations:** The total reservoir capacity up to dam spillway crest is apportioned within the HEC-5 program according to specific storage allocations (Figure 4). For modeling purposes, the storage allocations are normally given designations of inactive storage, buffer storage, conservation storage, and flood control storage. The allocations are the basis for HEC-5 to make specific releases from reservoirs and are used in conjunction with other operating criteria to determine release patterns for a simulation run.

**Channel Characteristics:** Channel characteristics include the channel carrying capacity, flow travel times in a channel, and flow routing properties of a channel.

## 2. PROGRAM CAPABILITIES AND LIMITATIONS

An HEC-5 program model for a dam and reservoir system can be configured for a variety of operating criteria. Scheduled releases, for instance, can be based on reservoir water surface elevation, time of year, reservoir inflow, or combinations of these parameters. Diversions can be made from the reservoirs or from points in the river channels. The magnitude of diversion flows can be based on elevations, reservoir inflows, or channel flow, and can be specified for a particular time of year. Diversions can be made to either return to the total reservoir/river system at a specific downstream location or be abstractions (withdrawals or losses) from the system. As a result of the diversion capability of HEC-5, natural flow losses to the reservoir/river system can be mimicked.

HEC-5 is a surface water modeling program, and has no internal capability to model groundwater flow. Groundwater characteristics in a river system can, at best, be approximated using the various HEC-5 input options. Groundwater basin response was simulated in the Technical

Committee HEC-5 model using groundwater data on the Bill Williams River from Harshman and Maddock (1993). However, for detailed and thorough modeling of a groundwater system, a groundwater computer program should be used.

## 3. MODEL INPUTS IN TECHNICAL COMMITTEE STUDY

The following sections describe the input used in the HEC-5 model of the Bill Williams River for the Technical Committee study. A schematic of the Bill Williams River system, as modelled by HEC-5, is shown in Figure 6.

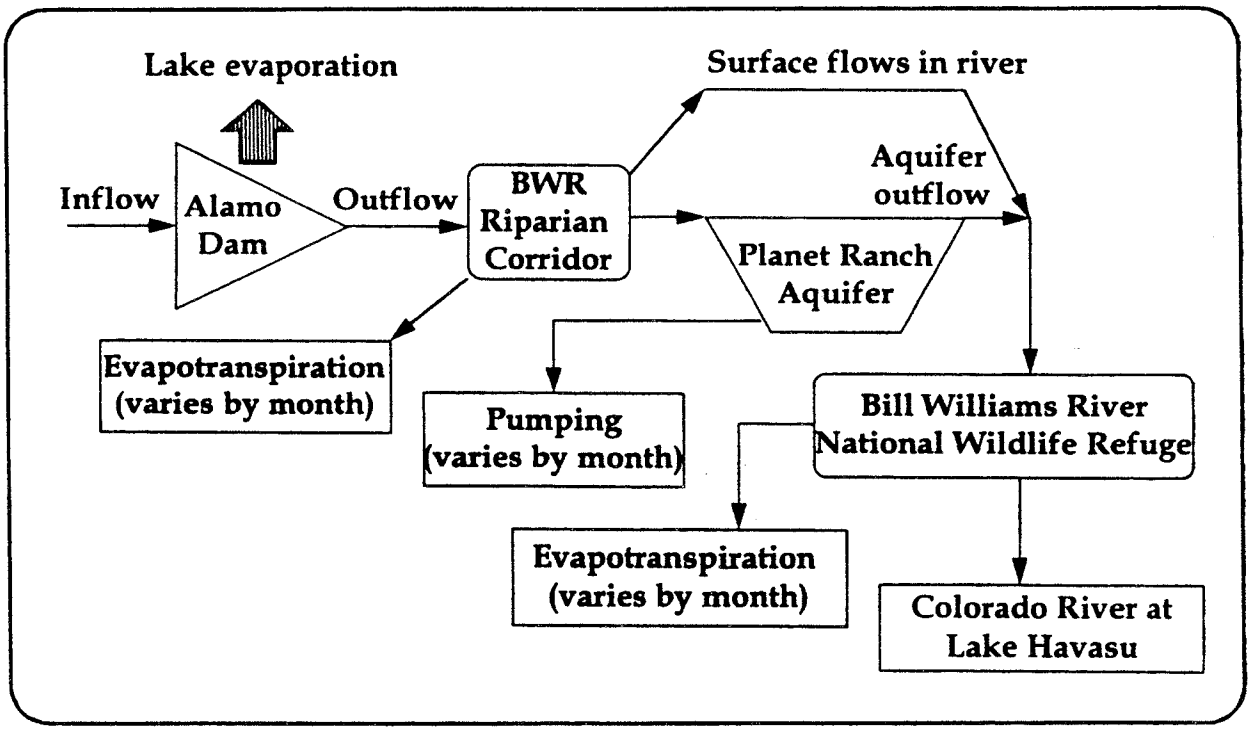


Figure 6. Hydrologic schematic of Bill Williams Reservoir and River system.

