US Army Corps of Engineers
Hydrologic Engineering Center

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

Appendix G - Antecedent Precipitation Characteristics for the American River Watershed

September 2005

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14. ABSTRACT
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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ANTECEDENT PRECIPITATION CHARACTERISTICS FOR THE AMERICAN RIVER WATERSHED

December 30, 2000

OVERVIEW

Antecedent precipitation is defined as precipitation that has occurred from October 1st to the end-of-month that is selected for the occurrence of the extreme storm. Antecedent precipitation is used in the stochastic simulations for conducting soil moisture accounting in the various zones of mean annual precipitation. Antecedent precipitation from a *key precipitation station* is also used as an explanatory variable in correlation analyses with snowpack and reservoir storage. The correlation relationships developed using antecedent precipitation from the key station will be used to allocate snowpack throughout the watershed, and to select initial reservoir storage in the five reservoirs in the upper American River watershed.

ZONES OF MEAN ANNUAL PRECIPITATION

The spatial allocation of snowpack requires that the watershed be subdivided into zones of mean annual precipitation[2,10] and zones of elevation. The magnitude of antecedent precipitation varies with mean annual precipitation. Therefore, probabilistic information about antecedent precipitation must be developed in a manner that is consistent with the manner in which the watershed is subdivided for mean annual precipitation. Mean annual precipitation[2,10] varies from about 25-inches to 75-inches in the American River watershed with a basin-average near 50-inches. Table 1 lists the proposed zones of mean annual precipitation to be used for subdivision of the watershed.

Table 1 – Proposed Subdivision of American River Watershed into Zones of Mean Annual Precipitation

ZONES OF MEAN ANNUAL PRECIPITATION (inches)													
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Range	20-28	28-32	32-36	36-40	40-44	44-48	48-52	52-56	56-60	60-64	64-68	68-72	72-80
Median	26 in	30 in	34 in	38 in	42 in	46 in	50 in	54 in	58 in	62 in	66 in	70 in	74 in

PRECIPITATION MEASUREMENTS STATIONS

Nine precipitation measurement stations were used for describing the variation of antecedent precipitation over the American River watershed. These stations are located within or near the watershed and are representative of the range of mean annual precipitation within the watershed. Data from the 1966-1998 period were used for conducting the analyses of antecedent precipitation. Table 2 lists the stations used in these analyses and some of the physical and climatic characteristics of the measurement sites.

Table 2 – Precipitation Measurement Stations Used in Analyses of Antecedent Precipitation

STATION ID	STATION NAME	LATITUDE	LONGITUDE	ELEVATION (feet)	MEAN ANNUAL PRECIPITATION[2,10] (inch)
04-7630	Sacramento FAA Airport	38.5167	121.5000	18	18.2
04-7370	Represa	38.7000	121.1667	295	22.5
04-0383	Auburn	38.9000	121.0833	1292	36.9
04-6963	Placerville	38.7333	120.8167	1791	39.4
04-9105	Twin Lakes	38.7000	120.0333	8000	48.8
04-6597	Pacific House	38.7500	120.5000	3440	52.3
04-4288	Iowa Hill	39.1167	120.8333	3100	53.7
04-1018	Bowman Dam	39.4500	120.6500	5383	69.3
04-4713	Lake Spaulding	39.3167	120.6333	5155	74.5

MAGNITUDE-FREQUENCY CHARACTERISTICS OF ANTECEDENT PRECIPITATION

Numerous studies[4,11,12,13] have found that monthly and multi-month precipitation is well-described by the three-parameter Gamma distribution[1,9,14]. Findings from this study also confirmed the Gamma distribution to be a suitable choice for describing antecedent precipitation. Regional estimates of the mean, coefficient of variation, and coefficient of skewness were used in a method of moments[1,14] solution for describing antecedent precipitation. Use of a regional approach serves to minimize uncertainties in solution of distribution parameters that arise due to sampling variability. An example of a three-parameter Gamma distribution fitted to historical antecedent precipitation data for the Lake Spaulding station is shown in Figure 3.

