Attachment D

Probable Maximum Flood Study

TECHNICAL SERVICE CENTER
Denver, Colorado

SAN JOAQUIN RIVER NEW DAM
AT RIVER MILE 286

PROBABLE MAXIMUM FLOOD HYDROGRAPH

CALIFORNIA

Prepared by
Flood Hydrology Group
Water Resources Services

US. Department of the Interior
Bureau of Reclamation

MAY 2004

UNITED STATES DEPARTMENT OF THE INTERIOR

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May 18, 2004

MEMORANDUM

To: Team Leader: Bureau of Reclamation, Technical Services Center
San Joaquin River Mile 286 Dam Design Team
Attention: D-8313 (Pabst)

From: Kenneth Bullard, Hydraulic Engineer
Flood Hydrology Group
Technical Service Center

Kenneth L. Bullard

Subject: Probable Maximum Flood (PMF) Study and Frequency Floods for Proposed Dam on the San Joaquin River at River Mile 286, California

The attached report provides the requested probable maximum flood for the proposed River Mile 286 Dam on the San Joaquin River. This study also contains flood routings of the concurrent PMF flood hydrographs through six of the seven large upstream dams. These upstream dam flood routings all assumed the reservoirs to be full to their spillway crests at the start of the PMF sequence. This is a very severe assumption and results in relatively high reservoir releases for the upstream dams. These flood routings do have an impact on the resulting PMF hydrograph at the River Mile 286 Dam.

Future studies of the operations of the seven upstream dams as well as the new River Mile 286 Dam and the downstream Friant Dam may cause the assumed starting water surface elevations in the upstream dams to change, possibly becoming significantly lower for several upstream dams at the start of a PMF sequence. Such a change could have a major impact on the peak and volume of the resulting PMF hydrograph at River Mile 286, and at Friant Dam, possibly making the resulting PMF peak and volume significantly lower. It is recommended that this study be further refined, in conjunction with future river basin operation studies, or if it becomes critical for the safety of either the new River Mile 286 Dam or for Friant Dam. Such future studies would require much additional input and advice from the Southern California Edison Company, Pacific Gas and Electric Company, and the Corps of Engineers.

The PMF hydrographs and the frequency flood peaks and hydrographs contained in this study are considered suitable for all current design and construction activities at River Mile 286 Dam site. Specifically, the PMF is considered suitable for overtopping analysis, including depth and duration of such overtopping, at the proposed new River Mile 286 dam. Also, the 100-year balanced hydrograph and unregulated peak flow frequency curve from the Corps of Engineers' Friant Dam Regulation Manual are suitable for flood routings requiring smaller floods. Information on how to use the Corps of Engineers 100-year balanced hydrograph and flood frequency curves is contained in the report.

If you have any questions regarding this study, please contact me at 303-445-2539 or E-mail at kbullard@do.usbr.gov.

Attachments Bc D-8130 (Hinchcliff), D-8530 (Bullard/Schreiner/File)

San Joaquin River New Dam at River Mile 286
Probable Maximum Flood Hydrograph

Authorization: Funds for studies related to the feasibility of construction of a new dam on the San Joaquin River at River Mile 286, near the old Kerckhoff Dam site were provided by the Mid-Pacific Region in FY 2004. The Bureau of Reclamation had begun preliminary investigations into the proposed dam location for several potential sites on the San Joaquin River in FY2003. This study was requested by the Bureau of Reclamation TSC design team to be an upgrade of previous appraisal level PMF studies. Specific authorization for the Flood Hydrology Group to proceed with this study was provided by a service agreement prepared in January 2004.

Summary of Results:

Table 1
San Joaquin River Mile 286 Dam
Feasibility Level PMF Study

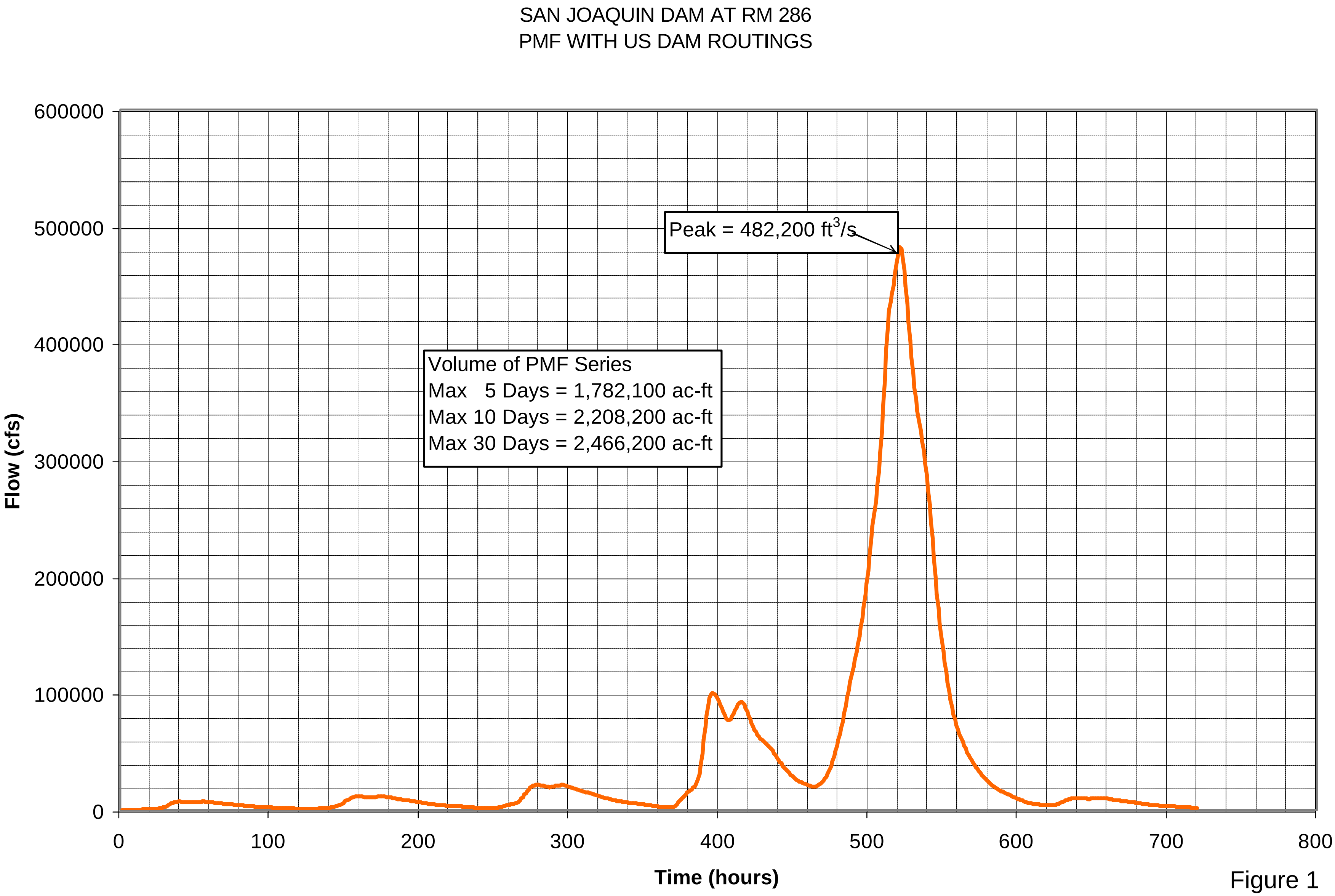
Flood Description	Regulated Peak (ft^3/s)	Volume (acre-feet)	Duration
Winter General PMP Storm (with 100-yr antecedent rain-on-snow flood – Nov. – Mar.)	482,800	1,783,900 2,210,700 2,465,700	5-days 10-days 30-days

This hydrograph is displayed in figure 1 and in Appendix A of this report.

This hydrograph was created with an attempt to account for the large amount storage available in several privately owned upstream dams.

No local storm PMF study was produced for this basin. The current dam design plans will allow the dam to be safely overtopped by the PMF. The depth and duration of such overtopping will be much larger with the long duration general storm PMF than with a shorter duration local storm PMF.

Previous Studies: An appraisal level PMF study for the old Kerckhoff Dam was produced by the USBR in August 2002 (USBR, 2002). That PMF study was based on the previous USBR PMF studies for Friant Dam in 1988 (USBR 1998). The appraisal level study had a peak of 553,300 ft^3/s and a 25-day volume of 2,503,800 acre-feet. That study did not include the most recent estimates for PMP (Probable Maximum Precipitation) or make any attempt to account for the upstream dams.



SAN JOAQUIN DAM AT RM 286
PMF WITH US DAM ROUTINGS
Peak = 482,200 ft³/s
Volume of PMF Series
Max   5 Days = 1,782,100 ac-ft
Max 10 Days = 2,208,200 ac-ft
Max 30 Days = 2,466,200 ac-ft
Flow (cfs)
0
100000
200000
300000
400000
500000
600000
0
100
200
300
400
500
600
700
800
Time (hours)

Figure 1

Project location and basin description: The new dam is to be located on the San Joaquin River, just upstream of the existing Friant Dam. The new dam will be approximately 15 miles northeast of Fresno, California. The San Joaquin River above Friant Dam has a total drainage area of 1593 square miles. The total drainage area above the river mile 286 site is 1460 square miles.

