US Army Corps
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Hydrologic Engineering Center

Stochastic Modeling of Extreme Floods on the American River at Folsom Dam

Appendix I - Analysis of Seasonal Reservoir Storage for Reservoirs in the Upper American River Watershed

September 2005

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This report presents the results of the application of a stochastic flood model to develop flood-frequency relationships for the American River at Folsom Dam. Flood-frequency relationships are presented for flood characteristics of peak discharge, maximum 24-hour discharge, maximum 72-hour discharge, maximum reservoir release, runoff volume, and maximum reservoir level.

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ANALYSIS OF SEASONAL RESERVOIR STORAGE FOR RESERVOIRS IN THE UPPER AMERICAN RIVER WATERSHED

February 5, 2001

INTRODUCTION

There are five dam and reservoir projects located in the upper American River watershed. Two reservoirs provide irrigation water-supply to downstream areas, and hydropower production is a secondary benefit. The other three reservoirs are operated solely for hydropower production. None of the five projects have any provisions in their reservoir operation plans to provide flood control. Nonetheless, as part of their standard seasonal operations, the reservoirs are usually drawn down through the late-fall and winter period in anticipation of capturing winter runoff and the spring snowmelt runoff volume. As such, a significant volume is typically available for floodwater storage during the winter flood season. The five reservoirs typically have a combined total of about 360,000 acre-feet of floodwater storage capacity in the October through March period. This equates to about 3.6 inches of runoff from the 1,860 mi^2 American River watershed. The actual amount of floodwater storage that is available at these reservoirs when a large storm occurs is a major factor in the ability of the Folsom Dam and reservoir to accommodate floodwaters and to regulate flood discharges. Therefore, information on the floodwater storage capacity at the group of five reservoirs is a critical consideration in the flood analyses for the American River watershed.

The amount of floodwater storage capacity at these reservoirs at any given time of the year is highly variable, depending primarily upon the manner in which the late-fall and winter precipitation occurs. If a large number of precipitation events occur in the liquid phase, then the reservoir levels are generally higher due to the runoff that is generated. Conversely, if the majority of precipitation events occur as snowfall, then less runoff occurs and the reservoir levels are generally lower. The cumulative precipitation total for the water-year amplifies the above behavior, with reservoir levels being generally higher in wetter years, and lower in drier years.

This analysis of reservoir storage is intended to answer several basic questions about reservoir operations/behavior. First, what has been the historical relationship between antecedent precipitation and reservoir storage? In short, how do seasonal storage volumes vary with antecedent precipitation for the range of very dry to very wet climatic years? Second, what relationships exist between reservoir storage volumes at the five reservoirs, and what is the level of synchronous behavior in operation of the five reservoirs? These questions will be answered through probabilistic analyses of reservoir storage volume. The findings will be used in Monte Carlo simulation of reservoir storage at the five projects as part of the stochastic flood simulations for the American River.

RESERVOIR CHARACTERISTICS

Hell Hole and French Meadows reservoirs are owned by Placer County Water Agency and are operated to provide irrigation water, and produce hydropower as a secondary benefit. These projects are joined by a tunnel that allows joint operation to meet irrigation demands and maximize hydropower production. The goals for irrigation supply and hydropower production are not in conflict in wet years. Conversely, in dry years, the requirement to meet irrigation demands takes precedence, and discharges for hydropower are made in a manner consistent with meeting the irrigation demands in the summer period. It will be shown later that the seasonal storage volumes in these two reservoirs are highly correlated.

Union Valley, Loon Lake and Ice House reservoirs are owned by Sacramento Municipal Utility District (SMUD) and are operated for hydropower production. The primary objective of hydropower projects is to pass water through the turbines for power generation and to minimize releases through auxiliary spillways. Thus, the SMUD hydropower projects are operated in a manner to maximize the capture of winter and spring runoff and pass it through the turbines. Accordingly, these reservoirs are commonly drawn down through the late-fall and winter flood season to create storage capacity for the spring snowmelt. It will also be shown later that there is a moderate level of correlation between storage volumes at Union Valley and Loon Lake, which are the larger of the SMUD reservoirs.

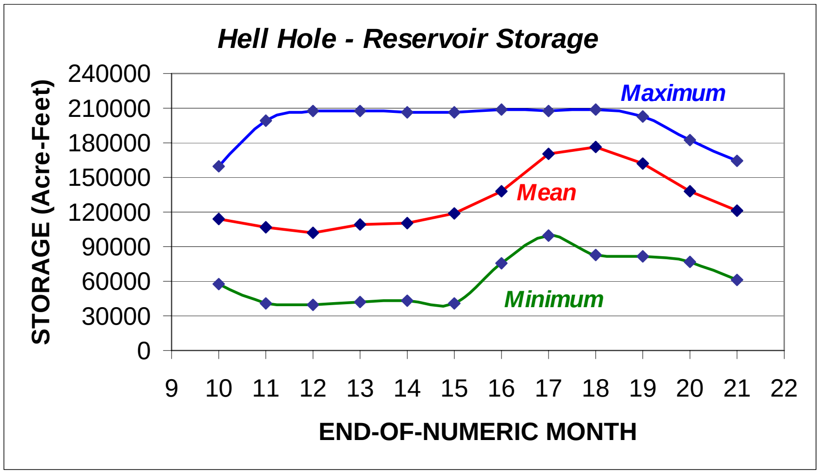
Table 1 provides a general comparison of the relative storage capacities of the five reservoirs. Column 3 lists the storage volume when the reservoir is filled to the maximum pool elevation, the maximum level allowed under normal operating conditions[6]. Column 4 lists the mean October to March storage volume. These values are based on the period of record, which is generally from the early to mid-1960s to present. The fifth column is the difference between columns 3 and 4, and represents the typical amount of storage capacity available in the October to March period for storage of floodwaters. A review of Table 1 shows that about 360,000 acre-feet of floodwater storage is typically available in the five reservoirs during the winter flood season.

However, reservoir levels and reservoir storage volumes[2] vary widely from year-to-year and seasonally for the five reservoirs. This variability is seen in Figure 1a, which depicts the minimum, mean, and maximum historical storage volumes at Hell Hole reservoir. Figure 1b shows the variation of end-of-month storage volume for Hell Hole. The behavior seen in Figures 1a,b is typical of all of the five reservoirs. Appendix A contains additional information on the reservoir characteristics for the five reservoirs and depicts companion graphics to Figures 1a,b.

Many of the graphics for these analyses are plotted based on end-of-month values where numeric months are used for plotting convenience. The numeric months begin at the start of the water-year with 10 for end-of-October, progress through 13 for end-of-January, and 21 is used for the end-of-September.

Table 1 – Reservoir Storage Characteristics for the Five Reservoirs
Located in the Upper American River Watershed

RESERVOIR	NOMINAL NORMAL POOL ELEVATION	STORAGE VOLUME AT MAXIMUM POOL (Acre-Feet)	MEAN VALUE OCTOBER - MARCH STORAGE VOLUME (Acre-Feet)	MEAN VALUE OCTOBER - MARCH STORAGE AVAILABLE FOR FLOODWATERS (Acre-Feet)
Union Valley	4870 feet	271,000	147,700	123,300
Hell Hole	4630 feet	209,000	110,100	98,900
French Meadows	5263 feet	133,700	67,100	66,600
Loon Lake	6410 feet	77,000	33,700	43,300
Ice House	5454 feet	45,960	21,700	24,260
Total				**356,360 acre-feet**



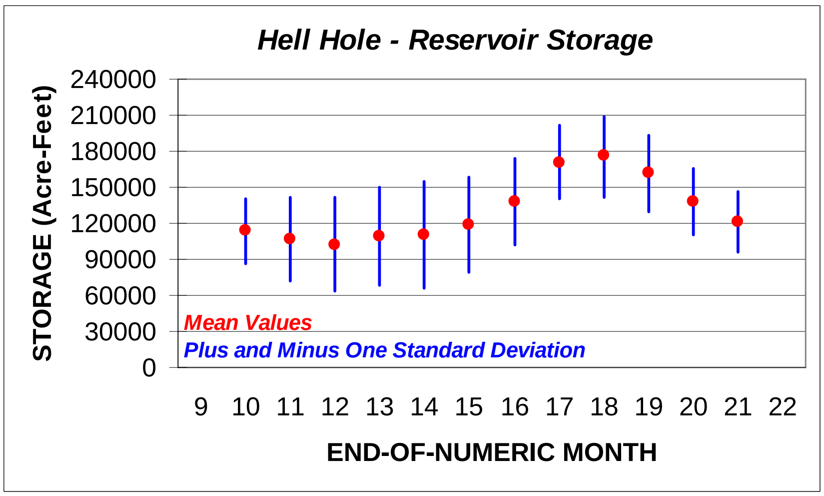


Figure 1a,b – Seasonal Variation of Reservoir Storage Volume at Hell-Hole Reservoir

RELATIONSHIP OF RESERVOIR STORAGE WITH ANTECEDENT PRECIPITATION

It would be expected that reservoir storage volumes would be correlated with antecedent precipitation. Higher reservoir levels would be expected in wet years and lower reservoir levels would be expected in dry years. Antecedent precipitation as defined here means the cumulative precipitation from October 1st, the start of the water-year, to the end-of-month of interest. The precipitation gage at Lake Spaulding is used as the key station for regression analyses of antecedent precipitation[8] with reservoir storage. The Lake Spaulding station has also been used as the key precipitation station for analyses of snowpack[9].