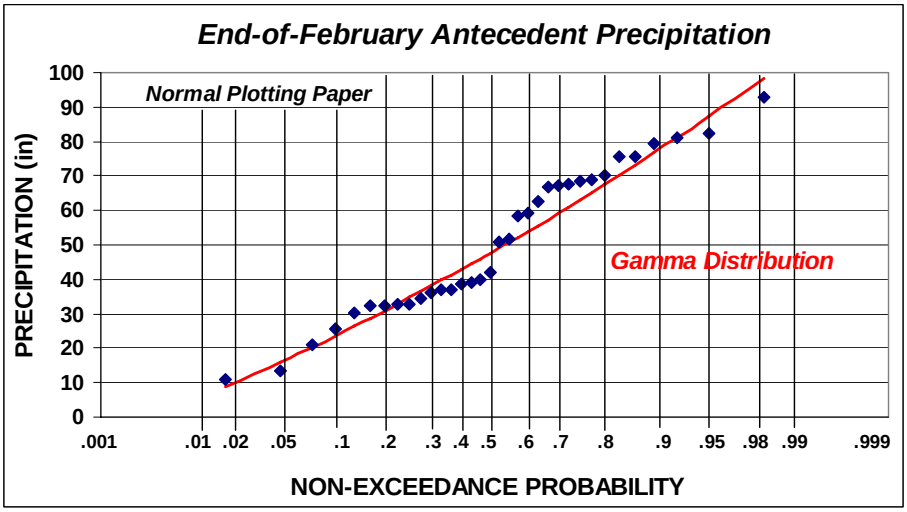

Figure 3 – Probability-Plot of End-of-February Antecedent Precipitation Data for Lake Spaulding as Fitted by a Gamma Distribution

Regional Solutions

Sample statistics were computed for end-of-month antecedent precipitation for each of the nine stations listed in Table 2. Standard regression methods[5,6] were then used to obtain regional solutions[14] of the mean, and coefficients of variation and skewness for the various zones of mean annual precipitation listed in Table 1.

Mean Values – End-of-month mean values were found to vary linearly with mean annual precipitation across the watershed. Table 3 lists the regression parameters for estimation of end-of-month mean values as a linear function of mean annual precipitation. Figure 4 depicts an example regression solution for end-of-month mean values. Appendix A lists the end-of-month mean values for the zones of mean annual precipitation listed in Table 1 based on the regional regression solutions.

Table 3 – Linear Regression Solutions for Antecedent Precipitation as a Function of Mean Annual Precipitation

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Intercept	-.25	-.03	-.34	.27	.71	1.05	.91	.43
Slope	.0583	.1904	.3553	.5344	.6736	.8170	.8927	.9416
Correlation Coefficient	.995	.997	.999	.999	.999	.999	.999	.999

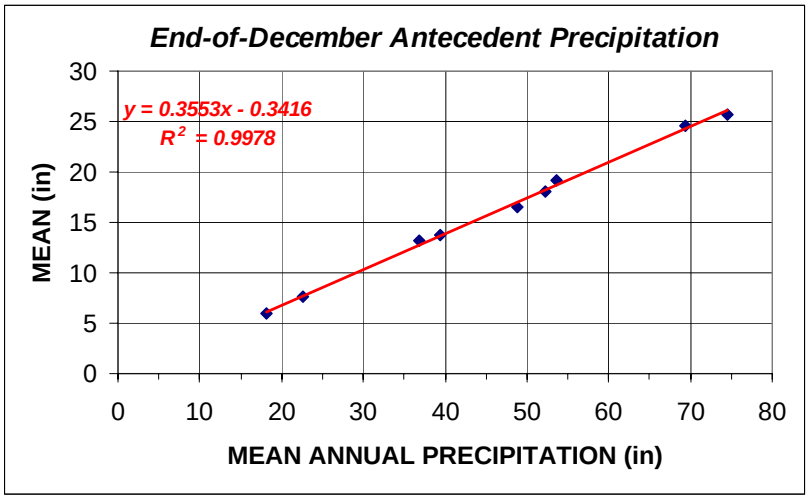

Figure 4 –Linear Regression Solution of End-of-December Antecedent Precipitation for the American River Watershed

Coefficients of Variation – End-of-month coefficients of variation for antecedent precipitation were found to vary with mean annual precipitation for the months of October and November. The coefficients of variation were found to be essentially constants for all other end-of-month periods.

Figure 5a depicts regional solutions of the coefficient of variation as a function of mean annual precipitation for the months of October and November. Figure 6 depicts the regional solution for the seasonal variation of the coefficient of variation of antecedent precipitation for the months of December through May. Appendix A lists the regional solutions for the end-of-month coefficient of variation values for the zones of mean annual precipitation listed in Table 1.

