Appendix N

Geomorphology, Sediment Transport, and Vegetation Assessment

Draft
Program Environmental Impact Statement/Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

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Geomorphology, Sediment Transport, and Vegetation Assessment

Report Prepared by:

Blair P. Greimann, P.E., Ph.D., Hydraulic Engineer
Sedimentation and River Hydraulics Group, Technical Service Center

Signature:___________________________________

Lisa Fotherby, P.E., Ph.D., Hydraulic Engineer
Sedimentation and River Hydraulics Group, Technical Service Center

Signature:___________________________________

Peer Reviewed by:

Elaina Holburn, P.E., M.S., Hydraulic Engineer
Sedimentation and River Hydraulics Group, Technical Service Center

Signature:___________________________________

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List of Abbreviations and Acronyms

ALS	Average Levee Setback
cfs	cubic feet per second
ka	kiloannum
Ma	megaannum
MEI	Mussetter Engineering, Inc.
MLS	Maximum Levee Setback
mm	millimeter
PEIS/R	Program Environmental Impact Statement/Report
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RP	river post
SJRRP	San Joaquin River Restoration Program
SRH-1D	Sedimentation and River Hydraulics – One Dimensional
USGS	U.S. Geological Survey
TSC	Technical Service Center

1.0 Introduction

The Denver Technical Service Center (TSC) of the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) was requested to perform an analysis of the geomorphology, sediment transport, and vegetation effects in the San Joaquin River between Friant Dam and the Merced River resulting from implementation of the San Joaquin River Restoration Program (SJRRP). This report is intended to support the Program Environmental Impact Statement/Report (PEIS/R). Previous analyses of the sediment transport characteristics have been performed by McBain and Trush (2002) and Mussetter Engineering, Inc. (MEI) (2002a). The purpose of this study is to verify those previous analyses and compare the conditions under the SJRRP to Baseline Conditions. Baseline Conditions and conditions under the SJRRP are detailed in Appendix H, Modeling, of the PEIS/R. Conditions under the SJRRP are termed Project Conditions in this report.

To perform this assessment, we compared the geomorphic, sediment transport, and vegetation response to changes between Baseline Conditions and Project Conditions. Baseline Conditions are defined as those conditions that will persist into the future without the implementation of the SJRRP. Project Conditions are those conditions under the implementation of the SJRRP. The analyses presented here focus on the difference in responses due to the change in river flows between Baseline Conditions and Project Conditions.

Four separate analyses were performed:

1. **Geomorphic assessment of the San Joaquin River from Friant Dam to Highway 99 (Attachment 2).** This study reviewed previous geomorphology studies in this reach and analyzed changes to the river form since the construction of Friant Dam. Geomorphic data in this study provide information about the characteristics of the river channel, and the dominant fluvial processes operating before dam construction and extensive in-channel gravel mining.

2. **Bed material mobility of the San Joaquin River between Friant Dam to Mendota Dam (Attachment 3).** This study analyzed the mobility of the bed sediment under Baseline Conditions and Project Conditions.

3. **Sediment transport and erosion/deposition in all project reaches (Attachments 4 and 5).** A mobile bed sediment transport model (SRH-1D) was used to estimate sediment transport rates and to predict future erosion and deposition under Baseline Conditions and Project Conditions.

4. **Vegetation response to hydrologic changes (Attachment 6).** An extension to the SRH-1D model, called SRH-1DV, was used to predict the vegetation response to Baseline Conditions and Project Conditions. SRH-1DV has a vegetation

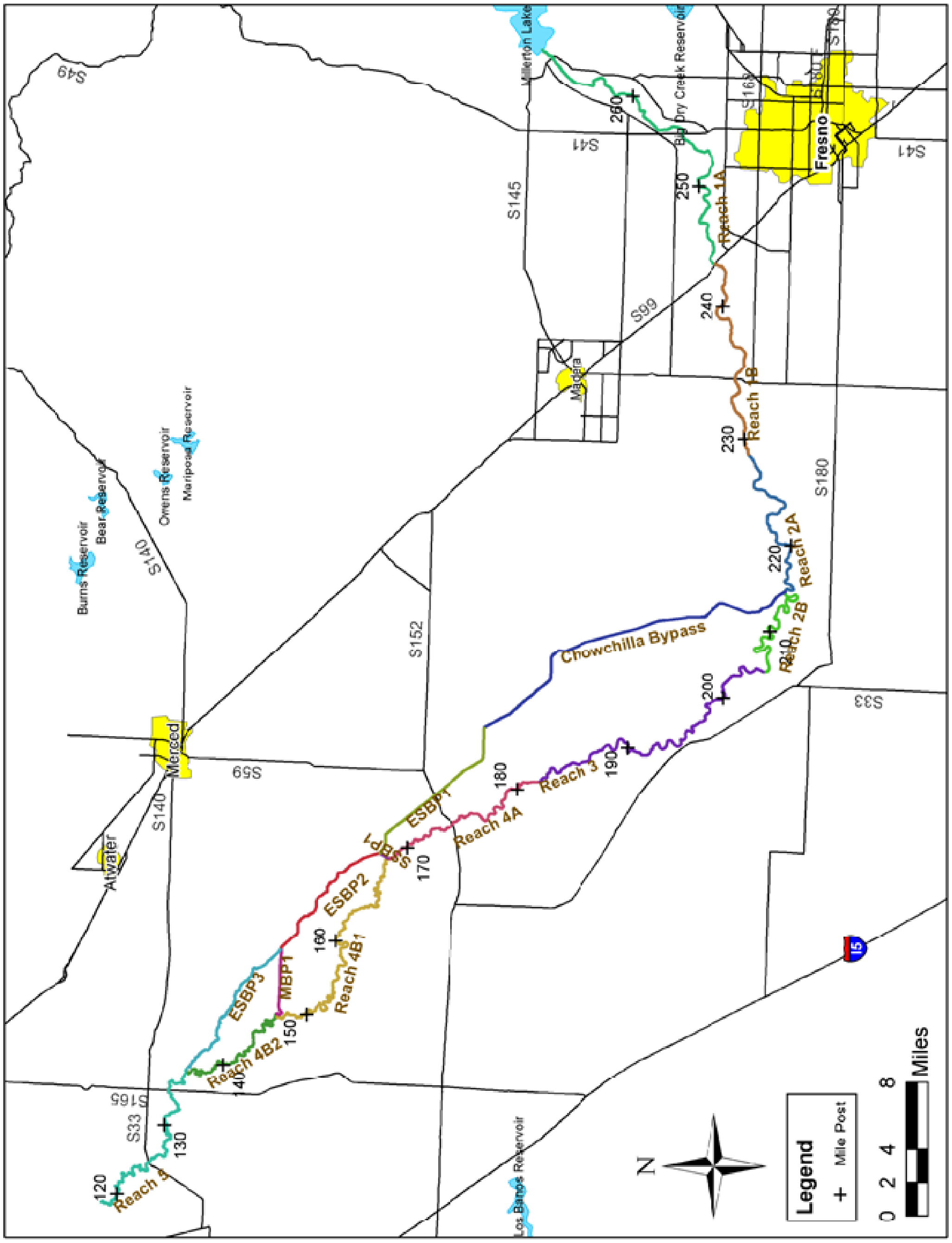
module that computes the response of vegetation to flow and sediment transport conditions.

This report summarizes the results of these investigations. Detailed descriptions of the individual analyses are provided as attachments to this report.

2.0 Reach Descriptions

Project reaches are defined by changes in the channel and valley morphology or by structures that significantly alter the flow regime. Locations of the project reaches are shown in Figure 2-1. The profile of the project reaches is given in Figure 2-2.

