DRAFT

Geomorphic Analysis for the San Joaquin River Reach 2B Alternative Evaluation

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A geomorphic analysis was performed by Tetra Tech, Inc., dba Mussetter Engineering (Tt-MEI) to assist the San Joaquin River Restoration Program (SJRRP) Project team in understanding the likely response of the river to the various levee setback and Mendota Pool Bypass alternatives in Reach 2B. The analysis considered the effects of changes in flow regime and upstream sediment load associated with the restoration releases on vertical and lateral stability of the existing channel. The analysis also considered the potential for adjustments in the size and character of the main channel under full restoration conditions. This memorandum describes the methods, assumptions and results of the analysis.

As noted in the Analysis Methodology Memorandum (Mussetter and Greimann, 2011), three different levels of detail can be applied to the analysis, depending on the specific objectives:

1. Screening level – the simplest and most basic level of analysis, used to screen a large number of alternatives (usually more than 5),

2. Feasibility level – used to identify the preferred alternative, usually performed on a reduced set of alternatives (usually less than 5), and

3. Design level – the last phase of the analysis, used to support the final design.

The analysis for this memorandum was performed primarily at the screening level.

VERTICAL STABILITY

Analysis Procedures and Assumptions

1. Vertical stability (i.e., aggradation/degradation tendency) is determined by the balance between the upstream sediment supply and the transport capacity of the reach. The transport capacity for any particular discharge is a function of the hydraulic conditions (i.e., velocity, depth, energy gradient, and resulting bed shear stress) and the bed-material size.
2. To facilitate analysis of the relative balance between the sediment supply and transport capacity in Reach 2B, a series of bed-material transport capacity rating curves were developed by subdividing the reach into six subreaches based on the locations of hydraulic controls and similarity of hydraulic conditions (**Figure 1**), developing subreach-averaged hydraulic conditions for each subreach, and estimating the bed-material transport capacity over the range of anticipated flows for each subreach based on the reach-averaged hydraulics and representative bed-material gradations.
3. The hydraulics in Reach 2B were developed based on results from the updated HEC-RAS models for each of the various levee setback and bypass alternatives (**Figures 2a through 2c**), and the hydraulics for the supply reach were developed from the updated Reach 2A model. The topography and bathymetry in these models was taken from the 2008 LiDAR

mapping, supplemented with in-channel bathymetry collected in 2008 by DWR in the portions of the reach that were wet when the LiDAR data were collected.

4. The sediment supply to Reach 2B is controlled by the amount of sediment that passes through the Chowchilla Bypass Bifurcation Structure. Hydraulic conditions and the bed-material transport capacity in the downstream portion of Reach 2A, and the relative amount of sediment that passes downstream into the river and Chowchilla Bypass, are affected by the water-surface elevations in Reach 2B and/or the Bypass, depending on the relative flow split at the Bifurcation Structure, particularly at high flows. Since the high-flow water-surface elevations at the head of Reach 2B for any particular discharge are different for the different levee setback conditions and bypass alternatives, it was necessary to develop a family of downstream hydraulic-control rating curves for the Reach 2A model for the range of discharges and flow splits in the flow records. The specific procedures used to develop these curves are described in detail in Tetra Tech, dba Mussetter Engineering, Inc. (Tt-MEI, 2010a).

5. Flow records used for the analysis were based on the daily disaggregated flows that were developed by MWH for Reclamation's sediment-transport analysis [Fut_Base-Sediment_Data.xls and Fut_Alt_A-Sediment_Data.xls for baseline (i.e., no-project), and project conditions, respectively]. The complete records in the file that was provided to Tt-MEI extend from January 1, 1980, through September 30, 2003. To facilitate development of annual averages, the portion of the record from January 1 through September 30, 1980, was not used in the analysis. The data used for the analysis, thus, represents 23 complete water years.

6. Bed-material sediment gradations used in the sediment-transport analysis were developed from the data collected by Reclamation in Reach 2A in 2008, and by Mussetter Engineering, Inc (MEI) in Reach 2B in 1998. Based on the composite of eight surface grab samples, the bed-material gradation in the approximately 8.5-mile portion of Reach 2A within the project levees is relatively consistent, with median (D_{50}) size of 0.66 mm, and D_{84} and D_{16} sizes of 0.29 and 1.62 mm, respectively (**Figures 3 and 4**). The only available bed-material sample in Reach 2B was collected by MEI in 1998 (MEI, 2002). The D_{50}, D_{84}, and D_{16} of this sample were 0.65, 2.5 and 0.2 mm, respectively, which is very similar to the composite gradation in the leveed portion of Reach 2A.

