US Army Corps of Engineers
Hydrologic Engineering Center

Arizona Water Resources Study: Single Reservoir Simulation

September 1995

PR-29

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
September 1995	Project Report	

4. TITLE AND SUBTITLE
Arizona Water Resources Study: Singel Reservoir Simulation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
CEIWR-HEC

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
PR-29

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
.

14. ABSTRACT
This report documents Phase IV of the five phase Arizona Water Resources Study, this study is a cooperative multi-agency study to determine the potential for increased water yield through vegetative management in Arizona watersheds.

Reservoir inflow data, reflecting alternative watershed management strategies, were developed at the University of Arizona. The primary question addressed in this study is whether the existing reservoirs could effectively utilize increased watershed yield. Reservoir operation simulations were performed, with the derived flow data, to determine reservoir yield. Statistical analyses for the simulation results were performed to summarize the reservoir operations.

15. SUBJECT TERMS
Phase IV, Arizona Water Resources Study, water yield, vegetative management, watersheds, reservoir, inflow, watershed yield, operation, simulations, flow data, reservoir yield, statistical, HEC-5, stochastic

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	50	19b. TELEPHONE NUMBER

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Foreword

The investigation reported herein is Phase IV of the five phase Arizona Water Resources Study. The Arizona Water Resources Study is a cooperative multi-agency study to determine the potential for increased water yield through vegetative management in Arizona watersheds.

Reservoir inflow data, reflecting alternative watershed management strategies, were developed at the University of Arizona. The primary question addressed in this study is whether the existing reservoirs could effectively utilize increased watershed yield. Reservoir operation simulations were performed, with the derived flow data, to determine reservoir yield. Statistical analyses of the simulation results were performed to summarize the reservoir operations. Inconsistencies in the results from San Carlos reservoir simulation suggest that the provided flow sequences are not consistent with their intended representation.

This study was conducted by the Hydrologic Engineering Center (HEC) Davis, California. Tony Pulokas, a University of California, Davis, graduate intern at HEC, assembled data, developed and applied the HEC-5 reservoir simulation models, and post-processed simulation results. Richard Hayes, senior engineer, developed source code modifications to computer program HEC-5 and contributed to the overall analysis. Dr. David Goldman, senior engineer, provided guidance in the application of stochastic flow data. Adela Pucci assisted in typing the report. Final editing and formatting were done by Josie Garcia-Moreno. Vernon Bonner, Chief of the Training Division, provided study direction and management. Darryl Davis, Director, provided general supervision and guidance for the project.

Chapter 1

Introduction

1.1 Purpose

This report documents the development of reservoir system models for simulation of three basins in Arizona. This work is a part of the Arizona Water Resources Study which is investigating the potential for increased water yield through vegetative management practices in Arizona watersheds. Stochastic flow sequences representing three levels of water-yielding vegetative management practices were simulated at the University of Arizona. These flow data were input to each of the three reservoir models developed in this study. The reservoir-operation simulation was used to estimate the effective reservoir yield with the potential increased runoff.

1.2 Background

The Arizona Water Resources Study is a cooperative multi-agency study to investigate the potential for increasing water yield through alternative vegetative management practices on seven Arizona watersheds. The Hydrologic Engineering Center (HEC) was requested to simulate reservoir operation in three of the watersheds which supply single reservoir systems. The reservoirs and watersheds investigated are: Alamo Lake on the Bill Williams River; Lake Pleasant on the Agua Fria River; and San Carlos Reservoir on the Upper Gila River.

For these simulations, the Phoenix Area Office, Los Angeles District, USACE, provided HEC with stochastic inflow sequences. For each of the three watersheds, data for three scenarios were provided: low, medium, and high vegetative management practices. Each of the flow sequences represented 2,000 years of monthly interval flow data. The HEC time-series data storage system, HEC-DSS (USACE, 1995) was used extensively to facilitate data storage and the analysis of study results.

The Corps of Engineers generalized reservoir simulation program HEC-5, "Simulation of Flood Control and Conservation Systems" (USACE, 1982), was used for all reservoir simulations. Because simulations involved time blocks in excess of 100 years, the HEC-5 source code was modified to handle changing centuries in the dates. Also, the code was modified to account for multiple ownership of the conservation storage in a reservoir.

1.3 Report Overview

Chapter 2 presents the study objective, and then it summarizes the study approach, the stochastic inflow data, the HEC-5 program, and the modifications made to HEC-5 specifically for this study.

Chapter 3 overviews the physical data and present operation of the reservoir systems studied.

Chapter 4 gives details about the development of HEC-5 models of each reservoir system.

Chapter 5 presents study results in the form of annual averages and frequency of exceedance plots for relevant output variables. Also reported are performance variables from the Bill Williams River Corridor Technical Committee study. Finally, the reliability of water delivery without shortages is presented.

Chapter 6 contains a summary of the modeling effort.

References cited in this report are listed in Appendix A. Appendix B lists the HEC-5 input files. Appendix C consists of a diskette containing the HEC-5 input files for each of the reservoir systems, and HEC-DSS files which contain the stochastic inflow data.

Chapter 2

Problem and Approach

2.1 The Problem

The primary goal of this investigation is to determine the effect of vegetative management practices on long term water yield at selected reservoirs in Arizona. Previous studies (Collings and Myrick, 1966; Robinson, 1966) and have shown that the reduction of evapotranspiration resulting from brush clearing or phreatophyte removal can increase streamflow.

An increase in runoff due to a vegetative management practice cannot be directly translated to an increase in water delivery from the reservoirs. In many areas of Arizona potential evaporation rates are among the highest observed in the United States. The seasonality of evapotranspiration and streamflow coupled with the timing of water demands and the loss of stored water to evaporation from reservoir surfaces complicates the relationship between watershed yield and water delivery to users.

2.2 General Approach

The general procedure used in this study is referred to as stochastic flow simulation. The flow simulation allows analysis of reservoir operation given that the inflow is uncertain. A model of the inflow is created from the statistical parameters of the historical inflow record, and a random number generator. With this model, equally probable artificial time series of flow are generated. Then, the artificial time series of flow are used as input in a reservoir simulation.

The stochastic time series of flow were developed at the University of Arizona and were provided by the Phoenix Area Office of the Los Angles District Corps of Engineers. The 2000 years of simulated flow were duplicated and adjusted for three watershed management scenarios: (1) the "plan"representing current vegetative management practices; (2) "low" representing no vegetative management; and (3) "high" representing a prescribed increase in vegetative management. For each management plan, the data were divided into ten 200-year blocks and provided to HEC in spread-sheet files.

HEC transferred the flow data into HEC-DSS files. HEC-5 data models were created for each of the three reservoir systems. The models read the DSS files to define reservoir inflow. Except for inflow, all model variables, such as water demand and evaporation rate, were assumed to be deterministic (they did not change with time). Reservoir operation was then simulated for each 200-year flow set, and the results were summarized by averages and frequency curves, allowing comparison of the results of the three levels of vegetative management.

The time series of inflow do not reflect long-term changes in the conditions which produce inflow. Likewise, the reservoir models developed here assume no long-term changes. For instance, the models assume no change in demands, storage, or operating policy under the different watershed management scenarios. These assumptions may not valid because it is possible that water use would increase in response to a supply increase, or operating zones might be reallocated.

The selection of initial conditions warrants careful attention. Ideally, these simulations should be independent of any initial conditions. The best approach is to have a startup period of sufficient length that the effect of the initial condition becomes negligible. The results from the startup period would then be truncated from the simulated record. However, the stochastic time series supplied to this study did not contain a startup period. Therefore, all of the results of this study are conditional upon the assumed starting conditions.

Starting conditions need to be reasonable. In this study, reservoir storage is the only variable for which an initial condition is defined. All simulations begin in October, so the value of initial storage should be a reasonable value for that month. For example, reservoirs in Arizona typically are low in the autumn. If the simulation were to be started with a full reservoir, the results would be unrealistic. To estimate an appropriate value for October, October storage values were chosen from late in the simulation period, when the effect of the initial storage was negligible. These values were then averaged to arrive at a realistic initial storage.

After the simulations were performed, output variables of interest, such as shortages, spills, and evaporation losses, were summarized by annual averages and frequency exceedance plots.

2.3 Stochastic Flow Data

The annual averages of the inflow data used in this study are presented in Table 2.1. As expected, the "low" watershed management scenario produces less runoff than the "plan" scenario, and the "plan" scenario provides less runoff than the "high" scenario. However, in the upper Gila watershed, which drains into San Carlos Reservoir, there are some discrepancies in the flow data. During some of the years with very high runoff, the "low" and "plan" scenarios have more runoff than the "high" scenario. At that location, lower-level management scenarios may have more water during some months. However, there are some years when the lower management scenarios yield much more water for the annual total. One year was found where the low option inflow exceeded the high option inflow by 203,000 acre-feet. From one 200-year sequence, 17 of the months had lower inflow in the "high" scenario than in the low scenario.

Table 2.1
Annual Average of Simulation Input: Reservoir Inflow

		LOW	PLAN	HIGH
Alamo Lake	acre-feet	101126	101955	105997
	change from plan (acre-feet)	-829		4042
	% change	-0.8%		4.0%
Lake Pleasant	acre-feet	61333	62666	69389
	change from plan (acre-feet)	-1333		6723
	% change	-2.1%		10.7%
San Carlos Reservoir	acre-feet	280191	280988	287066
	change from plan (acre-feet)	-797		6078
	% change	-0.3%		2.2%

2.4 HEC-5 Model

HEC-5, Simulation of Flood Control and Conservation Systems, is a Corps of Engineers generalized reservoir simulation program. HEC-5 can simulate the essential features and operation goals of simple or complex systems of reservoirs with simulation intervals ranging from minutes up to a month. Analysis may include operation for flood control, hydropower and/or water supply goals. Water supply simulation can include reservoir and downstream flow requirements in addition to diversions and returns. The ability to read and write to the HEC-DSS data management system facilitates period-of-record time-series analysis.

All reservoir simulations for this study were performed with the August 1995 developmental version of HEC-5 on a Gateway 486 PC. Computation times for 200 years of flow data were about 1 ½ minutes for Alamo and San Carlos, and 3 ½ minutes for Lake Pleasant.

2.5 Software Modifications

Several aspects of this study required that the HEC-5 code be modified. The first problem was that continuous simulations over a period of 200 years were necessary. The current program, March 1991 version, presumes that times-series data would be only from the current century (1900's). However, dates in other centuries had to be utilized if more than 100 years of continuous operation were to be simulated. The code was changed so that any century could be used. The century corresponding to the starting date of a simulation (input in field 7 of the BF record) may now be specified in the tenth field of the BF record.

Furthermore, the storage-accounting practice in Lake Pleasant required that new features be added the HEC-5 code. Formerly, HEC-5 only provided a priority system based on reservoir levels (field 7 of the CP record) for allocating reservoir releases between downstream water demand sites. Deliveries from Lake Pleasant, however, are based on a storage accounting system which tracks storage in two separate accounts, one representing the volume of water owned by the Maricopa Water District (MWD) and a second storage account which represents water owned by the Central Arizona Project (CAP). Evaporation losses from Lake Pleasant are apportioned between the MWD and CAP based on the ratio of their respective storage accounts to the total conservation storage. A schematic was developed to simulate the multiple accounts of the system (see Section 4.2). To apply this system, two program options were added to HEC-5.