Figures 2a,b show typical regression solutions for the relationship between reservoir storage and antecedent precipitation for the two largest reservoirs. Similar results were found for the other reservoirs. Appendix B lists the regression parameters obtained from the analyses for the five reservoirs. All regression solutions were based on the period from water-year 1967 through water-year 2000. This period was chosen because it was the longest contiguous period when reservoir storage volume data were available at all reservoirs.

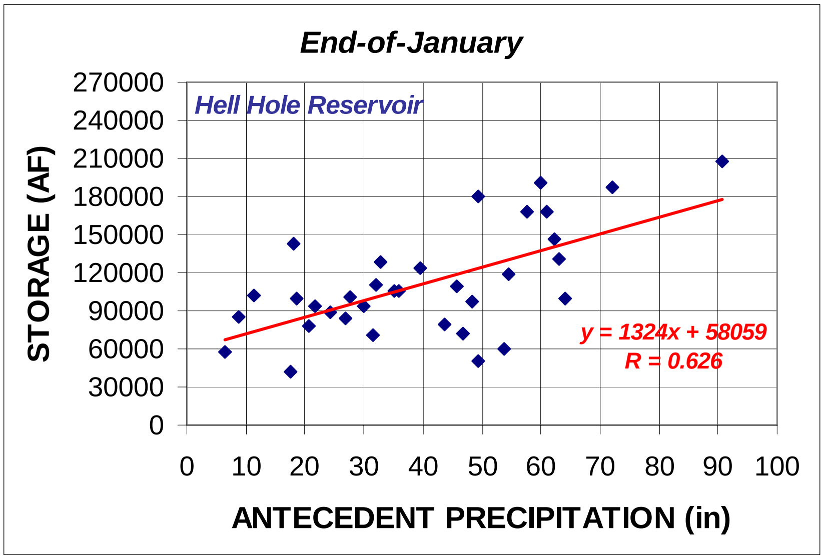


Figure 2a – Relationship Between Reservoir Storage at Hell Hole Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-January

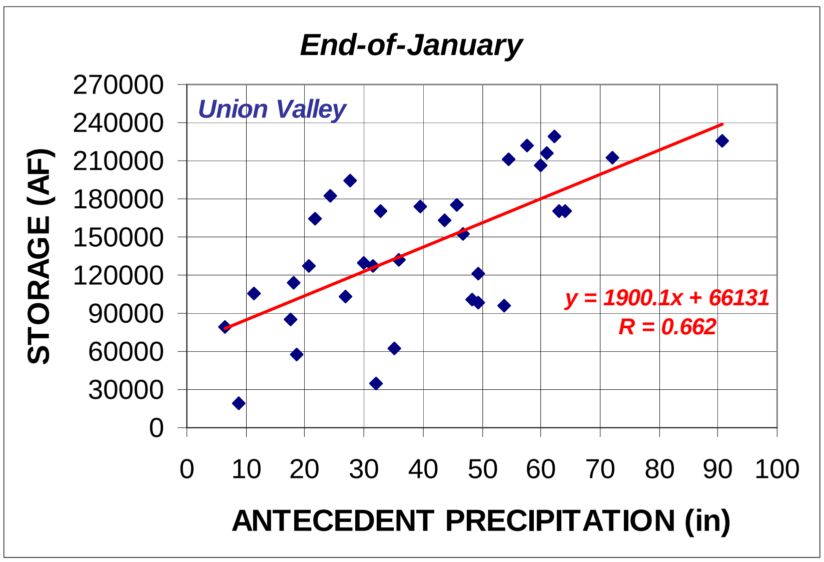


Figure 2b – Relationship Between Reservoir Storage at Union Valley Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-January

Figures 3a,b depicts the seasonal variation of the linear correlation coefficient for the regression solutions for the two largest reservoirs. In general, it is seen that there is a moderate level of correlation between storage volume and antecedent precipitation, and the seasonal behavior is similar at both reservoirs. The level of correlation is sufficiently high that the magnitude of antecedent precipitation will be an important factor in determining the initial reservoir storage at the start of an extreme storm and flood. Therefore, antecedent precipitation must be accounted for in the Monte Carlo simulation of reservoir operation/reservoir storage.

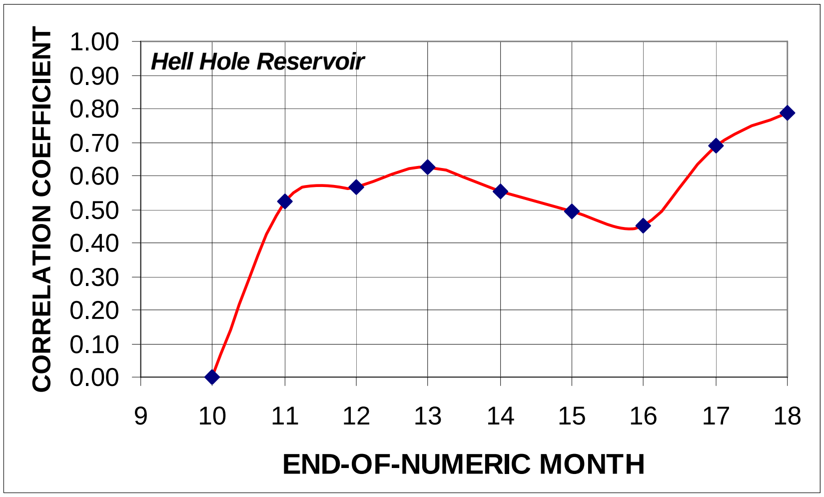


Figure 3a – Seasonal Variation of Linear Correlation Coefficient for Relationship Between Reservoir Storage at Hell Hole and Antecedent Precipitation at Lake Spaulding

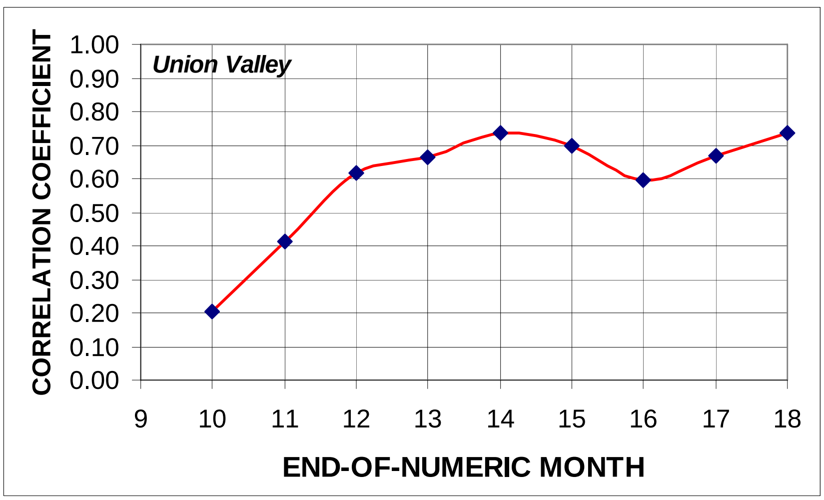


Figure 3b – Seasonal Variation of Linear Correlation Coefficient for Relationship Between Reservoir Storage at Union Valley and Antecedent Precipitation at Lake Spaulding

RELATIONSHIP OF STORAGE VOLUMES BETWEEN RESERVOIRS

Information about the joint operation of reservoirs as reflected in storage volumes is needed in order to conduct stochastic simulations of reservoir storage. This information was obtained by conducting correlation analyses[3] between end-of-month reservoir storage volumes for the five reservoirs. Tables 2a-2h list the cross-correlation matrices for the end-of-October through the end-of-May, respectively.