**Inflow to Alamo Reservoir:** Inflows to Alamo Reservoir were daily average flows in cfs for the period October 1, 1928 through December 31, 1993. This period of record was compiled from three data sources including U.S Geological Survey (USGS) stream gage data at the Alamo site (1939-68), computed flow values from the Corps daily operational records of Alamo Dam (1968-93), and flows derived from correlating measured flows at the USGS gages at the Alamo and Planet Ranch sites (1929-39). The measured flows were from the period 1940-46 when both gages were simultaneously in operation.

Monthly inflows into Alamo Reservoir for the period of record are shown in Figure 7. These inflows illustrate the pattern of inflows used by the HEC-5 model. More importantly, large fluctuations in annual precipitation create conditions where substantial amounts of water are available some years and for other years only limited amounts. For the HEC-5 model, inflow data from 1929-93 were used since they were available on a

daily basis. Hydrologic records for the Bill Williams River from 1890-1927 were available only on a monthly basis.

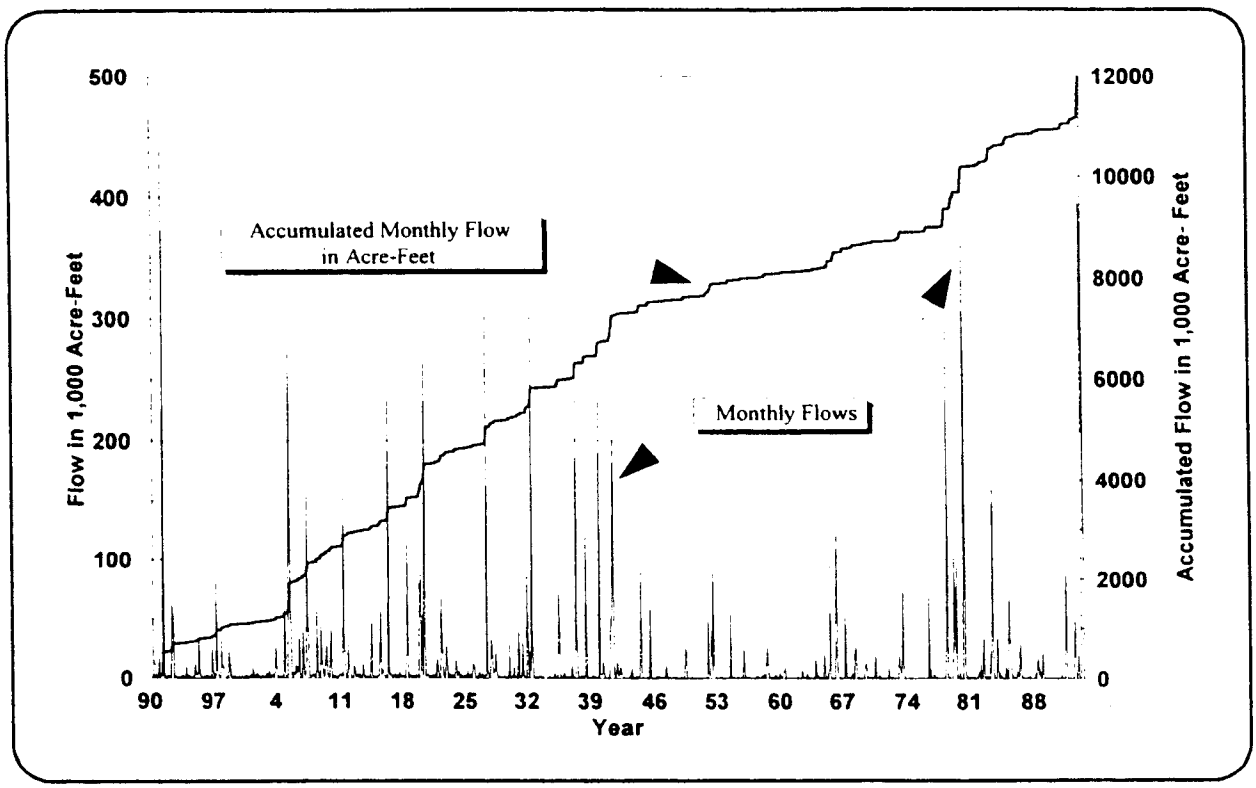


Figure 7. Alamo Dam historic monthly inflows (1890-1993).

**Evaporation Losses:** Mean monthly evaporation values at Alamo Reservoir were computed from pan evaporation data obtained over the period January 1976-March 1988. These monthly average evaporation values were applied to the entire 1929-1993 period of record modeled by the HEC-5 program.

**Reservoir Elevation-Area/Capacity Values:** The reservoir elevation-area and elevation-capacity values used in the HEC-5 model were from the Corps' June 1993 elevation-area/capacity table (Appendix H, Volume II), which is the most recent table and includes revisions for sedimentation.

**Evapotranspiration Losses:** Evapotranspiration (ET) losses along the Bill Williams River corridor from Alamo Dam to Planet Ranch and in the Refuge were obtained from Harshman and Maddock (1993). The report contained annual average ET values. Monthly average ET values for the river corridor and Refuge locations were estimated by applying the monthly average distribution pattern of Alamo Reservoir evaporation to the respective annual ET values.

**Planet Ranch Groundwater Pumping:** Monthly average pumping rates of Planet Ranch groundwater were obtained from Harshman and Maddock (1993). The pumping was treated as an abstraction from the Bill Williams River system; no irrigation return flow was assumed to enter the aquifer or the Bill Williams River.