First, a diversion option was created so that, within the same time step, the diversion at a dependent node would be equal to the flow at an independent reference location. In the case of Lake Pleasant, the program computes the flow representing the MWD delivery from old Wadell Reservoir (based on a monthly schedule and limited by the availability of water in the MWD storage account). This computed flow is then the basis for a diversion demand which Lake Pleasant will operate for. The new diversion option is input on the DR record in fields 7 and 10. The diversion type as indicated in field 7 is -6, the reference location upon which the diversion is based is input into field 10.

Second, an evaporation option was created so that the evaporation at a dependent reservoir would be equal to the evaporation at an independent reservoir times the ratio of its volume to that of the independent reservoir. Specifically, the program computes the evaporation at Lake Pleasant from the water surface area and the monthly evaporation rate and then calculates the evaporation to be applied to the MWD storage account (old Lake Pleasant) by determining the ratio of MWD storage to Lake Pleasant storage times the monthly evaporation volume.

MWD evaporation is computed within HEC-5 with the following equation:

$$\text{MWP EVAP} = \left(\frac{\text{MWD STOR}}{\text{TOTAL STOR}}\right) \bullet \text{TOTAL EVAP} \tag{2-1}$$

where:

MVD EVAP	=	volume of evaporation subtracted from MWD storage account
MWD STOR	=	storage in the MWD storage account
TOTAL STOR	=	total conservation storage in Lake Pleasant
TOTAL EVAP	=	total monthly volume of evaporation from Lake Pleasant

Evaporation computations were checked against spreadsheet computations for a 200 year simulation period. A difference of about 0.02 ft^3/s or 15 acre-feet/year on an annual basis was noted. This difference was found to occur during the months when the MWD storage account was depleted. A further discussion of evaporation and storage accounting for Lake Pleasant appears in section 4.2.

Chapter 3

Reservoir Systems

3.1 Alamo Lake

Alamo Dam impounds the Bill Williams River to form Alamo Lake, 39 miles upstream from the river's confluence with the Colorado in Lake Havasu, in west central Arizona. The Lake is on the border of La Paz and Mohave Counties (BWRCTC, 1994).

Alamo Dam is operated primarily for flood control on the Colorado River, and for recreation on Alamo Lake. The multi-agency Bill Williams River Corridor Technical Committee (BWRCTC) has reviewed the operation of Alamo Dam, and has proposed new operating policies. These revised operating procedures are designed as a balanced plan to protect and enhance flood control, water conservation, recreation, fisheries, and wildlife associated with the lake, as well as the riparian vegetation on the downstream reach of the Bill Williams River. This report assumes that those operating policies will be approved and adopted in the near future.

The BWRCTC proposal features a target water surface elevation of 1125 feet. The operating policy is described by a table from which the reservoir release is determined from the water surface elevation and the time of year (Table 4.1). The releases are limited by the downstream flood control capacity of 7,000 ft^3/s (BWRCTC, 1994).

Additionally, the reservoir must be drawn down once every five years so that the Corps of Engineers can do a complete inspection and engineering evaluation of the condition of the dam. In order for the outlet tunnel to be inspected, the reservoir must be drawn down to a water surface elevation of 1100 feet. The BWRCTC has prescribed that these drawdowns should occur at a certain rate, beginning as early as June of the year of the inspection, and reaching 1100 feet in November (BWRCTC, 1994).

3.2 Lake Pleasant

New Waddell Dam impounds the Agua Fria River to form Lake Pleasant, in central Arizona, northwest of Phoenix. The old Waddell Dam was submerged when New Waddell Dam was completed in 1993. The expansion of Lake Pleasant serves as storage for Central Arizona Project (CAP) water. During winter months, the CAP pumps water from the Colorado River through the Hayden-Rhodes aqueduct, then to Lake Pleasant via the Waddell Canal. The CAP chooses to pump in the winter because of lower energy costs. The water is released for power generation and water consumption by CAP customers during the summer months. (Arizona Department of Water Resources, 1994).

In addition to storage for the CAP, "replacement space" is provided for the Maricopa Water District (MWD), a local supplier of irrigation water. The replacement space is a right to store water up to the storage capacity which MWD controlled behind old Waddell Dam. Lake Pleasant is thus a "storage accounting reservoir," since both entities, the CAP and MWD, have storage accounts which specify how much of the water in Lake Pleasant each one owns. The CAP owns all water pumped from the Colorado River. MWD has rights to all water which the reservoir receives from the Agua Fria watershed, until the MWD account is full. Agua Fria water which exceeds the capacity of the MWD account, which would have been spilled over old

Waddell Dam, is claimed by the CAP (US Bureau of Reclamation, 1986). Losses of water to evaporation are charged to each account in proportion to the volume of each account (Henning, 1995).

3.3 San Carlos Reservoir

Coolidge Dam forms the San Carlos Reservoir on the upper Gila River in southeastern Arizona, approximately 90 miles east of Phoenix. The reservoir is primarily used for supplying water to the San Carlos Irrigation Project, and does not have a designated flood control capacity.

Chapter 4

HEC-5 Simulation Models

4.1 Alamo Lake

Stewart (1995) provided the input data set for the HEC-5 model of Alamo Lake which was used in the BWRCTC study. The BWRCTC Alamo Lake model included multiple downstream reaches and diversions intended to represent the effects of ground water pumping at Planet Ranch from the shallow aquifers below Alamo Lake. The BWRCTC model was simplified to be consistent with the needs of this study. The schematic of the HEC-5 Alamo Lake model is shown in Figure 4.1 below:

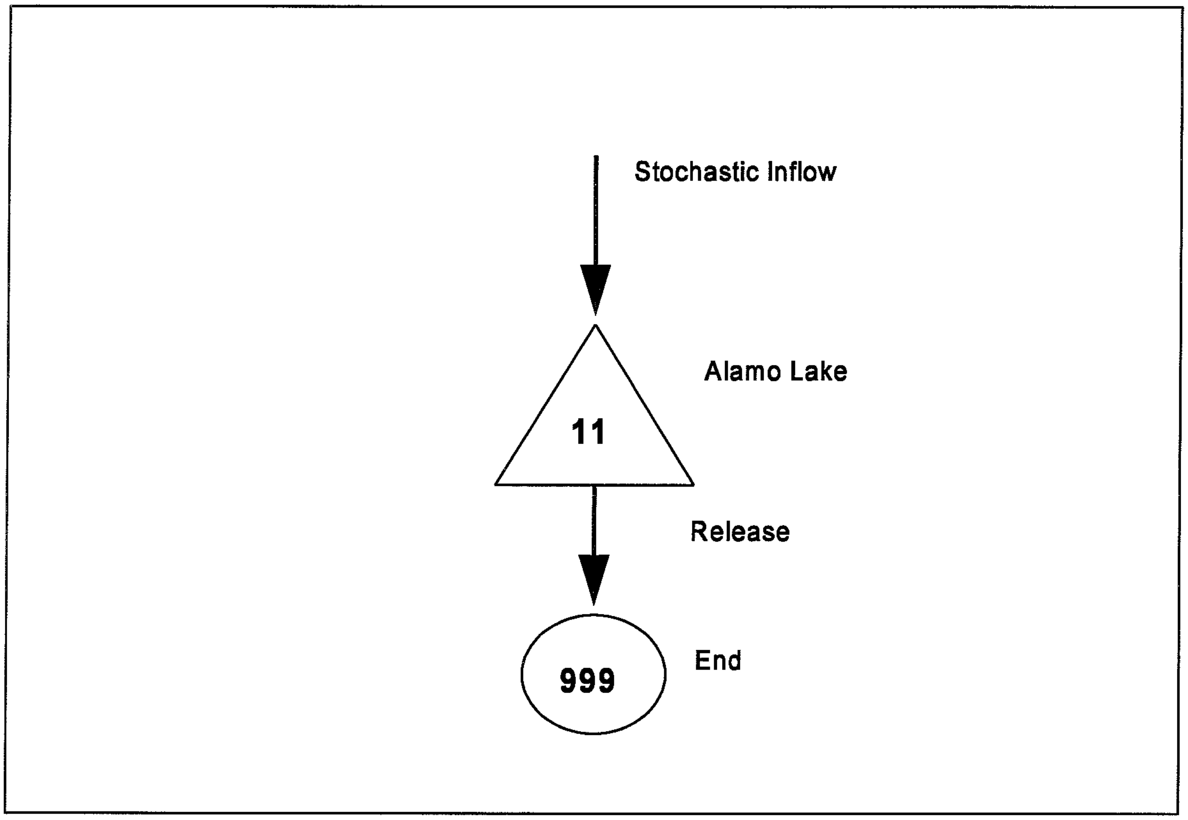

Figure 4.1 Schematic of Alamo Lake System.

The BWRCTC HEC-5 model file included the elevation-capacity-area relationship, the outlet capacity curve, the operating levels of the reservoir, and the designated release as a function of elevation (Table 4.1), the monthly evaporation rate (Table 4.2), and the prescribed drawdown rate, to occur once every five years.

Table 4.1
Generalized Alamo Dam Release Schedule as Recommended by the Bill Williams River Corridor Technical Committee

If current lake elevation < 1125 feet, then:

Lake Elevation (feet)	Alamo Dam Releases (ft^3/s)			
	October	November-January	February-April	May-September
990-1070	10	10	10	10
1070-1100	15	10	25	25
1100-1125	40	25	40	50

If current lake elevation > 1125 feet, then:

Lake Elevation (feet)	Alamo Dam Releases (ft^3/s)
1125-1126	transition up to 1000
1126	1000
1127	2000
1128	3000
1129	4000
1130	5000
1131	6000
1132	6621-7000
1148.4	7000
Up to 1235 (spillway crest)	7000
From 1235 to 1265 (top of dam)	over 7000

Table 4.2
Evaporation at Alamo

Month	Net Evaporation inches
January	1.70
February	2.08
March	3.68
April	5.55
May	7.42
June	9.69
July	9.43
August	8.52
September	6.35
October	4.35
November	2.42
December	1.50

The monthly time step for simulation was found adequate for simulating the low-level releases that occur when the reservoir is below the target elevation. However, for the large releases that are prescribed for times when the reservoir is above target, the monthly time step is too large. This is because the large releases should only last until the reservoir returns to the target elevation. Thus, the large releases generally only need to last a few days. However, when HEC-5 computed the larger releases, the release was applied too a single time step of one month. Therefore, when the reservoir went above target, HEC-5 would release too much water and lower the reservoir far below the target in the next time step. The problem was relieved by setting the bottom of the flood control pool at the target elevation, and ignoring the specifics of the large releases. This should be a reasonable solution because the release rates specified in the operating rule will draw down the reservoir from an elevation of 1150 to 1125 feet in about one week; well under one month used in simulation.

The 5-year maintenance drawdown pattern was copied from the BWRCTC model. The drawdown pattern was interpreted from a daily to a monthly time step. The flood periods were reorganized into 10-year intervals, since each decade has the same pattern (two drawdowns). The drawdown sequence is shown in Table 4.3.

Table 4.3
Pattern of Drawdown to Occur Once
Every Five Years at Alamo Lake

Month	Target for Drawdown at the End of the Month	
	Elevation (ft)	Storage (acre-feet)
May	1124.5	158956
June	1119.5	140427
July	1114.5	123148
August	1109.5	107163
September	1104.0	91162
October	1100.0	80411
November	1100.0	80411

The reservoir drawdown simplified the selection of a starting storage. By making the first drawdown occur during the very first time step, a reasonable initial storage is automatically known, and it also happens to be unconditional.