The project area analyzed includes the main stem of the San Joaquin River and the associated flood bypass system from Friant Dam to the Merced River. The main stem of the San Joaquin River is divided into five main project reaches and nine subreaches (1a, 1b, 2a, 2b, 3, 4a, 4b1, 4b2, and 5). The extent and description of each reach and subreach is given in Table 2-1. More detailed descriptions of the reaches are provided in the summary of the results section (Section 5). McBain and Trush, Inc. (2002) have written an extensive description of the Historical and Existing conditions of these reaches.



Key: ESBP = Eastside Bypass MBP = Mariposa Bypass SSBP = Sand Slough Bypass

Figure 2-1.
Overview Map of Study Area

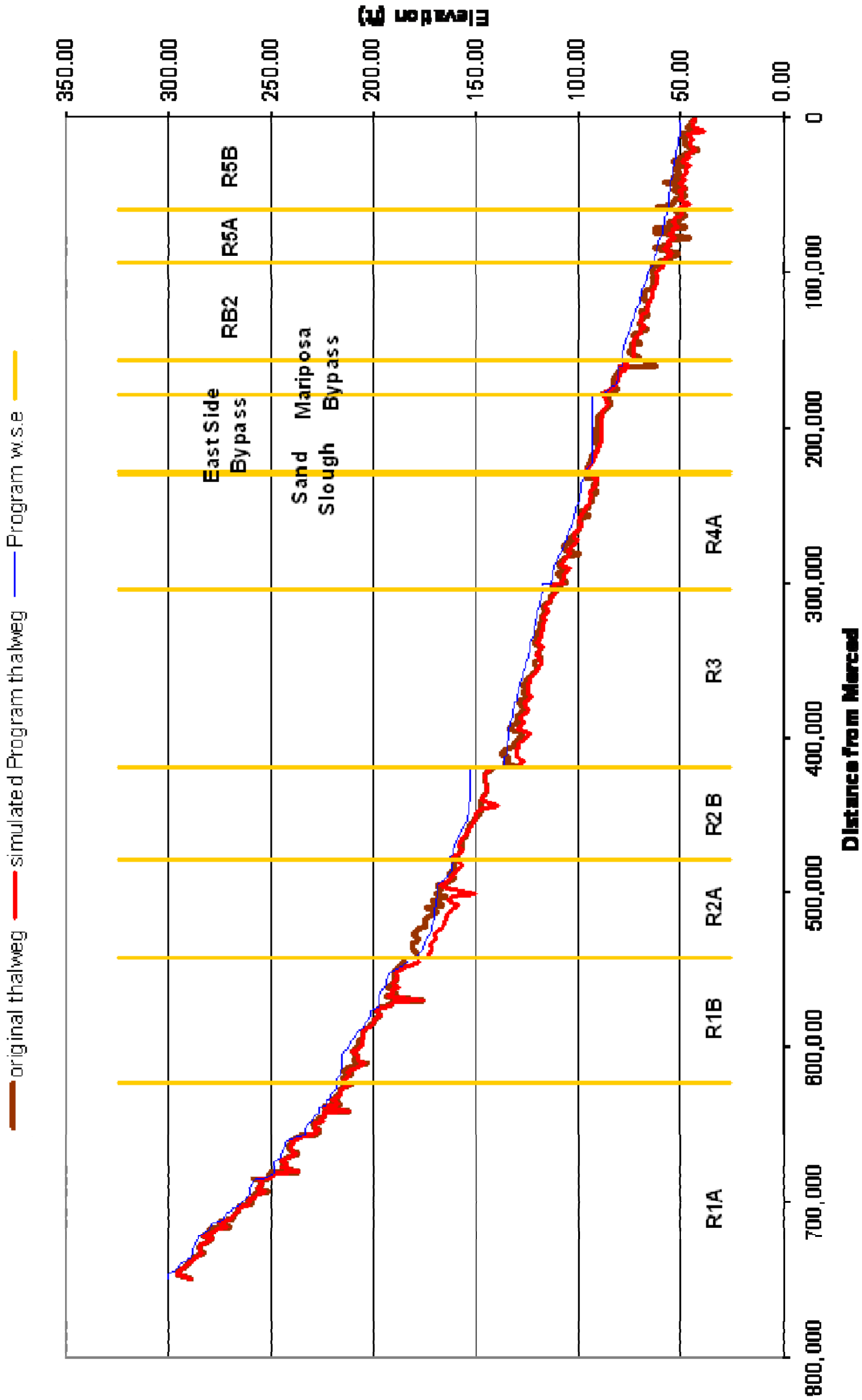


Figure 2-2.
Profile of Project Reaches

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Table 2-1.
Reach Locations Defined by the San Joaquin River Restoration Study Background Report (Modified from McBain and Trush, Inc., 2002)

Reach	Subreach	Ranch Boundary (River Post)	General Description
1	1a	267.5 – 243.2	Friant Dam to State Route 99
	1b	243.2 – 229.0	State Route 99 to Gravelly Ford
2	2a	229.0 – 216.1	Gravelly Ford to the Chowchilla Bifurcation Structure
	2b	216.1 – 204.8	Chowchilla Bifurcation Structure to Mendota Dam
3	3	204.8 – 182.0	Mendota Dam to Sack Dam
4	4a	182.0 – 168.5	Sack Dam to the Sand Slough Control Structure
	4b1	168.5 – 147.2	Sand Slough Control Structure to the Confluence with the Mariposa Bypass
	4b2	147.2 – 135.8	Confluence with the Mariposa Bypass to the confluence with Bear Creek and the Eastside Bypass
5	5	135.8 – 118.0	Confluence with Bear Creek and the Eastside Bypass to the Merced River confluence

3.0 Description of Hydrologic Scenarios

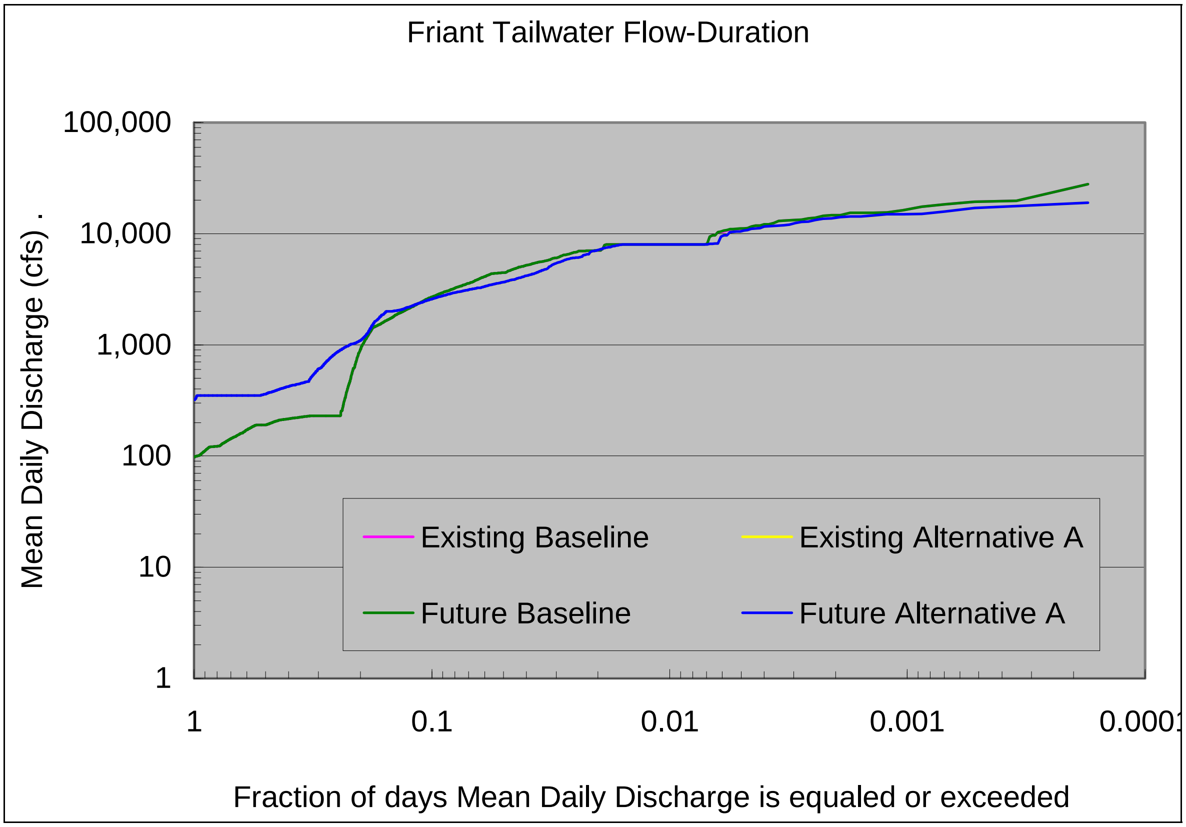
Three different hydrologic data sets were analyzed in this report: Baseline Conditions, Project Conditions, and Historical Gage data (referred to as Historical Conditions).