The San Joaquin River basin is located on the east slopes of the Sierra Nevada Mountain Range. The upper portion of the basin includes the area of California between Yosemite and Kings Canyon National Parks. The area in the upper reaches of the basin is characterized by dense forests with large trees and much forest litter. Many areas of granite rock outcrops are also noted. Snow cover to great depths can cover much of the upper portions of the basin between December and April of each year. Much of the potential runoff comes from melting snow, either as a result of above freezing temperatures or in more severe flooding events the snow melt combines with warmer rainfall.

In the lower reaches of the river, below about 5,000 feet in elevation, the vegetation becomes brushier and grass covered. Steep hillsides and thin soils exist in these areas. The lower portions of the basin are subject to much more flash flood type conditions.

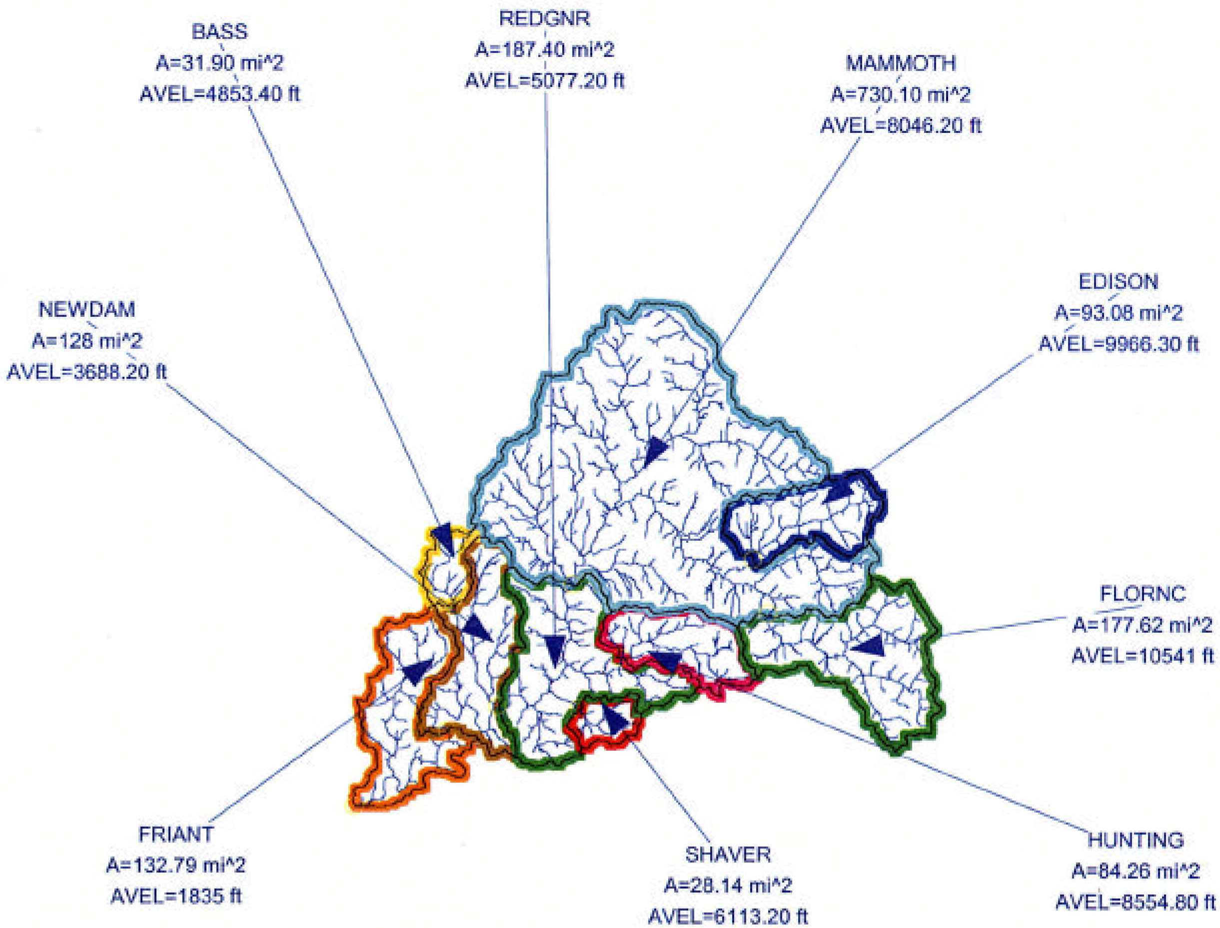
Upstream Dams: Seven privately owned large upstream dams exist in this basin. These structures were built at various times between 1912 and 1970. Florence Dam, Edison Dam, Huntington Dam, Mammoth Pool Dam, Shaver Dam and Redinger Dam are owned and operated by the Southern California Edison Company. Bass Dam is owned and operated by Pacific Gas and Electric Company. Together these dams contain approximately 500,000 acre-feet of storage. Many of the dams are large concrete structures. Depending on the starting water surface elevations assumed, the impact of these dams could be substantial on flood calculations for the River Mile 286 Dam site. Contacts with Southern California Edison Company were made to obtain sufficient data to include these dams with the current study. The information that was supplied by the Southern California Edison Company had been previously given to the Federal Energy Regulatory Commission (FERC) at various times as part of the hydropower license approval process (Southern California Edison, May 2004). Specific information about how these dams may be operated in times of flooding or what, if any, rule curves may be followed for determining starting water surface elevations at various times of the year with consideration given to accumulated snowpack and antecedent rainfall was not made available. This information is considered proprietary for the Southern California Edison Company. PMF studies for the six Southern California Edison dams were completed in the past. In all cases the dams are considered safe in the event of a PMF occurring above each structure. Some amount of overtopping may be experienced, but such events are not considered to be dam threatening.

For this study, all upstream reservoirs were assumed to be at their spillway crest at the start of the entire PMF and 100-year antecedent flood sequence. This is a very conservative assumption and severely limits the flood control capacity of the upstream reservoirs. There is insufficient information at the time of this study to make any other

General Location Map
River Mile 286 Dam Site and Drainage Basin
Above Friant Dam
Near Fresno California

Figure 2

River Mile 286 Dam Site



River Mile 286 Dam Drainage Basin

Subbasin Boundary Map

Figure 3

assumptions. Future studies may make different assumptions in this regard and could produce different results for PMF hydrographs at the River Mile 286 Dam or for Friant Dam.

The Southern California Edison Company also operates numerous other smaller diversion structures in the river basin. Several tunnels and diversions exist and are operated for hydropower production purposes. All of these diversions replace the diverted water into the San Joaquin main river above the proposed River Mile 286 site. These numerous diversions were not considered in the current PMF study.

No information was requested or obtained for Bass Lake Dam owned by Pacific Gas and Electric Company. This dam controls a relatively small portion of the basin and will not have much impact on the final PMF derivation for the River Mile 286 Dam site.

For this study the total basin above Friant Dam was included. The total basin was divided into nine subbasins. Each upstream dam, plus the new dam site at River Mile 286, received its own subbasin in the rainfall-runoff model developed for this study.

Figure 2 displays a general location map, and figure 3 displays the subbasin delineation map for this study, including the subbasin above Friant Dam. Table 2 displays the various map measurements related to each subbasin, and table 3 displays the amount of area in each subbasin below 1,000-foot elevation contours.

Table 2
San Joaquin New Dam
Subbasin Unit Hydrograph Parameters

BASIN	AREA (sq. mi.)	C	L (mi)	LCA (mi)	S (ft/mi)	M exponent	LAG (hours)
FLORENCE	177.6	3.2	26.24	12.56	221.76	0.33	8.89
HUNTINGTON	84.3	3.2	19.27	7.90	175.94	0.33	7.16
EDISON	93.1	3.2	18.78	7.41	319.02	0.33	6.30
MAMMOTH	730.1	3.2	49.36	15.87	206.53	0.33	11.97
REDINGER	187.4	2.8	27.34	11.25	290.40	0.33	7.27
BASS	31.9	3.2	14.21	4.20	326.20	0.33	4.75
SHAVER	28.1	3.2	9.00	3.17	266.55	0.33	3.85
NEW DAM	128.0	2.8	35.13	21.25	209.67	0.33	10.29
FRIANT	132.8	2.5	29.48	15.31	146.32	0.33	8.25
Total	1593.3						

Bass Lake received a “C” of 3.2 because of the dense vegetation shown in some photographs of the area, even though the average elevation is somewhat low compared to the other subbasins.