A review of the matrices shows that, with the exception of Ice House, the smallest reservoir, significant positive correlation exists for the four largest reservoirs for all months. This clearly indicates that the reservoir storage volumes are not random, and that there is some synchronicity to the behavior of reservoir storage at the five reservoirs.

In particular, the storage volumes at Hell Hole and French Meadows reservoirs have a high level of correlation (Figure 4). This is not surprising because the reservoirs are joined by a tunnel, have the same owner, and are operated for the same purposes, irrigation water-supply and hydropower.

A review of the matrices also shows that storage volumes at Union Valley and Loon Lake reservoirs have moderate levels of correlation (Figure 5). These are the two largest reservoirs and are operated by SMUD for hydropower production.

There is also low to moderate levels of correlation between the largest reservoirs, Hell Hole (Placer County) and Union Valley (SMUD). This correlation increases through the winter season and is likely due to standard reservoir operations in response to the occurrence of wet or dry climatic years (Figure 6). Reservoirs generally have higher water levels in wet years and lower levels in dry years.

To summarize, the cross-correlations of storage volumes between reservoirs are sufficiently large that they must be explicitly accounted for in conducting stochastic simulations.

Table 2a – Cross-Correlation Coefficients for End-of-October Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	**Union Valley**	**French Meadows**	**Loon Lake**	**Ice House**
Hell Hole	1.000	0.331			
Union Valley	0.331	1.000			
French Meadows	0.617	0.453	1.000		
Loon Lake	0.288	0.431	0.130	1.000	
Ice House	0.158	0.313	0.105	0.331	1.000

Table 2b – Cross-Correlation Coefficients for End-of-November Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	**Union Valley**	**French Meadows**	**Loon Lake**	**Ice House**
Hell Hole	1.000				
Union Valley	0.313	1.000			
French Meadows	0.710	0.405	1.000		
Loon Lake	0.467	0.527	0.309	1.000	
Ice House	-0.106	0.499	-0.100	0.205	1.000

Table 2c – Cross-Correlation Coefficients for End-of-December Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	**Union Valley**	**French Meadows**	**Loon Lake**	**Ice House**
Hell Hole	1.000				
Union Valley	0.428	1.000			
French Meadows	0.831	0.492	1.000		
Loon Lake	0.474	0.570	0.398	1.000	
Ice House	-0.046	0.623	0.052	0.272	1.000

Table 2d – Cross-Correlation Coefficients for End-of-January Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	Union Valley	French Meadows	Loon Lake	Ice House
Hell Hole	1.000				
Union Valley	0.554	1.000			
French Meadows	0.890	0.647	1.000		
Loon Lake	0.488	0.560	0.452	1.000	
Ice House	0.196	0.689	0.360	0.456	1.000

Table 2e – Cross-Correlation Coefficients for End-of-February Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	Union Valley	French Meadows	Loon Lake	Ice House
Hell Hole	1.000				
Union Valley	0.587	1.000			
French Meadows	0.884	0.687	1.000		
Loon Lake	0.621	0.552	0.560	1.000	
Ice House	0.452	0.766	0.509	0.672	1.000

Table 2f – Cross-Correlation Coefficients for End-of-March Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	Union Valley	French Meadows	Loon Lake	Ice House
Hell Hole	1.000				
Union Valley	0.514	1.000			
French Meadows	0.872	0.593	1.000		
Loon Lake	0.568	0.389	0.510	1.000	
Ice House	0.456	0.690	0.455	0.641	1.000

Table 2g – Cross-Correlation Coefficients for End-of-April Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	Union Valley	French Meadows	Loon Lake	Ice House
Hell Hole	1.000				
Union Valley	0.589	1.000			
French Meadows	0.860	0.653	1.000		
Loon Lake	0.573	0.441	0.670	1.000	
Ice House	0.635	0.636	0.700	0.689	1.000

Table 2h – Cross-Correlation Coefficients for End-of-May Reservoir Storage Volume for the Five Reservoirs Located in the Upper American River Watershed

CROSS-CORRELATION COEFFICIENTS FOR RESERVOIR STORAGE					
	Hell Hole	Union Valley	French Meadows	Loon Lake	Ice House
Hell Hole	1.000				
Union Valley	0.748	1.000			
French Meadows	0.841	0.807	1.000		
Loon Lake	0.425	0.594	0.632	1.000	
Ice House	0.654	0.799	0.766	0.827	1.000

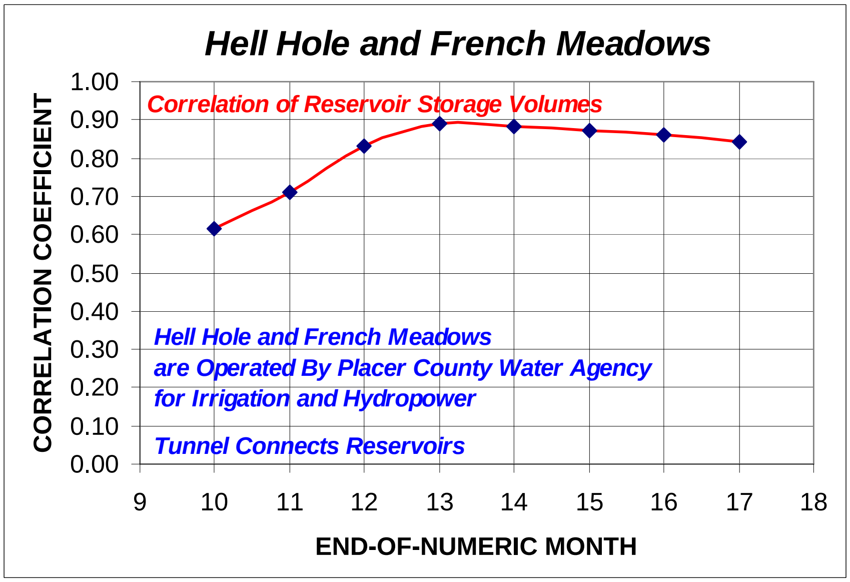


Figure 4 – Seasonal Variation of Cross-Correlation Coefficient for Relationship Between Reservoir Storage at Hell Hole and French Meadows Reservoirs

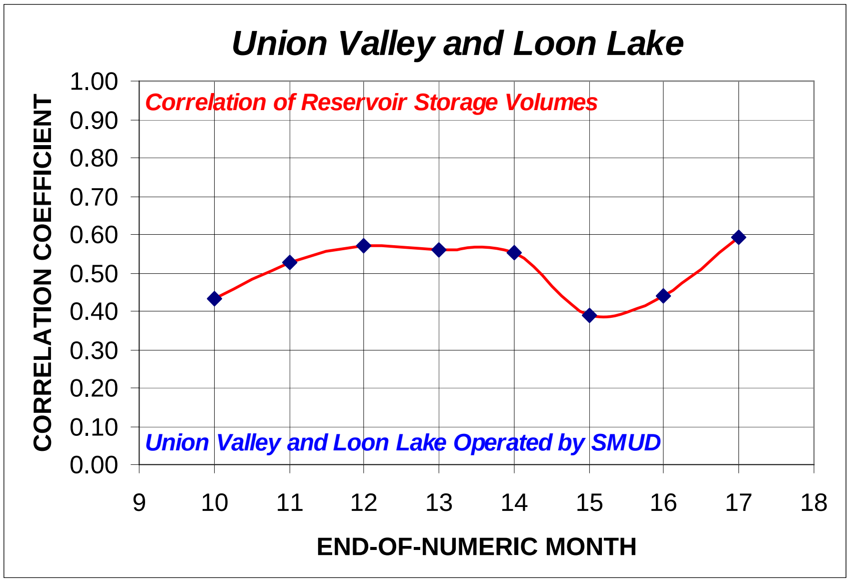


Figure 5 – Seasonal Variation of Cross-Correlation Coefficient for Relationship Between Reservoir Storage at Union Valley and Loon Lake Reservoirs