Baseline Conditions refer to simulated flows developed through CalSim II, assuming that current water operations would continue into the future, and the Historical hydrologic conditions occur again. Monthly average flows from CalSim II were then downscaled to daily flows. These daily flows were also used in HEC5Q simulations of the river temperature. Additional details of the hydrologic modeling of the Baseline Conditions are given in Appendix H of the PEIS/R.

In this report, Project Conditions are also referred to as Alternative A and represent the Exhibit B flow schedule, assuming the historic hydrology inputs (e.g., annual rainfall) to the system were to occur again. Alternative A represents with-project flow conditions under all Program Alternatives described in the PEIS/R. Project Conditions also assume that the maximum flows into Reach 2b and Reach 4b1 will be 4,500 cubic feet per second (cfs) and 475 cfs, respectively. More details of the Baseline and Project scenarios are found in Appendix H of the PEIS/R.

Two sets of Baseline and Project scenarios were developed: Future and Existing. For the purposes of this report, however, the Future and Existing scenarios are considered identical. This is based upon an analysis of the flow-duration curves that found no significant difference between the two scenarios (Figure 3-1).

Historical gage data were derived from U.S. Geological Survey (USGS) stream gages given in Table 3-1. A comparison between the daily average flows simulated under Baseline Conditions and Project Conditions (Alternative A) is shown in Figure 3-2 from January 1, 1980, to September 30, 2003, and in Figure 3-3 from January 1, 1998, to September 30, 2003. Compared to Baseline Conditions, base flows are increased under Project Conditions, and almost every year is characterized by a flow of at least 1,000 cfs. However, the peak flows during the wet years under Project Conditions are generally decreased from Baseline Conditions.



Notes:
The flow-duration curves are based upon the period from January 1, 1980 to May 31, 1997. The existing and future lines coincide with one another.

Figure 3-1.
Comparison Between the Existing and Future Conditions at Friant Dam

Table 3-1.
Stream Gages Used in Historical Flow Analysis

Description	Stream Gage ID	River Post	HEC-RAS XC	Agency	Description
San Joaquin River below Friant Dam	MIL	267.5	XS596	Reclamation	1944 – Present
Donny Bridge	H41	255	XS425	Reclamation	1989 – Present
Highway 145 Bridge (Skaggs Bridge)	SKB	234	XS92	Reclamation	1988 – Present
San Joaquin River near Gravelly Ford	GRF	227.5	XSA213	Reclamation	1974 – Present
Chowchilla Bypass downstream from Chowchilla Bifurcation Structure	CBP	-	-	DWR	1974 – Present
San Joaquin River downstream from Chowchilla Bifurcation Structure	SJB	216	XSA97	Reclamation	1986 – Present
San Joaquin River near Mendota	11254000	202	XS730	USGS	1940 –1954
				Reclamation	1974 – 1997 2000 – present
San Joaquin River near Dos Palos	11256000	181	XS464	USGS	1941 – 1954
				Reclamation	1986, 1987, 1995
San Joaquin River near El Nido	11260000	168	XS304	USGS	1940 – 1949
Eastside Bypass near El Nido	ELN	N/A	N/A	DWR	1980 – present
Mariposa Bypass near Crane Ranch	N/A	N/A	N/A	DWR	1981 – 1994
Eastside Bypass below Mariposa Bypass	EBM	N/A	N/A	DWR	1980 – present
Bear Creek below Eastside Canal	BBE	N/A	N/A	DWR	1980 – present
San Joaquin River near Stevinson	SJS	133	XS199M	DWR	1981 – present
Salt Slough at HW 165 near Stevinson	11261100	N/A	N/A	USGS	1986 – 1994, 1996 – present
				DWR	1980 – present
San Joaquin River at Fremont Ford Bridge	11261500	125	XS99M	USGS	1937 – 1989
Mud Slough near Gustine	11262900	N/A	N/A	USGS	1986 – present
Merced River near Stevinson	11272500	N/A	N/A	USGS	1941 – Present
San Joaquin River near Newman	11274000	118	XS1M	USGS	1912 – present

Key:
DWR = California Department of Water Resources
ID = Irrigation District
USGS = U.S. Geological Survey

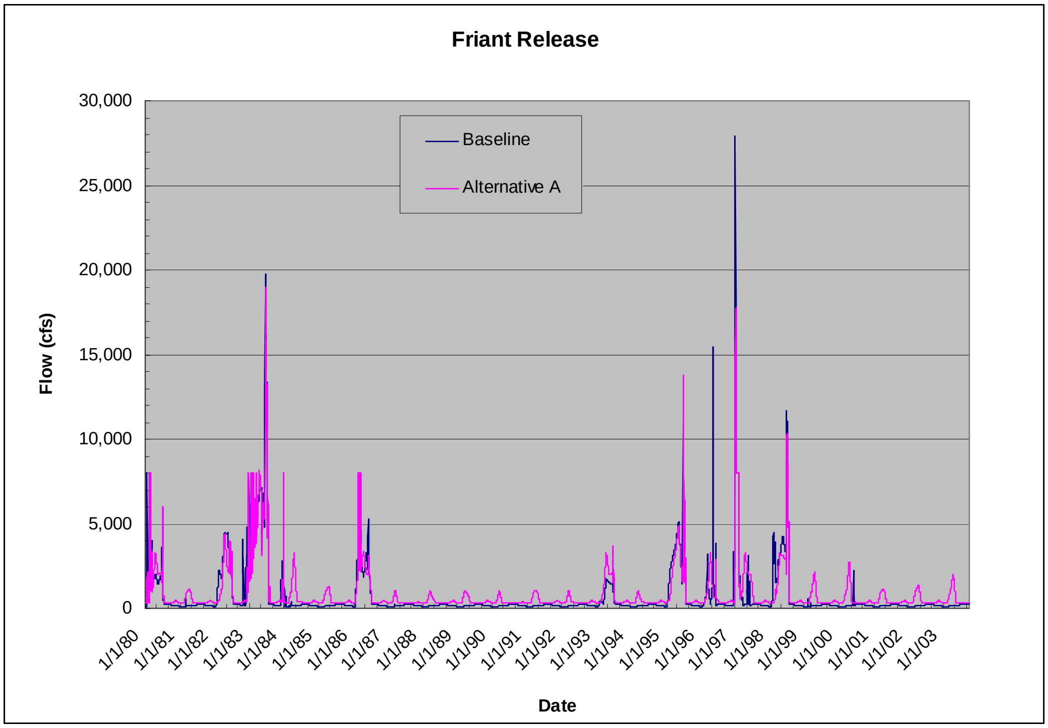


Figure 3-2.
Simulated Daily Flows from January 1, 1980, to September 30, 2003, at Friant Dam for Baseline and Project Conditions (Alternative A)