Table 3
San Joaquin River Basin, above Friant Dam
Summary of areas below 1.000-foot elevation contours
Data from WMS program output with 30 meter 1:250000 scale USGS DEMs

Basin Top of Elevation Band (feet)	Friant Dam (sq. mi.)	River Mile 286 (sq. mi.)	Redinger Dam (sq. mi.)	Bass Dam (sq. mi.)	Shaver Dam (sq. mi.)	Mammoth Pool Dam (sq. mi.)	Huntington Dam (sq. mi.)	Edison Dam (sq. mi.)	Florence Dam (sq. mi.)
1000	49.2	17.5							
2000	102.4	52.0	16.9						
3000	126.5	75.2	48.4						
4000	132.8	88.5	92.6	14.4		55.1			
5000		102.7	130.0	22.9		109.2			
6000		122.5	151.1	28.8	18.6	251.6			
7000		127.2	171.3	31.3	24.9	380.5	12.4		
8000		128.0	184.7	31.9	28.1	504.8	34.3	18.1	19.4
9000			187.4			617.0	70.1	35.8	43.8
10000						695.0	84.3	54.5	80.9
11000						725.4		84.0	144.3
12000						729.7		92.3	174.2
13000						730.1		93.1	177.6
14000									177.6

Probable Maximum Precipitation Study: The Friant Dam and River Mile 286 Dam basins are located in a region covered by HMR 54 and HMR 59 (Hydrometeorological Report Numbers 58 and 59, NOAA, 1998 and NOAA , 1999) for the purposes of defining PMP (Probable Maximum Precipitation).

Large antecedent floods would be more likely to occur in the winter months. Since the dam is being allowed to safely overtop by the PMF hydrograph, the season of flooding that produces the largest volume for flooding needs to be considered. Thunderstorm PMFs can be calculated, but they usually result from much more intense rainfall over a shorter time period, cover smaller areas, and occur mainly in the warmer summer and fall months. For this large basin the thunderstorm PMF is not likely to be a critical event for any current design consideration.

In calculating the PMP amounts, an approximate total basin area above Friant Dam of 1,593 square miles was used for area reductions to the point PMP. The total drainage area above the River Mile 286 Dam is only 1,460 square miles, but in the HMR procedures there is no further reduction in the PMP values for the additional drainage area above

Friant Dam. Mean basin elevations for the various subbasins were calculated from the WMS program and were also used in the PMP calculations.

With nine subbasins to consider, some type of storm centering was required. For this study the PMP storm was considered to be centered in the lower subbasins. In this instance, all of the subbasins below Mammoth Pool Dam were considered to be in the main center of the storm. The four subbasins above Mammoth Pool Dam were considered to be in the concurrent storm area.

The table 4 summarizes the accumulated values of areally reduced PMP calculated for this study. Figure 4 of this report displays a depth versus duration plot of these PMP data.

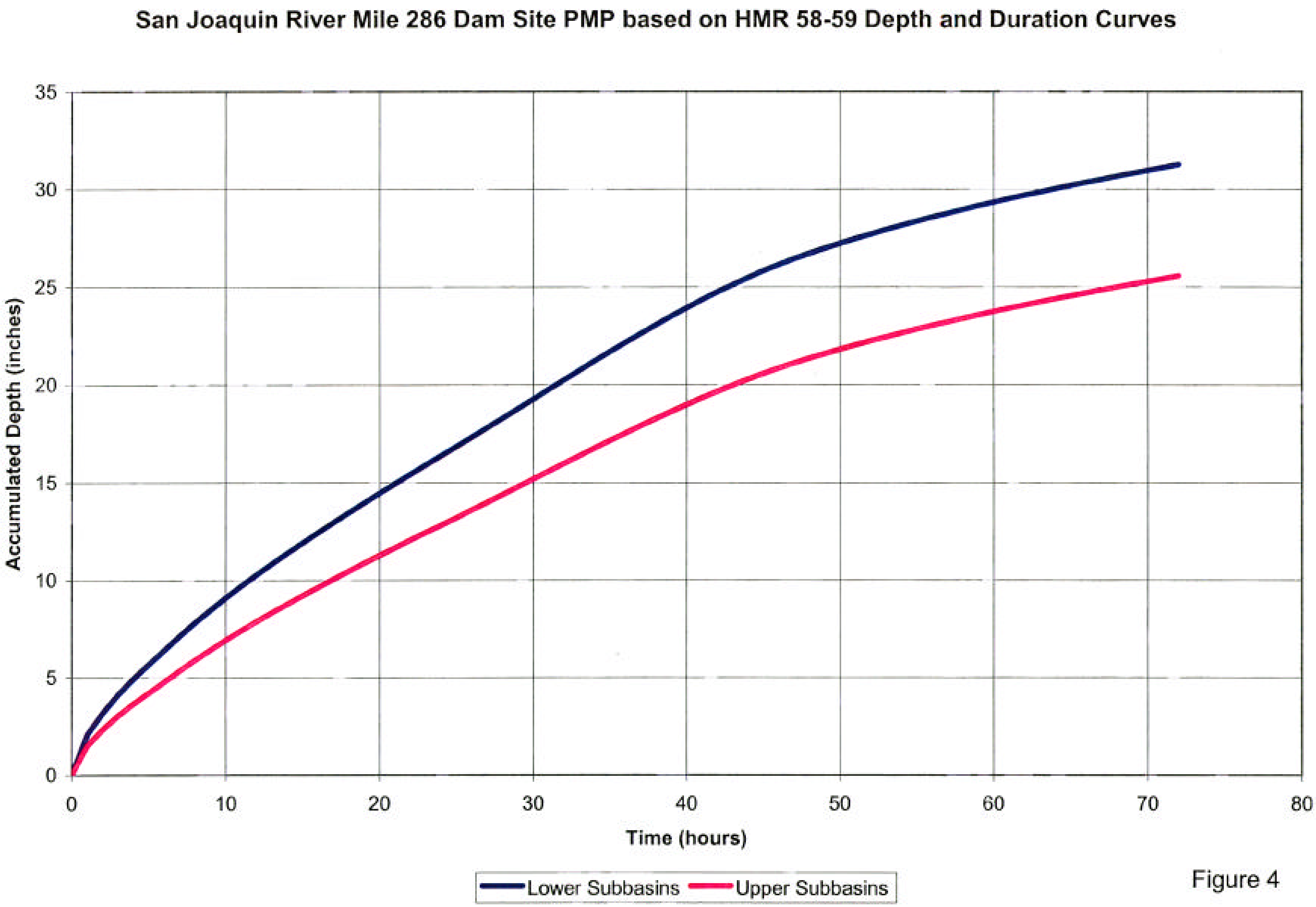

San Joaquin River Mile 286 Dam Site PMP based on HMR 58-59 Depth and Duration Curves
Accumulated Depth (inches)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
Time (hours)
Lower Subbasins
Upper Subbasins

Figure 4

Table 4

General Storm PMP Values from HRM 58 for Upper and Lower basins on the San Joaquin River Basin for River Mile 286 Dam Site PMF Study		
	Accumulated Precipitation (inches)	
.		
Hours	Lower Basins	Upper Basins
0	0	0
1	2.06	1.5
6	6.41	4.78
12	10.27	7.88
24	16.38	12.83
48	26.73	21.37
72	31.27	25.57

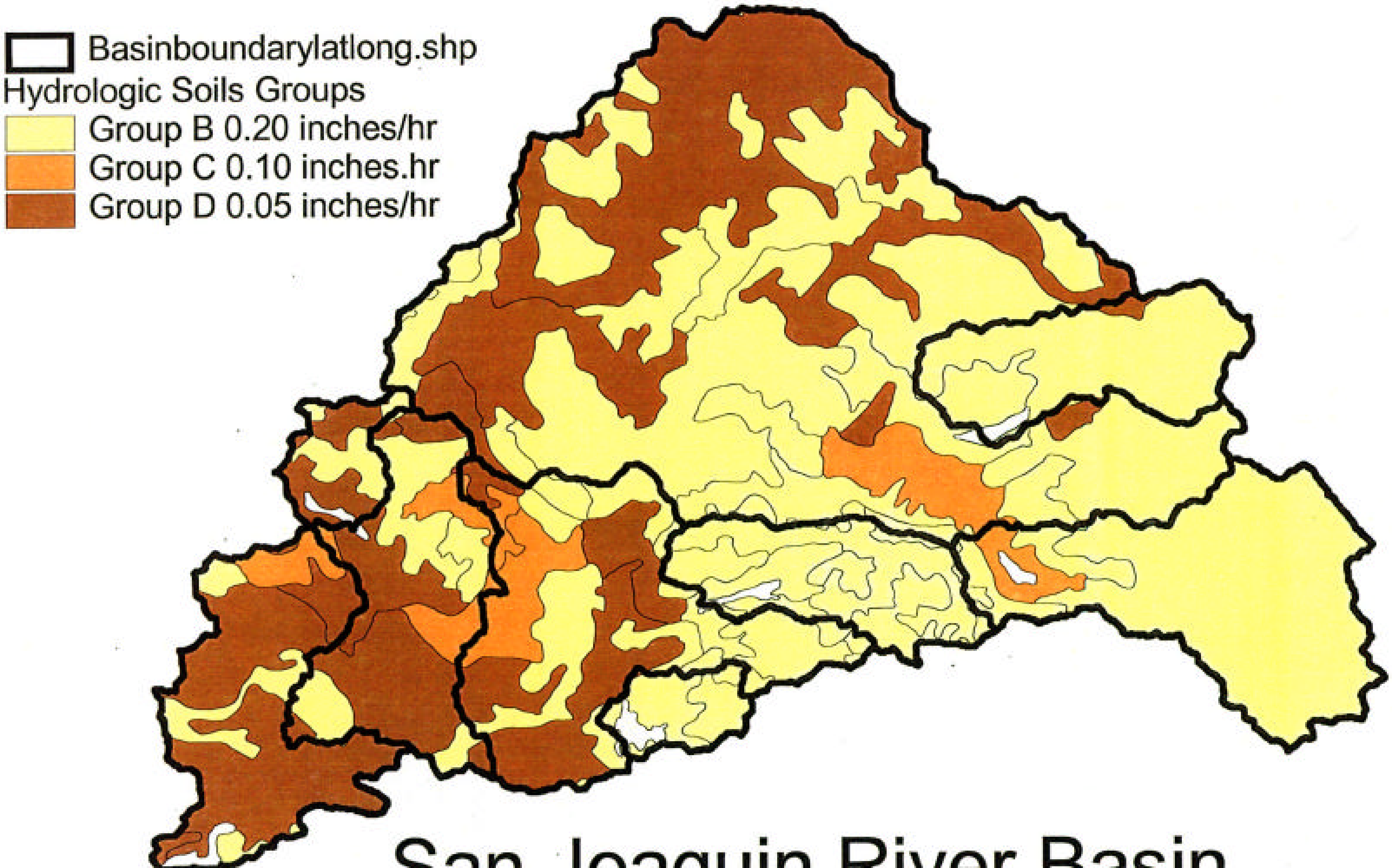
The data from the depth-duration plots were read at 1-hour time increments, subtracted to create incremental precipitation values and then rearranged according to the Bureau of Reclamation's criteria. In this storm sequence the maximum incremental rainfall value is placed at the 2/3 point of the storm duration and the remaining incremental values are alternated in decreasing order about this point to create the design storm sequence. This rainfall distribution is the standard PMP design storm arrangement as specified in the Bureau of Reclamation's Flood Hydrology Manual (Cudworth, 1989). The incremental precipitation amounts at 1-hour increments were then input into the Corps of Engineers HEC-1 rainfall-runoff program for further processing.