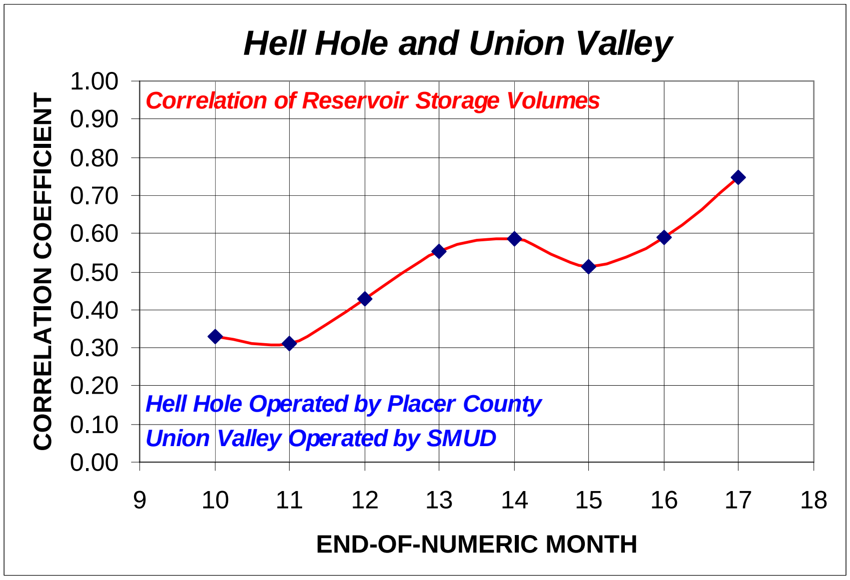


Figure 6 – Seasonal Variation of Cross-Correlation Coefficient for Relationship Between Reservoir Storage at Hell Hole and Union Valley Reservoirs

STOCHASTIC SIMULATION OF RESERVOIR STORAGE

An initial storage volume is needed for each of the five reservoirs prior to the start of the extreme storm for each flood simulation. This will be accomplished using a variation of the Salas et al[7] autoregressive multivariate hydrologic time-series model with cross-correlation of the residuals from the multiple sites. Specifically, the stochastic generation of storage volume for each reservoir will be comprised of two components. The first component will be the deterministic portion based on the regression relationship with antecedent precipitation (Appendix B). The second component will be the residual term, where the residuals from the relationships with antecedent precipitation will be generated in a manner that preserves the cross-correlation of reservoir storage among the five sites. This algorithm, written in matrix notation for the five reservoirs, has the following format:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{bmatrix} + \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \end{bmatrix} [x] + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \end{bmatrix} \tag{1}$$

where: y_i is the end-of-month reservoir storage volume at reservoir i, x is the end-of-month antecedent precipitation at the Lake Spaulding key precipitation station selected through standard Monte Carlo procedures[4], α_i and β_i are regression parameters for the intercept and slope, and ε_i is a Normally distributed residual term that accounts for the unexplained variance in the relationship with antecedent precipitation, and is cross-correlated with the other residual terms.

The solution of the residual terms (ε_i) is based on the lower triangular matrix method proposed by Lane[5,7] for use with multivariate and disaggregation procedures, and:

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \end{bmatrix} = \begin{bmatrix} \delta_1 & \delta_2 & \delta_3 & \delta_4 & \delta_5 \end{bmatrix} \left(\begin{bmatrix} \kappa_{11} & 0 & 0 & 0 & 0 \\ \kappa_{21} & \kappa_{22} & 0 & 0 & 0 \\ \kappa_{31} & \kappa_{32} & \kappa_{33} & 0 & 0 \\ \kappa_{41} & \kappa_{42} & \kappa_{43} & \kappa_{44} & 0 \\ \kappa_{51} & \kappa_{52} & \kappa_{53} & \kappa_{54} & \kappa_{55} \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \eta_4 \\ \eta_5 \end{bmatrix} \right) \tag{2}$$

where: δ_i is the square root of the unexplained variance in the relationship with antecedent precipitation for reservoir *i*, κ_{ij} are factors that are functions of the cross-correlation matrix (Tables 2a-2h) that are solved through the Lane[5,7] method, and η_i is a Normally distributed random variate with mean of zero and variance of unity. A separate set of regression parameters (Equation 1) and coefficients (Equation 2) are required for stochastic simulation for each end-of-month.

This approach will preserve both the correlation structure with antecedent precipitation for each reservoir, and preserve the cross-correlation structure of reservoir storage volume between the five reservoirs. This stochastic generation scheme is well suited to the simulation of the storage volumes at the five reservoirs.

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APPENDIX A

CHARACTERISTICS OF RESERVOIRS LOCATED IN THE UPPER AMERICAN RIVER WATERSHED

This appendix contains information on reservoirs located in the upper American River Watershed. Reservoir storage data are plotted based on end-of-month values where numeric months are used for plotting convenience. The numeric months begin at the start of the water-year with 10 for end-of-October, progress through 13 for end-of-January, and 21 is used for end-of-September, which is the end of the water-year.

French Meadows Reservoir

Table A1 – Characteristics of French Meadow Reservoir

RESERVOIR CHARACTERISTIC	DESCRIPTION
Reservoir Name	French Meadows
Project Owner	Placer County Water Agency
Project Purposes	Irrigation Water Supply, Hydropower
First Year Operation	1964
Reservoir Data	First-of-Month Reservoir Storage, 1964 - present
Maximum Storage Capacity	133,700 acre-feet
Normal Pool Elevation	5,263 feet
Spillway for Flood Discharge	Gated Spillway
Related Projects	Connected to Hell Hole Reservoir by Tunnel

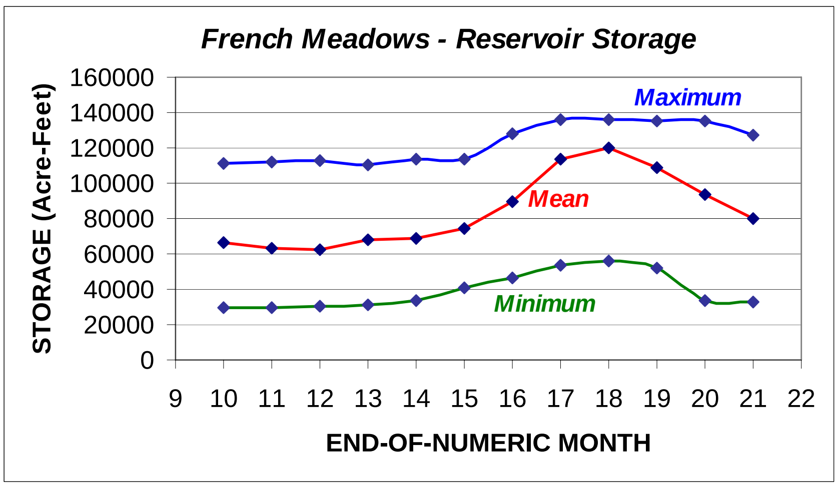

Figure A1a – Seasonal Values of Reservoir Storage for French Meadows Reservoir, 1964-2000

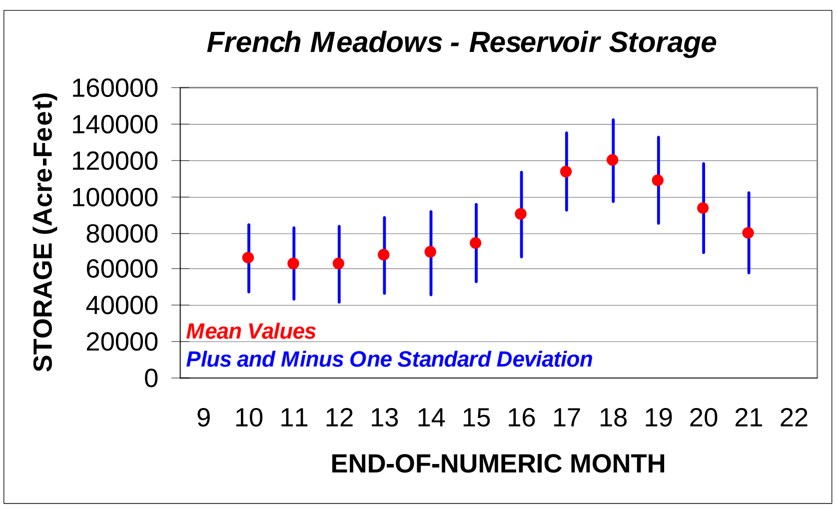

Figure A1b – Seasonal Variability of Reservoir Storage at French Meadows Reservoir