7. For consistency with the sediment-transport modeling that is being performed by Reclamation, bed-material transport capacity rating curves were developed for each subreach under each of the levee setback and bypass alternatives using the Engelund-Hansen (1967) total load relationship, as implemented in the USACE's SAMWin (2003) software package, with the associated subreach-averaged hydraulic conditions and the representative bed-material gradations.

8. The total volume of bed material transported through each portion of the reach was determined by integrating the respective transport capacity rating curves (i.e., relationship between discharge and transport capacity) over the 23-year period of mean daily flows.

9. The aggradation/degradation tendencies in Reach 2B under the various alternatives was evaluated by comparing the bed-material transport capacity with the supply passing through the Chowchilla Bypass Bifurcation Structure.

ANALYSIS RESULTS

1. In Reach 2A, the annual flow volume approaching the Chowchilla Bypass Bifurcation Structure averages about 413,000 ac-ft over the 23-year period under baseline conditions, and this increases by 32 percent to about 542,000 ac-ft under project conditions (**Figure 5**). The average annual flow volume at the head of Reach 2B increases from about 91,000 ac-ft under baseline conditions to nearly 412,000 ac-ft under project conditions, an approximately 450-percent increase.

2. In spite of the 32-percent increase in total flow volume, the amount of bed material transported through the downstream approximately 2-mile portion of Reach 2A to the Chowchilla Bypass Bifurcation Structure does not change significantly from baseline to project conditions, averaging slightly more than 90,000 tons/year under baseline conditions, and varying from about 83,000 to 90,000 tons for the various alternatives under the project conditions (**Figure 6**). The similarity in annual bed-material load between baseline and project conditions results from a significant re-distribution of the flow volume from high to low flows and the non-linearity of the transport capacity rating curves. Based on the flow records used for the analysis, the downstream portion of Reach 2A is dry nearly 60 percent of the time under baseline conditions, but the magnitude of high flows that are equaled or exceeded less than 10 percent of the time is greater than under project conditions (**Figure 7**). Conversely, this portion of the reach will carry flow throughout the year under project conditions, with minimum flow during the 23-year period of about 50 cfs and median flow of about 230 cfs. Under baseline conditions, nearly half the total flow volume through the reach occurs at discharges greater than 4,500 cfs and less than 3 percent of the volume occurs at discharges less than 500 cfs. Under project conditions, less than 30 percent of the volume occurs at discharges greater than 4,500 cfs and about 20 percent of the total flow volume occurs at discharges less than 500 cfs. The bed-material transport capacity varies with discharge raised to the 1.5 to 2 power; thus, a 10-percent increase in discharge will result in a 15- to 20-percent increase in transport capacity and a 25-percent increase in discharge will result in a 40- to 60-percent increase in transport capacity. The longer duration of high flows that carry proportionately more sediment under baseline conditions; thus, compensates for the increased volume and duration of lower flows under project conditions.

3. Although the total bed-material load in the lower portion of Reach 2A is similar under baseline and project conditions, the amount of that sediment that will be delivered through the Chowchilla Bypass Control Structure into Reach 2B will increase significantly under project conditions because of the increased amount of flow. Under the assumption that the sediment reaching the Control Structure will be split between the downstream river and the Chowchilla Bypass in direct proportion to the flow split, the average annual bed-material supply to Reach 2B is about 16,800 tons under baseline conditions, increasing to 44,000 tons (IAFP1[1]) to 49,000 tons (IAFP5) under the various project alternatives (Figure 6).

4. Integration of the transport capacity rating curves over the flow records indicates that the transport capacity through Reach 2B is slightly lower than the amount delivered through the Chowchilla Bypass Control Structure under baseline conditions and all of the project scenarios that were analyzed (**Figure 8**). Under baseline conditions, the average annual

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[1] IA refers to the Initial Alternative (aka Settlement Alignment for the Mendota Bypass Channel; Compact refers to the Compact Alignment for the Bypass Channel, and FSD refers to the Fresno Slough Dam Alternative. FP1 through FP5 refer to the narrowest to widest levee setback alternatives.