Basin Lag Times and Unit Hydrograph Computations: The standard Bureau of Reclamation lag time equation was used to develop unit hydrographs for the different storm conditions on this basin. The lag time is computed by the following equation:

$$\text{Lag} = C*[(L * Lca)/(S)^{0.5})]^{0.33} \text{ (hours)}$$

Where:

C = a runoff efficiency coefficient for a basin and storm type
L = Length of the longest watercourse (miles)
(Measured to the upstream edge of the reservoir at the top of active conservation elevation)
Lca = Length to the centroid of the basin (miles)
(Measured along the longest watercourse)
S = Slope along the longest watercourse (feet/mile)



San Joaquin River Basin
Above Friant Dam
STATSGO Data Base
Hydrologic Soils Groups

Figure 5

The HEC-WMS program (Brigham Young University, 2002) computed the required lengths and channel slopes with topography data input from available USGS 30-meter DEMs.

Table 2 displays the various measurements and the calculations leading to the lag times used with the unit hydrograph derivation for each basin. The “C” values were selected based on experience with other PMF studies for similar basins in the California Sierra Nevada Mountains. The “C” values were also based in part on a brief visit to the basin in April of 2004 by the author of this report. Dense forest cover at the higher elevations, very steep channels, and much exposed granite all play a part in the “C” value selections.

The dimensionless graph selected for use with this study was originally prepared for the California and Cascade mountain ranges. This dimensionless graph is referred to as the CALCAS dimensionless graph in the USBR flood hydrology manual. The process to convert the dimensionless graph to a unit hydrograph is described in the USBR Flood Hydrology Manual (Cudworth, 1989). In this study the USBR FHAR program (USBR, 1986) was used to develop the individual unit hydrographs for each subbasin. These individual unit hydrographs were then copied into the HEC-1 rainfall-runoff program for further computations.

Loss Rates: Figure 5 depicts the general soil hydrologic classifications taken from the NRCS STATSGO database (NRCS, undated) for this basin. For the different hydrologic soil groups indicated the USBR Flood hydrology manual provides minimum loss rates to be used. The minimum loss rates for the various soils groups in this basin are indicated on figure 5.   The various soil groups were measured using ARCVIEW (ESRI,2000) and the resulting areas were used to help compute an area weighted constant loss rate for use on all of the land areas of this basin. Table 5 displays the measurements and computations used to derive the final constant loss rate for the entire land surface area of this basin.

There is snow cover assumed on this basin during the winter season and loss rates associated with snow cover are 0.05 inches per hour. For the purpose of computing loss rates, the basin areas above 5,000 feet are assumed to be covered with snow prior to the onset of the PMF, areas below 5,000 feet are assumed to be snow free.

Table 5

Compute Loss Rates assuming Snow Cover above 5000 feet
Loss Rate on melting snow is assumed to be 0.05 in/hr
For Drainage Basins above Friant Dam on the San Joaquin River, California

Basin name	TOTAL Drainage Area (Sq. Mi.)	TOTAL Drainage Below 5,000 ft (Sq. Mi.)	Loss Rate for saturated soils Below 5,000 ft (in/hr)	TOTAL Drainage Above 5,000 ft (Sq. Mi.)	Loss Rate for snow covered Above 5,000 ft (Sq. Mi.)	Weighted Average Loss Rate (in/hr)
FRIANT	132.8	132.8	0.06	0.0	0.05	0.06
NEW DAM	128.0	102.7	0.08	25.3	0.05	0.07
BASS	31.9	22.9	0.11	9.0	0.05	0.09
REDINGER	187.4	130	0.14	57.4	0.05	0.11
MAMMOTH	730.1	109.2	0.16	620.9	0.05	0.07
EDISON	93.1	0	0.18	93.1	0.05	0.05
FLORENCE	177.6	0	0.18	177.6	0.05	0.05
HUNTINGTON	84.3	0	0.14	84.3	0.05	0.05
SHAVER	28.1	0	0.18	28.1	0.05	0.05
Total	1593.3					

By definition the PMF hydrographs calculated by Reclamation assume a saturated basin prior to the onset of the PMP storm. This assumption allows for the elimination of any initial losses or any decaying loss rate function during the early time periods of the PMP storm. This soils information was not verified during the field inspection. The field investigation was only to the basins above Shaver and Hunting Lake Dams and the primary purpose was to judge the vegetation and overall slopes of the basins away from the main channels. If the PMF hydrograph is to become a critical element of the design for the new dam then prior to any final designs a field investigation of the site should be made by a qualified flood hydrologist to verify the soils and loss rate information used in this study as well as other hydrologic parameters that have been estimated.

Snow Analysis for January 1997 Flood Event: A major rain-on-snow flood event occurred on this basin in early January, 1997. A review of available snow and temperature data for the upper San Joaquin River basin indicates that snowmelt from the higher elevations did not contribute appreciably to the flooding in January 1997 (CDEC, 2004). Hourly temperature data available for the Agnew Pass gage (elevation 9450 feet) indicate that temperatures in the upper basin beginning at midnight on January 1, 1997 were only a few degrees above freezing (about 34 to 37 degrees Fahrenheit) for the first 24 hours. Beginning about 8 pm on January 2, 1997 the temperatures fell dramatically below freezing and remained below freezing for the next several days. Daily snow water accumulation as measured at the Tamarac Summit gage (elevation 7550 feet) remained constant during the period of January 2 through January 12 indicating that none of the previously accumulated snowmelt water was lost during the storm period that could contribute to the downstream flooding. Daily snow water equivalent measurements at the Volcanic Knob gage (elevation 10050 feet) site indicated that the snow water equivalent measurements actually increased slightly during the storm period of January 1 to January 6, 1997, also denying the possibility that appreciable accumulated snowpack contributed to major flooding during this period. Other data for snow courses in the basin are measured and reported on a monthly basis; generally beginning about February 1 of each year and as such was not helpful in this analysis.

Little would be gained by trying to run a snow compaction and melting model with data specific to the January 1997 flood event. This flood event was caused by large amounts of rainfall falling on mostly frozen ground or a frozen snowpack resulting in quick runoff of a large volume of water, but with little additional snowmelt contribution from the previously accumulated snowpack.

In general, there are no snowpack measurements in the San Joaquin basin for any month prior to February in any water year. Most of the large floods have occurred in December or January. This lack of snowpack data in months when floods historically occur precludes any good attempts to model the snowmelt for this basin.

In lieu of a snowmelt computation based on this historical event, the PMF study for the new San Joaquin River dam will proceed with a 100-year antecedent flood as a base below the rain flood generated portion of the PMF. The Corps of Engineers have provided 100-year balanced hydrographs, with and without the effects of regulation included, for Friant Dam flood control studies. These hydrographs can be used as the 100-year base flood condition. The rain flood portion of the PMF will be computed with Bureau of Reclamation procedures, assuming snow covered ground conditions above elevation 5,000 feet in the San Joaquin River Basin.

Corps of Engineers 100-year Balanced Hydrograph and Unregulated and Regulated Peak Flow Frequency Curves: The U. S Army Corps of Engineers has authority over flood control storage and releases at Friant Dam. As part of their reservoir regulation manual (USACE, 1955, rev 1980) the Corps of Engineers has developed 30-day, 100-year balanced hydrographs representing both regulated and unregulated inflows into Friant Dam. These hydrographs are displayed on figure 6. The digital ordinates of the unregulated hydrograph have been given to the Bureau of Reclamation design engineers.