Hell Hole Reservoir

Table A2 – Characteristics of Hell Hole Reservoir

RESERVOIR CHARACTERISTIC	DESCRIPTION
Reservoir Name	Hell Hole
Project Owner	Placer County Water Agency
Project Purposes	Irrigation Water Supply, Hydropower
First Year Operation	1965
Reservoir Data	First-of-Month Reservoir Storage, 1965 - present
Maximum Storage Capacity	209,000 acre-feet
Normal Pool Elevation	4,630 feet
Spillway for Flood Discharge	Ungated Spillway
Related Projects	Connected to French Meadows Reservoir by Tunnel

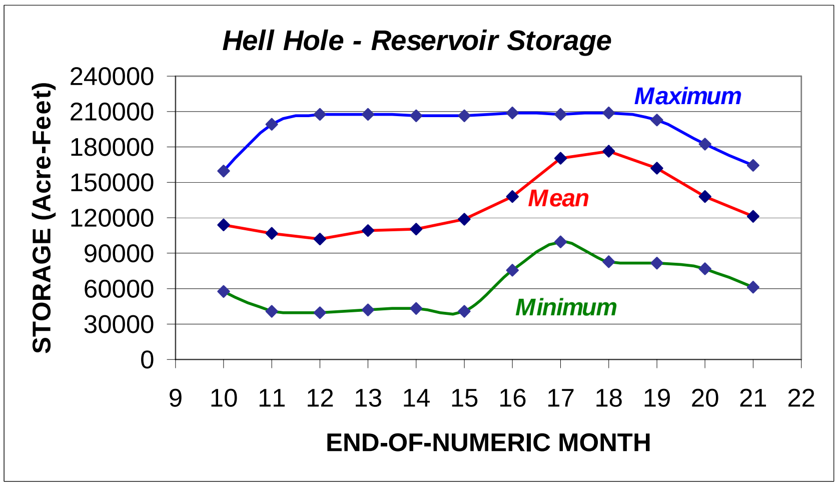

Figure A2a – Seasonal Values of Reservoir Storage for Hell Hole Reservoir, 1965-2000

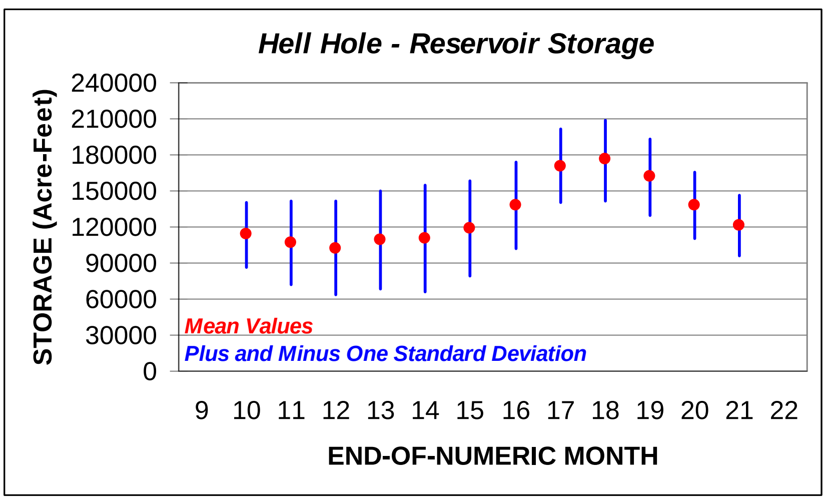

Figure A2b – Seasonal Variability of Reservoir Storage at Hell Hole Reservoir

Union Valley Reservoir

Table A3 – Characteristics of Union Valley Reservoir

RESERVOIR CHARACTERISTIC	DESCRIPTION
Reservoir Name	Union Valley
Project Owner	Sacramento Municipal Utility District
Project Purposes	Hydropower
First Year Operation	1962
Reservoir Data	First-of-Month Reservoir Storage, 1962 - present
Maximum Storage Capacity	271,000 acre-feet
Normal Pool Elevation	4,870 feet
Spillway for Flood Discharge	Gated Spillway
Related Projects	Operated with Loon Lake and Ice House Reservoirs

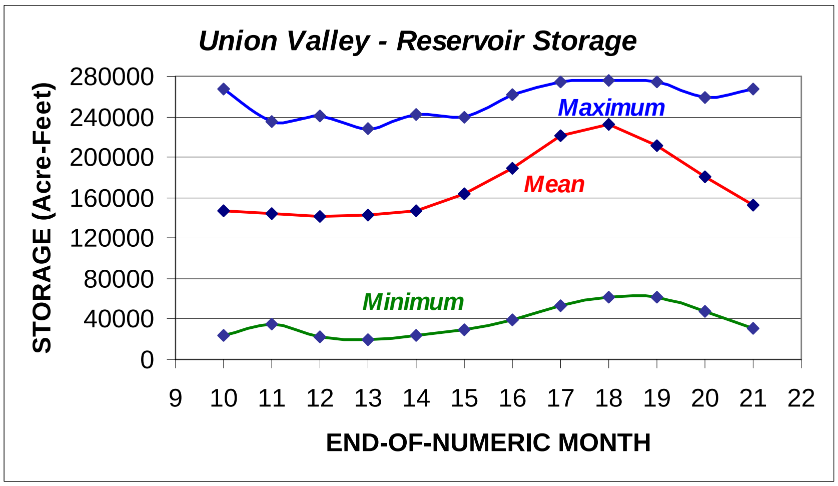

Figure A3a – Seasonal Values of Reservoir Storage for Union Valley Reservoir, 1962-2000

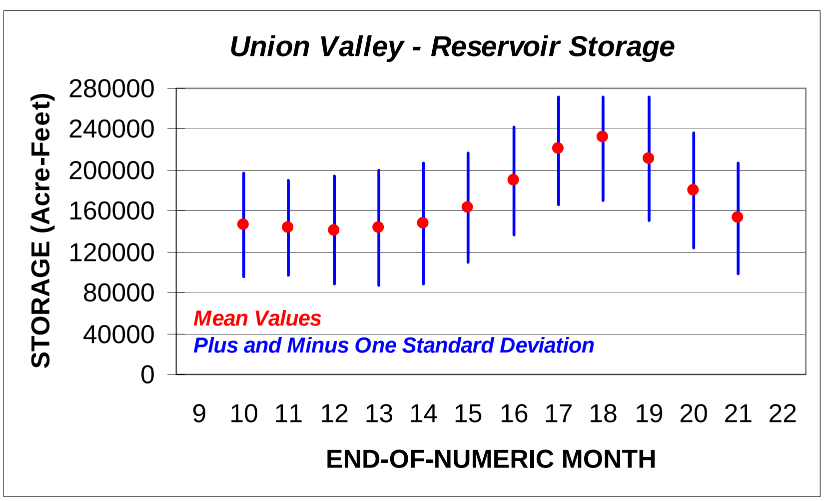

Figure A3b – Seasonal Variability of Reservoir Storage at Union Valley Reservoir

Loon Lake Reservoir

Table A4 – Characteristics of Loon Lake Reservoir

RESERVOIR CHARACTERISTIC	DESCRIPTION
Reservoir Name	Loon Lake
Project Owner	Sacramento Municipal Utility District
Project Purposes	Hydropower
First Year Operation	1963
Reservoir Data	First-of-Month Reservoir Storage, 1963 - present
Maximum Storage Capacity	77,000 acre-feet
Normal Pool Elevation	6,410 feet
Spillway for Flood Discharge	Ungated Spillway
Related Projects	Operated with Union Valley and Ice House Reservoirs

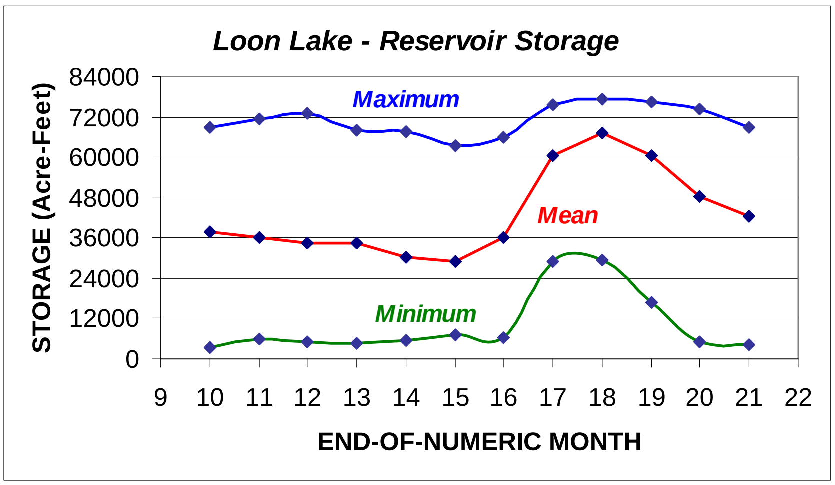

Figure A4a – Seasonal Values of Reservoir Storage for Loon Lake Reservoir, 1963-2000