transport capacity varies from about 6,000 tons in Subreach 2B.3 to about 13,000 tons in Subreach 2B.2, or 64 to 22 percent less than the upstream supply. Under project conditions, the average annual transport capacities range from about 16,000 tons in Subreach 2B.4 for the Compact Alignment FP5 alternative to about 60,000 tons in this same subreach under the Fresno Slough Dam (FSD) FP1 alternative. These results indicate that short-term[2], average annual aggradation rates in Reach 2B will range from about 0.01 feet for the Settlement Alignment IAFP1 to about 0.06 feet the Compact Alignment FP5, and long-term[2] rates will range from 0.05 feet (IAFP1) to 0.11 feet (Compact FP1) (**Figure 9**). In general, the average transport capacity through Reach 2B is highest for the Fresno Slough Dam Alternatives and lowest for the Compact Alignment Alternatives, suggesting that the aggradational tendencies will be smallest for the Fresno Slough Dam Alternatives and largest for the Compact Alignment Alternatives. This result is reasonable considering that the average gradient of the reach from just below the Chowchilla Bypass Bifurcation Structure to the invert of the downstream hydraulic control (Mendota Bypass Control Structures or sill of Mendota Dam) is steepest for the Fresno Slough Dam Alternative (1.45 ft/mi), flattest for the Compact Alignment (1.01 ft/mi), and 1.1 ft/mi for the Settlement Alignment.

5. For each of the three bypass alternatives, the overall transport capacities tend to be highest and the aggradation rates lowest for the narrower levee setback alternatives (FP1), and the capacities tend to be lowest and aggradation rates be highest with the wider levee setback alternatives (FP5). This occurs because of the increased overbank conveyance and resulting reduction in main channel discharge at high flows with the wider levee setback. Similarly, the transport capacities tend to be lower and the aggradation rates higher for IAFP3 that calls for re-grading of portions of the overbanks to permit more inundation, than for IAFP2 that has the same levee setback alignment. Although the sediment-continuity analysis was not performed for the FP2 and FP3 setback alternatives for the Compact Alignment and Fresno Slough Dam, the relative differences are expected to be similar.

6. With a few exceptions, the transport capacities in Reach 2B for the various project alternatives are within about 25 percent of the estimated sediment supply to the head of the reach. Considering the general high level of uncertainty in estimates of the sediment-transport capacity and the amount of sediment that will actually pass through the Chowchilla Bypass Control Structure, these differences are not believed to be sufficient to cause systematic instability in the reach. In addition, the relatively subtle differences among the alternatives are related, at least in part, to the overall gradient of the reach that is established by the inverts of the control structures and the proposed San Mateo Road crossing that have been used for the feasibility-level designs. It may be possible to adjust these inverts during the detailed design phase to minimize the differences between the supply and capacity, while still maintaining an appropriate level of overbank inundation at high flows. It will also be very important to perform a more detailed assessment of the amount of sediment that will pass through the Chowchilla Bypass Control Structure, probably using 2-dimensional modeling, to refine the estimates of the upstream sediment supply to the reach.

[2] Short-term aggradation/degradation rates were estimated based on the difference between the transport capacity of each subreach with that of the next upstream subreach. Long-term rates were estimated based on the difference between the capacity of each subreach with the supply to the head of Reach 2B from the Chowchilla Bypass Control Structure, under the assumption that the reach will eventually adjust to this supply.

7. Based on the above analysis, no significant differences in vertical channel stability are anticipated among the various levee setback and bypass alternatives.

LATERAL MIGRATION POTENTIAL

1. An analysis of lateral migration potential and lateral channel stability under the various alternatives was performed by integrating a range of qualitative and quantitative techniques. Lateral stability can be strongly affected by the sediment balance in the reach because aggradation can lead to braiding and channel widening, and degradation can lead to oversteepened, unstable banks. It is important to understand, however, that lateral migration is a normal process in alluvial streams, even when they are in approximate equilibrium from a sediment balance perspective.

2. To gain a historical perspective on lateral erosion potential in the restoration reach, Reclamation compared the banklines on the 1938 and 2004 photographs and identified areas where significant change occurred or there appeared to be a high likelihood of significant change in the future (Greimann, 2008). The only site in Reach 2B identified in their analysis that met this criteria a narrow strip of overbank at the neck of the first meander bend downstream from the Chowchilla Bypass Bifurcation Structure (downstream limb at RM 214.5 and upstream limb at RM 215.8). Although this area has not eroded significantly during the period of available photography, the distance between the banklines across this neck is only about 280 feet (about one channel width); thus, the bend could cut off very rapidly if lateral erosion does occur at this location.