**Planet Ranch Aquifer Model:** Since HEC-5 is not a groundwater modeling program, simulating the Planet Ranch aquifer's response to inflows (i.e., releases from Alamo Dam) was accomplished by considering the aquifer as a reservoir. In simulating inflows to Planet Ranch, it was assumed that a significant portion of surface flows percolated into the aquifer (Table 10).

Using known geological information, the aquifer itself was estimated to have a net holding capacity of 366,000 acre-feet. When this capacity was filled, excess percolation was assumed to flow from the aquifer in a manner similar to free flow from a dam's ungated spillway. The excess percolation was combined with the surface flows through the Planet Ranch area; this combined flow was routed to the Refuge.

Table 10. Estimated percolation of Bill Williams River surface flow into the Planet Ranch aquifer. (Correlation based on daily average surface flows recorded at both the Alamo Dam site and near Planet Ranch from 1940-46. Inflows in excess of 3,200 cfs were assumed to lose a constant 1,000 cfs to percolation. Flows in excess of those percolated were treated as surface flows through the Planet Ranch area.)

| River Flows (cfs) | |
|---|---|
| Above Planet Ranch | Percolating into Planet Ranch aquifer |
| 296 | 236 |
| 466 | 425 |
| 1,360 | 638 |
| ≥ 3,200 | 1,000 |

**Routing of Channel Flows:** Channel flows were routed from Alamo Dam to Planet Ranch, approximately 26 miles downstream, assuming a 29-hour travel time. Flows were routed from Planet Ranch to Lake Havasu (Colorado River), an 8-mile reach through the Refuge, assuming a 27-hour travel time.

## 4. MODEL OUTPUTS IN TECHNICAL COMMITTEE STUDY

A statistical analysis was performed on the various output parameters of the HEC-5 model. The results of these statistics for the 14 alternative plans modeled are summarized in Appendix I, Volume II. The HEC-5 model output summaries consist of information useful in evaluating the performance of the 14 alternative reservoir operating plans (Table 11).

Table 11. Codes, "target" lake elevations and descriptions of Technical Committee alternative operation plans modeled using HEC-5.

| Alternative Plan Code | "Target" Lake Elevation (ft) | Description |
|---|---|---|
| GDM Plan | 1070 | General Design Memorandum. Alamo Dam operations as occurred from 1968-88. With 5 year inspection drawdown. |
| Current Op. | 1100 | Current Operations. "Target" elevation changed in response to USFWS 1988 request for bald eagle concerns. With 5 year inspection drawdown. |
| A1115D05 | 1115 | Model run with 5 year inspection drawdown. |
| A1120D05 | 1120 | " " " " " " " |
| A1123D05 | 1123 | " " " " " " " |
| A1125D05 | 1125 | " " " " " " " |
| A1127D05 | 1127 | " " " " " " " |
| A1130D05 | 1130 | " " " " " " " |
| A1140D05 | 1140 | " " " " " " " |
| A1171D05 | 1171.3 | Model run with 5 year inspection drawdown. |
| A1125NP5 | 1125 | Model run with 5 year inspection drawdown and no Planet Ranch pumping. |
| A1125D10 | 1125 | Model run with 10 year inspection drawdown. |
| A1125D15 | 1125 | Model run with 15 year inspection drawdown. |
| A1125WOD | 1125 | Model run without inspection drawdown. |

## B. EVALUATION CRITERIA

The criteria for selecting the recommended alternative operation plan was based on the Technical Committee evaluation of the degree to which each plan benefitted the various resource needs, as well as the impact (positive or negative) on authorized project purposes. The needs or concerns for the resource demands of Alamo Dam and Reservoir are lake fisheries, wildlife concerns, lake recreational opportunities, riparian habitat, flood control ability and water conservation potential. Table 12 summarizes the evaluation criteria that the Subcommittees decided upon for each of the above categories. Each of the alternative plans were tested and evaluated with respect to each of the elements in Table 12 and then compared to each other to select the preferred plan.

## C. EVALUATION OF ALTERNATIVES

Of the 14 alternatives considered and run through the HEC-5 model to identify performance in meeting resource evaluation criteria, two represented baseline scenarios (GDM and current

Table 12. Listing of criteria evaluated in the HEC-5 model for riparian, fisheries, wildlife, recreation, water conservation and flood control categories.

Riparian Criteria

RA1 - Percent of time streamflows at Refuge equal or exceed 18 cfs
RA2 - Percent of time WSE between 1100 - 1171.3 feet
RA3 - Percent of time Alamo Dam releases greater than or equal to 25 cfs in November through January.
RA4 - Percent of time Alamo Dam releases greater than or equal to 40 cfs in February through April and in October
RA5 - Percent of time Alamo Dam releases are greater than or equal to 50 cfs in May through September
RA6 - Total number of occurrences that Alamo Dam releases equal or exceed 1,000 cfs seven or more consecutive days in November through February
RA7 - Total number of occurrences that Alamo Dam releases equal or exceed 1,000 cfs seven or more consecutive days in March through October

Fisheries Criteria

F1 - Percent of time WSE between 1110 - 1125 feet
F2 - Percent of time in March 15-May 31 WSE fluctuates more than 2" per day
F3 - Percent of time in March 15-May 31 WSE fluctuates more than 0.5" per day
F4 - Maximum WSE drop, in feet, in June-September for the period of record (1929-93)
F5 - Average daily release during June-September
F6 - Average daily release during October-May
F7 - Percent of time streamflows at Refuge equal or exceed 25 cfs

Wildlife Criteria

W1 - Percent of time WSE at or above 1100 feet
W2 - Number of times during the year that WSE exceeds elevation 1135 feet two or more consecutive days.
W3 - Number of times from December 1-June 30 that WSE exceeds elevation 1135 feet two or more consecutive days.