4.2 Lake Pleasant

Fisher (1995) supplied outlet discharge rating and storage zone data for Lake Pleasant. The dead-storage zone of Lake Pleasant is 37,800 acre-feet. The conservation-storage zone has a volume of 811,800 acre-feet, 157,600 of which belongs to the MWD, the remainder belonging to the CAP. The flood control storage zone is 45,700 acre-feet, and the surcharge storage zone is 251,400 acre-feet (Fisher, 1995). Preliminary simulations showed that reasonable values for storage at the start of October, and thus for initial storages, were 78,800 and 30,000 acre-feet for the MWD and CAP accounts, respectively. The fact that two agencies operate from the conservation pool in Lake Pleasant required some innovations to the HEC-5 program code, as described in Section 2.5.

The schematic of the system is shown in Figure 4.2. The monthly demand for MWD water, and the monthly CAP demand and pumping schedule are shown in Table 4.4.

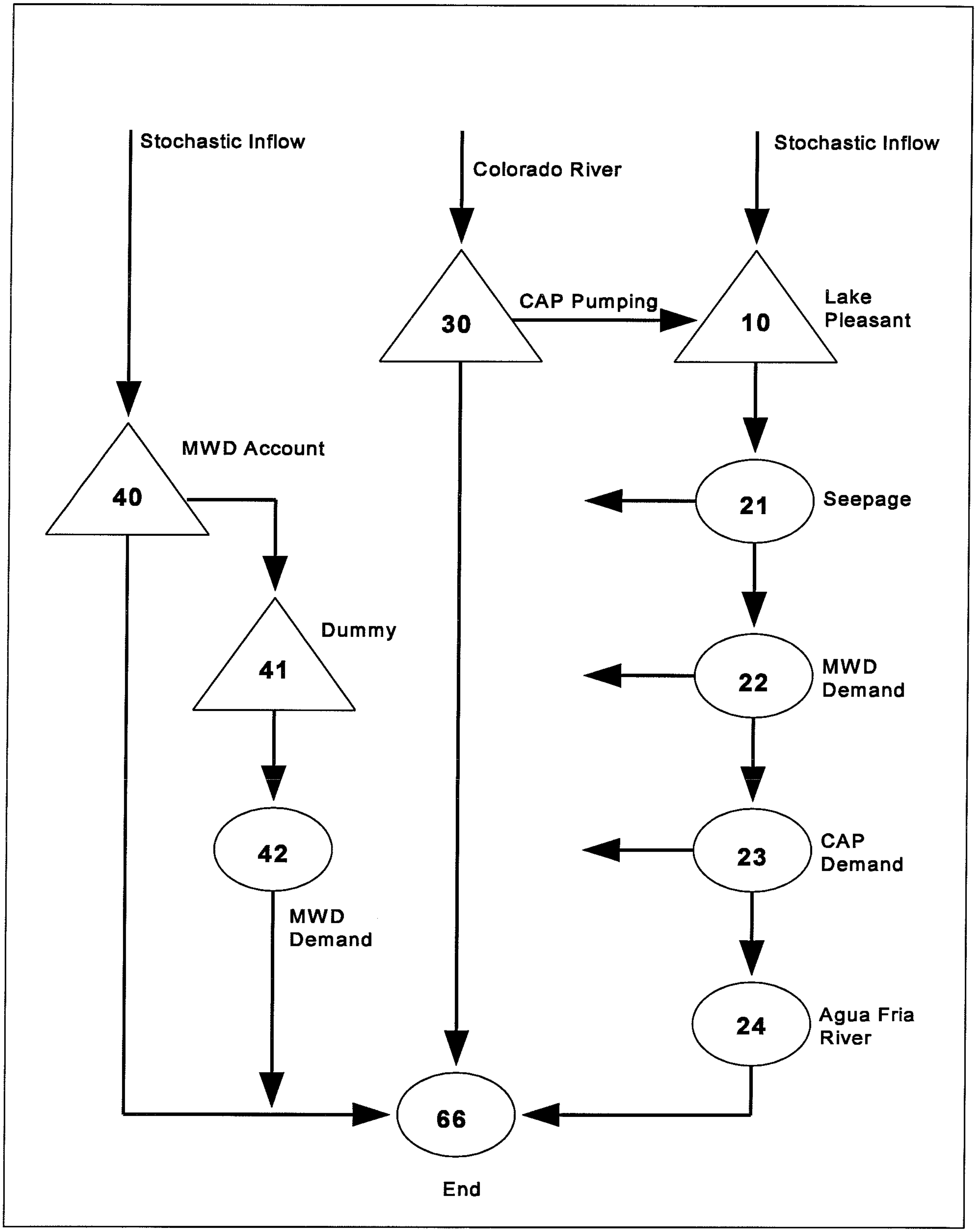

Figure 4.2 Schematic of Lake Pleasant System.

Table 4.4
Lake Pleasant Input Variables Which Vary by Month

Month	Net Evaporation inches	MWD Demand acre-feet	CAP pumping acre-feet	CAP demand acre-feet
January	-0.21	65	110000	0
February	1.31	950	0	0
March	2.20	4200	50000	0
April	5.27	5800	90000	0
May	7.84	5750	90000	0
June	8.79	7420	0	131300
July	6.85	9580	0	159800
August	4.37	6000	0	137000
September	4.99	4025	0	68500
October	3.23	2800	60000	28500
November	1.37	1460	110000	0
December	-0.29	0	60000	0

In Figure 4.2, Reservoir 10 represents Lake Pleasant. Reservoir 30 represents the Colorado River, which is kept full because this study assumes that the CAP supply is never limited. The diversion from reservoir 30 to 10 is for pumping CAP water into Lake Pleasant. The diversion at node 23 represents the withdrawals for CAP customers. The construction of this model assumes that the CAP never faces a shortage for its customers, because it pumps as much as it needs. The pumping schedule is programmed into HEC-5 though a diversion requirement.

The matter is complicated by transfers from the Agua Fria watershed to the CAP. In these cases, the CAP should avoid pumping extra water. To overcome this problem, it is first assumed that the CAP account will only contain bonus water when the MWD account is full. Thus, the maximum storage target for pumping is assigned a yearly pattern, equal to the volume of an MWD account that has been filled, plus the target volume of pumped CAP water, minus monthly releases. The MWD account is also contained in Reservoir 10. However, a separate reservoir has been created from which operating decisions for the MWD account are based.

Reservoir 40 represents the MWD account alone, which happens to be equivalent to the former, smaller Lake Pleasant behind old Waddell Dam. The demand for MWD water is simulated by the diversion from reservoir 40 to the dummy reservoir 41. The water flows straight to the demand node, node 42. Water spilling out of reservoir 40 represents the transfer of water to the CAP account. The release decisions made from reservoir 40 are communicated to reservoir 10 by setting a diversion requirement on node 22. The requirement at node 22 is equal to the flow at node 42 (see description of this option, Section 2.5).

The CAP pumps about 45,000 acre-feet more into the reservoir than it withdraws, because some will be lost to seepage and evaporation (Henning, 1995). Following the example of the study from the US Bureau of Reclamation (1986), losses of water through seepage are not charged to the MWD account. In order to simulate seepage, a diversion is applied at node 21. This diversion is equal to a constant 500 acre-feet per month, completely independent of other variables (as in US Bureau of Reclamation, 1986).

The CAP and MWD accounts share the evaporative losses in proportion to their volumes (Henning, 1995). Thus, in order to properly simulate the MWD account in reservoir 40, the evaporation in reservoir 40 is set equal to the evaporation in reservoir 10 times the volume ratio of reservoir 40 to reservoir 10 (see description of this option, Section 2.5). The dead- storage zone had to be subtracted from both reservoirs 40 and 10 so that the program could properly compute the storage ratios of the conservation storage volumes.

As previously noted in Section 2.5 computations to verify this new HEC-5 evaporation option indicated that a slight excess of water was being released from reservoir 10 during the month when the MWA storage account (reservoir 40) becomes dry. The water flows to node 24, so that post-processing routines count it as spill. This error was estimated to total on the order of 15 extra acre-feet of spill annually, less than a one percent error in the total annual spill. In comparison, the seepage is set at 6,000 acre-feet every year, and the average annual evaporation is about 27,000 acre-feet. Therefore, the effect of this excess release is considered insignificant compared to the accuracy inherent in the computation of reservoir losses.

Henning (1995) supplied reservoir evaporation rates (Table 4.4). Precipitation came from the Cordes, AZ weather station (National Oceanic and Atmospheric Administration, 1982).

4.3 San Carlos Reservoir

In contrast to the other two reservoir systems, the San Carlos Reservoir model is not complicated. The reservoir stores water for irrigation but has no flood control storage. The capacity of the reservoir is 885,000 acre-feet (Christenson, 1995). Preliminary reservoir simulation indicated a reasonable storage value for the start of October, and thus for the initial storage, was 130,000 acre-feet. The schematic of the system is shown in Figure 4.3.

Christenson (1995) supplied a spillway rating curve and an elevation-capacity table. He stated that during water year 1994, full deliveries were made to downstream demands, and no excess water was spilled. Thus, for water year 1994, the recorded flow at USGS gage 09469500, on the Gila River about ½ mile below Coolidge Dam, was representative of the demand from San Carlos Reservoir. The record was found in Weesner (1994). However, Warm Springs discharges a small amount of water between the dam and the gage (Christenson, 1995). To estimate the Warm Springs release, a constant 150 acre-feet per month was subtracted from the gage record. The resulting estimated water demand is shown in Table 4.5.

Allred (1995) provided local monthly pan evaporation rates. The net reservoir evaporation rates, shown in Table 4.5, were computed with monthly pan-to-reservoir factors and precipitation rates from USGS (1977). Allred (1995) also provided an elevation-area table for the reservoir.

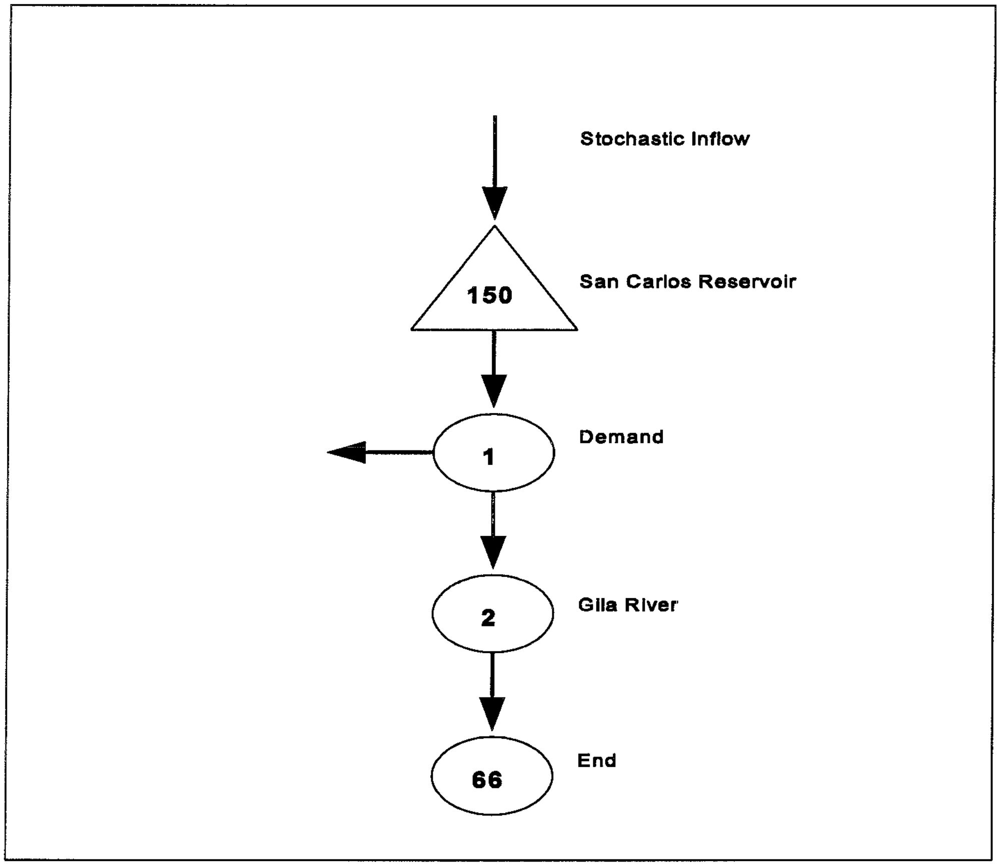

Figure 4.3 Schematic of San Carlos Reservoir System.