This hydrograph represents several bursts of rainfall that produce an unregulated inflow hydrograph with a correct 100-year peak, 100-year 1-day, 2-day, 3-day, 5-day,7-day, 15-day and 30-day volume. This hydrograph has an unregulated peak flow of 144,200 ft^3/s. This hydrograph is useful in studying various flood control operations at Friant. The same hydrograph may be translated to the River Mile 286 dam site location without much loss of accuracy for use in determining the frequency of peak outflows from the new dam.

100-Year Balanced Hydrographs for Use with River Mile 286 Dam Site above Friant Dam

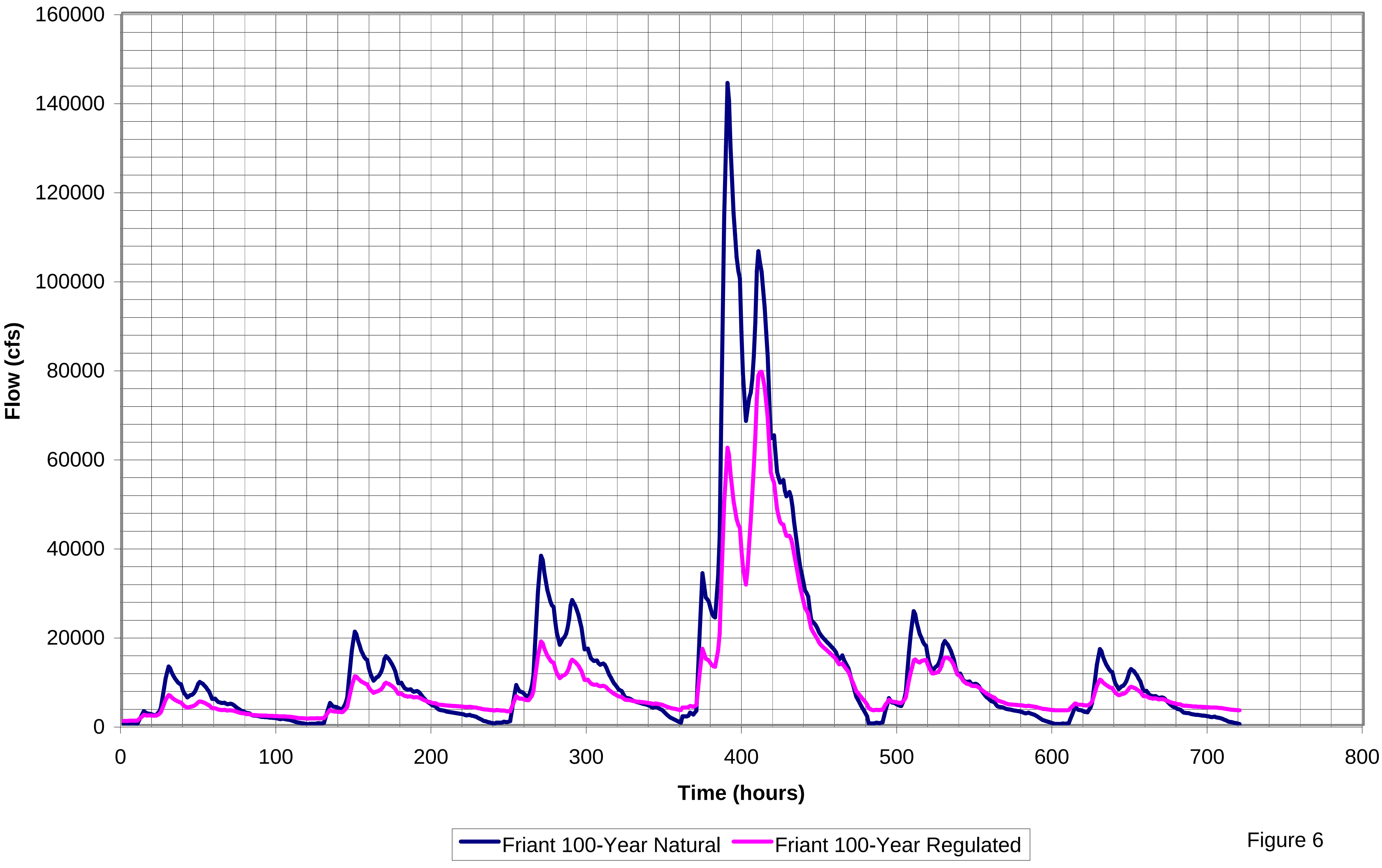
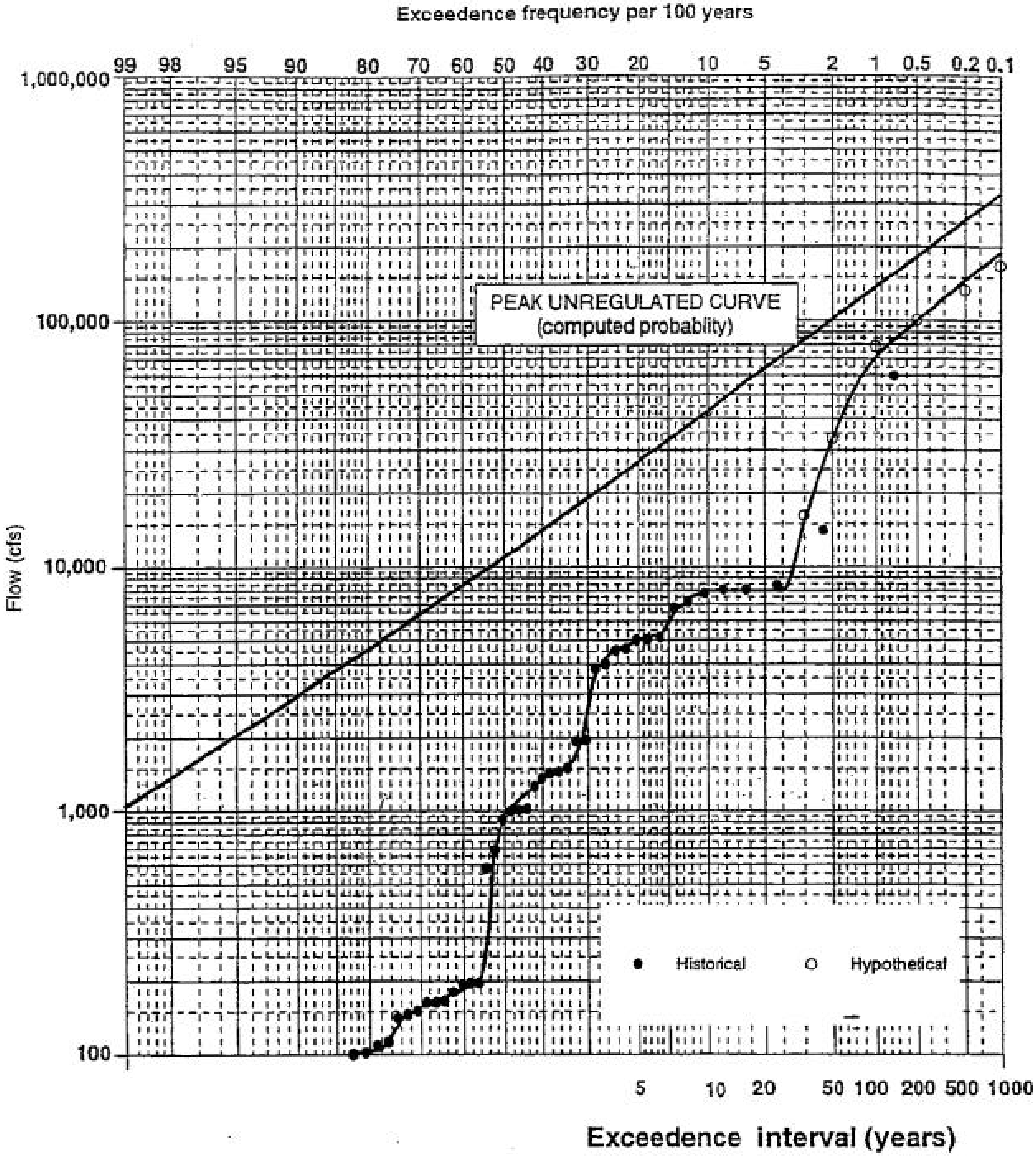


Figure 6



NOTES:

1. Median Plotting Positions
2. Drainage Area: 1676 sq. mi.
3. 49 years of record (1949 to 1997)
4. 1997 event plotted as maximum in 94 years.