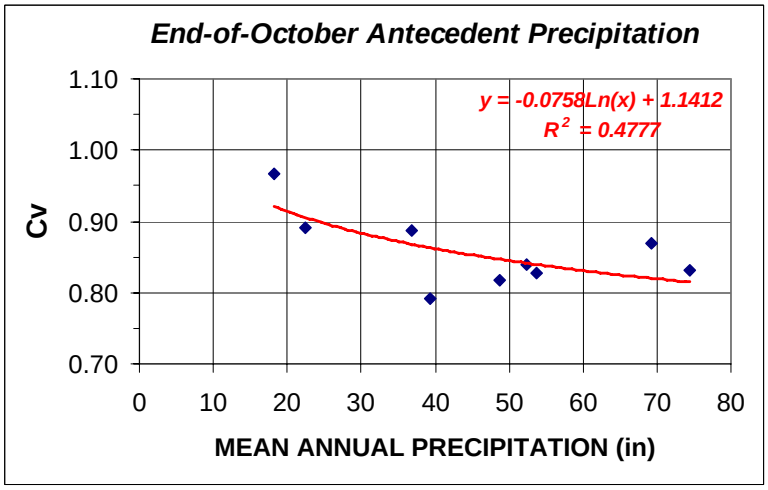

Figure 5a – Regional Solution of Coefficient of Variation for End-of-October Antecedent Precipitation

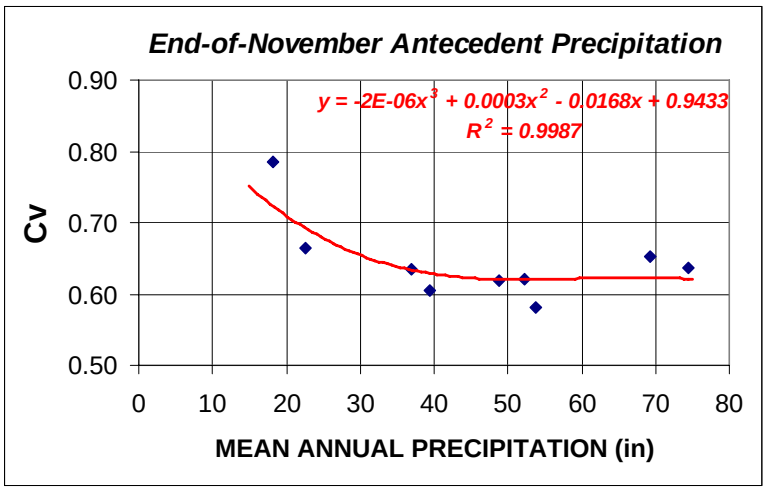

Figure 5b – Regional Solution of Coefficient of Variation
for End-of-November Antecedent Precipitation

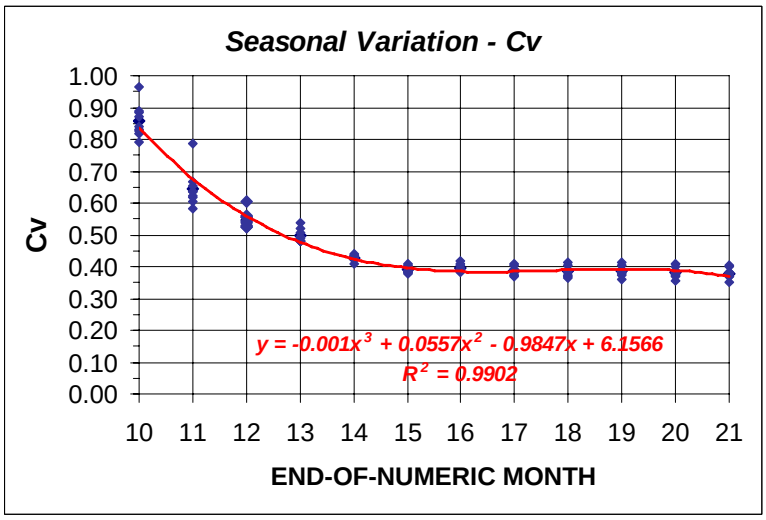

Figure 6 – Regional Solution for Seasonal Variation of Coefficient of Variation
for End-of-Month Antecedent Precipitation Used for December through May

Coefficients of Skewness – End-of-month coefficients of skewness for antecedent precipitation were found to vary seasonally. Sample estimates for the coefficient of skewness are subject to high sampling variability. Accordingly, a hierarchical approach[3] was used to estimate regional values of the coefficient of skewness to minimize uncertainties due to sampling variability. Figure 6 depicts the regional solution for seasonal variation of the coefficient of skewness for end-of-month antecedent precipitation. The generalized smooth curve shown in Figure 7 departs slightly from the sample data for the months of February and March. However, the adopted solution is consistent with the findings of numerous other analyses of antecedent precipitation where the coefficient of skewness was found to slowly decay from larger values in October to smaller values toward the end of the water-year. Appendix A lists the regional solutions for the end-of-month coefficient of skewness values.