Table 4.5
San Carlos Input Variables Which Vary by Month

Month	Net Evaporation (inches)	Demand (acre-feet)
January	0.23	10600
February	0.97	10680
March	2.46	47500
April	5.02	35510
May	7.95	44040
June	9.62	63320
July	9.52	73790
August	7.27	66000
September	6.00	19780
October	4.67	9290
November	2.92	150
December	0.39	11780

Chapter 5

Reservoir Data Analysis

5.1 Alamo Lake

There are no diversions for water use from Alamo Lake or the Bill Williams River below Alamo Dam. However, the water which is released from Alamo Dam recharges groundwater which is pumped for municipal supply, and the river feeds the Colorado River system (BWRCTC, 1994). Alamo Dam releases were based on a recommended schedule (Table 4.1) developed by the BWRCTC which varies releases with both season and pool elevation.

Table 5.1 summarizes average annual Alamo Lake evaporation, release and pool elevations for the three simulated scenarios. Also shown in the table are the differences between the "Low" and "High" vegetative management scenarios and "Plan," the current vegetative management condition.

Table 5.1
Alamo Lake Annual Averages of Simulation Outputs

		LOW	PLAN	HIGH
evaporation	acre-feet	17298	17326	17411
	change from plan (acre-feet)	-28		85
	% change	-0.2%		0.5%
release	acre-feet	84132	84936	88905
	change from plan (acre-feet)	-804		3969
	% change	-0.9%		4.7%
elevation	acre-feet	1113.7	1113.8	1114.1
	change from plan (acre-feet)	-0.1		0.3
	% change	N/A	N/A	N/A

The BWRCTC evaluated the reservoir operation for multiple uses. The evaluation criteria identified by the BWRCTC reflect important goals for the reservoir, so the criteria which were most closely analyzed by the BWRCTC are evaluated in this study (BWRCTC, 1994). The results are presented in Table 5.2. Some of the BWRCTC criteria were not applicable due to the monthly time step of the simulation in this study.

Table 5.2
Performance of Alamo Reservoir on Selected Evaluation Criteria from the Bill Williams River Corridor Technical Committee Report

	Evaluation Criteria	LOW	PLAN	HIGH
RA3	Percent of time releases > 25 ft^3/s in Nov-Jan	95.5%	95.6%	95.8%
RA4	Percent of time releases > 40 ft^3/s in Feb-Apr and in Oct	98.1%	98.2%	98.3%
RA5	Percent of time releases > 50 ft^3/s in May-Sep	96.5%	96.6%	96.9%
F1	Percent of time WSE between 1110-1125 feet	66.9%	67.4%	68.8%
W1	Percent of time WSE at or above 1100 feet	88.0%	88.2%	88.8%
RE3	Percent of time WSE at or above 1108 feet	71.9%	72.3%	73.7%
RE4	Percent of time WSE between 1115-1125 feet	54.6%	55.1%	56.9%

Two figures show the frequency of exceedance for output variables of the Alamo Lake simulation: Figure 5.1 shows the monthly elevation, and Figure 5.2 shows the annual release.

5.2 Lake Pleasant

This study assumed that water supply from the Colorado River is never limiting to the CAP, and consequently, the CAP pumps as much water as it needs and never experiences a shortage. However, the watershed management still affects the CAP, because if inflow to Lake Pleasant is increased, the CAP is likely to get more water in the form of transfers, water which exceeds the maximum capacity of the MWD account.

Table 5.3 presents the average amounts of shortage in MWD service, actual delivery of water by MWD, losses to spillage and evaporation, the transfer of Agua Fria water to the CAP, and the amount of Colorado River water pumped by the CAP into Lake Pleasant.

Table 5.3 shows the annual average value of the output criteria. Below that, the table shows the difference between the average output in the given scenario and the average output of the "plan" scenario. Below that is the percent change of the average value from the "plan" scenario.

Figures 5.3, 5.4, and 5.5 show frequency of exceedance for the annual values of output variables of the Lake Pleasant simulation. Figure 5.3 shows the annual shortage for water demands. Figure 5.4 shows the annual amount of spillage. Figure 5.5 shows the annual amount which was transferred from the Agua Fria watershed to the CAP account.

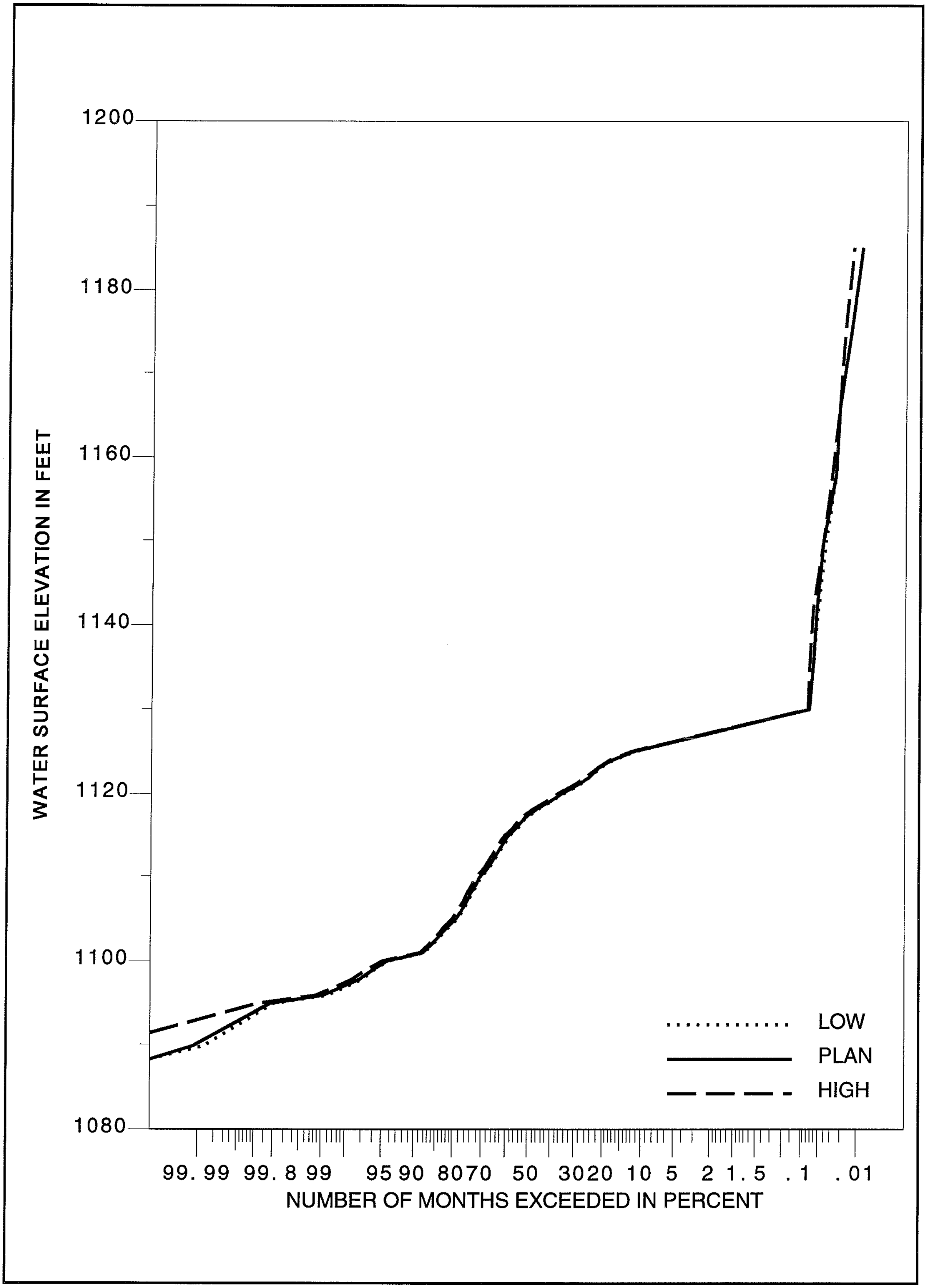

Figure 5.1 Frequency of Water Surface Elevation at Alamo Lake.

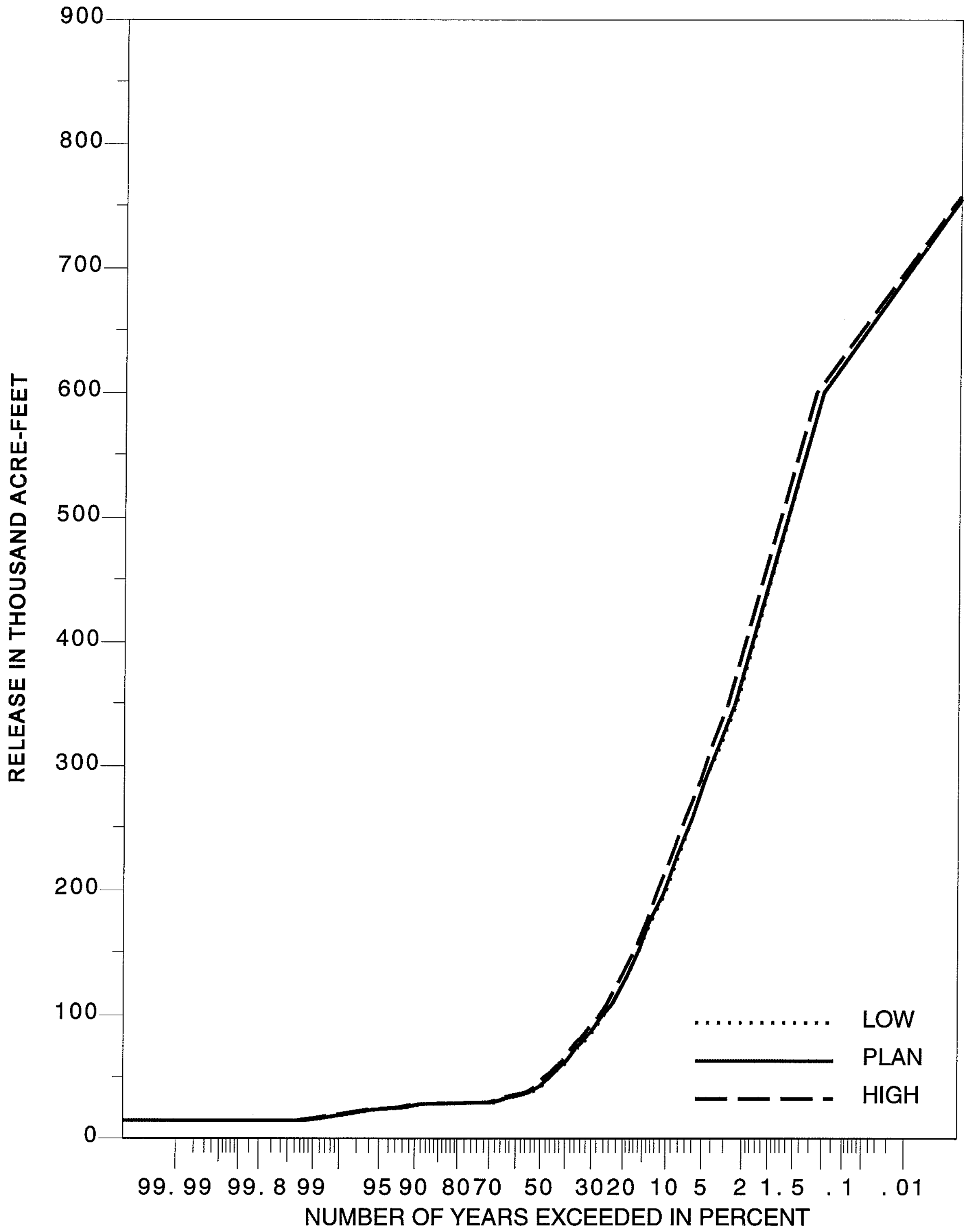

Figure 5.2 Frequency of Release from Alamo Lake.

