Santa Rosa Subregional Long-Term Wastewater Project

RESERVOIR SPILLWAY HYDROLOGY ANALYSIS

SANTA ROSA SUBREGIONAL LONG-TERM WASTEWATER PROJECT

Prepared for

City of Santa Rosa
and
U.S. Army Corps of Engineers

December 1995

Prepared by

DAMES & MOORE
221 MAIN STREET, SUITE 600, SAN FRANCISCO, CA 94105 • 415/896-5858

For

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for

HARLAND BARTHOLOMEW AND ASSOCIATES, INC.

Final

TECHNICAL MEMORANDUM

Reservoir Spillway Hydrology Analysis

TO: Harland Bartholomew & Associates, Inc.

FROM: April Fallon - Dames & Moore, San Francisco

DATE: December 1995

RE: Santa Rosa Subregional Long-Term Wastewater Project
Reservoir Spillway Hydrology Analysis

SUMMARY

A hydrologic analysis was performed to estimate the design flow rate for preliminary sizing of the spillways at ten (10) proposed reservoir sites. Each reservoir was classified according to the U.S. Army Corps of Engineers hazard classification system for determining the appropriate design flood frequency for each spillway. Based on the dam height and storage capacity of each reservoir, the Probable Maximum Flood (PMF) is the appropriate design flood frequency for all reservoirs. The spillway design peak inflow for the PMF was calculated using two methods: 1) the unit hydrograph method using the Probable Maximum Precipitation (PMP) and the flood hydrograph computer model HEC-1 and 2) the empirical method using extreme flood formulas. The design flow was selected based on a comparison of the results from both methods. A reservoir routing analysis to determine attenuation of the peak flow was not performed.

PURPOSE

A hydrologic analysis was performed to determine the appropriate hydraulic design criteria for conceptual layout of the spillway at each reservoir site. The results of the analysis were used by Parsons ES to locate and size the spillway so that an estimate of the project cost could be prepared.

METHODOLOGY

The scope of work for this task included:

1. analysis of a maximum of ten dam and reservoir sites,

2. determination of the hazard classification for each dam based on the U.S. Army Corps of Engineers hazard classification system,

3. calculation of the design flood frequency for each dam using the Army Corps of Engineers spillway design criteria,

4. calculation of spillway design peak inflow for each reservoir, neglecting peak flow attenuation caused by reservoir routing.

The Corps of Engineer's criteria for the hazard classification of each dam is based on the height of the dam, the volume of water stored in the reservoir and the potential loss of life and potential economic loss if the dam were to fail (Department of the Army, 1976). The Corps of Engineers has also established spillway design flood requirements corresponding to each hazard classification. This criteria was applied to each reservoir site to determine the hazard classifications and the spillway design criteria. For all reservoirs under consideration, the Probable Maximum Flood is the appropriate design criteria for the spillway.

The reservoir inflow hydrograph for the PMF was calculated using the Probable Maximum Precipitation (PMP) (NOAA, 1969, 1984) and the Soil Conservation Service unit hydrograph procedure (Soil Conservation Service, 1985). Attenuation of the inflow hydrograph resulting from temporarily storing floodwater in the reservoir was neglected in the analysis. The spillway design flow was assumed equal to the peak reservoir inflow rate.

A second method was used to estimate the spillway design flow for comparison to the flow calculated using the unit hydrograph method. Empirical equations have been developed by several researchers for predicting the extreme runoff from watersheds of various sizes (National Research Council, 1983). These equations were applied to each reservoir to estimate the peak inflow rate.

The results of both methods were compared on the basis of runoff per square mile of watershed area. The unit hydrograph method and one of the two empirical methods were in very close agreement. Therefore, a unit runoff rate expressed in cfs per square mile of watershed area was selected for each reservoir by averaging the results of the two methods.

FINDINGS

Reservoir Data

Table 1 lists the ten reservoir sites analyzed and pertinent reservoir data provided by Engineering-Science, Inc. for each site.

TABLE 1

SUMMARY OF RESERVOIR DATA

	Active Storage Volume		Dam Height (feet)
Dam Site	**(M.G.)**	**(Acre-ft)**	
Adobe Road (AD-1B)	3,500	10,740	205
Two Rock (T6A)	4,400	13,500	225
Tolay-A (S39A)	4,850	14,890	90
Tolay-C (S39C)	4,600	14,120	115
Lakeville Hillside (L-2A)	1,300	3,990	135
Sears Point (SP-1)	3,600	11,050	115
Bloomfield (B1-A)	4,400	13,500	190
Valley Ford East (V4)	4,600	14,120	140
Carroll Road North (V7)	4,600	14,120	195
Huntley (T-1)	4,300	13,200	210

Source: Parsons Engineering Science

Note: Active storage includes capacity for reclaimed water storage and captured surface water runoff. (Dead storage is not included.)

Spillway Design Flood

Dams are classified in accordance with size and hazard potential in order to determine the required spillway design flood. Using the U.S. Army Corps of Engineers[1] guidance document, the size and hazard potential were calculated for each reservoir site. The classification for size is based on the height of the dam and storage capacity, as shown in Table 2.