Recreation Criteria

RE1 - Percent of time WSE at or above 1090 feet
RE2 - Percent of time WSE at or above 1094 feet
RE3 - Percent of time WSE at or above 1108 feet
RE4 - Percent of time WSE between 1115 - 1125 feet
RE5 - Percent of time WSE between 1144 - 1154 feet
RE6 - Percent of time outflow is between 300 and 7,000 cfs
RE7 - Percent of time in March-May WSE between 1115 -1125 feet

Water Conservation Criteria

WC1 - Average annual delivery of water to lower Colorado River (Lake Havasu)
WC2 - Average annual Alamo Reservoir evaporation in Acre Feet for period 1929-93

Flood Control Criteria

FC1 - Number of days WSE above 1171.3 feet during period of record (1929-1993)
FC2 - Maximum percent of flood control space used during period of record

Note: WSE = Water Surface Elevation of Alamo Reservoir

operations), eight represented "target" lake elevations ranging from 1115-1171.3 feet, and four were special runs.

## 1. ALTERNATIVES CONSIDERED

Table 13 summarizes the results of 10 of the computer simulations using the HEC-5 model and the analysis of each of the evaluation criteria noted in Table 12. Simulations were based on daily inflow values for a 65 year period of record from 1929-93. While this period of hydrologic record may not necessarily repeat itself in the future, the Technical Committee assumed that this period of record had predictive value. What is most important, however, is the comparative value in evaluating each alternative with respect to current operating conditions.

The Table 13 summary provided a means to compare the relative improvement, in terms of percent of time or actual numbers, in achieving the evaluation criteria for each alternative. Alternatives could, for example, be compared against the present situation (Current Op) or against alternatives with higher or lower "target" elevations. Note that for some evaluation criteria a lower value is better (e.g., WC2, FC1, FC1, F2).

Alternatives storing more water than the current operation (i.e., target elevation $>1100$ feet) performed much better in terms of meeting evaluation criteria. Flood control criteria were significantly improved for all of the alternatives evaluated, because large or maximal releases (up to 7,000 cfs) can be made much earlier than under GDM or current operation (up to 2,000 cfs in water conservation pool). When modeled using the 1929-93 period of hydrologic record, the rapid evacuation capability while in the water conservation pool means lake levels would never reach the flood control pool (1171.3 feet) for the six alternatives between 1115-1130 feet (Table 13).

The improvement between alternatives for a number of categories is relatively small. Differentiating between similar percentages may not be appropriate for most criteria since values are relatively imprecise. Some criteria are based on a narrow lake elevation range (e.g., RE4 -the percent of time the water surface elevation is between 1115' and 1125') and lake operations outside that range will have significantly lower occurrence values. Some criteria were also recognized as having greater importance than others.

Caution must be exercised in evaluating "average daily" and "percent of time" values. These values may mask seasonal and unusual event sequences which may either positively or adversely affect a particular resource. The Technical Committee made every effort to examine the HEC-5 runs on a daily, seasonal, and annual basis to better understand the reliability and limitations of the summarized values shown in Table 13.

In evaluating the eight water management alternatives with target elevations from 1115-1171.3 feet, it becomes readily apparent that each represents significant improvements in nearly all criteria categories compared to current (1100 foot) operations (Table 13).

Table 13. HEC-5 model evaluation criteria summary. Descriptions of the Alternative Operation Plans are in Table 11. WSE = Water Surface Elevation.

(GDM, Present Conditions, and Runs with 5-Year Drawdown)