Table 5.3
Lake Pleasant Annual Averages of Simulation Outputs

		LOW	PLAN	HIGH
MWD shortage	acre-feet	8232	7916	6498
	change from plan (acre-feet)	316		-1418
	% change	4.0%		-17.9%
MWD delivery	acre-feet	39141	39457	40876
	change from plan (acre-feet)	-316		1419
	% change	-0.8%		3.6%
spillage	acre-feet	1647	1827	2955
	change from plan (acre-feet)	-180		1128
	% change	-9.9%		61.7%
evaporation	acre-feet	27338	27355	27441
	change from plan (acre-feet)	-17		86
	% change	-0.1%		0.3%
CAP pumping	acre-feet	538135	537311	533192
	change from plan (acre-feet)	824		-4119
	% change	0.2%		-0.8%
CAP transfer	acre-feet	18635	19585	24554
	change from plan (acre-feet)	-950		4969
	% change	-4.9%		25.4%

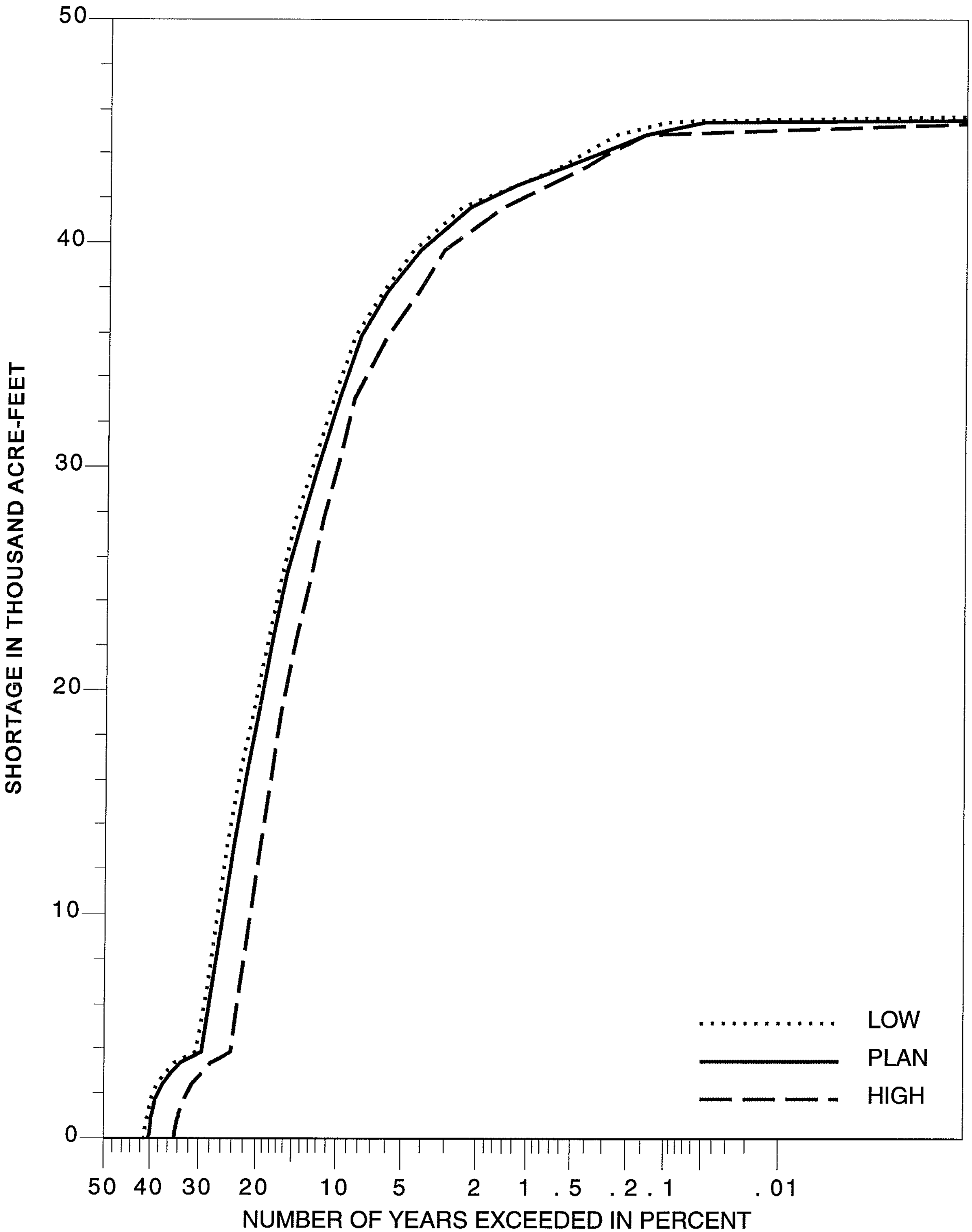

Figure 5.3 Frequency of Shortages in MWD Service from Lake Pleasant.

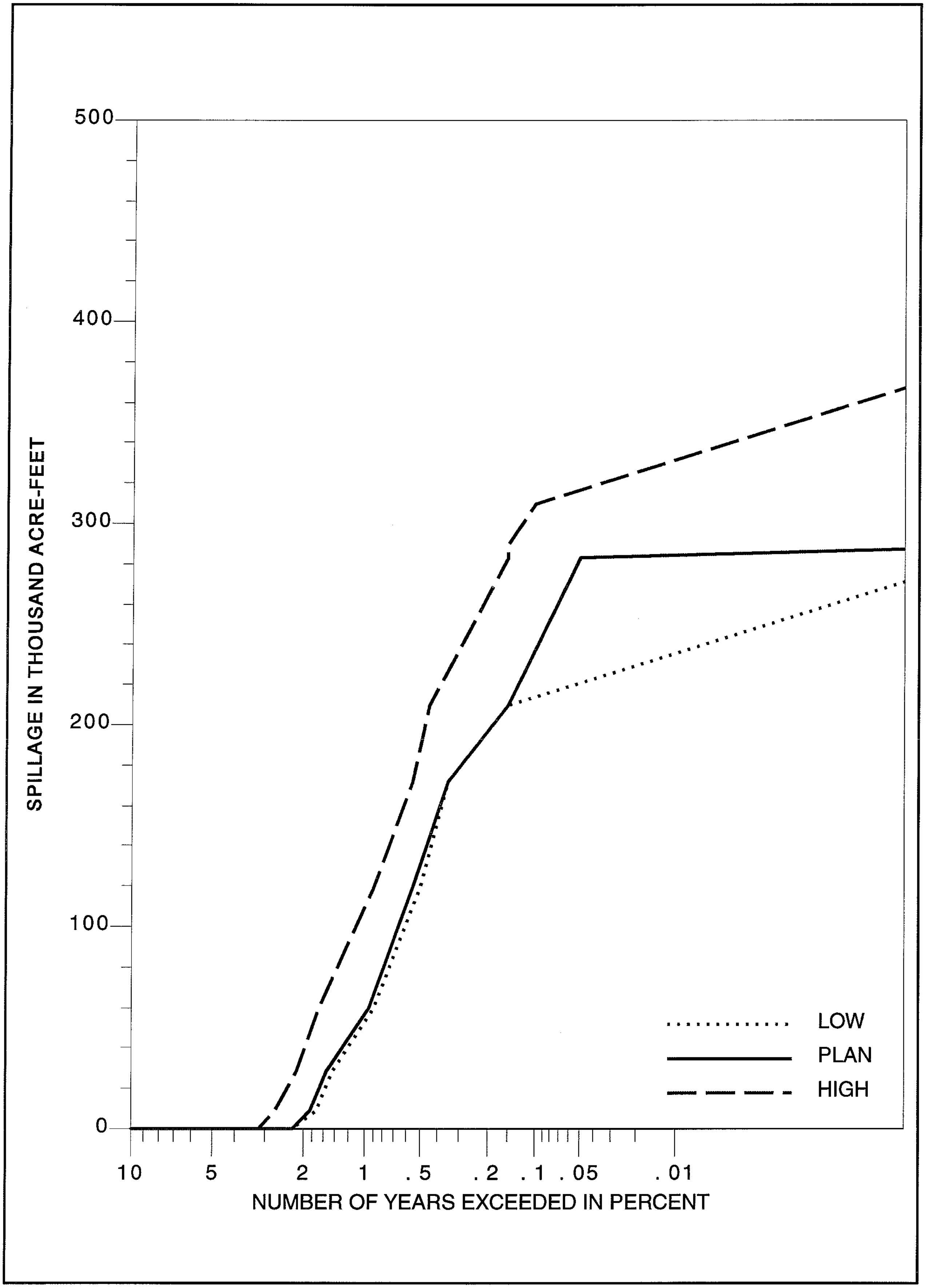

Figure 5.4 Frequency of Spillage from Lake Pleasant.