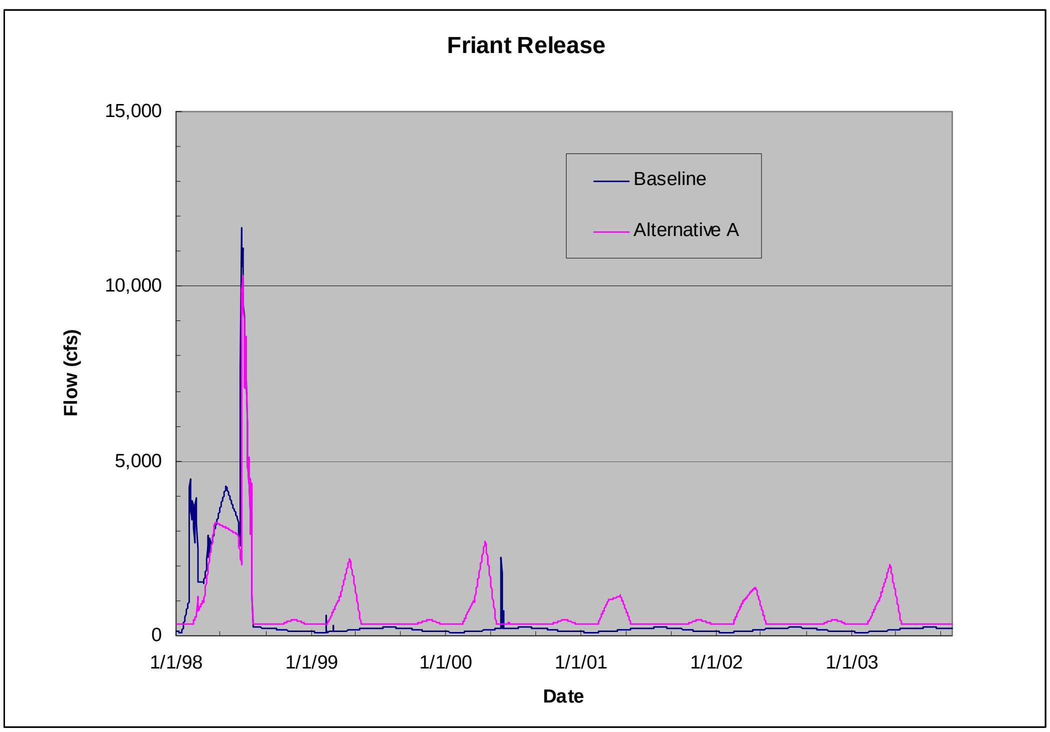


Figure 3-3.
Simulated Daily Flows from January 1, 1998, to September 30, 2003, at Friant Dam for Baseline and Project Conditions (Alternative A)

Flow-duration curves using the Historical Gage data, Baseline Conditions, and Alternative A (Project Conditions) were developed. The common period used to develop the flow-duration curves was from January 1, 1980, to May 31, 1997. This period of flow record was available for the stream gage locations: San Joaquin River Below Friant Dam, Gravelly Ford, Mendota Dam, and Eastside Bypass at El Nido.

At Friant Dam, Alternative A has an increase in flow in the range between 350 cfs and 2,300 cfs, as compared to Baseline Conditions (Figure 3-4). The minimum flow is approximately 350 cfs under Alternative A, whereas under Baseline Conditions, the minimum flow is approximately 100 cfs. Alternative A hydrology also has a slightly lower frequency of flows above 2,300 cfs than Baseline Conditions. The increase in flows below 2,300 cfs results in more available storage in Millerton Reservoir. Therefore, during wet years, more storage would be available in the reservoir, and the dam would spill less often.

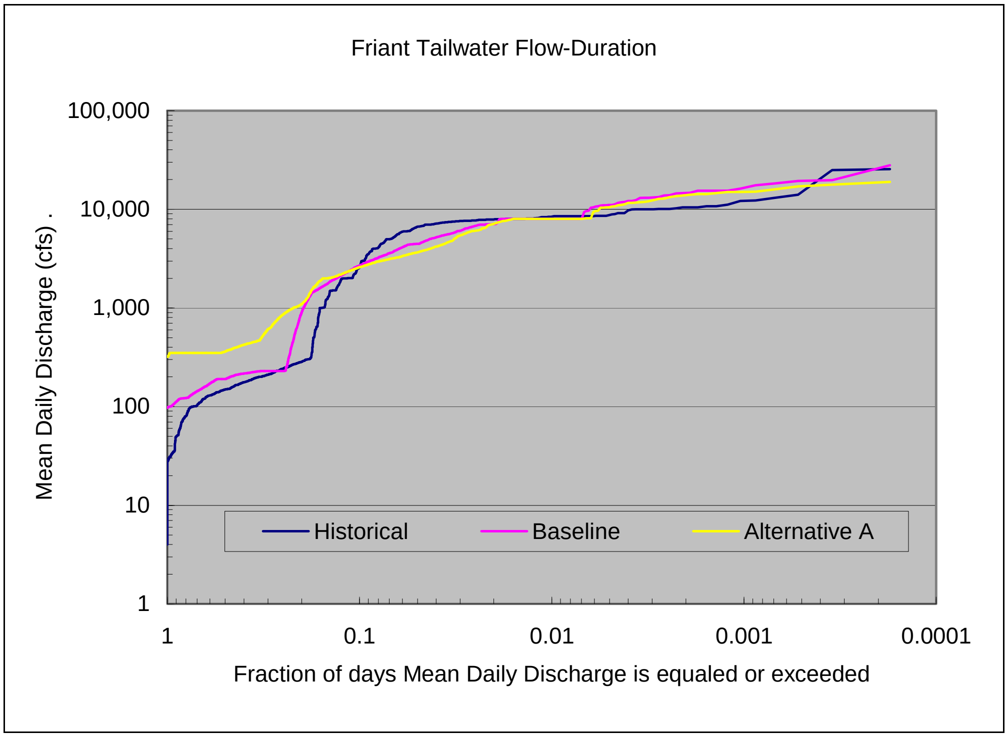
At Gravelly Ford, a comparison between Alternative A and Baseline Conditions (Figure 3-5) shows similar patterns as those at Friant Dam. Alternative A has a higher frequency of flows between 100 and 2,300 cfs and a lower frequency of flows above 2,300 cfs. An important consequence of the lower frequency of flows above 2,300 cfs is that the peak flood flows may be reduced under Project Conditions in Reaches 1 and 2 because there is more storage available in Millerton Reservoir.

At San Joaquin below the Chowchilla Bifurcation Structure, Alternative A is characterized by an increased frequency of flow at all discharges, as compared to Baseline Conditions (Figure 3-6). Under Alternative A, the flow at this gage is above 100 cfs 90 percent of the time, whereas under Baseline Conditions, the flow is essentially 0 cfs about 44 percent of the time. Significant differences exist between Baseline Conditions and the Historical Gage data. However, the hydrologic model is not intended to exactly reproduce Historical Gage data because the operations at Friant Dam and the Chowchilla Bifurcation Structure may have been different in the past, and Baseline Conditions assume that operations are as they are now.