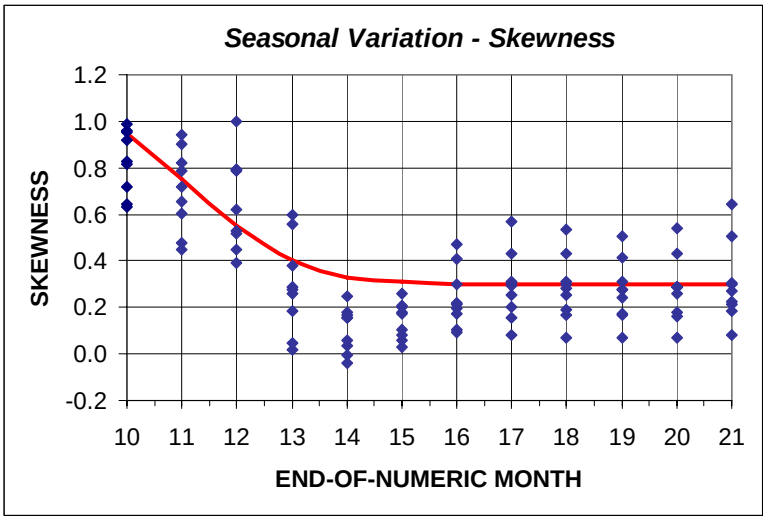

Figure 7 – Regional Solution for Seasonal Variation of Coefficient of Skewness for End-of-Month Antecedent Precipitation

SELECTION OF KEY PRECIPITATION STATION

As discussed previously, antecedent precipitation is used in the stochastic simulations[15] for conducting soil moisture accounting in the various zones of mean annual precipitation. Antecedent precipitation from a *key precipitation station* is also used as an explanatory variable in correlation analyses with snowpack and reservoir storage.

Ideally, the key precipitation station should be a long-term station, centrally located within the watershed, and be in the mid-range of mean annual precipitation for the watershed. These criteria are intended to provide antecedent precipitation values that best represent the characteristics of the watershed. The Lake Spaulding precipitation station is a high-quality long-term station that best meets these criteria. It was chosen as the key precipitation station and will be used for correlation analyses with snowpack and reservoir storage. The regional solutions of the end-of-month mean, coefficient of variation, and coefficient of skewness for the Lake Spaulding station are listed in Table 4.

Table 4 – Regional Solutions of End-of-Month Mean and Coefficients of Variation and Skewness for Antecedent Precipitation for the Key Precipitation Station at Lake Spaulding

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Mean (inches)	3.98	13.77	25.42	39.01	49.55	60.28	65.63	68.70
Coefficient of Variation	0.817	0.625	0.562	0.482	0.431	0.405	0.400	0.400
Coefficient of Skewness	0.95	0.75	0.55	0.40	0.33	0.31	0.30	0.30

REFERENCES

1. Benjamin JR and Cornell CA, Probability, Statistics and Decision for Civil Engineers, McGraw-Hill, 1970.

2. Daly C, Neilson RP, and Phillips DL, A Statistical-Topographic Model for Mapping of Climatological Precipitation over Mountainous Terrain (PRISM Parameter-Elevation Regression on Independent Slopes Model), Journal of Applied Meteorology, Volume 33, pp140-158, 1994.

3. Fiorentino MS, Gabrielle S, Rossi F and Versace P, Hierarchical Approach for Regional Frequency Analysis, *Regional Frequency Analysis*, Edited by VP Singh, pp35-49, Reidel, Norwell Massachusetts, 1979.

4. Haan CT, Statistical Methods in Hydrology, Iowa State University Press, 1977.

5. Helsel DR, and Hirsch, RM, Statistical Methods in Water Resources, Studies in Environmental Science 49, Elsevier, 1992.

6. Hirsch RM, Helsel DR, Cohn TA and Gilroy EJ, Statistical Analysis of Hydrologic Data, Chapter 17, *Handbook of Hydrology*, McGraw Hill, 1992.