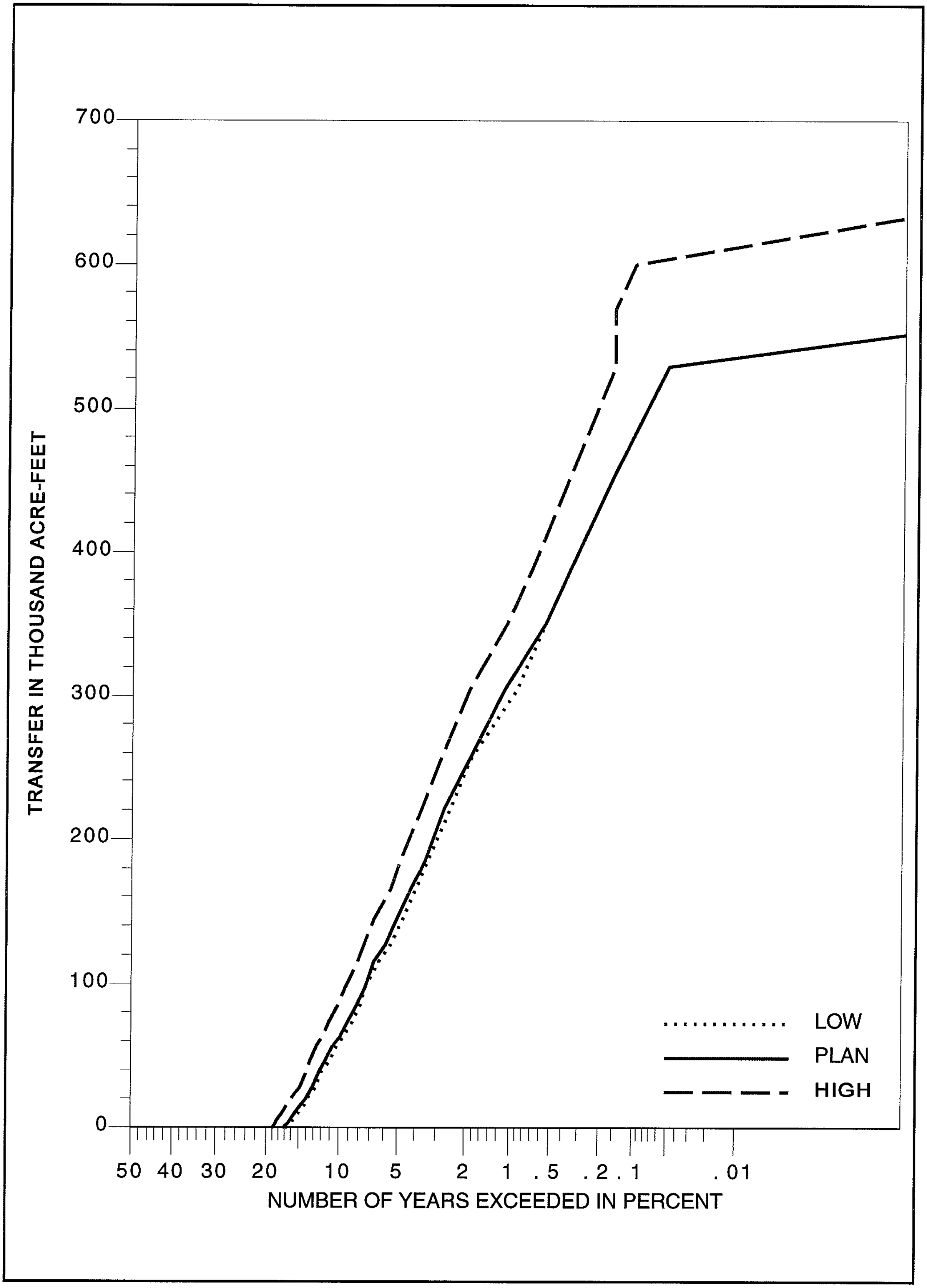

Figure 5.5 Frequency of Transfers of Agua Fria Water to the Cap Account.

5.3 San Carlos Reservoir

Table 5.4 presents the annual averages of the amounts of shortage to demands, the actual delivery to meet the demands, spillage, and evaporation for San Carlos Reservoir. Table 5.4 shows the annual average value of the output criteria. Below that is shown the difference between the average output in the given scenario and the average output of the "plan" scenario. Below that is the percent change of the average value from the "plan" scenario.

Table 5.4
San Carlos Reservoir Annual Averages of Simulation Outputs

		LOW	PLAN	HIGH
shortage	acre-feet	151161	150662	145322
	change from plan (acre-feet)	499		-5340
	% change	0.3%		-3.5%
delivery	acre-feet	238292	238791	244131
	change from plan (acre-feet)	-499		5340
	% change	-0.2%		2.2%
spillage	acre-feet	24981	25206	27396
	change from plan (acre-feet)	-225		2190
	% change	-0.9%		8.7%
evaporation	acre-feet	17515	17586	18362
	change from plan (acre-feet)	-71		776
	% change	-0.4%		4.4%

Figure 5.6 is the frequency of exceedance plot for the annual shortage to water demands at San Carlos Reservoir. Figure 5.7 is the frequency of exceedance plot for the annual amount of spillage over Coolidge Dam. In Figure 5.7, note that the spillage for the "high" scenario is lower than the spillage for the "low" scenario for the very low probability events. This was found to be a result of higher inflows in the "low" scenario, which makes these results questionable.

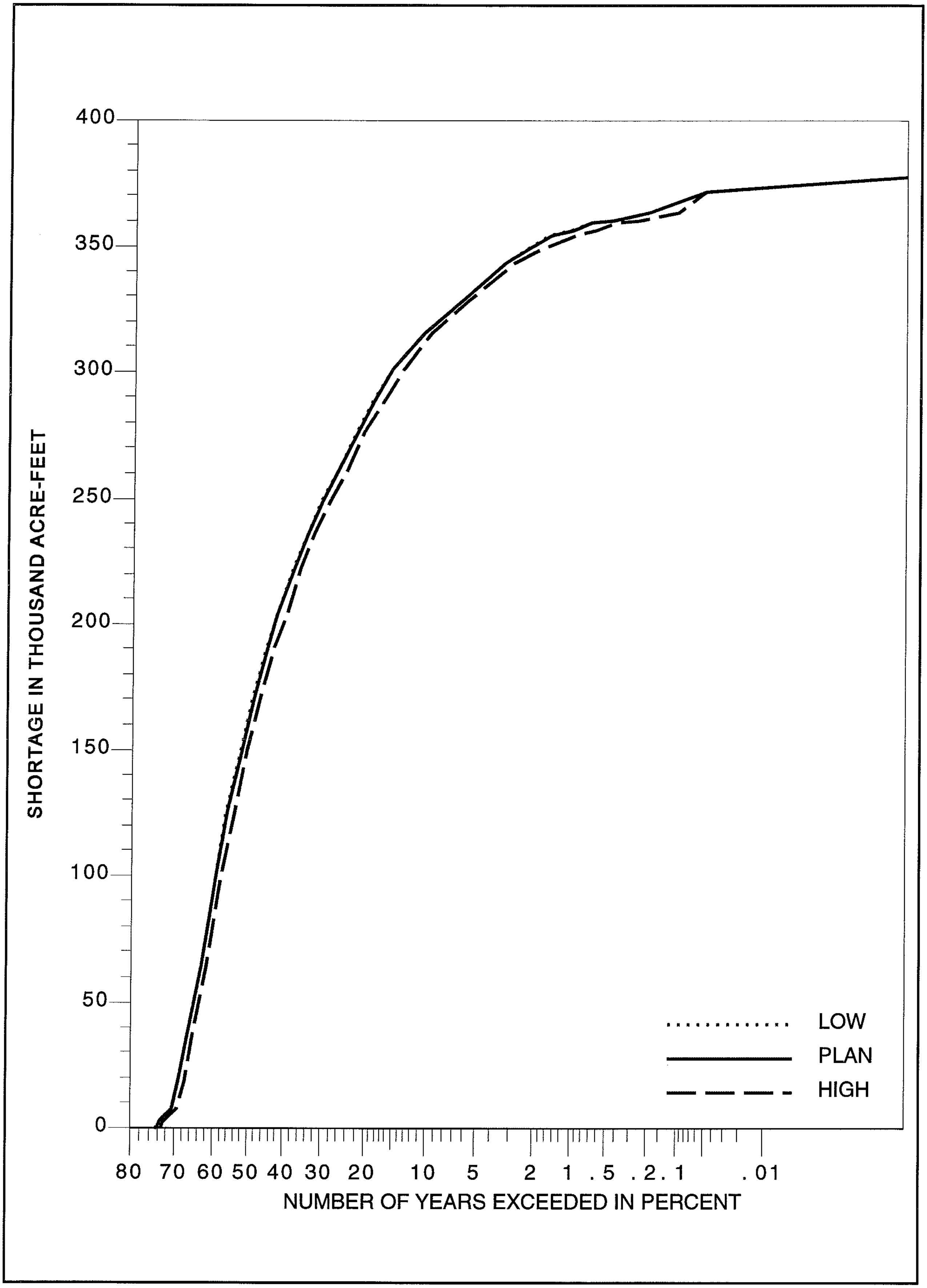

Figure 5.6 Frequency of Shortage from San Carlos Reservoir.

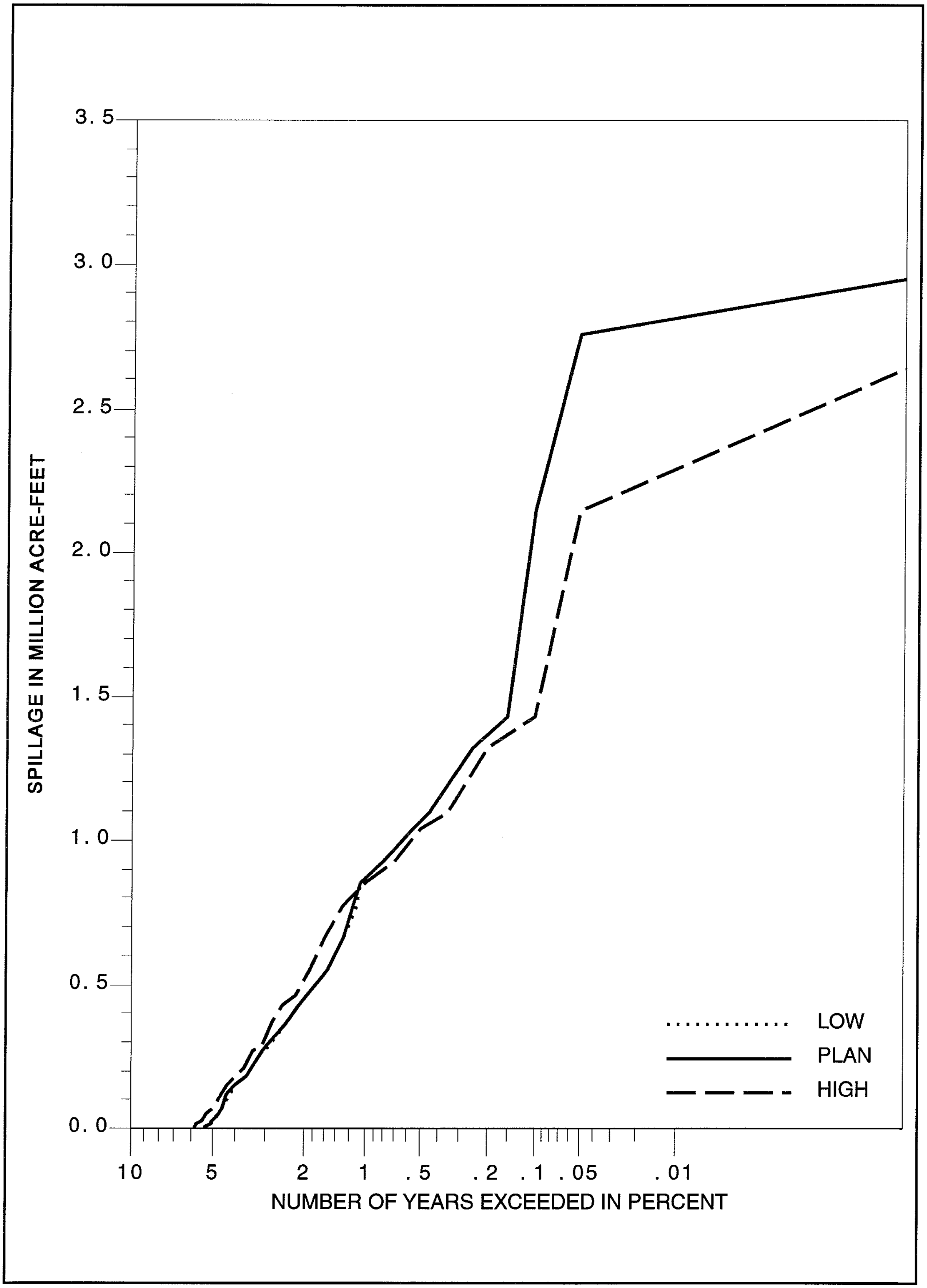

Figure 5.7 Frequency of Spillage from San Carlos Reservoir.