Below Mendota Dam, in Reach 3, Alternative A has a significant increase in the frequency of flow above 250 cfs, as compared to Baseline Conditions (Figure 3-7). A similar pattern is true below Sack Dam, in Reach 4a (Figure 3-8).

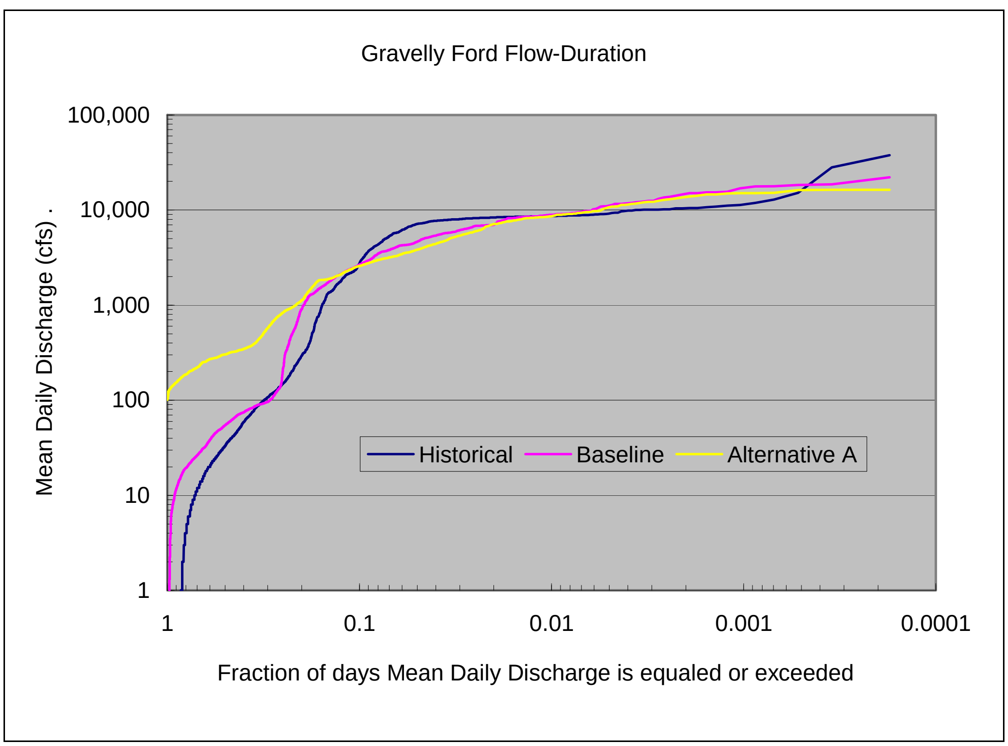
In Reach 4b1, the flows are substantially increased under Alternative A, relative to Baseline Conditions (Figure 3-9). Under Baseline Conditions, the maximum flow in the Sand Slough is about 4 cfs, and under Project Conditions, the maximum flow is 475 cfs with a minimum flow of above 100 cfs.

Below the return of the Mariposa Bypass to the San Joaquin River, in Reach 4b2, the frequency of flow above 100 cfs and below 475 cfs is substantially increased (Figure 3-10) under Project Conditions. Below the return of the Eastside Bypass to the San Joaquin River (Figure 3-11), in Reach 5, the frequency of flow between 200 and 2,000 cfs is also substantially increased from Baseline Conditions to Project Conditions.



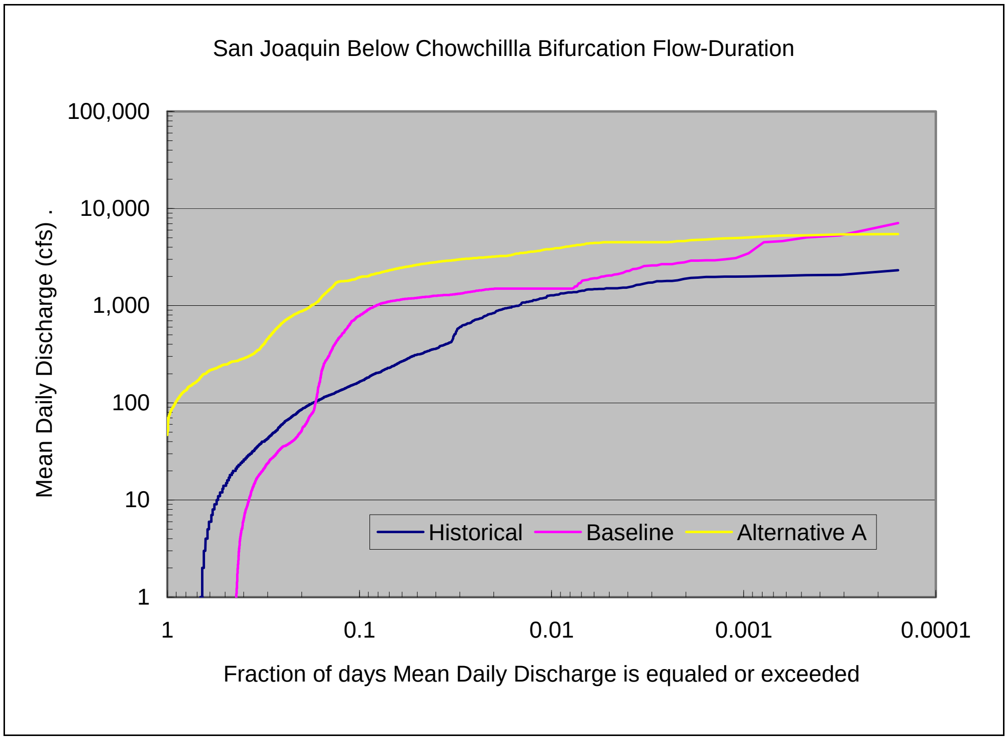
Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

Figure 3-4.
Flow-Duration Curves at Friant Dam



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

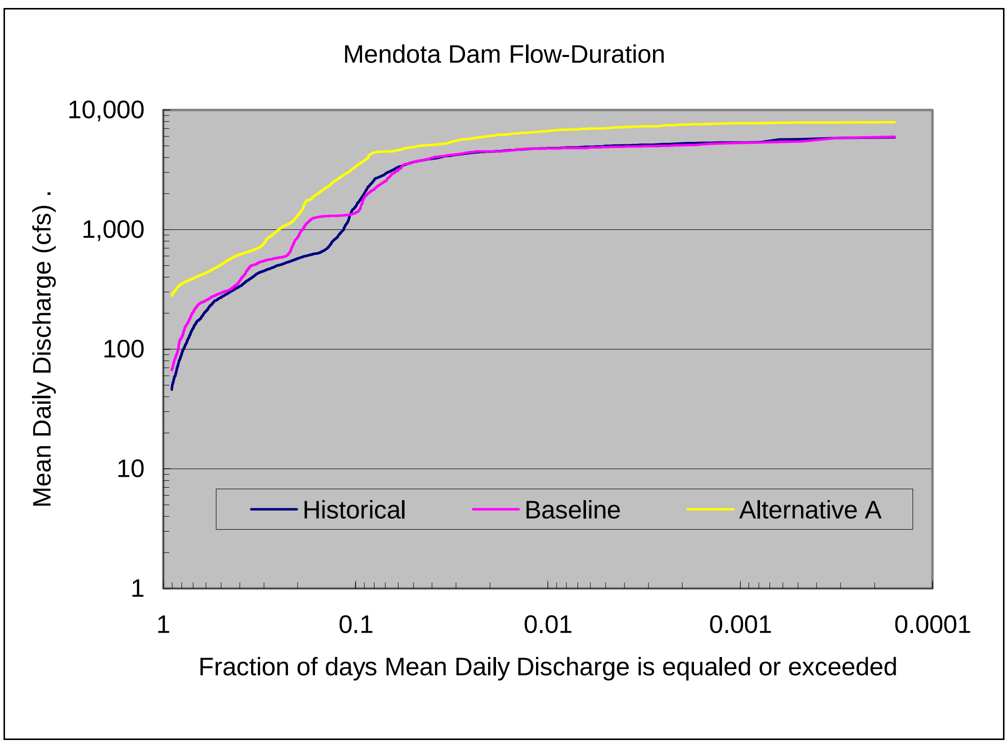
Figure 3-5.
Flow-Duration Curves at Gravelly Ford



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997

Figure 3-6.