| Alternative Operation Plans | Minimum WSE Feet | Mean WSE Feet | Maximum WSE Feet | Recreation | | | | | | | Water Con. | | Flood Cntl | | Wildlife | | | Fisheries | | | | | | | Riparian | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RE1 | RE2 | RE3 | RE4 | RE5 | RE6 | RE7 | WC1 | WC2 | FC1 | FC2 | W1 | W2 | W3 | F1 | F2 | F3 | F4 | F5 | F6 | F7 | RA1 | RA2 | RA3 | RA4 | RA5 | RA6 | RA7 |
| | | | | % | % | % | % | % | % | % | af | af | # | % | % | # | # | % | % | % | ft | cfs | cfs | % | % | % | % | % | % | # | # |
| GDM Plan | 1,035.9 | 1,068.3 | 1,183.3 | 2.8% | 2.4% | 1.8% | 0.4% | 0.3% | 6.7% | 0.9% | 65322 | 5857 | 16 | 13.8% | 2.1% | 3 | 3 | 0.7% | 13.1% | 42.6% | 67 | 48 | 171 | 24.9% | 30.7% | 2.1% | 15.2% | 22.9% | 9.3% | 17 | 26 |
| **Present Cond.** | **1,080.5** | **1,098.1** | **1,185.8** | **93.5%** | **79.7%** | **3.2%** | **0.6%** | **0.2%** | **6.5%** | **1.6%** | **58735** | **13145** | **27** | **16.8%** | **36.9%** | **6** | **6** | **1.2%** | **11.5%** | **19.9%** | **36** | **37** | **161** | **21.4%** | **27.8%** | **36.8%** | **13.8%** | **20.9%** | **6.8%** | **17** | **24** |
| A1115D05 | 1,084.9 | 1,104.2 | 1,164.3 | 96.7% | 89.1% | 34.7% | 2.5% | 0.1% | 4.2% | 4.7% | 55113 | 14807 | 0 | 0.0% | 64.9% | 7 | 7 | 29.8% | 4.6% | 27.7% | 12 | 58 | 147 | 19.0% | 43.7% | 64.9% | 54.2% | 67.5% | 54.3% | 14 | 17 |
| A1120D05 | 1,084.9 | 1,106.7 | 1,167.1 | 96.7% | 89.5% | 46.0% | 26.6% | 0.1% | 4.4% | 41.5% | 54013 | 15501 | 0 | 0.0% | 67.4% | 10 | 10 | 41.3% | 4.5% | 29.0% | 16 | 63 | 142 | 19.3% | 46.2% | 67.4% | 55.2% | 68.8% | 59.0% | 11 | 17 |
| A1123D05 | 1,084.9 | 1,108.0 | 1,168.8 | 96.7% | 90.1% | 47.5% | 30.9% | 0.2% | 4.5% | 40.8% | 53463 | 15844 | 0 | 0.0% | 69.2% | 11 | 11 | 44.0% | 4.5% | 26.4% | 19 | 69 | 139 | 19.3% | 49.5% | 69.2% | 59.6% | 69.8% | 60.6% | 11 | 16 |
| **A1125D05** | **1,084.9** | **1,109.0** | **1,170.0** | **96.7%** | **90.5%** | **49.0%** | **34.6%** | **0.2%** | **4.7%** | **40.6%** | **53174** | **16106** | **0** | **0.0%** | **69.5%** | **11** | **11** | **43.6%** | **4.6%** | **27.1%** | **20** | **72** | **137** | **19.0%** | **51.3%** | **69.5%** | **59.6%** | **70.3%** | **61.2%** | **12** | **16** |
| A1127D05 | 1,084.9 | 1,110.0 | 1,171.3 | 96.7% | 90.6% | 51.5% | 21.2% | 0.2% | 4.7% | 14.4% | 53015 | 16377 | 0 | 0.0% | 69.8% | 13 | 13 | 29.0% | 4.6% | 27.6% | 20 | 73 | 136 | 18.5% | 52.8% | 69.8% | 59.6% | 71.1% | 61.6% | 12 | 14 |
| A1130D05 | 1,084.9 | 1,111.5 | 1,173.1 | 96.7% | 90.6% | 54.1% | 18.4% | 0.2% | 4.7% | 13.5% | 52375 | 16773 | 3 | 2.0% | 70.6% | 17 | 16 | 27.0% | 4.5% | 27.5% | 22 | 76 | 134 | 17.1% | 53.8% | 70.6% | 61.1% | 72.6% | 61.8% | 12 | 14 |
| A1140D05 | 1,084.9 | 1,115.4 | 1,179.2 | 96.7% | 90.8% | 56.0% | 10.2% | 0.4% | 5.1% | 7.4% | 51267 | 17842 | 7 | 8.8% | 71.9% | 25 | 21 | 15.9% | 4.4% | 26.0% | 31 | 91 | 124 | 15.4% | 56.0% | 71.9% | 61.4% | 74.1% | 63.9% | 9 | 10 |
| A1171D05 | 1,084.9 | 1,122.0 | 1,200.2 | 97.0% | 90.9% | 56.5% | 7.8% | 4.7% | 6.0% | 7.3% | 49125 | 20130 | 362 | 36.3% | 72.2% | 28 | 25 | 13.2% | 4.0% | 19.3% | 61 | 158 | 85 | 9.9% | 49.8% | 70.7% | 61.5% | 58.3% | 68.7% | 5 | 18 |

Notes:

Recreation
- RE1 - Percent of time WSE at or above 1090'
- RE2 - Percent of time WSE at or above 1094'
- RE3 - Percent of time WSE at or above 1108'
- RE4 - Percent of time WSE between 1115' and 1125'
- RE5 - Percent of time WSE between 1144' and 1154'
- RE6 - Percent of time Outflow is between 300 and 7,000 cfs
- RE7 - Percent of time in March thru May WSE between 1115' and 1125'

Water Con.
- WC1 - Average annual delivery of water to LCR (Lake Havasu)
- WC2 - Average Annual Evaporation in Acre Feet for period 1929-1993

Flood Control
- FC1- Number of days WSE above 1171.3 during period of record (1929-1993)
- FC2 - Maximum percent of flood control space used during period of record.

Wildlife
- W1 - Percent of time WSE at or above 1100'
- W2 - Number of times during the year that WSE exceeds elevation 1135' two or more consecutive days.
- W3 - Number of times from 1 December through 30 June that WSE exceeds elevation 1135' two or more consecutive days.