FRIANT DAM AND MILLERTON LAKE
SAN JOAQUIN RIVER, CALIFORNIA

PEAK RAIN FLOOD FREQUENCY CURVE
(REGULATED CONDITIONS)

SAN JOAQUIN RIVER AT FRIANT DAM

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

DEVELOPED BY RJS

Figure 7

The Corps of Engineers uses the 100-year balanced hydrograph to help develop the regulated peak flow frequency curve for Friant Dam. The use of the 100-year balanced hydrograph in this procedure also involves an unregulated peak flow frequency curve. The Corps of Engineers has also developed the unregulated peak flow frequency curve based on the stream gage located below Friant Dam. Both the unregulated and regulated peak flow curves are reproduced and shown as figure 7 in this report. Again, due to the proximity of the new River Mile 286 Dam to the existing Friant Dam the unregulated peak flow frequency curve for Friant may also be considered appropriate for the new dam site. Table 6 provides some selected values from the frequency curves presented on figure 7 and linearly extrapolated values for the 2,000-year and 10,000-year return periods for the unregulated peaks.

Table 6

Frequency Curve Values from Corps of Engineers
For Friant Dam and for use with River Mile 286 Dam

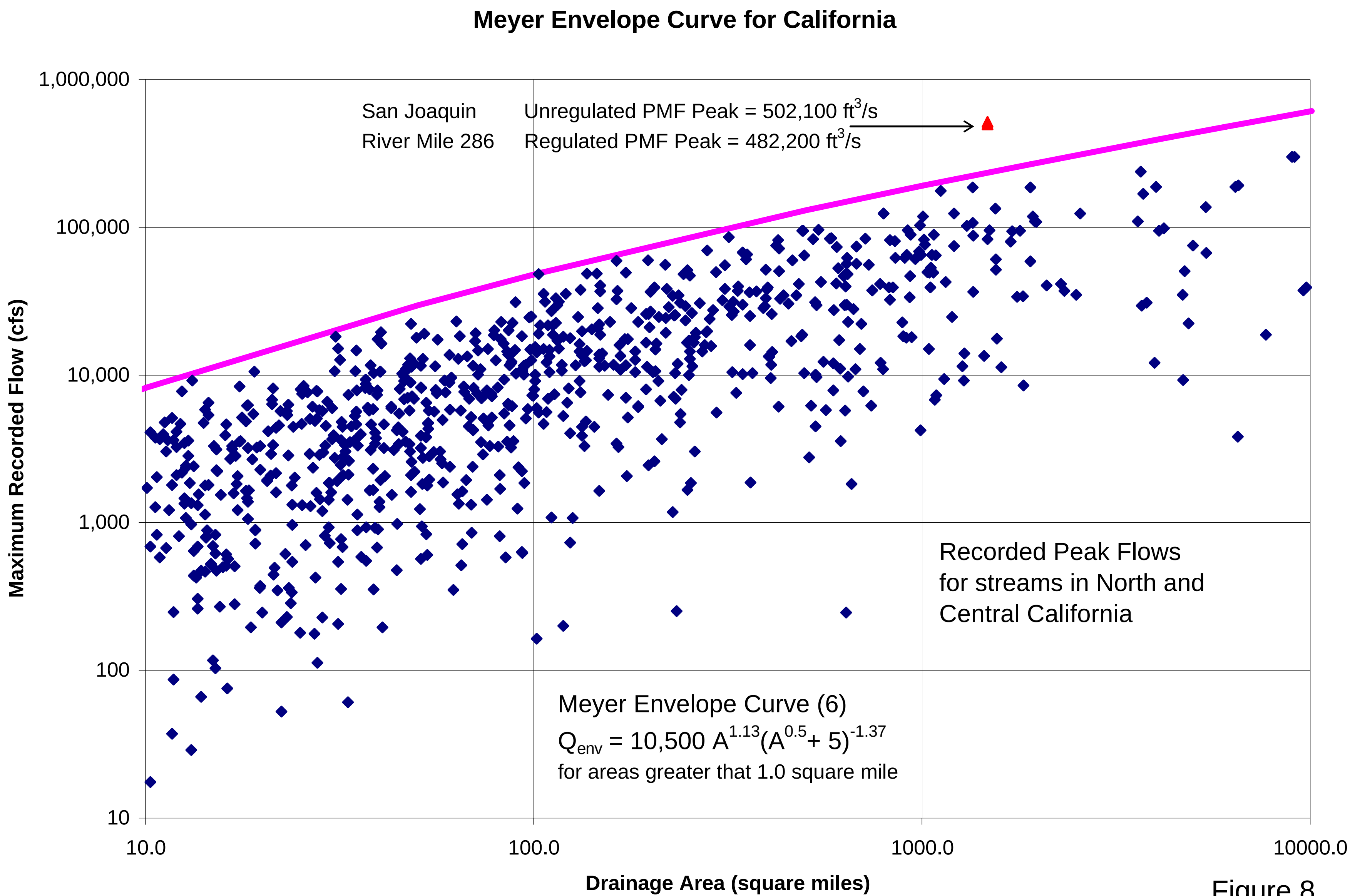
Return Period Years	River Mile 286 Dam Peak Inflow Unregulated Peak (ft^3/s)	Friant Dam Regulated Outflow Peak (ft^3/s)
100	144,200	80,000
200	183,000	100,000
500	268,000	145,000
1000	335,000	180,000
2000	413,600	NA
10000	649,200	NA

To determine a frequency for a peak discharge from the new dam, all of the ordinates of the balanced unregulated 100-year hydrograph should be multiplied by a ratio. The return period of the resulting peak flow for this new hydrograph can be determined by reading the unregulated peak flow frequency curve at this discharge. A reservoir routing of the new hydrograph through the new reservoir will produce a new peak outflow. This new peak outflow will have a return period equal to the return period of the unregulated peak inflow provided that the starting water surface elevation is not a variable.. Several ratios of the unregulated 100-year balanced hydrograph may be tried. For each new ratio a new peak outflow and return period for the peak outflow can be determined. In this way the return period for any desired peak outflow from the new dam, such as150,000 ft^3/s can be determined. If the starting water surface elevation is unknown, or can only be described by a rule curve or some form of elevation vs. duration curve then additional computations that include the probability of the starting reservoir elevation would also be required to calculate the probability of the resulting peak outflows. This complication for the new River Mile 286 Dam can not be considered with out a complete river basin operation study.

Data is not available to do a good job of snowmelt modeling on the San Joaquin for inclusion with the PMF computations. In lieu of the snowmelt modeling the Corps of Engineers100-year balanced hydrograph is used as a base flow condition for this PMF study. It has been an established practice for Bureau of Reclamation dams, where snowmelt can be a significant portion of the PMF hydrograph, but no snowmelt modeling is available, to include a 100-year balanced hydrograph as a base flow for the PMF hydrograph. The usual practice for Reclamation dams is to produce a 100-year balanced snowmelt hydrograph by limiting the data used in the calculation to those historic events that represented mainly snowmelt runoff. The intent of the Bureau of Reclamation 100-year snowmelt base hydrograph is to include snowmelt events only, without the influence of rain-on-snow.

The Corps of Engineers 100-year balanced hydrograph represents a total year condition and includes the influence of rain-on-snow events, at least during the major burst of flooding near the center of the hydrograph. The remaining portions of the hydrograph are considered to be mainly snowmelt. In this instance the Corps of Engineers 100-year unregulated balanced hydrograph is included in the PMF calculations in such a way that the PMP rainfall does not coincide with the maximum burst of the balanced hydrograph. The PMP is delayed by 5 days after the peak of the 100-year balanced hydrograph and instead coincides with the peak flow in the burst following the maximum peak of the 100-year balanced hydrograph. The intention of this arrangement is to eliminate a possible double counting of rainfall, by not adding the effects of a potential rainfall leading to a 100-year flood on top of the PMP.

To further simulate the variation of the potential antecedent flood distribution in the basin, the total 100-year unregulated balanced hydrograph was proportioned between the various subbasins. The proportion of the total hydrograph assigned to each subbasin was determined by calculating the proportion of the total basin area between 5,000 feet and 10,000 feet that exists in each subbasin. The total 100-year balanced hydrograph was then proportioned between the various subbasins using the same ratio. The intent here was to give a distribution of the antecedent flood, resulting mostly from snowmelt, which resembled the proportions of the total basin that would most likely be contributing to that flood. Areas above 10,000 feet were considered to not contribute much snowmelt because of low temperatures, and areas below 5,000 feet were considered to not contribute much to the snowmelt due to lack of snow accumulation. Table 7 displays the computations leading to the ratio for the 100-year balanced hydrograph applied to each subbasin.