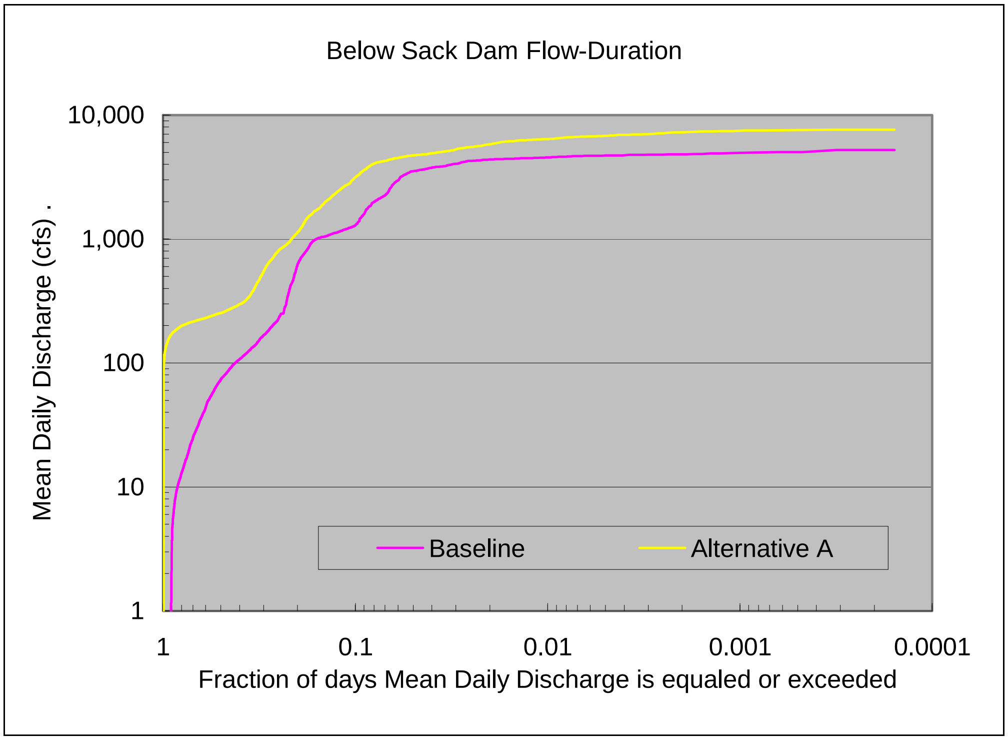
Flow-Duration Curves at San Joaquin Below Chowchilla Bifurcation Structure



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

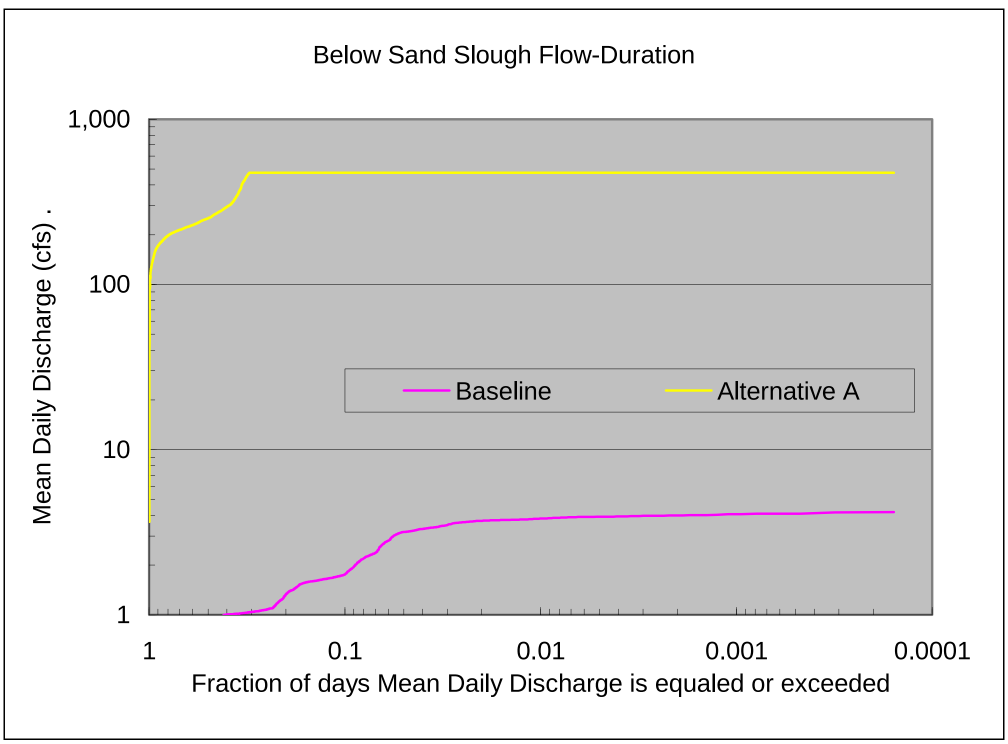
Figure 3-7.

Flow-Duration Curves at San Joaquin Below Mendota Dam



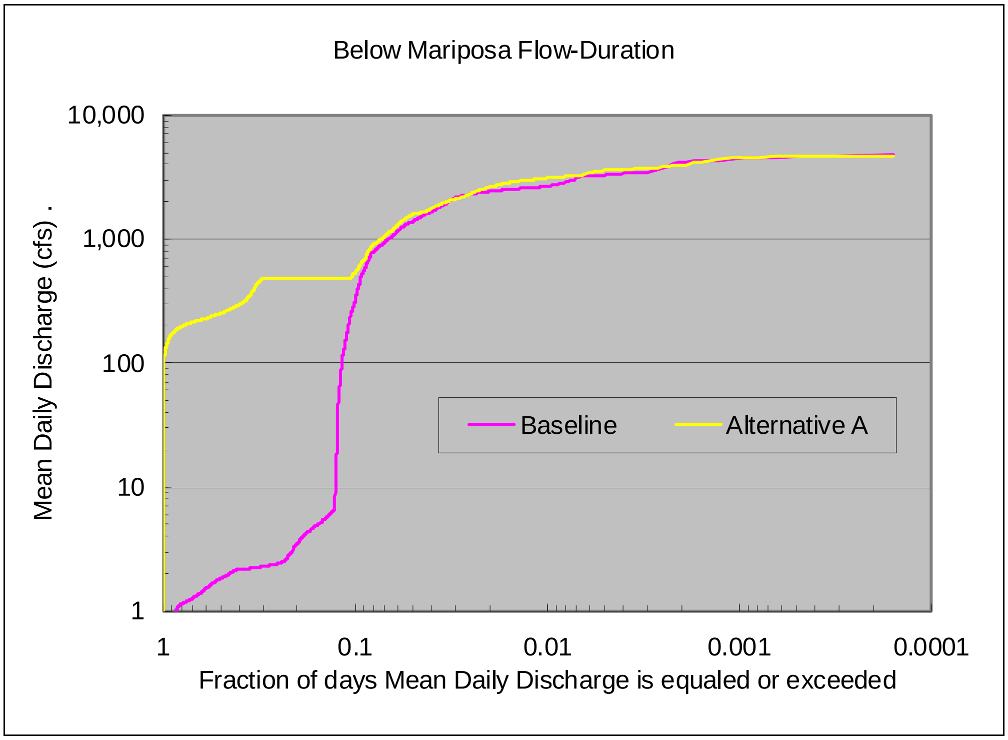
Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