Fisheries
- F1 - Percent of time WSE between 1110' and 1125'
- 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 (1929-1993)
- F5 - Average daily release during June thru September
- F6 - Average daily release during October thru May
- F7 - Percent of time streamflows at BW Refuge equal or exceed 25 cfs

Riparian
- RA1 - Percent of time streamflows at BW Refuge equal or exceed 18 cfs
- RA2 - Percent of time WSE between 1100' and 1171.3'
- RA3 - Percent of time Alamo Releases greater than or equal to 25 cfs in November thru January.
- RA4 - Percent of time Alamo releases greater than or equal to 40 cfs in February - April & October
- RA5 - Percent of time Alamo releases are greater than or equal to 50 cfs in May thru Sept.
- RA6 - Total number of occurrences that Alamo releases equal or exceed 1,000 cfs seven or more consecutive days in Nov. thru Feb.
- RA7 - Total number of occurrences that Alamo releases equal or exceed 1,000 cfs seven or more consecutive days in March thru October

## 2. UNACCEPTABLE ALTERNATIVES

Alternatives found to be unacceptable in terms of meeting all resource objective criteria were the 1140 and 1171.3 foot target elevation plans. These plans performed poorly in meeting objectives for flood control, and recreation and fisheries objectives that called for maintaining lake levels in the 1110-1125 foot range (Table 13). Maintaining lake elevations in the 1140 and 1171.3 foot range greatly increases lake surface area and subsequently annual evaporation amounts, resulting in further reductions of annual water deliveries to the Colorado River. Evaluation criteria performances for these two plans and for the 1115 foot plan were considerably lower in recreation (RE3, RE4 and RE7) and fisheries (F1) resource categories than the other five plans.

## 3. PROPOSED ALTERNATIVE

The desired outcome of the Technical Committee is to develop a balancing of the five resource objectives within the limits of the existing water supply and Alamo Dam operational constraints. By consensus, the 1125 foot target elevation water management alternative was selected as the plan which best meets optimal resource objectives within operational constraints and objectives of Alamo Dam. The 1120, 1123, and 1127 foot plans performed similarly in nearly all other resource categories. The 1125 foot plan represented an optimal lake elevation whereby benefits were maximized most effectively. The 1125 foot plan provides 80,000 acre-feet of lake storage above the 1100 foot minimum desired lake level. This large-volume storage is available for riparian, fish, wildlife, and recreational benefits. Details of this proposed 1125 foot plan are discussed in Chapter V.

## 4. SPECIAL RUNS

Special runs using the HEC-5 model were made to determine changes to evaluation criteria values from: 1) no Planet Ranch pumping; 2) Alamo Dam maintenance drawdowns every 10 years and every 15 years; and 3) no Alamo Dam maintenance drawdowns (Table 14). These runs were conducted for the 1125 foot target elevation to evaluate opportunities that would further enhance benefits from this preferred alternative.

### a. No Planet Ranch pumping

By eliminating Planet Ranch groundwater pumping, significant benefits can be realized in terms of average annual water delivered to the Lower Colorado River (WC1) and percent of time Bill Williams River streamflows at the Refuge exceed 18 cfs (RA1). The proposed 1125 foot target elevation alternative provides 53,174 acre-feet of water per annum to Lake Havasu with Planet Ranch pumping factored in. Without pumping, the same alternative provides 66,341 acre-feet, a 13,000 acre-foot increase in per annum water yield. In terms of water conservation, the HEC-5 model runs for the 1125 foot plan indicate that Planet Ranch pumping reduces Bill Williams River water supplies to the Lower Colorado River by up to 25% per annum.

Table 14. HEC-5 model evaluation criteria special runs for target elevation 1125 feet. Descriptions of the Alternative Operation Plans are in Table 11. WSE = Water Surface Elevation.

**(GDM, Present Conditions, and A1125D05 (recommended alternative))**

| Alternative Operation Plans | Minimum WSE Feet | Mean WSE Feet | Maximum WSE Feet | Recreation | | | | | | | Water Con. | | Flood Cntl | | Wildlife | | | Fisheries | | | | | | | Riparian | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RE1 | RE2 | RE3 | RE4 | RE5 | RE6 | RE7 | WC1 | WC2 | FC1 | FC2 | W1 | W2 | W3 | F1 | F2 | F3 | F4 | F5 | F6 | F7 | RA1 | RA2 | RA3 | RA4 | RA5 | RA6 | RA7 |
| | | | | % | % | % | % | % | % | % | af | af | # | % | % | # | # | % | % | % | ft | cfs | cfs | % | % | % | % | % | % | # | # |
| GDM Plan | 1,035.9 | 1,068.3 | 1,183.3 | 2.8% | 2.4% | 1.8% | 0.4% | 0.3% | 6.7% | 0.9% | 65322 | 5857 | 16 | 13.8% | 2.1% | 3 | 3 | 0.7% | 13.1% | 42.6% | 67 | 48 | 171 | 24.9% | 30.7% | 2.1% | 15.2% | 22.9% | 9.3% | 17 | 26 |
| **Present Cond.** | **1,080.5** | **1,098.1** | **1,185.8** | **93.5%** | **79.7%** | **3.2%** | **0.6%** | **0.2%** | **6.5%** | **1.6%** | **58735** | **13145** | **27** | **16.8%** | **36.9%** | **6** | **6** | **1.2%** | **11.5%** | **19.9%** | **36** | **37** | **161** | **21.4%** | **27.8%** | **36.8%** | **13.8%** | **20.9%** | **6.8%** | **17** | **24** |
| **A1125D05** | **1,084.9** | **1,109.0** | **1,170.0** | **96.7%** | **90.5%** | **49.0%** | **34.6%** | **0.2%** | **4.7%** | **40.6%** | **53174** | **16106** | **0** | **0.0%** | **69.5%** | **11** | **11** | **43.6%** | **4.6%** | **27.1%** | **20** | **72** | **137** | **19.0%** | **51.3%** | **69.5%** | **59.6%** | **70.3%** | **61.2%** | **12** | **16** |