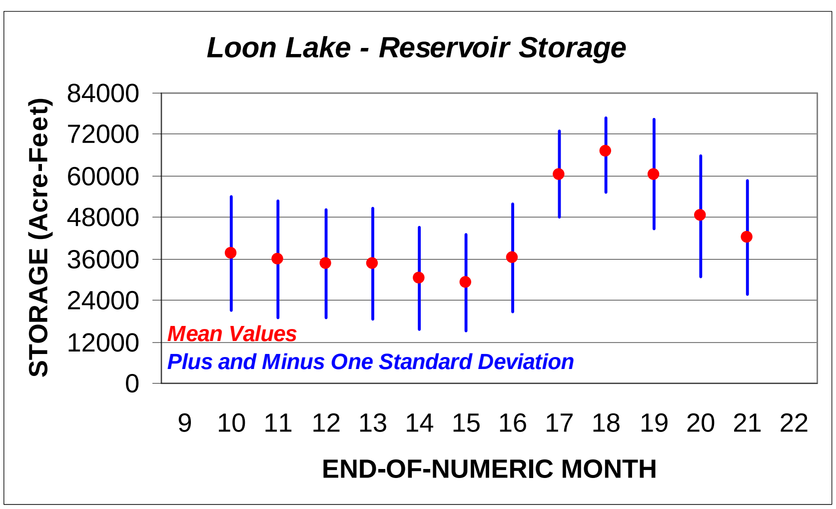

Figure A4b – Seasonal Variability of Reservoir Storage at Loon Lake Reservoir

Ice House Reservoir

Table A5 – Characteristics of Ice House Reservoir

RESERVOIR CHARACTERISTIC	DESCRIPTION
Reservoir Name	Ice House
Project Owner	Sacramento Municipal Utility District
Project Purposes	Hydropower
First Year Operation	1959
Reservoir Data	First-of-Month Reservoir Storage, 1959 - present
Maximum Storage Capacity	45,960 acre-feet
Normal Pool Elevation	5,454 feet
Spillway for Flood Discharge	Gated Spillway
Related Projects	Operated with Loon Lake and Union Valley Reservoirs

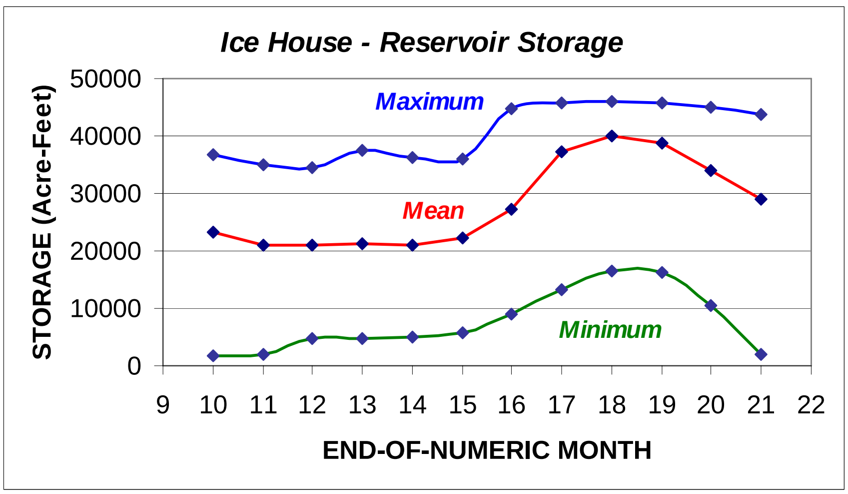

Figure A5a – Seasonal Values of Reservoir Storage for Ice House Reservoir, 1959-2000

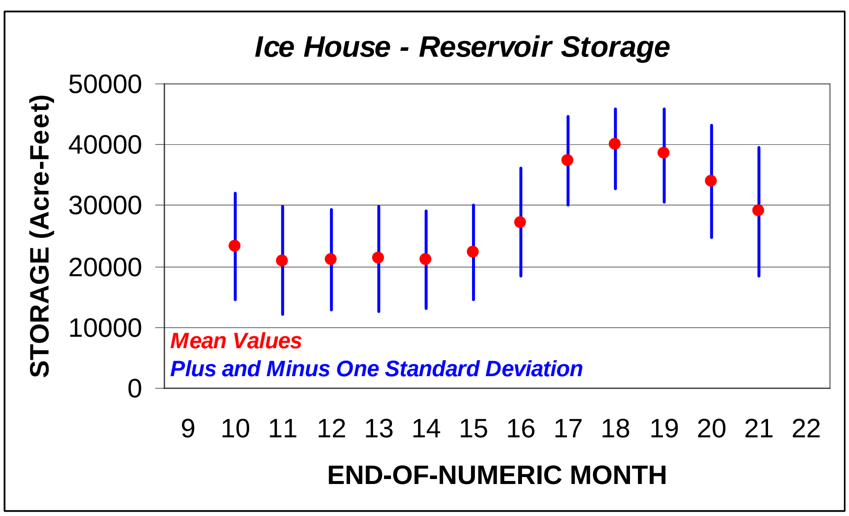

Figure A5b – Seasonal Variability of Reservoir Storage at Ice House Reservoir

APPENDIX B

RELATIONSHIPS BETWEEN RESERVOIR STORAGE AND ANTECEDENT PRECIPITATION FOR RESERVOIRS LOCATED IN THE UPPER AMERICAN RIVER WATERSHED

This appendix contains information on the regression relationships between reservoir storage and antecedent precipitation for the five reservoirs located in the upper American River Watershed. An example regression relationship and the end-of-month regression parameters are presented for each of the reservoirs. All relationships are based on the record of reservoir storage (acre-feet) for water-years from 1967 to 2000 and utilize antecedent precipitation data from the Lake Spaulding precipitation station.

Graphics for linear correlation coefficients that vary seasonally are plotted based on end-of-month values where numeric months are used for plotting convenience. The numeric months begin at the start of the water-year with 10 for end-of-October, progress through 13 for end-of-January, and 21 is used for the end-of-September, which is the end of the water-year.

French Meadows Reservoir

Table B1 – Regression Parameters for Relationship Between Storage at French Meadows Reservoir and Antecedent Precipitation at Lake Spaulding

REGRESSION PARAMETERS	END-OF-MONTH							
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Intercept (α)	64848	46232	42731	39644	35365	48719	70243	77955
Slope (β)	0	1114	740	677	628	387	262	487
Correlation Coefficient (ρ)	0.000	0.527	0.525	0.641	0.571	0.419	0.292	0.579
Standard Deviation Storage	17192	18430	20222	20995	23439	21458	22872	21478

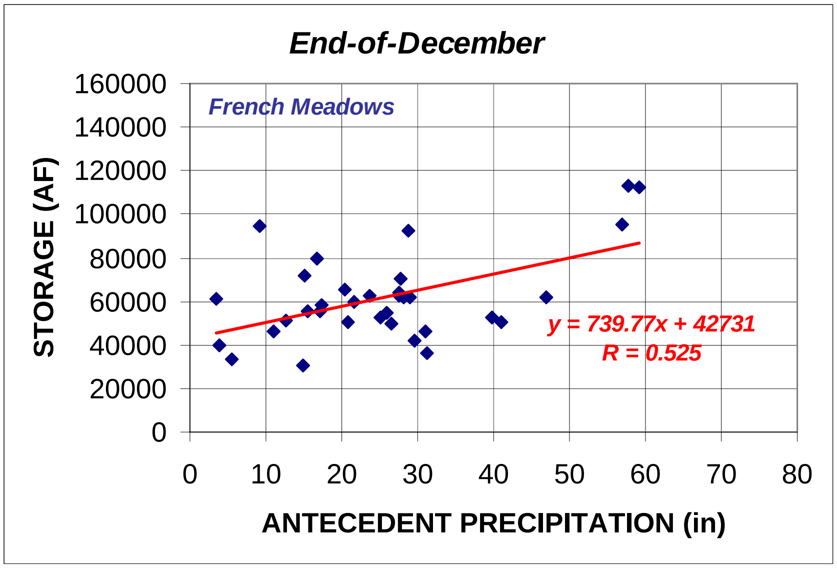

Figure B1a – Regression Solution for Relationship Between Storage at French Meadows Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-December