Figure 3-8.
Flow-Duration Curves at San Joaquin Below Sack Dam



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

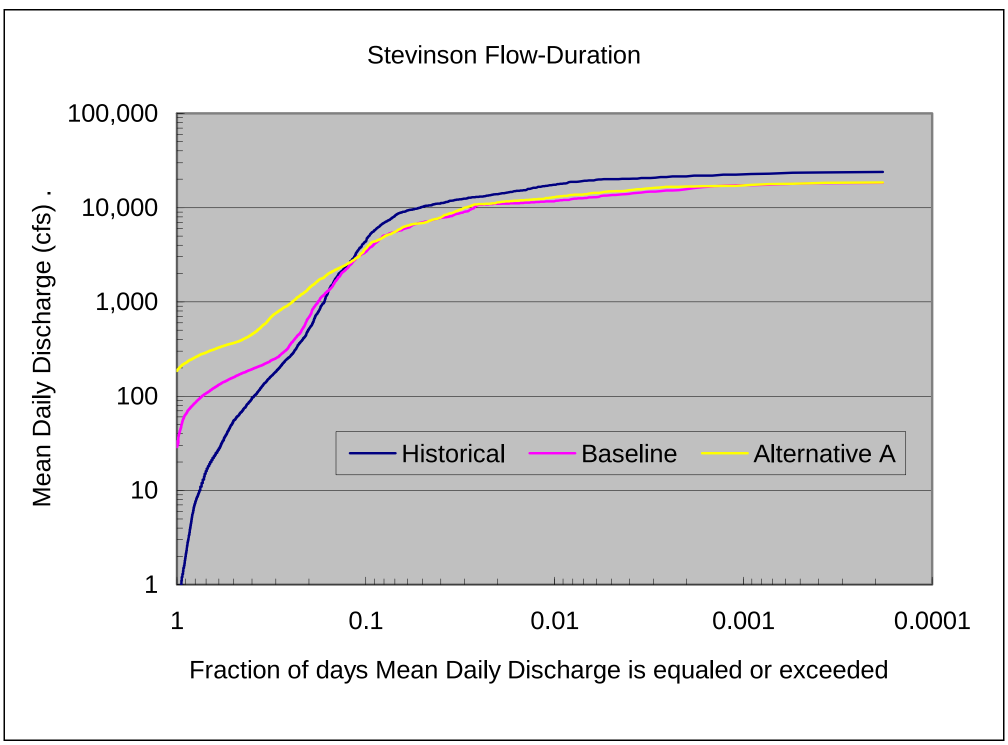
Figure 3-9.
Flow-Duration Curves Below Sand Slough Control Structure



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997

Figure 3-10.

Flow-Duration Curves Below Mariposa Bypass

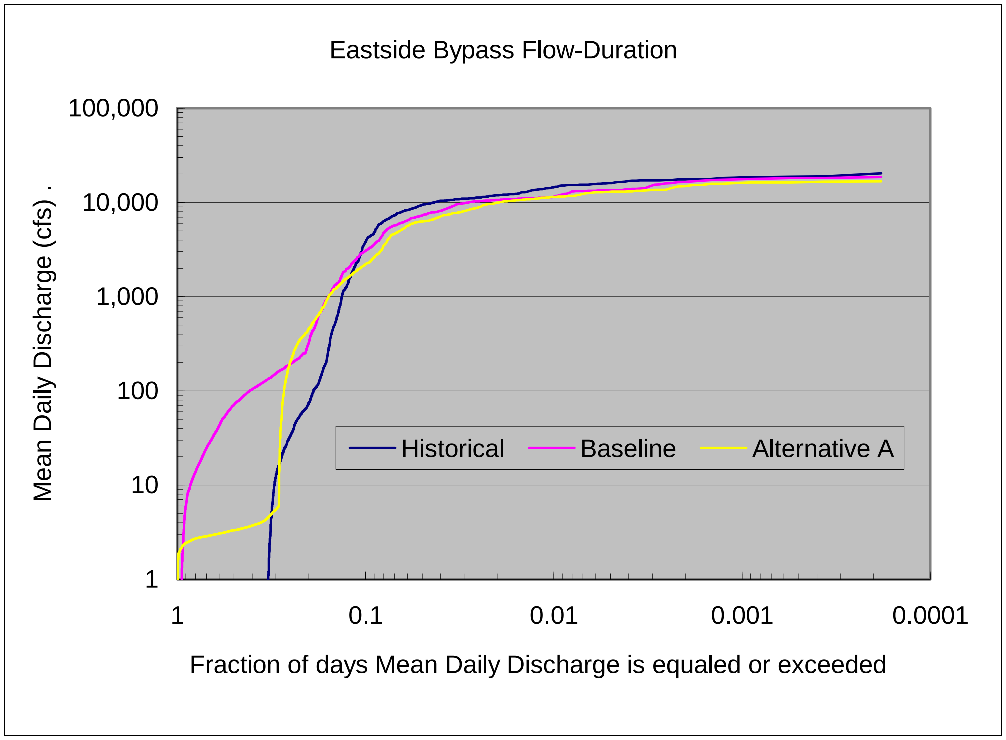


Note: The flow-duration curves are based upon the period from Oct 1, 1981, to May 31, 1997.

Figure 3-11.