Meyer Envelope Curve for California
1,000,000
100,000
10,000
1,000
100
10
Maximum Recorded Flow (cfs)
San Joaquin
River Mile 286
Unregulated PMF Peak = 502,100 ft3/s
Regulated PMF Peak = 482,200 ft3/s
Recorded Peak Flows
for streams in North and
Central California
Meyer Envelope Curve (6)
Qenv = 10,500 A1.13(A0.5+ 5)-1.37
for areas greater that 1.0 square mile
10.0
100.0
1000.0
10000.0
Drainage Area (square miles)

Figure 8

Table 7

CALCULATION OF AREA IN EACH BASIN BETWEEN 5,000 AND 10,000 FEET
(used for percentage distribution of 100-year natural flow base hydrograph above basins)

HEC-1 BASIN NUMBER	BASIN NAME	AREA BELOW 5,000 FEET (SQ.MI.)	AREA BELOW 10,000 FEET (SQ.MI.)	AREA BETWEEN 5,000 AND 10,000 FEET (SQ.MI.)	FRACTION OF TOTAL AREA
1	FRIANT	132.8	132.8	0	0
2	NEW DAM	102.7	128	25.3	0.027
3	BASS	22.9	31.9	9.0	0.010
4	REDINGER	130	187.8	57.8	0.062
5	MOMMOTH	109.2	695	585.8	0.633
6	EDISON	0	54.5	54.5	0.059
7	FLORENCE	0	80.9	80.9	0.087
8	HUNTINGTON	0	84.3	84.3	0.091
9	SHAVER	0	28.1	28.1	0.030
	TOTAL			925.7	1.000

PMF Rainfall-Runoff Computation: All of the data derived for the entire basin above Friant Dam; the design storm PMP arrangement, the loss rates, the unit hydrographs, the proportions of the antecedent 100-year flood hydrograph, and limited information regarding the upstream dams flood routing capabilities were placed in the Corps of Engineers HEC-1 rainfall-runoff program (USACE, 1998). This program then produced the resulting general storm PMF hydrograph at the River Mile 286 site and also for Friant Dam. The resulting PMF hydrograph at Friant Dam does not consider any potential flood routing effects of the River Mile 286 Dam. Additional flood routing information for the new dam may be added to this HEC-1 model at some point in the future. Two versions of this HEC-1 model were created, one with the upstream dams included and one without. Appendix B of this report displays the input and output summary for this HEC-1 model with the upstream dams included.

The resulting PMF hydrograph for the River Mile 286 dam is displayed on figure 1. Digital ordinates for this hydrograph have been given to the Reclamation design engineers for use with the current designs for this dam.

Envelope Curve Comparison: Figure 8 displays an envelope curve of 1,296 recorded peak flows in northern and central California prepared by Robert Meyer of the USGS (Meyers, 1994) in 1994. The unregulated peak and regulated peak flows from this general storm PMF computation are 502,100 ft^3/s and 482,200 ft^3/s, respectively. These peaks are plotted for comparison on this envelope curve. The envelope curve provides a value of 227,000 ft^3/s for a drainage area of 1,460 square miles. This general storm unregulated PMF peak is 2.2 times greater than the envelope curve. This is acceptable for PMF peaks in this part of California.

Recommendation for Future Study: At some point in the future the entire San Joaquin River basin will need additional study for purposes of flood control and general water operations at the new dam at river mile 286 and at Friant Dam. This additional study should involve the Southern California Edison Company and the Pacific Gas and Electric Company reservoir operation staffs as well as the Corps of Engineers and other interested agencies. Such a study would most likely produce different starting reservoir elevations for most of the upstream dams based on some flood prediction capability and measurements of existing snowpack and antecedent precipitation. Such additional information could have a large impact on the peak and volume of the PMF hydrograph prepared in this study.

Acknowledgement: This report was prepared by Mr. Kenneth L. Bullard, Hydraulic Engineer, with the assistance of Mr. Walter Johnson, Meteorologist. Mr. Bob Swain, Hydraulic Engineer, provided peer review. All of these individuals are employed in the Flood Hydrology Group of the Bureau of Reclamation's Technical Service Center in Denver, Colorado.

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Appendix A
PMF Hydrograph
For River Mile 286 Site

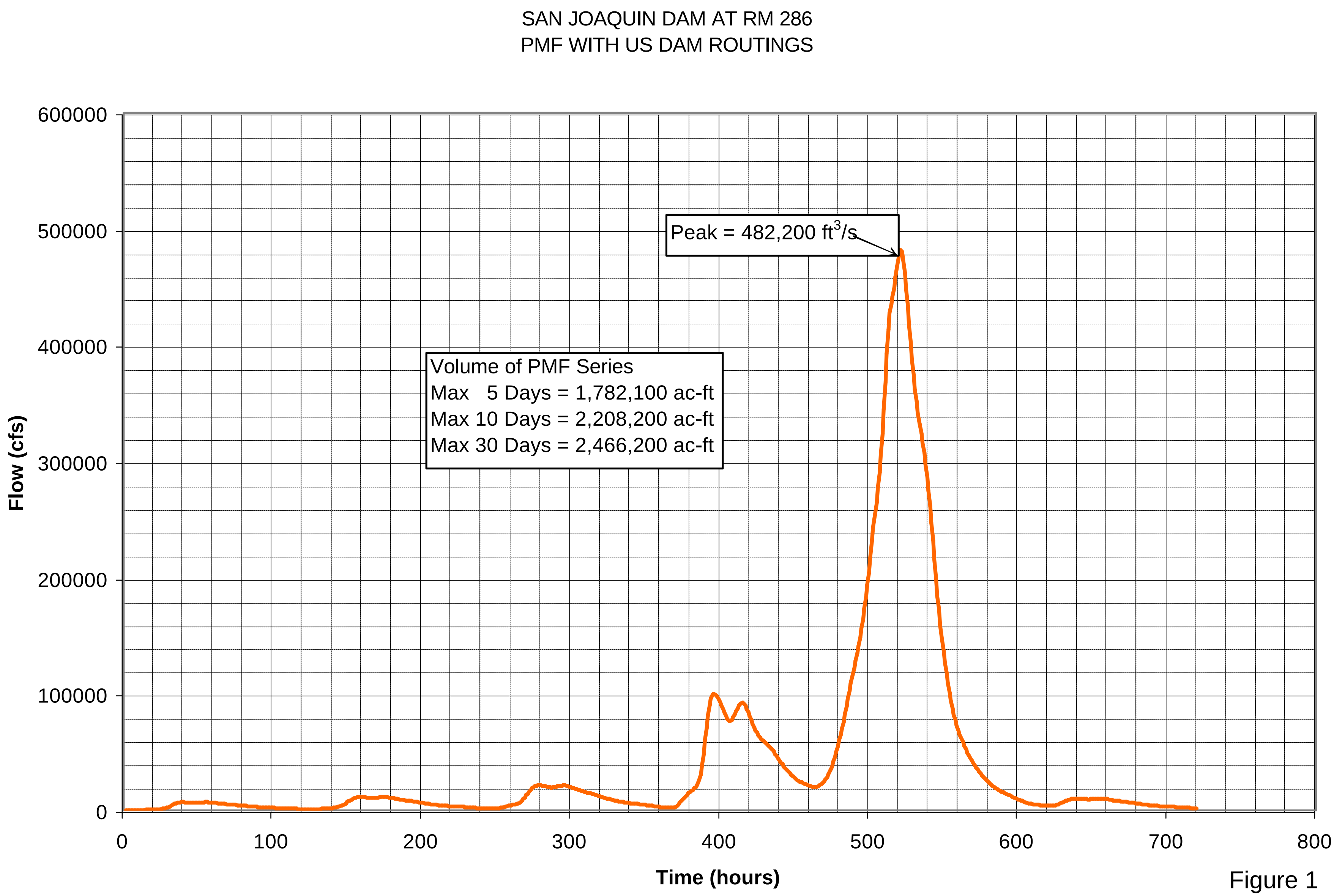
SAN JOAQUIN DAM AT RM 286
PMF WITH US DAM ROUTINGS
Peak = 482,200 ft^3/s
Volume of PMF Series
Max 5 Days = 1,782,100 ac-ft
Max 10 Days = 2,208,200 ac-ft
Max 30 Days = 2,466,200 ac-ft
600000
500000
400000
300000
200000
100000
0
Flow (cfs)
0
100
200
300
400
500
600
700
800
Time (hours)

Figure 1

River Mile 286 PMF
River Mile 286 Dam Site

San Joaquin River

HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS
0	0	50	6,481	100	2,294	150	5,269
1	7	51	6,522	101	2,238	151	6,072
2	8	52	6,599	102	2,184	152	6,944
3	9	53	6,697	103	2,134	153	7,852
4	10	54	6,805	104	2,087	154	8,727
5	12	55	6,895	105	2,038	155	9,521
6	16	56	6,962	106	1,991	156	10,177
7	19	57	6,982	107	1,946	157	10,739
8	23	58	6,959	108	1,903	158	11,234
9	28	59	6,918	109	1,857	159	11,488
10	33	60	6,841	110	1,810	160	11,599
11	60	61	6,717	111	1,760	161	11,605
12	89	62	6,567	112	1,707	162	11,512
13	127	63	6,410	113	1,650	163	11,366
14	171	64	6,251	114	1,590	164	11,164
15	196	65	6,093	115	1,528	165	10,934
16	229	66	5,936	116	1,462	166	10,717
17	268	67	5,779	117	1,395	167	10,550
18	314	68	5,633	118	1,329	168	10,458
19	364	69	5,503	119	1,261	169	10,465
20	415	70	5,385	120	1,206	170	10,506
21	468	71	5,272	121	1,198	171	10,585
22	522	72	5,164	122	1,186	172	10,745
23	588	73	5,059	123	1,172	173	10,935
24	656	74	4,959	124	1,157	174	11,128
25	737	75	4,857	125	1,140	175	11,280
26	866	76	4,752	126	1,126	176	11,379
27	1,003	77	4,640	127	1,108	177	11,392
28	1,169	78	4,522	128	1,090	178	11,327
29	1,334	79	4,399	129	1,075	179	11,231
30	1,523	80	4,270	130	1,059	180	11,075
31	1,828	81	4,143	131	1,076	181	10,846
32	2,968	82	4,016	132	1,099	182	10,577
33	3,935	83	3,883	133	1,134	183	10,307
34	4,749	84	3,751	134	1,180	184	10,094
35	5,424	85	3,628	135	1,195	185	9,869
36	5,957	86	3,507	136	1,227	186	9,638
37	6,367	87	3,387	137	1,265	187	9,400
38	6,674	88	3,270	138	1,316	188	9,173
39	6,859	89	3,157	139	1,518	189	8,967
40	6,968	90	3,053	140	1,885	190	8,779
41	7,014	91	2,953	141	2,165	191	8,595
42	6,999	92	2,860	142	2,380	192	8,418
43	6,949	93	2,773	143	2,565	193	8,247
44	6,858	94	2,691	144	2,722	194	8,080
45	6,744	95	2,613	145	2,889	195	7,912
46	6,631	96	2,542	146	3,161	196	7,737
47	6,535	97	2,474	147	3,502	197	7,549
48	6,476	98	2,410	148	3,964	198	7,354
49	6,465	99	2,351	149	4,534	199	7,146