5.4 Reliability

Tables 5.3 and 5.4 report the change in the amount of water delivered to the demands under the different vegetative management scenarios for Lake Pleasant and San Carlos Reservoir, respectively. Figure 5.1 does not report a similar value for Alamo, because Alamo does not have a direct water demand. However, in the models of Lake Pleasant and San Carlos Reservoir, the assumption that water demand remains the same under the different scenarios means that the water use cannot increase more than the current amount of shortage. With the model structured this way, the real benefit of increased runoff is an increase in reliability of the water supply system. Reliability of delivery can be determined from Figures 5.3 and 5.6. If we define reliability as the probability of having zero shortage in a year, then the reliability is equal to 100 percent minus the percentage of years which exceed zero shortage. The reliability results are summarized in Table 5.5.

Table 5.5
Simulated Reliability of Full Water Delivery

	LOW	PLAN	HIGH
Alamo Lake	N/A	N/A	N/A
Lake Pleasant	58.8%	59.9%	65.3%
San Carlos Reservoir	25.5%	25.7%	26.8%

Chapter 6

Summary

At Alamo Lake, the "low" watershed management option caused an average reservoir inflow decrease of 829 acre-feet/yr, or 0.8% less than the plan option. Annual average simulated reservoir release for the low management option decreased 804 acre-feet, or 0.9% less than for the plan option. The high watershed management option caused an average reservoir inflow increase of 4042 acre-feet/yr, or 4.0% more than the plan option. Annual average simulated reservoir release for the high management option increased 3969 acre-feet, or 4.7% more than for the plan option.

At Lake Pleasant, two potential benefits of increased inflow were counted. The benefits are increased yield for the MWD, and decreased pumping of Colorado River water by the CAP. At Lake Pleasant, the low watershed management option caused an average reservoir inflow decrease of 1333 acre-feet/yr, or 2.1% less than the plan option. Annual average simulated MWD delivery for the low management option decreased 316 acre-feet, or 0.8% lower than the plan scenario. The annual average simulated CAP pumpage increased 824 acre-feet, or 0.2% more than under the plan scenario. The high watershed management option caused an average reservoir inflow increase of 6723 acre-feet/yr, or 10.7% more than the plan option. Annual average simulated MWD delivery for the high management option increased 1419 acre-feet, or 3.6% more than for the plan option, while the annual average simulated CAP pumpage decreased 4119 acre-feet, or 0.8%, less than for the plan option.

At San Carlos Reservoir, the low watershed management option caused an average reservoir inflow decrease of 797 acre-feet/yr, or 0.3% less than the plan option. Annual average simulated water delivery for the low management option was 499 acre-feet lower, or 0.2% less, than for the plan option. The high watershed management option caused an average reservoir inflow increase of 6078 acre-feet/yr, or 2.2% more than the plan option. Annual average simulated reservoir release for the high management option increased 5340 acre-feet, or 2.2%, more than for the plan option.

The validity of the inflows at San Carlos is doubtful, because at certain times, the "low" scenario contains much higher inflows than the "high" scenario. Of course, reservoir simulations using invalid inflows would be invalid. It is recommended that the inflow sequences should be examined, and San Carlos simulation may have to be redone.

Appendix A

References

Allred, Jon W., 1995, personal correspondence-facsimile transmission, Office of the Gila Water Commissioner, Safford, Arizona; August 25.

Arizona Department of Water Resources, 1994, "Arizona Water Resources Assessment: Volume II: Hydrologic Summary"; 236p.

Bill Williams River Corridor Technical Committee (BWRCTC), 1994, "Proposed Water Management Plan for Alamo Lake and the Bill Williams River"; final report, volume I, submitted to the Bill Williams River Corridor Steering Committee.

Christenson, Carl, 1995, personal correspondence-facsimile transmission, U.S. Bureau of Indian Affairs, San Carlos Irrigation Project, Coolidge, Arizona; August 1.

Collings, M.R., and Myrick, R.M., 1966, "Effects of Juniper and Pinyon Eradication on Streamflow from Corduroy Creek Basin, Arizona"; U.S. Geological Survey Professional Paper 491-B, 12p.

Fisher, Jody, 1995, personal correspondence-facsimile transmission, U.S. Army Corps of Engineers, Los Angeles District; March 22.

Henning, Brian, 1995, personal communication-telephone conversation, Central Arizona Water Conservation District, Phoenix, Arizona; May 24, May 31, and June 21.

Kipple, F.P., 1977, "The Hydrologic History of the San Carlos Reservoir, Arizona, 1929-71, with Particular Reference to Evapotranspiration and Sedimentation"; U.S. Geological Survey Professional Paper 655-N, 40p.

Lee, Michael, 1995, personal correspondence-facsimile transmission, U.S. Bureau of Reclamation, Phoenix Area Office, Phoenix, Arizona; April 27.

National Oceanic and Atmospheric Administration, 1982, "Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951-80: Arizona"; Climatography of the United States No. 81, National Climatic Center, Asheville, North Carolina.

Robinson, T.W., 1966, "Introduction, Spread and Areal Extent of Saltcedar (Tamarix) in the Western States"; U.S. Geological Survey Professional Paper 491-A, 12p

Stewart, Bob, 1995, personal correspondence-computer files, U.S. Army Corps of Engineers, Los Angeles District; May 2, 1995.

USACE (1982) HEC-5, Simulation of Flood Control and Conservation Systems, User's Manual, HEC, Davis, CA.

USACE (1995) HEC-DSS, User's Guide and Utility Manuals, HEC, Davis, CA.

USACE (1995) HEC-DSS, User's Guide and Utility Manuals, HEC, Davis, CA.

U.S. Bureau of Reclamation, 1986, "Central Arizona Project, May 1986 Water Supply Study"; Lower Colorado Region, Arizona Projects Office, 37p.

Weesner, DL, 1994, "Fifty-Ninth Annual Report: Distribution of the Waters of the Gila River, by the Gila Water Commissioner to the United States District Court, in and for the District of Arizona"; Office of the Gila Water Commissioner, Safford, Arizona.

Appendix B

HEC-5 Input Files

B.1. Alamo Lake

There are twenty flood periods, each ten years long, in the simulation. Except for the starting date and century, the set of cards for each flood period are identical. Three of them are shown below (at the end of the input file) but the rest have been omitted for brevity.

```
T1      ALAMO08.DAT
T2      Model of Alamo Lake and Alamo Dam
T3      Tony Pulokas, September 1995
C
J1      0       1       5       3       4       2       0       0       0
J2      0     1.0    .143                      10
J3      5     132
C
C   EVAPORATION BASED ON OBSERVED DATA -- 1976-1988
C
J6  1.70    2.08    3.68    5.55    7.42    9.69    9.43    8.52    6.35    4.35
J6  2.42    1.50
C
J8 11.22   11.219  11.109
C
C   ALAMO DAM AND RESERVOIR
C
RL     11   -1104     0.0   24372  160500  995300 1451300
RO
C    AREAS AND CAPACITIES ARE BASED UPON THE TABLE GENERATED 24 JUNE 1993
C
RS     26       0    1282    8168   24372   38058   56619   80411  108699  142224
RS160500  179730  221453  260399  321716  386931  445866  521170  605774  700080
RS809220  930210  995300 1063500 1209100 1367400 1451300
C
RQ     26       0    3515    4314    4974    5274    5571    5834    6095    6351
RQ   6420    6594    6732    7000    7000    7000    7000    7000    7000    7000
RQ   7000    7000    7000   11295   24603   51934   65197
C
RA     26       0     170     542    1151    1596    2139    2600    3086    3606
RA   3800    4075    4574    5063    5881    6743    7519    8488    9436   10390
RA  11520   12740   13300   14000   15200   16500   17100
C
RE     26     990    1030    1050    1070    1080    1090    1100    1110    1120
RE   1125    1130    1140  1148.4  1160.4  1171.3    1180    1190    1200    1210
RE   1220    1230    1235    1240    1250    1260    1265
C
CP     11    7000      50      10
ID ALAMO
RT     11     999
C
C  === Elevation-Season-Discharge Criteria ===
C
CS     10       1      31      32     120     121     273     274     304     305
CS    365
C
CG-4.010    1100    1100    1070    1070    1070    1070    1070    1070    1100
CG  1100
CG-4.015 1100.01 1100.01 1070.01 1070.01 1070.01 1070.01    1100    1100 1100.01
CG1100.1
CG-4.025    1125    1125    1100    1100    1100    1100 1100.01 1100.01    1125
CG  1125
```

```
CG-4.040 1125.01 1125.01    1125    1125 1100.01 1100.01    1125    1125 1125.01
CG1125.1
CG-4.050 1125.02 1125.02 1125.01 1125.01    1125    1125 1125.01 1125.01 1125.02
CG1125.2
QM   -11      10      15      25      40      50
C
CP   999   99999
ID LAKEHAVASU
RT   999
ED
C
C   ST RECORDS ARE TARGET STORAGES FOR 5-YEAR DRAWDOWN
C   EACH "FLOOD PERIOD" IS TEN YEARS LONG
C
BF     2     120     120        01100100       0     720                      1500
ZR=IN11  A=BILL WILLIAMS RIVER,B=ALAMO,C=FLOW,F=IN
ZW  A=BILL WILLIAMS RIVER,B=ALAMO,F=COMP
ST     11      -1       0   80411
ST     11      -2       0   80411
ST     11      -3       0 -160500
ST     11     -56       0  158956
ST     11     -57       0  140427
ST     11     -58       0  123148
ST     11     -59       0  107163
ST     11     -60       0   91162
ST     11     -61       0   80411
ST     11     -62       0   80411
ST     11     -63       0 -160500
ST     11    -116       0  158956
ST     11    -117       0  140427
ST     11    -118       0  123148
ST     11    -119       0  107163
ST     11    -120       0   91162
EJ
BF     2     120     120        11100100       0     720                      1500
ZR=IN11  A=BILL WILLIAMS RIVER,B=ALAMO,C=FLOW,F=IN
ZW  A=BILL WILLIAMS RIVER,B=ALAMO,F=COMP
ST     11      -1       0   80411
ST     11      -2       0   80411
ST     11      -3       0 -160500
ST     11     -56       0  158956
ST     11     -57       0  140427
ST     11     -58       0  123148
ST     11     -59       0  107163
ST     11     -60       0   91162
ST     11     -61       0   80411
ST     11     -62       0   80411
ST     11     -63       0 -160500
ST     11    -116       0  158956
ST     11    -117       0  140427
ST     11    -118       0  123148
ST     11    -119       0  107163
ST     11    -120       0   91162
EJ
BF     2     120     120        21100100       0     720                      1500
ZR=IN11  A=BILL WILLIAMS RIVER,B=ALAMO,C=FLOW,F=IN
ZW  A=BILL WILLIAMS RIVER,B=ALAMO,F=COMP
ST     11      -1       0   80411
ST     11      -2       0   80411
ST     11      -3       0 -160500
ST     11     -56       0  158956
ST     11     -57       0  140427
ST     11     -58       0  123148
ST     11     -59       0  107163
ST     11     -60       0   91162
ST     11     -61       0   80411
ST     11     -62       0   80411
ST     11     -63       0 -160500
ST     11    -116       0  158956
ST     11    -117       0  140427
```

```
ST    11    -118        0  123148
ST    11    -119        0  107163
ST    11    -120        0   91162
EJ
```