**(Special Runs)**

| Alternative Operation Plans | Minimum WSE Feet | Mean WSE Feet | Maximum WSE Feet | Recreation | | | | | | | Water Con. | | Flood Cntl | | Wildlife | | | Fisheries | | | | | | | Riparian | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RE1 | RE2 | RE3 | RE4 | RE5 | RE6 | RE7 | WC1 | WC2 | FC1 | FC2 | W1 | W2 | W3 | F1 | F2 | F3 | F4 | F5 | F6 | F7 | RA1 | RA2 | RA3 | RA4 | RA5 | RA6 | RA7 |
| | | | | % | % | % | % | % | % | % | af | af | # | % | % | # | # | % | % | % | ft | cfs | cfs | % | % | % | % | % | % | # | # |
| A1125NP5 | 1,084.9 | 1,109.0 | 1,170.0 | 96.7% | 90.5% | 49.0% | 34.6% | 0.2% | 4.7% | 40.6% | 66341 | 16106 | 0 | 0.0% | 69.5% | 11 | 11 | 43.6% | 4.6% | 27.1% | 20 | 72 | 137 | 50.3% | 76.3% | 69.5% | 59.6% | 70.3% | 61.2% | 12 | 16 |
| A1125D10 | 1,085.8 | 1,110.7 | 1,170.0 | 97.7% | 92.6% | 56.8% | 41.1% | 0.2% | 3.9% | 45.1% | 51915 | 16521 | 0 | 0.0% | 74.1% | 11 | 11 | 51.0% | 4.6% | 28.3% | 20 | 60 | 141 | 16.6% | 50.5% | 74.1% | 67.9% | 74.7% | 71.1% | 14 | 16 |
| A1125D15 | 1,084.9 | 1,111.1 | 1,170.0 | 96.7% | 90.9% | 59.4% | 43.3% | 0.2% | 3.6% | 47.1% | 51910 | 16620 | 0 | 0.0% | 73.9% | 13 | 12 | 53.5% | 4.6% | 28.2% | 20 | 58 | 141 | 15.9% | 49.2% | 73.9% | 68.1% | 74.6% | 70.7% | 15 | 16 |
| A1125WOD | 1,086.2 | 1,111.9 | 1,170.0 | 99.3% | 93.6% | 61.8% | 44.8% | 0.2% | 3.2% | 48.4% | 51490 | 16804 | 0 | 0.0% | 78.2% | 13 | 12 | 55.5% | 4.6% | 30.6% | 9 | 55 | 142 | 14.4% | 49.5% | 78.2% | 75.6% | 79.8% | 78.3% | 15 | 16 |

Notes:

Recreation
- RE1 - Percent of time WSE at or above 1090'
- RE2 - Percent of time WSE at or above 1094'
- RE3 - Percent of time WSE at or above 1108'
- RE4 - Percent of time WSE between 1115' and 1125'
- RE5 - Percent of time WSE between 1144' and 1154'
- RE6 - Percent of time Outflow is between 300 and 7,000 cfs
- RE7 - Percent of time in March thru May WSE between 1115' and 1125'

Water Con.
- WC1 - Average annual delivery of water to LCR (Lake Havasu)
- WC2 - Average Annual Evaporation in Acre Feet for period 1929-1993

Flood Control
- FC1- Number of days WSE above 1171.3 during period of record (1929-1993)
- FC2 - Maximum percent of flood control space used during period of record.

Wildlife
- W1 - Percent of time WSE at or above 1100'
- W2 - Number of times during the year that WSE exceeds elevation 1135' two or more consecutive days.
- W3 - Number of times from 1 December through 30 June that WSE exceeds elevation 1135' two or more consecutive days.