7. HydroSphere, Climate Data, HydroSphere Data Products, Boulder CO.

8. Jain R, The Art of Computer Systems Performance Analysis, John Wiley and Sons, 1991.

9. Johnson NL and Kotz S, Distributions in Statistics - Three Volume Set, John Wiley and Sons, 1970.

10. Oregon Climate Service, Mean Annual Precipitation Maps for Western United States, PRISM Model, Corvallis Oregon, 1997.

11. Salas JD, Delleur JW, Yevdjevich Y, and Lane WL, Applied Modeling of Hydrologic Time Series, Water Resources Publications LLC, 1980.

12. Schaefer MG and Barker BL, Stochastic Modeling of Extreme Floods for A.R. Bowman Dam, MGS Engineering Consultants, November 1997.

13. Schaefer MG and Barker BL, Stochastic Modeling of Extreme Floods for Keechelus Dam, MGS Engineering Consultants, September 1999.

14. Stedinger JR, Vogel RM, and Foufoula-Georgiou E, Frequency Analysis of Extreme Events, Chapter 18, *Handbook of Hydrology*, McGraw Hill, 1992.

15. SEFM, Stochastic Event Flood Model, MGS Engineering Consultants, Inc, 1998.

APPENDIX – A

REGIONAL SOLUTIONS FOR ESTIMATES OF MEAN, COEFFICIENT OF VARIATION, AND COEFFICIENT OF SKEWNESS OF ANTECEDENT PRECIPITATION FOR SELECTED ZONES OF MEAN ANNUAL PRECIPITATION

Table A1 – Mean Values of End-of-Month Antecedent Precipitation for American River Watershed

MEAN VALUES OF END-OF-MONTH ANTECEDENT PRECIPITATION (inches)									
ZONE OF MEAN ANNUAL PRECIPITATION	MEDIAN OF ZONE (in)	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1	26	1.27	4.92	8.90	14.16	18.22	22.29	24.12	24.91
2	30	1.50	5.68	10.32	16.30	20.92	25.56	27.69	28.68
3	34	1.73	6.44	11.74	18.44	23.61	28.83	31.26	32.44
4	38	1.97	7.21	13.16	20.58	26.31	32.10	34.83	36.21
5	42	2.20	7.97	14.58	22.71	29.00	35.36	38.40	39.98
6	46	2.43	8.73	16.00	24.85	31.70	38.63	41.97	43.74
7	50	2.67	9.49	17.43	26.99	34.39	41.90	45.55	47.51
8	54	2.90	10.25	18.85	29.13	37.08	45.17	49.12	51.28
9	58	3.13	11.01	20.27	31.27	39.78	48.44	52.69	55.04
10	62	3.36	11.77	21.69	33.40	42.47	51.70	56.26	58.81
11	66	3.60	12.54	23.11	35.54	45.17	54.97	59.83	62.58
12	70	3.83	13.30	24.53	37.68	47.86	58.24	63.40	66.34
13	74	4.06	14.06	25.95	39.82	50.56	61.51	66.97	70.11

Table A2 – Coefficient of Variation of End-of-Month Antecedent Precipitation for American River Watershed

COEFFICIENT OF VARIATION END-OF-MONTH ANTECEDENT PRECIPITATION			
ZONE OF MEAN ANNUAL PRECIPITATION	MEDIAN OF ZONE (in)	OCT	NOV
1	26	0.894	0.678
2	30	0.883	0.662
3	34	0.874	0.649
4	38	0.865	0.635
5	42	0.858	0.630
6	46	0.851	0.625
7	50	0.845	0.625
8	54	0.839	0.625
9	58	0.833	0.625
10	62	0.828	0.625
11	66	0.824	0.625
12	70	0.819	0.625
13	74	0.815	0.625

Table A3 – Coefficient of Variation for End-of-Month Antecedent Precipitation for American River Watershed

MONTH	COEFFICIENT OF VARIATION
OCT	Table A2
NOV	Table A2
DEC	0.562
JAN	0.482
FEB	0.431
MAR	0.405
APR	0.400
MAY	0.400

Table A4 – Coefficient of Skewness for End-of-Month Antecedent Precipitation for American River Watershed

MONTH	COEFFICIENT OF SKEWNESS
OCT	0.95
NOV	0.75
DEC	0.55
JAN	0.40
FEB	0.33
MAR	0.31
APR	0.30
MAY	0.30