TABLE 2

DAM SIZE CLASSIFICATIONS

	Impoundment	
Size Category	**Storage (acre-ft)**	**Height (ft)**
Small	<1000 and 50	<40 and 25
Intermediate	1000 and 50,000	40 and <100
Large	50,000	100

Source: Recommended Guidelines for Safety Inspection of Dams, p. D-8.

The classification of hazards potential is shown in Table 3. The hazards pertain to potential loss of human life or property damage in the area downstream of the dam in the event of failure or misoperation of the dam or appurtenant facilities.

TABLE 3

DAM FAILURE HAZARD CLASSIFICATIONS

Hazard Category	Potential Loss of Life (Extent of Development)	Potential Economic Loss (Extent of Development)
Low	None expected (No permanent structures for human habitation)	Minimal (Undeveloped to occasional structures or agriculture)
Significant	Few (No urban developments and no more than a small number of inhabitable structures	Appreciable (Notable agriculture, industry or structures)
High	More than a few	Excessive (Extensive community, industry or agriculture)

Source: Recommended Guidelines for Safety Inspection of Dams, p. D-9.

The recommended spillway design flood was determined based on criteria established by the U.S. Army Corps of Engineers for dams with varying hazard and size classifications. Table 4 presents a summary of the hazard, size, and design flood for each reservoir site.

Based on the size and hazard classification, the spillway design flood for all alternatives is the PMF. The dam size classification was determined by comparing Tables 1 and 2. The hazard classification is an estimate based on review of USGS maps showing structures and land uses in the area downstream from each reservoir.

TABLE 4

SPILLWAY DESIGN FLOOD

Dam Site	Dam Size Classification	Hazard Potential Classification	Spillway Design Flood
Adobe Road (AD-1B)	Large	High	PMF
Two Rock (T6A)	Large	Significant	PMF
Tolay-A (S39)	Intermediate	High	PMF
Tolay-C (S39C)	Large	High	PMF
Lakeville Hillside (L-2A)	Large	High	PMF
Sears Point (SP-1)	Large	High	PMF
Bloomfield (B1-A)	Large	High	PMF
Valley Ford East (V4)	Large	Significant	PMF
Caroll Road North (V7)	Large	Significant	PMF
Huntley (T-1)	Large	Significant	PMF

Watershed Data

Engineering-Science, Inc. provided data on the reservoir water surface area and the watershed area for each reservoir. The soil type for the area was identified by locating each reservoir site on the *Soil Survey of Sonoma County*. The hydrologic soil group was determined using the Soil Conservation Service (SCS) National Engineering Handbook (SCS, 1985). Using the hydrologic soil group identification, the runoff curve number (CN) was selected from Table 2.1 of the *Civil Engineering Reference Manual* (Lindeburge, 1989). The value selected from this table is for antecedent moisture condition II (AMC-II) corresponding to the typical soil condition before the maximum annual flood. AMC-I corresponding to dry soils, and AMC-III, corresponding to saturated soils due to heavy rainfall, were calculated using Table 6.8 in the manual to convert from AMC-II to AMC-I and AMC-III. A summary of these values is shown in Table 5 below.

TABLE 5

RESERVOIR WATERSHED DATA

Dam Site	Reservoir Water Surface Area (acres)	Watershed Area (acres)	Soil Type Name	Hydrologic Soil Group	Curve Number		
					AMC-II	AMC-I	AMC-III
Adobe Road (AD-1B)	170	1,050	Goulding	D	83	67	93
Two Rock (T6A)	230	704	Steinbeck / Los Osos	B,C	78	60	90
Tolay-A (S39A)	800	3,400	Diablo / Goulding	D	85	70	94
Tolay-C (S39C)	390	1,300	Diablo / Goulding	D	86	72	94
Lakeville Hillside (L-2A)	155	500	Diablo	D	86	72	94
Sears Point (SP-1)	270	6,080	Diablo	D	81	64	92
Bloomfield (B1-A)	195	601	Steinbeck / Los Osos	B,C	78	60	90
Valley Ford East (V4)	260	879	Steinbeck	B	73	54	87
Caroll Road North (V7)	235	846	Steinbeck / Los Osos	B,C	76	58	89
Huntley (T-1)	175	360	Steinbeck	B	80	63	91

Note: The watershed are for Tolay C (1,300 acres) does not includes the watershed area upstream from the backdam. Runoff from this area will pond behind the backdam and eventually flow over the watershed divide toward the Petaluma River before the water level reaches the crest elevation of the backdam. Therefore, the spillway capacity of the main dam is not required for runoff from the watershed above the backdam.

In addition to the above data, the lag time for each watershed is required as input data for the HEC-1 model. The time of concentration for each watershed was calculated using the following equation (USBR, 1977).

$$T = (11.9L^3/H)^{0.385}$$

where T = time of concentration in hours

L = length of longest watercourse in miles

H = elevation difference in feet

Lag time in hours was estimated to be 60 percent of the time of concentration, T. Table 6 provides the input data and calculated time of concentration and lag time in hours.