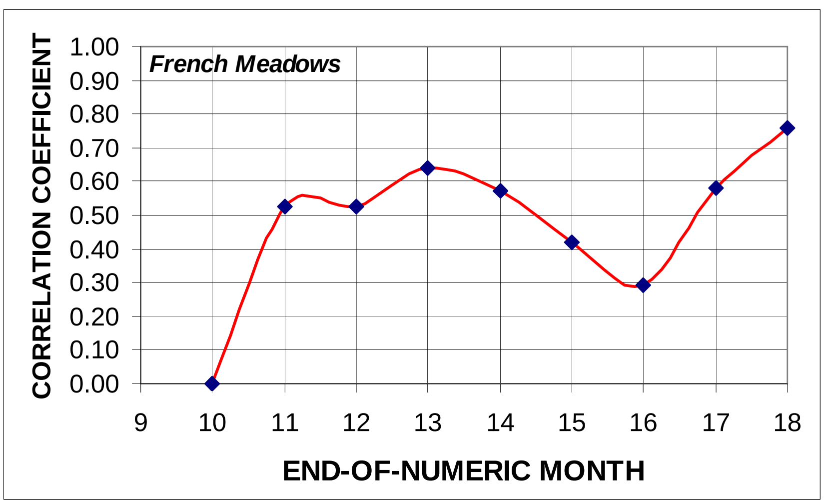

Figure B1b – Seasonal Variability of Correlation Coefficient for Relationship Between Reservoir Storage at French Meadows Reservoir and Antecedent Precipitation at Lake Spaulding

Hell Hole Reservoir

Table B2 – Regression Parameters for Relationship Between Storage at Hell Hole Reservoir and Antecedent Precipitation at Lake Spaulding

REGRESSION PARAMETERS	END-OF-MONTH							
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Intercept (α)	114433	78030	63813	58059	51751	66410	95329	113121
Slope (β)	0	2171	1596	1324	1165	850	629	817
Correlation Coefficient (ρ)	0.000	0.524	0.565	0.626	0.555	0.493	0.449	0.690
Standard Deviation Storage	27691	36136	40534	42060	44696	39949	35621	30261

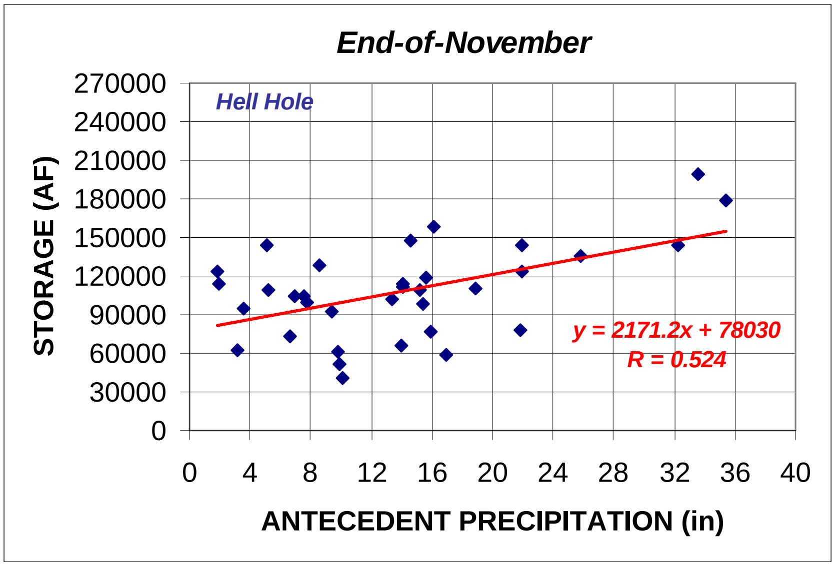

Figure B2a – Regression Solution for Relationship Between Storage at Hell Hole Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-November

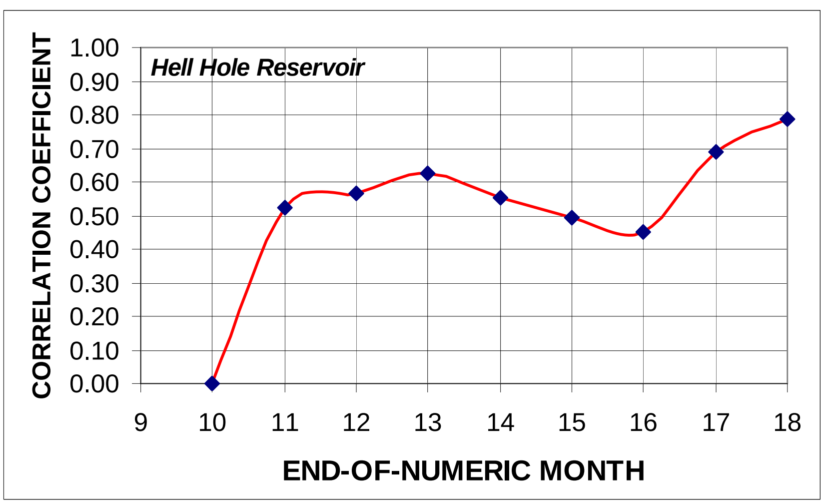

Figure B2b – Seasonal Variability of Correlation Coefficient for Relationship Between Reservoir Storage at Hell Hole Reservoir and Antecedent Precipitation at Lake Spaulding

Union Valley Reservoir

Table B3 – Regression Parameters for Relationship Between Storage at Union Valley Reservoir and Antecedent Precipitation at Lake Spaulding

REGRESSION PARAMETERS	END-OF-MONTH							
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Intercept (α)	133895	114035	82560	66131	39880	61418	103812	116543
Slope (β)	3330	2223	2212	1900	2080	1632	1250	1478
Correlation Coefficient (ρ)	0.203	0.412	0.615	0.662	0.737	0.700	0.594	0.667
Standard Deviation Storage	52973	47086	51611	57072	60112	54251	53509	56576

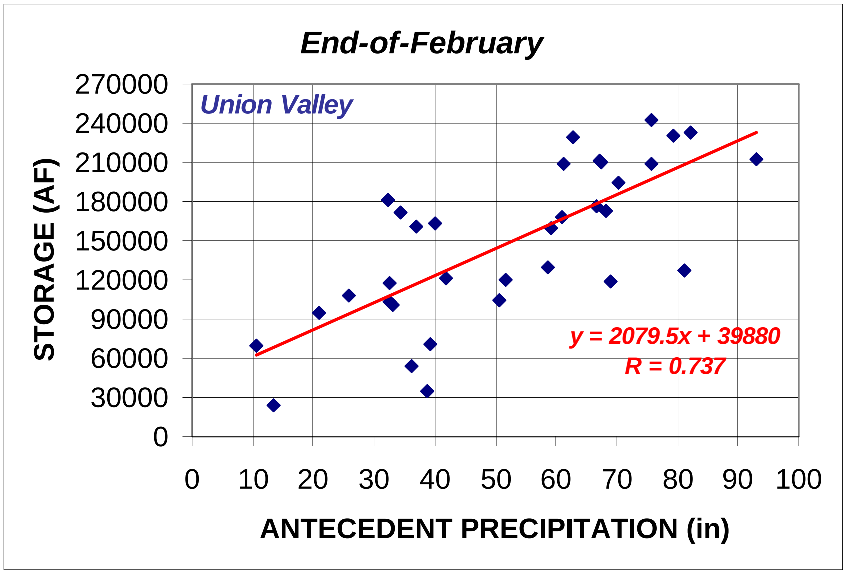

Figure B3a – Regression Solution for Relationship Between Storage at Union Valley Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-February