Fisheries
- F1 - Percent of time WSE between 1110' and 1125'
- 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 (1929-1993)
- F5 - Average daily release during June thru September
- F6 - Average daily release during October thru May
- F7 - Percent of time streamflows at BW Refuge equal or exceed 25 cfs

Riparian
- RA1 - Percent of time streamflows at BW Refuge equal or exceed 18 cfs
- RA2 - Percent of time WSE between 1100' and 1171.3'
- RA3 - Percent of time Alamo Releases greater than or equal to 25 cfs in November thru January.
- RA4 - Percent of time Alamo releases greater than or equal to 40 cfs in February - April & October
- RA5 - Percent of time Alamo releases are greater than or equal to 50 cfs in May thru Sept.
- RA6 - Total number of occurrences that Alamo releases equal or exceed 1,000 cfs seven or more consecutive days in Nov. thru Feb.
- RA7 - Total number of occurrences that Alamo releases equal or exceed 1,000 cfs seven or more consecutive days in March thru October

Streamflows at the Refuge are ≥ 18 cfs for 51.3% of the time (RA1) when Planet Ranch pumping occurs (Table 14). Without pumping impacts, flows ≥ 18 cfs occur at the Refuge 76.3% of the time for the 1929-93 period of record. This represents a significant increase in maintaining instream flows at the Refuge for riparian and wildlife enhancement.

**NOTE:** Estimated average withdrawal of groundwater at the Planet Ranch valley is approximately 15,000 acre-feet annually, equivalent to about 20 cfs (Rivers West, 1990). The storage capacity of the aquifer underlying Planet Ranch is large and when Alamo Dam releases are < 500 cfs , hydrologic effects of this aquifer significantly reduce downstream flows to the Refuge and consequently Lake Havasu (Table 10). In the spring of 1994, the City of Scottsdale curtailed agricultural production at Planet Ranch and essentially shut down groundwater pumping from the aquifer indefinitely. Impacts of no aquifer pumping to downstream Bill Williams River flows are currently being monitored.

**b. 10 and 15 year drawdown**

Results from special runs based on 10 and 15 year maintenance drawdown periods (Table 14) indicate moderate improvements to most evaluation criteria. The most significant improvements (≥ 10% change) occur for recreation, fisheries, and riparian resources. Recreation and fisheries improvements are due to the reduced frequency of lake fluctuations required during drawdown periods. With longer periods between drawdowns, lake levels are kept more stable which benefits recreation access and fish spawning and recruitment. Riparian communities are benefitted by higher reliability of base flows as lake storage does not have to be evacuated down to 1100 feet as often.

Consequences of less frequent lake drawdowns are that lake elevations can be maintained near target elevations as more water is available in lake storage to carry over from year to year. This increased storage over time results in slightly higher average annual evaporation losses (WC2) and subsequent reductions (1,264 acre-feet or 2.3%) in annual water delivery to the lower Colorado River averaged over a 65 year period (WC1) for the 15 year maintenance drawdown run.

**c. No drawdown**

Results from runs based on no drawdowns from the 1928-93 period of record indicate high improvements (≥ 20% change) in maintaining water surface elevations above 1108' and 1100' for recreation and wildlife resources, respectively. When drawdowns are eliminated, the percent of time Alamo releases meet or exceed acceptable base flow requirements for riparian resources is improved significantly for all seasons.

It should be recognized that major structural modifications to the outlet works inlet and bulkhead would be needed to enable required inspection and maintenance activities to occur at fixed five year intervals without reservoir drawdown below elevation 1110 feet. However, if the Corps were to exercise flexibility in scheduling outlet tunnel inspection

and maintenance activities to occur over a range of, say, 3-6 years when lake elevations are already below 1110 feet, the need for reservoir drawdowns may be greatly reduced.

# V. PROPOSED PLAN

## A. PLAN COMPONENTS

The alternative with the 1125-foot target elevation (A1125D05) was the consensus selection of the Technical Committee as the preferred operating plan. The selected plan provided the best overall performance with respect to the evaluation criteria presented in Table 13 and Subcommittee recommendations.

### 1. LAKE ELEVATION

Under the proposed alternative, Alamo Lake levels would be managed for a target elevation of 1125 feet. If a storm event raises the lake above that elevation, water would be released rapidly to return the lake to 1125 feet. When the lake elevation is below 1125 feet, water would only be released to meet maintenance base flows in the Bill Williams River and to satisfy downstream water rights. Large releases would not be made for storm events until lake elevations exceeded 1125 feet.

Table 15 illustrates comparative differences in Alamo Lake elevations over time for the proposed 1125 foot plan and the present 1100 foot plan. The impact of the five year inspection drawdowns (modeled to occur in years ending in a 3 and 8) on lake elevations is apparent in Table 15. For the proposed 1125 foot plan, the rate of drawdown for lake elevations in the 1100-1125 foot range is considerably less than for current operating conditions. Based on analysis of model runs for the period of hydrologic record, Alamo Lake elevations could remain below 1125 feet for long periods of time when inflow is minimal (i.e., extended drought periods). For the period of record from 1953-64, Alamo Lake elevations never exceeded 1118 feet and for nearly four consecutive years remained below 1100 feet (Table 15).

### 2. PRESCRIBED RELEASES

The prescribed releases for the 1125 foot proposed alternative are presented in Table 16. Alamo Dam releases for riparian base flow requirements would range from 25 cfs from November-January and 40-50 cfs during the spring-fall period.

The most idealistic flow releases from Alamo Dam cannot recreate the historical riparian vegetation diversity, density, and distribution along the Bill Williams River due to reduced flow magnitude, frequency, duration, and timing since Alamo Dam construction. But because the recommended (optimal) base flows are probably higher than pre-dam base flows, enhancements over historic conditions may occur in terms of riparian vegetation regeneration and recruitment. It is also known that the recommended flushing flows, while lower than pre-