TABLE 6

ESTIMATED WATERSHED LAG TIME

Dam Site	L Watercourse Length (miles)	H Elevation Difference (ft)	T Time of Concentration (hours)	Lag Time (hours)
Adobe Road (AD-1B)	1.7	875	0.35	0.21
Two Rock (T6A)	0.66	240	0.19	0.11
Tolay-A (S39A)	1.66	580	0.40	0.24
Tolay-C (S39C)	1.33	570	0.31	0.19
Lakeville Hillside (L-2A)	0.6	170	0.20	0.12
Sears Point (SP-1)	3.65	700	0.93	0.56
Bloomfield (B1-A)	0.6	665	0.12	0.07
Valley Ford East (V4)	0.6	305	0.16	0.10
Caroll Road North (V7)	0.66	500	0.15	0.09
Huntley (T-1)	0.38	190	0.11	0.07

Probable Maximum Precipitation (General Storm)

The Probable Maximum Precipitation (PMP) for each reservoir watershed was calculated according to Hydrometeorological Report No. 36 (NOAA, 1969). The following description summarizes the principal steps necessary to obtain generalized PMP values. The general storm PMP consists of three components:

1. Orographic component
2. Restricted convergence component
3. Unrestricted convergence component

The probable maximum orographic precipitation index map, the orographic PMP computation areas, the watershed-width variation, and the seasonal-duration variation were used in computing the orographic component of PMP. The restricted convergence PMP uses the probable maximum convergence precipitation index map and the variation of convergence PMP with watershed size

and duration figures. The unrestricted convergence PMP is 133 percent of the restricted convergence PMP.

The data in Table 7 were selected from charts and figures in Hydrometeorological Report No. 36 (NOAA, 1969) for calculating the general storm PMP.

TABLE 7

GENERAL STORM PMP CALCULATION FACTORS

Dam Site	Precipitation Index (inches)	Watershed Width Adjustment Factor[(1)]	Adjusted Precipitation Index (inches)	Convergence Precipitation Index (inches)
Adobe Road (AD-1B)	2	1	2	4
Two Rock (T6A)	2	1	2	4.1
Tolay-A (S39A)	1.5	1	1.5	4.1
Tolay-C (S39C)	1.5	1	1.5	4.1
Lakeville Hillside (L-2A)	1.5	1	1.5	4.1
Sears Point (SP-1)	1.5	1	1.5	4.1
Bloomfield (B1-A)	2	1	2	4
Valley Ford East (V4)	2.5	1	2.5	4.1
Caroll Road North (V7)	2.5	1	2.5	4.1
Huntley (T-1)	2	1	2	4.1

Note: (1) All watershed widths are less than 30 miles, therefore no adjustment is required.

The following calculations were made for each watershed and are presented in Tables 8 through 13 for October through April:

Table 8 Incremental Orographic PMP

Table 9 Incremental Restricted Convergence PMP

Table 10 Total Incremental PMP for Watershed (Sum of orographic and restricted convergence PMP)

Table 11 Total Accumulated PMP for Watershed (Sum of orographic and restricted convergence PMP)

Table 12 Incremental Unrestricted Convergence PMP

Table 13 Accumulated Unrestricted Convergence PMP.

Comparison of the unrestricted convergence PMP with the combined orographic PMP and restricted convergence PMP shows that the unrestricted convergence PMP is greater for 1 and 3 hour durations for each month; for the 6 hour duration, the combined orographic and restricted convergence PMP is greater than the unrestricted convergence PMP in the winter season; for the 12 hour and longer durations the combined values are the same or greater for each month.

The unrestricted convergence PMP data was used in the HEC-1 model because the values are larger for the short duration events. Because all of the reservoirs have very small watersheds, the short duration high-intensity precipitation produces higher peak runoff rates than larger duration lower-intensity precipitation

TABLE 8

INCREMENTAL OROGRAPHIC PMP (inches)

Adobe Road (AD-1B), Two Rock (T6A), Bloomfield (B1-A), Huntley (T-1)

Adj. Precip Index = 2

Time Period (hrs)

3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
0.85	1.58	1.40	1.21	1.07	0.94	0.83	0.72	0.63	0.55	0.48	0.42
0.86	1.62	1.43	1.24	1.09	0.96	0.85	0.73	0.64	0.56	0.49	0.43
0.90	1.69	1.49	1.29	1.14	1.00	0.88	0.76	0.67	0.59	0.51	0.45
0.92	1.72	1.52	1.32	1.16	1.02	0.90	0.78	0.68	0.60	0.52	0.46
0.87	1.63	1.44	1.25	1.10	0.97	0.86	0.74	0.65	0.57	0.49	0.44
0.80	1.50	1.32	1.15	1.01	0.89	0.78	0.68	0.59	0.52	0.45	0.40

Tolay-A (S39A), Tolay-C (S39C), Lakeville Hillside (L-2A), Sears Point (SP-1)

Adj. Precip Index =1.5

Time Period (hrs)

3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
0.63	1.19	1.05	0.91	0.80	0.70	0.62	0.54	0.47	0.41	0.36	0.32
0.65	1.21	1.07	0.93	0.82	0.72	0.63	0.55	0.48	0.42	0.37	0.32
0.68	1.26	1.12	0.97	0.85	0.75	0.66	0.57	0.50	0.44	0.38	0.34
0.69	1.29	1.14	0.99	0.87	0.77	0.68	0.59	0.51	0.45	0.39	0.35
0.66	1.23	1.08	0.94	0.83	0.73	0.64	0.56	0.48	0.43	0.37	0.33
0.61	1.12	0.99	0.86	0.76	0.67	0.59	0.51	0.44	0.39	0.34	0.30