.....cards for additional flood periods ommitted for brevity.....

```
ER
```

B.2. Lake Pleasant

```
T1       NEWWAD09.DAT
T2       NEW WADDELL DAM
T3
C
J1      0       1       6       4       5       2       3      10
J2     24     1.0      .4       0       0
J3      5                                       1
C
J8 10.22  40.319  40.039  24.049  10.219  10.039  40.109
C
C    ============= OLD WADDELL DAM -- REPRESENTS MWD ACCOUNT ===================
C
C    OPERATING LEVELS -- the new values of storage from 1993 survey have been accounted
C      37800 ac-ft has been subtracted from all storage values
C
RL     40   78800       1       2       3  157600  157601  157610
RO      0
C
C      STORAGES new values from 1993 survey
C      37800 ac-ft has been subtracted from all storage values
C
RS      7       0   12471   31910   57584   88246  125071  166936
C
C      DISCHARGES -- new points were interpolated from those in NWSPF95.DAT
C
RQ      7    7050    7175    7332    7478    7624    7759    78952
C
C     R2 Card for evaporation  -- the amount evaporated is proportionate
C     to the ratio of ( OLD WADDELL / NEW WADDELL )
C
R2                      -10
C
CP     40  999999
IDMWD ACCOUNT
C
C    "FLOOD CONTROL" REPRESENTS EXCESS WHICH GOES TO CAP ACCOUNT
RT     40      66       0
C
C    DIVERSIONS REPRESENT WITHDRAWLS FROM MWD ACCOUNT
DR     40      41       0                       0       1
QD     12    1.06   15.45   68.32   94.35   93.54  120.70  155.84   97.60   65.48
QD  45.55   23.75    0.00
C
C    ==== DUMMY RESERVOIR TO WHICH MWD DIVERSIONS ARE ROUTED ===============
C
RL     41
RO      0
RS      2       0    1000
RQ      2      -1      -1
CP     41  999999
IDDUMMY
C
RT     41      42
CP     42  999999
IDCP   42
RT     42      66
C
```

```
C    ======NEW WADDELL DAM -- REPRESENTS EXISTING PHYSICAL SYSTEM===============
C
C    OPERATING LEVELS -- the new values of storage from 1993 survey have been accounted
C        NOTE - the first RL card is ignored.
C          Additional RL cards are used so that the pump target moves by month
C
C      37800 ac-ft has been subtracted from all storage values
C
RL     10  108800       1       2  727600  811800  857300 1062200
RL      1      10      -1       0       1
RL      2      10      -1       0       2
RL      3      10       0       0  727535  726585  722385  716585  710835  701255
RL                                 695255  691230  688430  686970  686970  727600
RL      4      10      -1       0  811800
RL      5      10      -1       0  857300
RL      6      10      -1       0 1062200
RO      2      22      23
C
C      STORAGES new values from 1993 survey
C      37800 ac-ft has been subtracted from all storage values
C
RS     22       0   12471   31910   57584   88246  125071  166936  214069  266914
RS325544   388751  457331  531609  611859  698164  753580  811825  857300  862677
RS894200   948469 1004781
C
C      DISCHARGES -- new points were interpolated
C
RQ     22    7050    7175    7332    7478    7624    7759    7895    8022    8150
RQ  8271     8392    8507    8622    8730    8839    8904    8970    9017   10122
RQ 30543    96185  192226
C
C      AREA  new values from 1993 survey
C
RA     22    1411    1695    2245    2827    3332    3922    4474    5001    5553
RA  6061     6582    7150    7715    8305    9009    9467    9957   10340   10382
RA 10633    11063   11474
C
C      ELEVATIONS
C
RE     22    1552    1560    1570    1580    1590    1600    1610    1620    1630
RE  1640     1650    1660    1670    1680    1690    1696    1702  1706.5    1707
RE  1710     1715    1720
C
C    RESERVOIR EVAPORATION DATA FROM BRIAN HENNING, CAWCD, PHOENIX
C    PRECIP FROM CORDES, AZ GAGE.
C
R3 -0.21     1.31     2.2    5.27    7.84    8.79    6.85    4.37    4.99    3.23
R3  1.37    -0.29
C
CP     10   10000
IDNEW WADDELL
C
RT     10      21
C
C    DIVERSION REPRESENTS PUMPING FROM THE COLORADO RIVER, THRU AQUEDUCT,
C    TO NEW WADDEL.  PUMPING RATES COME FROM BRIAN HENNING, CAWCD, PHOENIX
C
DR     10      30       0                                  -4
QD     12 -1789.4       0  -813.4 -1512.9 -1464.1       0       0       0       0
QD   -976 -1849.1    -976
C
C    ============== REPRESENTATION OF COLORADO RIVER SOURCE ===================
C      This control point does not physically represent any real reservoir.  Its only
C      function is to keep a guaranteed flow coming into lake Pleasant from the
C      Aqueduct.
C
RL     30  200000     100     200  100000  200000  300000  400000
RO      0
RS      2       0  500000
RQ      2       0   10000
```

```
CP    30  999999
IDCOLORADO RIVER
C
C     The "Colorado River Source" reservoir discharges directly to the end point.
RT    30      66
C
C       DOWNSTREAM CONTROL POINTS
C
CP    21  999999
IDSEEPAGE
C
RT    21       22
C  DIVERSIONS REPRESENTING SEEPAGE FROM THE RESERVOIR WHICH IS CHARGED TO CAP ACCOUNT
DR    21        0        0                               0     8.5
CP    22  999999
IDCP 22
C
RT    22       23
C  DIVERSIONS REPRESENTING W/DRAWLS FROM MWD ACCOUNT--DYNAMICALLY LINKED TO CP  42
DR    22        0        0                              -6                      42
CP    23  999999
IDCP 23
RT    23       24
C
C  DIVERSIONS REPRESENTING W/DRAWLS FROM CAP ACCOUNT.  FROM BRIAN HENNING, CAWCD,
PHOENIX.
DR    23        0        0                               1
QD    12        0        0       0       0       0  2206.3  2599.2  2227.9  1151.1
QD 464.1        0        0
C
CP    24  999999
IDCP 24
RT    24       66
C
CP    66  999999
IDEND
RT    66
ED
C
BF     2      600      600        01100100       0      720                   1500
IN    30       -1                      599     3200
ZR=IN10  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
ZR=IN40  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
EJ
BF     2      600      600        51100100       0      720                   1500
IN    30       -1                      599     3200
ZR=IN10  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
ZR=IN40  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
EJ
BF     2      600      600        01100100       0      720                   1600
IN    30       -1                      599     3200
ZR=IN10  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
ZR=IN40  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
EJ
BF     2      600      600        51100100       0      720                   1600
IN    30       -1                      599     3200
ZR=IN10  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
ZR=IN40  A=AGUA FRIA RIVER,B=NEW WADDELL,C=FLOW,F=IN
EJ
ER
```

B.3. San Carlos Reservoir

```
T1   COOLIDGE DAM -- SAN CARLOS RESERVOIR, AZ
T2   SEPT 8, 1995
T3
C
J1     0       1       5       3       4       2       0       0       0
J2     0     1.0                               10
J3     5     132
C
C   EVAPORATION ARE 1965-1989 AVERAGES FROM JON ALLRED, GILA WATER COMMISSION.
C   PAN/RESERVOIR COEFFICIENTS AND PRECIP. COME FROM USGS PP-655N.
C   Net Evap in the J6 card = ( evap * coeff ) - precip
C
J6  0.23    0.97    2.46    5.02    7.95    9.62    9.52    7.27    6.00    4.67
J6  2.92    0.39
C
J8150.22   1.319   1.039   2.049 150.219
C
C   SAN CARLOS RESERVOIR
C
RL   150  130000     0.0      30  885000  885005 1033900
RO     1       1
C     CAPACITIES ARE FROM 1991 SURVEY PROVIDED BY ARIZONA USGS
C
RS    29       0      28    1450    5650   12350   21230   32400   45900   62360
RS 82600  106200  132650  161800  193460  228300  267100  309100  353600  401800
RS454900  512500  573860  639100  708400  782000  860100  885000  943800 1033900
C
C     OUTFLOWS COME FROM HEC-5 FILE PROVIDED BY JODY FISCHER, LA DISTRICT COE
C
RQ    29       0    4000    4000    4000    4000    4000    4000    4000    4000
RQ  4000    4000    4000    4000    4000    4000    4000    4000    4000    4000
RQ  4000    4000    4000    4000    4000    4000    4000    4000    6350   24300
C
C     AREAS COME FROM TABLE PROVIDED BY JON ALLRED, GILA WATER COMMISSIONER'S
C
RA    29       0      50     600    1090    1550    2000    2460    2930    2670
RA  4420    5015    5590    6080    6570    7360    8160    8650    9140   10140
RA 11130   11880   12650   13455   14260   15175   16090   16480   17385   18690
C
C     ELEVATIONS
C
RE    29    2383    2390    2395    2400    2405    2410    2415    2420    2425
RE  2430    2435    2440    2445    2450    2455    2460    2465    2470    2475
RE  2480    2485    2490    2495    2500    2505    2510  2511.5    2515    2520
C
CP   150  999999
IDCOOLIDGE
RT   150       1
CP     1  999999
IDIRRIGATORS
RT     1       2
C
C   DIVERSION AT NODE 1 REPRESENTS DEMANDS.
C   THE MONTHLY DEMANDS ARE FROM THE WY 1994 USGS GAGE RECORDS.  150 AC-FT PER
C   MONTH WAS SUBTRACTED TO ACCOUNT FOR WARM SPRING.
C
DR     1       0       0                                 1
QD    12     169     189     770     594     713    1045    1197    1071     329
QD   148       0     189
C
C    FLOW PAST NODE 2 IS COUNTED AS SPILL
C
CP     2  999999
IDSPILL
RT     2      66
CP    66  999999
ID END
```

```
RT    66
ED
C
BF      2     1200     1200           01100100        0      720                           1500
ZR=IN150 A=GILA RIVER,B=COOLIDGE,C=FLOW,F=IN
EJ
BF      2     1200     1200           01100100        0      720                           1600
ZR=IN150 A=GILA RIVER,B=COOLIDGE,C=FLOW,F=IN
EJ
ER
```

Appendix C

Computer Files on Diskette

C.1. Alamo Lake

ALAMO08.DAT ....HEC-5 Input file
BWLDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for low vegetative management.
BWPDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for plan vegetative management.
BWHDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for high vegetative management.

C.2. Lake Pleasant

NEWWAD09.DAT ......HEC-5 Input file
AFLDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for low vegetative management.
AFPDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for plan vegetative management.
AFHDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for high vegetative management.

C.3. San Carlos Reservoir

COOL02.DAT ....HEC-5 Input file
UGLDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for low vegetative management.
UGPDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for plan vegetative management.
UGHDSS.ZIP ....Zipped HEC-DSS files of Stochastic Inflow for high vegetative management.