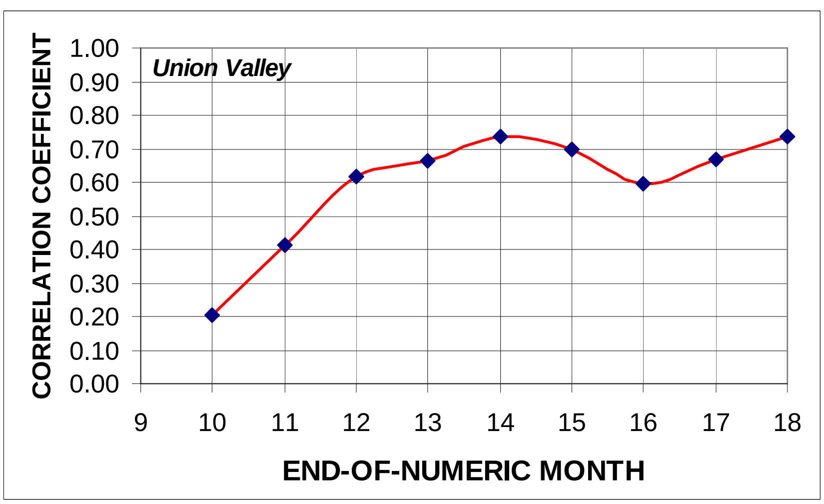

Figure B3b – Seasonal Variability of Correlation Coefficient for Relationship Between Reservoir Storage at Union Valley Reservoir and Antecedent Precipitation at Lake Spaulding

Loon Lake Reservoir

Table B4 – Regression Parameters for Relationship Between Storage at Loon Lake Reservoir and Antecedent Precipitation at Lake Spaulding

REGRESSION PARAMETERS	END-OF-MONTH							
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Intercept (α)	30416	25491	23410	22502	17373	20079	36211	53527
Slope (β)	1913	806	450	311	261	157	0	95
Correlation Coefficient (ρ)	0.380	0.412	0.406	0.385	0.367	0.258	0.000	0.191
Standard Deviation Storage	16263	17057	15919	16050	15150	14053	15923	12667

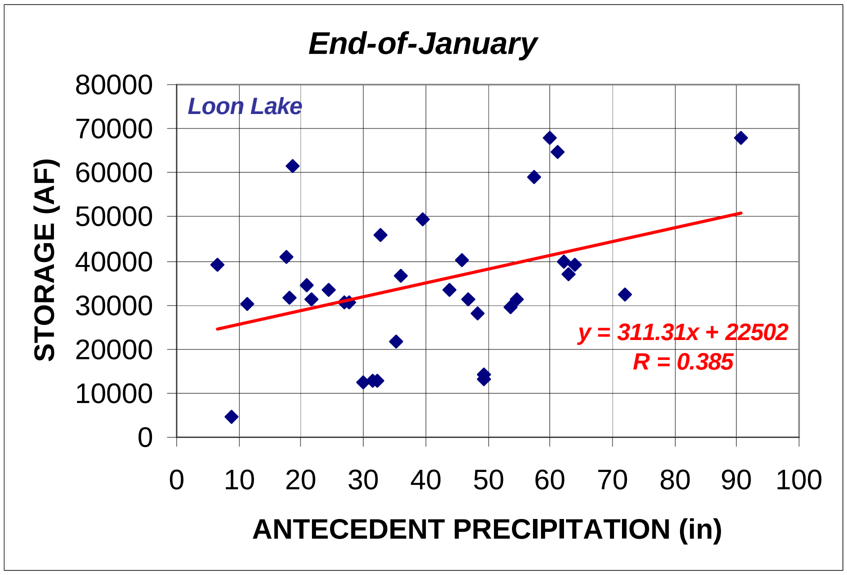

Figure B4a – Regression Solution for Relationship Between Storage at Loon Lake Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-January

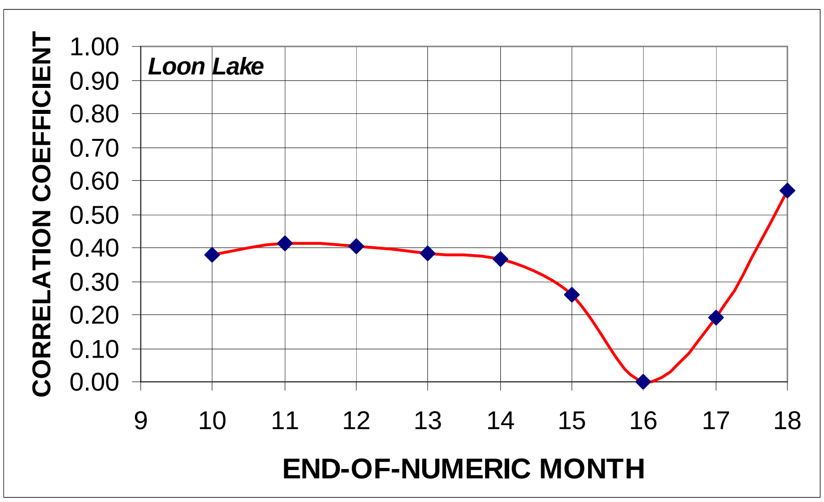

Figure B4b – Seasonal Variability of Correlation Coefficient for Relationship Between Reservoir Storage at Loon Lake Reservoir and Antecedent Precipitation at Lake Spaulding

Ice House Reservoir

Table B5 – Regression Parameters for Relationship Between Storage at Ice House Reservoir and Antecedent Precipitation at Lake Spaulding

REGRESSION PARAMETERS	END-OF-MONTH							
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Intercept (α)	23735	21206	18579	15329	12686	14877	23533	29813
Slope (β)	160	79	116	160	169	123	53	104
Correlation Coefficient (ρ)	0.066	0.087	0.235	0.416	0.465	0.375	0.148	0.340
Standard Deviation Storage	7899	7874	7097	7622	7750	7623	9161	7792

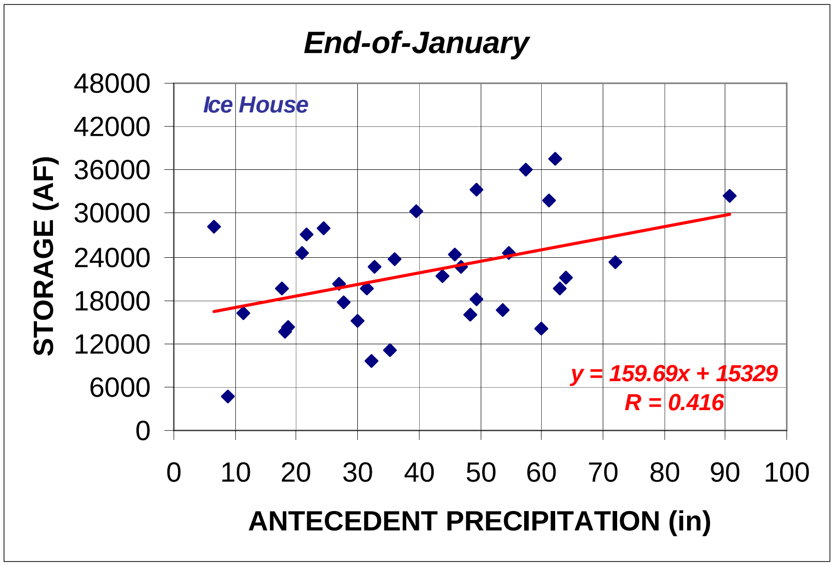

Figure B5a – Regression Solution for Relationship Between Storage at Ice House Reservoir and Antecedent Precipitation at Lake Spaulding for End-of-January

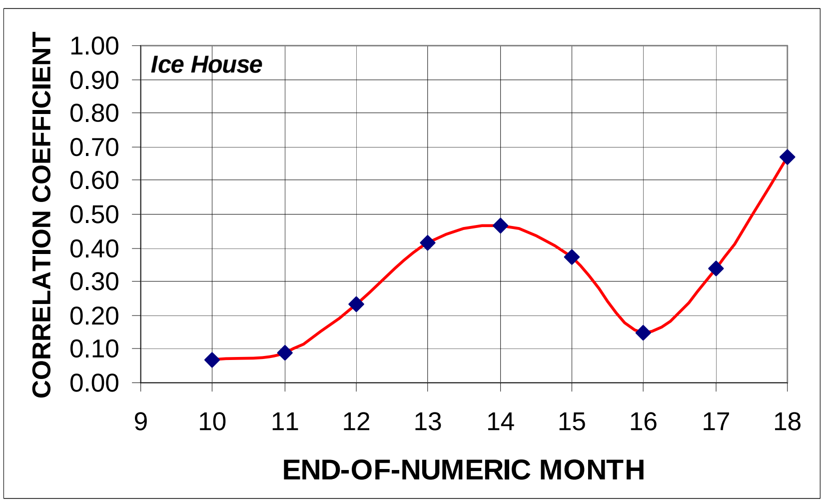

Figure B5b – Seasonal Variability of Correlation Coefficient for Relationship Between Reservoir Storage at Ice House Reservoir and Antecedent Precipitation at Lake Spaulding