Valley Ford East (V4), Caroll Road North (V7)

Adj. Precip Index =2.5

Time Period (hrs)

3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
1.06	1.98	1.75	1.52	1.33	1.17	1.04	0.90	0.78	0.69	0.60	0.53
1.08	2.02	1.79	1.55	1.36	1.20	1.06	0.92	0.80	0.71	0.61	0.54
1.13	2.11	1.86	1.62	1.42	1.25	1.10	0.96	0.83	0.74	0.64	0.56
1.15	2.15	1.90	1.65	1.45	1.28	1.13	0.98	0.85	0.75	0.65	0.58
1.10	2.04	1.81	1.57	1.38	1.21	1.07	0.93	0.81	0.71	0.62	0.55
1.01	1.87	1.65	1.44	1.26	1.11	0.98	0.85	0.74	0.65	0.57	0.50

TABLE 9

INCREMENTAL RESTRICTED CONVERGENCE PMP (inches)

Adobe Road (AD-1B), Bloomfield (B1-A)

Conv. Precip Ind. =4

Time Period (hrs)

3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
1.44	1.44	0.96	0.68	0.56	0.48	0.44	0.40	0.36	0.36	0.32	0.32
1.40	1.68	1.08	0.80	0.64	0.56	0.52	0.44	0.40	0.40	0.40	0.40
1.32	1.76	1/20	0.84	0.72	0.64	0.52	0.48	0.44	0.44	0.40	0.40
1.24	1.84	1.24	0.92	0.76	0.64	0.56	0.52	0.48	0.40	0.44	0.44
1.32	1.92	1.20	0.92	0.76	0.64	0.52	0.44	0.40	0.40	0.36	0.36
1.32	1.80	1.20	0.92	0.72	0.56	0.48	0.40	0.36	0.36	0.32	0.32

A), Tolay-A(S39A), Tolay-C (S39C), Lakeville Hillside (L-2A), Sears Point (SP-1), Valley Ford East (V4),

Caroll Road North (V7), Huntley (T-1)

Conv. Precip Ind. = 4.1

Time Period (hrs)

3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
1.48	1.38	0.98	0.70	0.57	0.49	0.45	0.41	0.37	0.37	0.33	0.33
1.43	1.72	1.11	0.82	0.66	0.57	0.53	0.45	0.41	0.41	0.41	0.41
1.35	1.80	1.23	0.86	0.74	0.66	0.53	0.49	0.45	0.45	0.41	0.41
1.27	1.89	1.27	0.94	0.78	0.66	0.57	0.53	0.49	0.41	0.45	0.45
1.36	1.97	1.23	0.94	0.78	0.66	0.53	0.45	0.41	0.41	0.37	0.37
1.35	5.41	1.85	1.23	0.94	0.74	0.57	0.49	0.41	0.37	0.33	0.33

TABLE 10

INCREMENTAL OROGRAPHIC AND RESTRICTED CONVERGENCE PMP (inches)

Tolay-A (S39A), Tolay-C (S39C), Lakeville Hillside (L-2A), Sears Point (SP-1)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.35	2.40	2.11	2.66	2.03	1.61	1.37	1.20	1.07	0.95	0.84	0.78	0.69	0.65
Nov.	2.99	2.24	2.08	2.93	2.18	1.75	1.47	1.29	1.17	1.00	0.89	0.83	0.78	0.73
Dec.	2.71	2.18	2.03	3.07	2.35	1.83	1.59	1.41	1.19	1.07	0.95	0.89	0.79	0.75
Jan.-Feb.	2.56	2.06	1.96	3.18	2.41	1.93	1.65	1.42	1.25	1.12	1.00	0.86	0.84	0.80
Mar.	2.58	2.04	2.01	3.19	2.31	1.88	1.61	1.38	1.17	1.01	0.89	0.84	0.74	0.70
Apr.	2.64	2.12	1.76	2.97	2.22	1.80	1.49	1.24	1.08	0.92	0.81	0.76	0.67	0.63

Valley Ford East (V4), Caroll Road North (V7)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.54	2.70	2.54	3.45	2.73	2.22	1.91	1.67	1.49	1.31	1.15	1.06	0.93	0.86
Nov.	3.18	2.56	2.51	3.74	2.89	2.37	2.02	1.77	1.59	1.37	1.21	1.12	1.02	0.95
Dec.	2.91	2.51	2.48	3.91	3.09	2.48	2.16	1.91	1.64	1.45	1.28	1.19	1.05	0.97
Jan.-Feb.	2.76	2.40	2.42	4.04	3.17	2.59	2.23	1.93	1.70	1.51	1.34	1.16	1.10	1.03
Mar.	2.77	2.37	2.44	4.01	3.04	2.51	2.16	1.87	1.60	1.38	1.22	1.12	0.99	0.92
Apr.	2.81	2.42	2.36	3.72	2.88	2.38	2.00	1.68	1.47	1.26	1.11	1.02	0.89	0.83