River Mile 286 PMF
River Mile 286 Dam Site
San Joaquin River

HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS
200	6,932	250	1,350	300	20,789	350	4,935
201	6,718	251	1,406	301	19,970	351	4,785
202	6,504	252	1,506	302	19,171	352	4,627
203	6,282	253	1,665	303	18,545	353	4,458
204	6,062	254	1,907	304	18,040	354	4,283
205	5,852	255	2,160	305	17,603	355	4,100
206	5,647	256	2,495	306	17,202	356	3,911
207	5,446	257	2,893	307	16,802	357	3,718
208	5,249	258	3,314	308	16,436	358	3,527
209	5,059	259	3,704	309	16,110	359	3,338
210	4,881	260	4,045	310	15,809	360	3,153
211	4,714	261	4,337	311	15,511	361	3,031
212	4,559	262	4,579	312	15,214	362	2,886
213	4,413	263	4,819	313	14,920	363	2,769
214	4,276	264	5,039	314	14,627	364	2,673
215	4,151	265	5,300	315	14,323	365	2,620
216	4,033	266	5,766	316	13,994	366	2,610
217	3,925	267	6,366	317	13,636	367	2,594
218	3,823	268	7,193	318	13,258	368	2,594
219	3,729	269	8,219	319	12,857	369	2,623
220	3,639	270	9,548	320	12,442	370	2,670
221	3,550	271	11,001	321	12,033	371	3,012
222	3,468	272	12,916	322	11,624	372	3,501
223	3,392	273	14,872	323	11,204	373	4,210
224	3,319	274	16,765	324	10,789	374	5,222
225	3,245	275	18,675	325	10,399	375	6,271
226	3,173	276	20,319	326	10,064	376	7,623
227	3,105	277	21,482	327	9,754	377	9,209
228	3,039	278	22,180	328	9,431	378	10,874
229	2,970	279	22,402	329	9,107	379	12,793
230	2,900	280	22,348	330	8,794	380	14,356
231	2,824	281	22,084	331	8,496	381	15,586
232	2,743	282	21,572	332	8,211	382	16,553
233	2,655	283	20,904	333	7,942	383	17,479
234	2,563	284	20,138	334	7,687	384	18,349
235	2,466	285	19,427	335	7,447	385	19,517
236	2,365	286	18,920	336	7,220	386	21,789
237	2,261	287	18,637	337	7,007	387	24,970
238	2,158	288	18,551	338	6,807	388	30,554
239	2,055	289	18,660	339	6,619	389	38,198
240	1,953	290	18,893	340	6,438	390	48,667
241	1,864	291	19,343	341	6,262	391	61,040
242	1,774	292	20,060	342	6,093	392	73,710
243	1,690	293	20,860	343	5,938	393	85,338
244	1,614	294	21,563	344	5,791	394	94,234
245	1,548	295	22,036	345	5,638	395	99,425
246	1,497	296	22,261	346	5,492	396	101,360
247	1,447	297	22,199	347	5,352	397	101,471
248	1,404	298	21,890	348	5,219	398	100,692
249	1,373	299	21,436	349	5,079	399	98,991

River Mile 286 PMF
River Mile 286 Dam Site
San Joaquin River

HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS
400	97,038	450	29,185	500	205,072	550	136,349
401	94,817	451	28,142	501	217,177	551	126,528
402	91,641	452	27,168	502	232,419	552	117,390
403	87,969	453	26,258	503	243,148	553	109,451
404	84,437	454	25,413	504	253,883	554	101,566
405	81,222	455	24,636	505	264,655	555	94,219
406	78,954	456	23,921	506	276,375	556	87,841
407	77,881	457	23,255	507	289,225	557	82,431
408	77,842	458	22,734	508	304,302	558	77,522
409	78,847	459	22,214	509	322,406	559	73,035
410	80,603	460	21,677	510	343,716	560	68,904
411	83,156	461	21,122	511	367,343	561	65,090
412	86,594	462	20,600	512	391,594	562	61,723
413	90,189	463	20,177	513	413,470	563	58,490
414	92,951	464	19,907	514	427,785	564	55,417
415	94,201	465	19,864	515	435,853	565	52,543
416	94,152	466	20,265	516	442,467	566	49,821
417	92,835	467	21,165	517	450,194	567	47,277
418	90,508	468	22,418	518	459,500	568	44,908
419	87,710	469	23,917	519	469,482	569	42,675
420	84,390	470	25,660	520	478,177	570	40,683
421	80,470	471	27,629	521	482,810	571	38,765
422	76,810	472	30,171	522	481,173	572	36,872
423	73,850	473	33,021	523	473,836	573	35,026
424	71,153	474	36,182	524	462,497	574	33,251
425	68,565	475	39,645	525	448,636	575	31,555
426	66,201	476	43,353	526	433,456	576	29,937
427	64,081	477	47,275	527	417,755	577	28,407
428	62,402	478	51,491	528	402,132	578	26,957
429	61,109	479	56,141	529	387,283	579	25,577
430	59,879	480	60,904	530	373,711	580	24,264
431	58,630	481	65,921	531	361,730	581	23,085
432	57,490	482	71,383	532	351,306	582	22,086
433	56,447	483	77,238	533	341,869	583	21,054
434	55,373	484	83,664	534	333,000	584	20,018
435	54,087	485	90,224	535	324,581	585	18,963
436	52,488	486	96,847	536	316,379	586	18,073
437	50,624	487	103,459	537	307,730	587	17,352
438	48,661	488	109,983	538	298,104	588	16,730
439	46,656	489	116,525	539	287,186	589	16,143
440	44,653	490	122,880	540	274,899	590	15,566
441	42,753	491	129,121	541	261,474	591	14,982
442	40,958	492	135,267	542	247,896	592	14,390
443	39,317	493	141,466	543	232,618	593	13,784
444	37,709	494	148,336	544	216,287	594	13,172
445	36,204	495	156,088	545	199,346	595	12,553
446	34,682	496	164,601	546	184,179	596	11,934
447	33,128	497	173,806	547	172,912	597	11,319
448	31,656	498	183,733	548	159,861	598	10,713
449	30,338	499	194,117	549	147,321	599	10,121

River Mile 286 PMF
River Mile 286 Dam Site

San Joaquin River

HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS	HOUR	FLOW CFS
600	9,654	631	6,072	662	9,558	693	4,102
601	9,169	632	6,730	663	9,351	694	3,985
602	8,670	633	7,428	664	9,137	695	3,875
603	8,169	634	8,104	665	8,925	696	3,770
604	7,676	635	8,719	666	8,711	697	3,674
605	7,200	636	9,228	667	8,496	698	3,583
606	6,746	637	9,635	668	8,292	699	3,497
607	6,314	638	9,945	669	8,107	700	3,414
608	5,908	639	10,123	670	7,937	701	3,334
609	5,531	640	10,221	671	7,771	702	3,257
610	5,180	641	10,250	672	7,613	703	3,186
611	4,889	642	10,209	673	7,458	704	3,118
612	4,640	643	10,131	674	7,307	705	3,049
613	4,436	644	10,005	675	7,156	706	2,981
614	4,291	645	9,851	676	6,998	707	2,917
615	4,169	646	9,696	677	6,831	708	2,856
616	4,099	647	9,567	678	6,658	709	2,791
617	4,076	648	9,484	679	6,476	710	2,724
618	4,076	649	9,465	680	6,288	711	2,654
619	4,075	650	9,480	681	6,099	712	2,579
620	4,067	651	9,525	682	5,911	713	2,501
621	4,046	652	9,620	683	5,717	714	2,418
622	4,015	653	9,743	684	5,524	715	2,332
623	3,993	654	9,878	685	5,342	716	2,242
624	3,971	655	9,992	686	5,164	717	2,150
625	3,978	656	10,078	687	4,989	718	2,056
626	4,086	657	10,101	688	4,820	719	1,964
627	4,264	658	10,071	689	4,656	720	1,872
628	4,554	659	10,017	690	4,505		
629	4,941	660	9,916	691	4,362		
630	5,475	661	9,755	692	4,228		