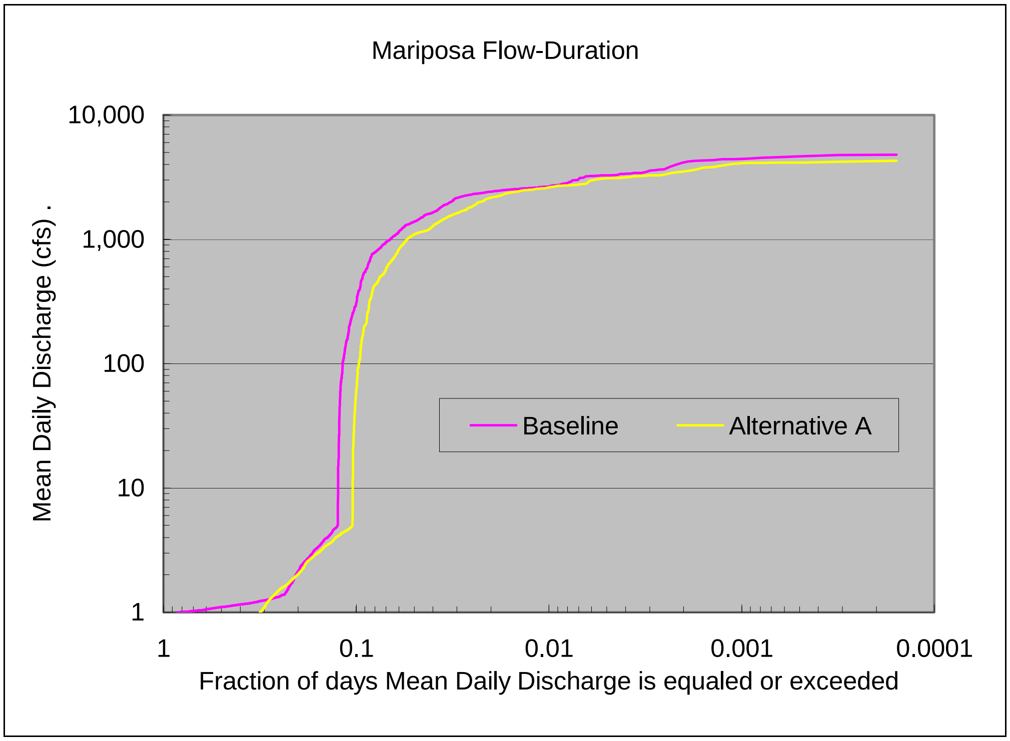
Flow-Duration Curves at Stevinson

In the Eastside Bypass, there is a substantial decrease in the frequency of flow above 2 cfs under Alternative A, relative to Baseline Conditions (Figure 3-12). Alternative A also experiences a slight reduction in the frequency of flow above 1,500 cfs, compared with Baseline Conditions. In the Mariposa Bypass, Alternative A has a reduced frequency of flow for all flows above 2 cfs (Figure 3-13).



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

Figure 3-12.
Flow-Duration Curves at East Side Bypass at El Nido Gage



Note: The flow-duration curves are based upon the period from January 1, 1980, to May 31, 1997.

Figure 3-13.
Flow-Duration Curves at Mariposa Bypass Just Downstream from Mariposa Control Structure

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4.0 Methods

As mentioned previously, four separate analyses were performed: a geomorphic assessment, a sediment mobility analyses, estimates of sediment erosion and deposition, and an assessment of the vegetation response to flow alterations.

4.1 Geomorphic Assessment

The geomorphic assessment analyzed changes in channel planform from between 1938 and 2007 (Attachment 2, Geomorphology Report). The study reach extends for approximately 24 miles from Friant Dam to the Route 99 bridge and is located only within Reach 1a. Significant geomorphic analyses have been previously reported in Cain (1997) and McBain and Trush (2002) for other reaches of the San Joaquin River. Additional investigations of geomorphology are also planned to be completed in the future for other downstream reaches. The assessment primarily relied upon georeferenced aerial photography from 1938 and 2007 that were used to measure changes in channel planform. For each year of photography, active channels, side channels, unvegetated bars, vegetated bars, and flood channels were mapped. Delineation and interpretation of these features identified pre-dam river conditions and post-dam river adjustments. Upon the release of larger flows, this assessment can be used to predict geomorphic characteristics that would most likely develop under an altered flow and sediment regime.

4.2 Sediment Mobility Analyses

The bed material mobility of the San Joaquin River between Friant Dam and Highway 99 was analyzed under Baseline Conditions and Project Conditions (Attachment 3, Sediment Mobilization). The MEI hydraulic model (2002a) and the sediment sampling data from Attachment 1were used in the analysis. The sediment bed mobility analysis was focused upon riffle sections of the river where the presence of gravels was identified from sediment sampling and field verification. Three categories of mobilization, based upon a non-dimensional number, known as Shield's number, are defined in Table 4-1. The Shield's number is the ratio of shear forces acting on a sediment particle to the weight of the particle. Greater Shield's numbers indicate greater amounts of sediment movement. Various values of the Shield's number have been associated with sediment mobilization, and this study made an initial recommendation as to the value of the Shield's number for various degrees of mobilization. Field data need to be collected to verify the values in Table 4-1.

Table 4-1.
Categories of Sediment Mobilization

Shield's Number	Description
0.03	Slight Mobilization: There is a small, but measurable, sediment transport rate.
0.045	Significant Mobilization: Many particles are moving, and there is a significant sediment transport rate. Some sand is mobilized in the interstitial spaces of the bed.
0.06	Full Mobilization: Practically all the bed material is in motion, and there is significant reworking of river bed sediment and mobilization of sand within interstitial spaces.

The degree of mobilization between Alternative A and Baseline Conditions was analyzed using an index that is a measure of the time that the bed material experiences given degrees of mobilization. To develop this index, the fraction of sediment sample sites experiencing various degrees of mobilization was computed using the MEI hydraulic model (2002a), sediment sampling data in Attachment 1, and pebble counts from Stillwater Sciences (2003). Hydraulic conditions and bed mobility were analyzed at each site where sediment samples were collected. The fraction of sites experiencing specific amounts of mobilization was computed for a range of flows, and an empirical function was fit to the results. This empirical function was then used in conjunction with the simulated daily average flows from the Baseline and Alternative A conditions to compute the mobilization index.

4.3 Sediment Transport and Erosions/Deposition

The bed erosion and deposition from Friant Dam to Mendota Dam was analyzed and described in detail in Attachment 4, Sediment Transport Modeling Friant to Mendota. SRH-1D (Huang and Greimann 2007) was used to estimate erosion and deposition under Baseline and Project conditions. SRH-1D requires several types of input: hydrology data, geometry data, and sediment data. Hydrology data were obtained from the simulated daily average flows from the Baseline and Alternative A scenarios for the Historical hydrologic period from January 1, 1980, to September 30, 2003 (see Appendix H, "Modeling"). Geometry data were extracted from MEI (2002a), and sediment data were derived from the sampling efforts described in Attachment 1. Measured Historical stream gage data were also used to simulate the behavior of the river. Bed erosion and deposition from Mendota Dam to the Merced River were analyzed in a similar manner, as described in Attachment 5, Sediment Transport Modeling Mendota to Merced.

4.4 Vegetation

An analysis of vegetation response to flow regimes and mechanical actions of the alternatives is presented in Attachment 6, Vegetation Analysis. A vegetation module was added to the sediment transport program, SRH-1D, which uses the same hydrology, geometry, and sediment inputs described in Attachments 4 and 5. Vegetation parameters were also incorporated that describe six vegetation types: Fremont cottonwood (*Populus* *fremontii*), Goodings black willow (*Salix gooddingii*), narrow-leaf willow or sandbar willow (*Salix exigua*), scarlet wisteria or red sespania (*Sesbania punicea*), arundo or giant reed (*Arundo donax*), and a generic grass. Fremont cottonwood, Goodings black willow, and narrow-leaf willow represent native plants; red sespania and arundo represent invasive plants; and the generic grass is used to identify ground cover for high, dry areas. Grass is the only vegetation type not subject to desiccation in the models. Mechanics of the establishment, growth, and mortality of these vegetation types are tracked daily by SRH-1DV at every point of every cross section, over the period of the hydrologic record. One point in a cross section can support the growth of multiple vegetation types and represents the vegetative cover for the area surrounding the point. The plant productivity area is computed by independently summing the total area where each vegetation type grows and then summing areas of native or invasive plant types. Because each plant type is computed independently, the total native or total invasive plant productivity area can be as much as two (invasives – red sespania and arundo) to three (natives – cottonwood, black willow, and narrow-leaf willow) times larger than the actual predicted area in the field. The plant productivity area divided by reach length provides a second indicator (plant productivity width) to compare vegetation conditions between reaches of the river.

Both sediment models, Friant Dam to Mendota Pool and Mendota Pool to Merced, were used in the vegetation analysis to provide an assessment of vegetation response to program actions in Reaches 1 to 5. The greatest strength of this tool is in predictive comparisons, rather than predictions of absolute values. Quantitative values of plant productivity are sometimes presented as ratios or percentages based on total plant productivity predicted for Historical flow conditions. Predicted outcomes are therefore described as relative increases or decreases with respect to Historical Conditions.

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