TABLE 11

ACCUMULATED OROGRAPHIC AND RESTRICTED CONVERGENCE PMP (inches)

Adobe Road (AD-1B), Bloomfield (B1-A)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.37	5.87	8.16	11.18	13.54	15.44	17.06	18.48	19.75	20.87	21.85	22.76	23.56	24.31
Nov.	3.02	5.38	7.64	10.94	13.45	15.49	17.22	18.74	20.10	21.27	22.31	23.28	24.17	25.00
Dec.	2.75	5.06	7.28	10.73	13.42	15.55	17.41	19.05	20.45	21.69	22.80	23.83	24.74	25.59
Jan.-Feb.	2.60	4.80	6.96	10.52	13.28	15.52	17.44	19.10	20.56	21.86	23.02	24.02	24.98	25.88
Mar.	2.62	4.79	6.98	10.53	13.18	15.35	17.21	18.82	20.20	21.38	22.43	23.40	24.25	25.05
Apr.	2.67	4.90	7.02	10.32	12.84	14.91	16.64	18.08	19.35	20.43	21.38	22.26	23.03	23.75

Two Rock (T6A), Huntley (T-1)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.44	6.00	8.32	11.38	13.76	15.67	17.31	18.74	20.02	21.15	22.14	23.06	23.87	24.62
Nov.	3.08	5.48	7.78	11.12	13.66	15.72	17.47	19.00	20.38	21.56	22.61	23.59	24.48	25.33
Dec.	2.81	5.16	7.41	10.90	13.62	15.78	17.65	19.31	20.72	21.98	23.10	24.14	25.05	25.92
Jan.-Feb.	2.66	4.89	7.08	10.69	13.48	15.74	17.68	19.36	20.83	22.15	23.32	24.33	25.30	26.21
Mar.	2.68	4.88	7.11	10.71	13.38	15.58	17.46	19.09	20.47	21.67	22.72	23.70	24.57	25.37
Apr.	2.73	5.00	7.15	10.49	13.05	15.14	16.88	18.35	19.62	20.71	21.67	22.56	23.34	24.07

TABLE 11

ACCUMULATED OROGRAPHIC AND RESTRICTED CONVERGENCE PMP (inches)

Tolay-A (S39A), Tolay-C (S39C), Lakeville Hillside (L-2A), Sears Point (SP-1)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.35	5.75	7.86	10.52	12.55	14.16	15.54	16.73	17.80	18.75	19.59	20.37	21.06	21.71
Nov.	2.99	5.23	7.31	10.25	12.43	14.18	15.65	16.94	18.11	19.11	20.00	20.84	21.61	22.35
Dec.	2.71	4.89	6.92	9.99	12.34	14.17	15.76	17.17	18.36	19.43	20.38	21.27	22.06	22.81
Jan.-Feb.	2.56	4.62	6.58	9.76	12.17	14.10	15.75	17.17	18.42	19.54	20.54	21.40	22.24	23.04
Mar.	2.58	4.62	6.63	9.83	12.14	14.02	15.63	17.01	18.18	19.19	20.09	20.92	21.66	22.36
Apr.	2.64	4.76	6.72	9.68	11.91	13.71	15.21	16.44	17.52	18.44	19.26	20.02	20.68	21.31

Lakeville Hillside (L-2A), Valley Ford East (V4)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.54	6.24	8.78	12.23	14.96	17.18	19.09	20.75	22.24	23.55	24.70	25.76	26.68	27.54
Nov.	3.18	5.74	8.25	12.00	14.89	17.26	19.28	21.05	22.64	24.01	25.22	26.33	27.36	28.31
Dec.	2.91	5.42	7.90	11.81	14.91	17.38	19.54	21.45	23.08	24.53	25.82	27.00	28.05	29.02
Jan.-Feb.	2.76	5.16	7.58	11.62	14.79	17.38	19.61	21.54	23.24	24.75	26.09	27.25	28.35	29.38
Mar.	2.77	5.14	7.58	11.59	14.63	17.14	19.29	21.16	22.76	24.14	25.36	26.48	27.47	28.38
Apr.	2.81	5.23	7.59	11.30	14.19	16.56	18.56	20.25	21.72	22.98	24.08	25.11	26.00	26.83

TABLE 12

INCREMENTAL UNRESTRICTED CONVERGENCE PMP (inches)

Adobe Road (AD-1B), Bloomfield (B1-A)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.99	2.50	1.92	1.92	1.28	0.90	0.74	0.64	0.59	0.53	0.48	0.48	0.43	0.43
Nov.	3.51	2.29	1.86	2.23	1.44	1.06	0.85	0.74	0.69	0.59	0.53	0.53	0.53	0.53
Dec.	3.14	2.18	1.76	2.34	1.60	1.12	0.96	0.85	0.69	0.64	0.59	0.59	0.53	0.53
Jan.-Feb.	2.93	2.02	1.65	2.45	1.65	1.22	1.01	0.85	0.74	0.69	0.64	0.53	0.59	0.59
Mar.	2.98	2.02	1.76	2.55	1.60	1.22	1.01	0.85	0.69	0.59	0.53	0.53	0.48	0.48
Apr.	3.09	2.18	1.75	2.39	1.60	1.22	0.96	0.74	0.64	0.53	0.48	0.48	0.43	0.43

Two Rock (T6A), Tolay-A(S39A), Tolay-C (S39C), Lakeville Hillside (L-2A), Sears Point (SP-1), Valley Ford East (V4), Caroll Road North (V7), Huntley (T-1)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	4.09	2.56	1.97	1.96	1.31	0.93	0.76	0.65	0.60	0.55	0.49	0.49	0.44	0.44
Nov.	3.60	2.34	1.91	2.29	1.47	1.09	0.87	0.76	0.71	0.60	0.55	0.55	0.55	0.55
Dec.	3.22	2.23	1.80	2.40	1.64	1.15	0.98	0.87	0.71	0.65	0.60	0.60	0.55	0.55
Jan.-Feb.	3.00	2.07	1.69	2.51	1.69	1.25	1.04	0.87	0.76	0.71	0.65	0.55	0.60	0.60
Mar.	3.05	2.08	1.80	2.62	1.64	1.25	1.04	0.87	0.71	0.60	0.55	0.55	0.49	0.49
Apr.	3.16	2.24	1.80	2.45	1.64	1.25	0.98	0.76	0.65	0.55	0.49	0.49	0.44	0.44

TABLE 13

ACCUMULATED UNRESTRICTED CONVERGENCE PMP (inches)

Adobe Road (AD-1B), Bloomfield (B1-A)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	3.99	6.49	8.41	10.32	11.60	12.50	13.25	13.89	14.47	15.00	15.48	15.96	16.39	16.81
Nov.	3.51	5.80	7.66	9.90	11.33	12.40	13.25	13.99	14.68	15.27	15.80	16.33	16.86	17.40
Dec.	3.14	5.32	7.08	9.42	11.01	12.13	13.09	13.94	14.63	15.27	15.85	16.44	16.97	17.50
Jan.-Feb.	2.93	4.95	6.60	9.04	10.69	11.92	12.93	13.78	14.52	15.22	15.85	16.39	16.97	17.56
Mar.	2.98	5.00	6.76	9.31	10.91	12.13	13.14	13.99	14.68	15.27	15.80	16.33	16.81	17.29
Apr.	3.09	5.27	7.02	9.42	11.01	12.24	13.19	13.94	14.58	15.11	15.59	16.07	16.49	16.92

Two Rock (T6A), Tolay-A(S39A), Tolay-C (S39C), Lakeville Hillside (L-2A), Sears Point (SP-1), Valley Ford East (V4), Caroll Road North (V7), Huntley (T-1)

	Time Period (hrs)													
Month	0-1	1-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60	60-66	66-72
Oct.	4.09	6.65	8.62	10.58	11.89	12.81	13.58	14.23	14.83	15.38	15.87	16.36	16.80	17.23
Nov.	3.60	5.94	7.85	10.14	11.61	12.71	13.58	14.34	15.05	15.65	16.20	16.74	17.29	17.83
Dec.	3.22	5.45	7.25	9.65	11.29	12.43	13.41	14.29	15.00	15.65	16.25	16.85	17.40	17.94
Jan.-Feb.	3.00	5.07	6.76	9.27	10.96	12.21	13.25	14.12	14.89	15.60	16.25	16.80	17.40	17.99
Mar.	3.05	5.13	6.93	9.54	11.18	12.43	13.47	14.34	15.05	15.65	16.20	16.74	17.23	17.72
Apr.	3.16	5.40	7.20	9.65	11.29	12.54	13.52	14.29	14.94	15.49	15.98	16.47	16.90	17.34

Eight of the ten watersheds have a convergence precipitation index of (4.1 inches) and two have an index of 4.0 inches (see Table 12). To simplify the HEC-1 model runs, the unrestricted convergence PMP developed using the convergence precipitation of 4.1 inches was used for all watersheds.

The computer model HEC-1 was used to calculate the watershed runoff hydrograph for each reservoir using two sets of monthly precipitation data: 1) October data were used with the antecedent moisture condition AMC-II and 2) January-February data were used with AMC-III. The selection of AMC-II with October data is based on the fact that soils will typically be wet in October. The selection of AMC- III with January-February data is based on the fact that soils are likely to be saturated in the winter months.

Rainfall data for 5-minute, 15-minute, and 2-hour durations are needed in addition to the 6-hourly durations calculated using Hydrometeorological Report No. 36. Rainfall intensities for durations less than one hour were calculated using "Rainfall Frequency Atlas of the Western United States," Vol. 11, CA. (Weather Bureau, 1973). Using the 1-hour value, the 5-minute and 15-minute precipitation was calculated as follows:

5-minute precipitation = .29 × 1-hour value

15-minute precipitation = .57 × 1-hour value

The precipitation values used in the HEC-1 model are presented in Table 14.

TABLE 14

GENERAL STORM PROBABLE MAXIMUM PRECIPITATION

Storm Period	Total Precipitation (inches)							
	5-min	15-min	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr
January-February	0.87	1.71	3.00	4.20	5.07	6.76	9.27	12.21
October	1.19	2.33	4.09	5.50	6.65	8.62	10.58	12.81

Probable Maximum Precipitation (Local Storm)

The local storm PMP for each watershed was calculated using Hydrometeorological Report No. 49 (NOAA, 1984). The incremental PMP for each watershed was calculated using a worksheet provided in Report No. 49, page 152 (Appendix B). The 5-minute and 15-minute, and 24-hour values calculated using the "Rainfall Frequency of the Western United States," Vol. 11, CA. The precipitation values used in the HEC-1 model are shown in Table 15.

TABLE 15

LOCAL STORM PROBABLE MAXIMUM PRECIPITATION

Dam Site	Precipitation (inches)					
	5-min	15-min	1-hr	2-hr	3-hr	6-hr
Adobe Road (AD-1B)	1.45	2.85	5.00	6.75	7.75	9.50
Two Rock (T6A)	1.45	2.85	5.00	6.75	7.75	9.50
Tolay-A (S39A)	1.28	2.51	4.40	6.00	7.00	8.80
Tolay-C (S39C)	1.28	2.51	4.40	6.00	7.00	8.80
Lakeville Hillside (L-2A)	1.45	2.85	5.00	6.75	7.75	9.50
Sears Point (SP-1)	1.22	2.39	4.20	5.80	6.70	8.50
Bloomfield (B1-A)	1.45	2.85	5.00	6.75	7.75	9.50
Valley Ford East (V4)	1.45	2.85	5.00	6.75	7.75	9.50
Caroll Road North (V7)	1.45	2.85	5.00	6.75	7.75	9.50
Huntley (T-1)	1.45	2.85	5.00	6.75	7.75	9.50

Probable Maximum Flood

A computer analysis of each reservoir was performed using HEC-1, a flood hydrograph software package developed by the U.S. Army Corps of Engineers. The program was used to develop a watershed unit hydrograph and a reservoir inflow hydrograph for the PMF resulting from the PMP. The watershed data developed above (watershed area, rainfall, lag time, curve number, etc.) were input in the HEC-1 model. The peak flows from the calculated reservoir inflow hydrographs are presented in Table 16. Complete HEC-1 model runs for each watershed are presented in Appendices C, D, and E.

Creager Method and Modified Myer Method

A review of historic data from other watersheds can help to determine the relative magnitude and the credibility of flood peak discharge estimates for a particular watershed. Also, such information about maximum floods of record in similar hydrologic regions can provide a basis for estimating flood potential at a given site.

A number of empirical formulas have been developed for describing the relationship between drainage area characteristics and maximum observed flood discharges. Figure 4-1 from *Safety of Existing Dams - Evaluation and Improvement* (NRC, 1983) shows curves based on two such relationships, the Creager and Myer formulas. The Creager formula is:

$$q = 46CA^{(0.894A^{-0.048}-1)}$$

where q = peak flood flow (cfs/sq. mi)

C = 100 for extreme event

A = watershed area (mi^2)

The modified Myer Method formulas is:

$$q = 10{,}000/A^{0.5}$$

where q = peak flood flow (cfs/sq. mi)

A = watershed area (mi^2)

Results of the Creager and Modified Myer Methods are presented on Table 16.

TABLE 16

SUMMARY OF PEAK FLOW DATA

(cfs)

Reservoir Site	Creager Method	Myer Method	Local Storm	General Storm October	General Storm Jan/Feb
Adobe Road (AD-1B)	7,090	12,800	8,840	7,080	5,780
Two Rock (T6A)	5,010	10,490	7,310	5,790	4,930
Tolay-A (S39A)	18,250	23,050	23,280	21,530	17,280
Tolay-C (S39C)	8,490	14,250	10,370	9,590	7,560
Lakeville Hillside (L-2A)	3,680	8,840	5,630	4,530	3,590
Sears Point (SP-1)	28,000	30,800	22,200	21,710	18,490
Bloomfield (B1-A)	4,348	9,690	7,230	5,730	4,880
Valley Ford East (V4)	6,080	11,700	8,560	6,690	6,050
Caroll Road North (V7)	5,880	11,500	9,070	7,150	6,220
Huntley (T-1)	2,710	7,500	4,470	3,560	2,960

CONCLUSIONS

The peak flows estimated in this investigation were compared on the basis of flow in cfs per square mile of watershed area. Figure 1 shows a plot of this data for each method and each reservoir alternative. The results obtained using the various methods are consistent, with the exception of the Myer method when applied to small watersheds with an area less than 2 square miles. The Myer method appears to significantly overestimate the peak flow for small watersheds in Sonoma County. The PMP local storm during October produces the highest peak flow of three storms investigated. The results are consistent with the Creager method for all watershed sizes.

It is recommended that the flow calculated for the local storm be used for sizing the spillway at each reservoir. The recommended design flow is suitable for developing a conceptual plan for each reservoir and for comparing the spillway construction costs. More detailed hydrologic investigations will be required to establish the spillway design flow for final design and permitting of the selected project.

The recommended flows are conservative and may slightly overestimate the appropriate spillway design flow because no consideration has been given to the flow attenuation provided by the storage capacity within each reservoir. During final design of the selected project, the PMF hydrograph should be routed through the reservoir to determine the appropriate spillway flow for design.

List of Tables

Table 1 - Summary of Reservoir Data

Table 2 - Dam Size Classifications

Table 3 - Dam Failure Hazard Classifications

Table 4 - Spillway Design Flood

Table 5 - Reservoir Watershed Data

Table 6 - Estimated Watershed Lag Time

Table 7 - General Storm PMP Calculation Factors

Table 8 - Incremental Orographic PMP in inches

Table 9 - Incremental Restricted Orographic

Table 10 - Incremental Convergence and Restricted Orographic PMP

Table 11 - Accumulated Convergence and Restricted Orographic PMP

Table 12 - Incremental Unrestricted Convergence PMP

Table 13 - Accumulated Unrestricted Convergence PMP

Table 14 - General Storm Probable Maximum Precipitation

Table 15 - Local Storm Probable Maximum Precipitation

Table 16 - Summary of Peak Flow Data

List of Figures

Figure 1 - Selected Design Flow versus Unit Flow

Appendices

Appendix A - Soil Survey Data

Appendix B - Report No. 49 Worksheets

Appendix C - HEC-1 Report No. 36 Output Data (January-February Rainfall Data)

Appendix D - HEC-1 Report No. 36 Output Data (October Rainfall Data)

Appendix E - HEC-1 Report No. 49 Output Data

List of References

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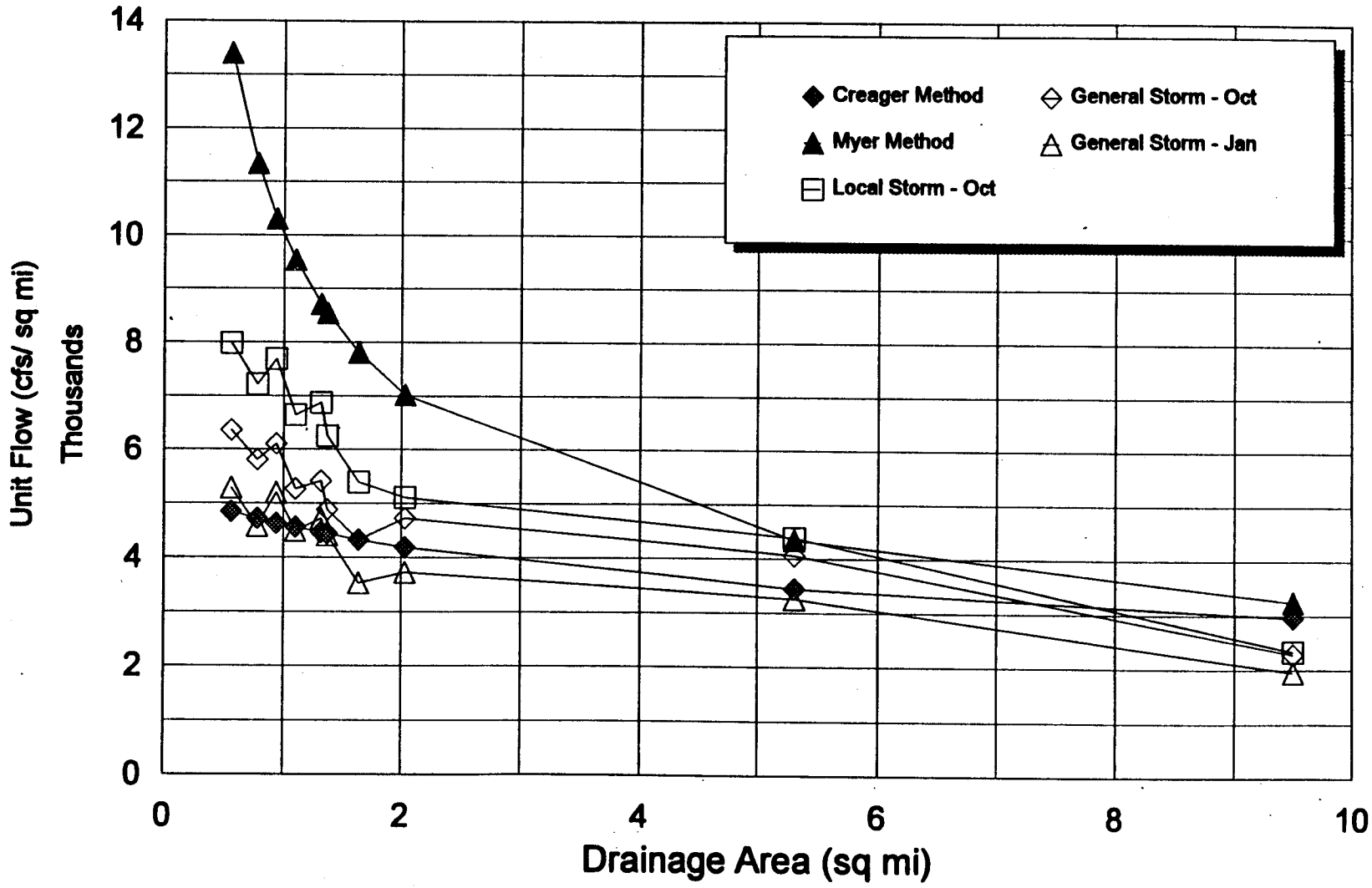
FIGURES

Figure 1
Comparison of Peak Spillway Flows



The Appendix to this document is filed as
Exhibit D-16