3. Recognizing that the duration and magnitude of flows in Reach 2B under restoration conditions will increase substantially, Tt-MEI (2010b) compared banklines on the 1998 and 2008 aerial photos and assessed other available information to identify potential lateral migration issues as part of an analysis for DWR to understand the potential impacts of the restoration flows on the flood-control system. The Tt-MEI (2010b) analysis identified 40 locations in Reach 2B where lateral erosion into the existing dominant levees could potentially occur under a new flow regime (even though very little erosion has occurred over the past several decades under the current flow regime) (**Figure 10**). Of these 40 sites, 21 were categorized as being low threat, 4 were high threat, and 15 need additional on-site evaluation before they can be categorized (**Table 1**). **It is important to note that the distance to listed levees in Table 1 is based on the location of the existing dominant levees, and the change in Bank Energy Index (BEI) values were determined based on comparison of the baseline (Fut_BASE) hydrology and estimates of the flow regime during the interim flow period.** In addition, the high threat ranking for Sites 221, 231, 235 and 237 is based on the very close proximity of the existing channel banks and the levees. These high ranking do not necessarily apply under the various levee setback alternatives for full restoration conditions.

4. The Tt-MEI (2010b) analysis was updated for this project by re-assessing the distance of each site to the proposed levees for each levee setback alternative and recalculating the change in BEI from baseline to full restoration (i.e., project) conditions using the Fut-AltA daily flow records, as described above for the sediment continuity analysis. In establishing the proposed levee alignments for the various setback alternatives, the project team specified a minimum distance of 300 feet from the existing top of bank to toe of the levee, except in special cases where existing infrastructure cannot reasonably be moved outside

the 300-foot zone. For the Settlement Alignment FP1 and FP2 alignments (Figure 2a), only Site 245, on the right bank at approximately RM 208.8 where the levee must stay between the river and the Pomona Canal, is less than the specified 300 feet. The levee alignments in this area would be the same under the Compact and Fresno Slough Dam alternative. In addition, most of the sites downstream from Site 246 are less than 300 feet from the levee under the Compact and Fresno Slough Dam alternatives.

5. As discussed above, the magnitude and duration of the full range of flows will increase significantly under full restoration conditions (Figure 5, **Figure 11**), and it is often typically flows in the range of one-half bankfull to bankfull that cause the most bank erosion. Under baseline conditions, the river in the part of Reach 2B outside the influence of Mendota Pool is dry nearly 80 percent of the time, flows exceed 400 cfs less 10 percent of the time and 1,100 cfs less than 5 percent of the time. Under restoration conditions, the minimum flow is greater than 50 cfs flows exceed 200 cfs over 50 percent of the time and 1,800 cfs, the approximate bankfull capacity, about 10 percent of the time. As a result of this increase, historical erosion rates (or lack of erosion) are not necessarily indicative of the anticipated erosion rates under restoration conditions.

   Although available analytical methods do not allow for detailed predictions of bank erosion rates, the Bank Energy Index (BEI) concept (Mussetter et al., 1995), in conjunction with information about the bank materials and other site characteristics, provides a means of quantifying the relative effects of changes in the flow regime associated with the restoration releases. The BEI is an index of the total energy applied to the banks at specific locations, and is computed based on the local hydraulic characteristics at each bend over the range of flows, the channel planform and the magnitude and duration of flows. Details of the computational procedures used to compute the BEI are included in Tt-MEI (2010b), although the analysis for that memo focuses on the changes under interim flow conditions. For purposes of this analysis, the change in BEI was estimated for each of the proposed Mendota Dam Bypass and levee setback alternatives using the project conditions hydrology records. As expected, the BEI values, and thus energy available to drive lateral erosion, increase significantly under project conditions. For the 33 sites upstream from the proposed Mendota Bypass Control Structure, the median ratio of BEI under project conditions to baseline conditions ranges from about 2.5 (Settlement FP5) to 4.4 for Fresno Slough Dam (FSD FP1), and the BEI increases by a factor of 10 or more at some sites (**Figure 12**). It is also interesting to note that the BEI actually decreases at some locations. In general, the greatest increases occur for the FP1 floodplain alignment because more flow is confined to the channel with the narrower levee setback and the smallest increases occur for the FP5 alignment because more flow is carried in the overbanks. The increase for Settlement FP3 is similar to the FP5 alternatives because the proposed high-flow channels have a similar impact on the amount of water conveyed in the main channel.

6. Based on the BEI results and the generally closer proximity of the levees to the existing channel, it is anticipated that the potential hazard due to lateral migration would be greatest for the FP1 alignments and wider setbacks.

Table 1 Summary of potential lateral erosion sites in Reach 2B under interim restoration flow conditions (modified from Tt-MEI, 2008, Table 4.3)											
Site	Representative Cross Section ID/Station	Bank Cover	Existing Bank Protection	Erosion Since 1998	Bend Radius	Bankful Top Width	Rc/Tw	Min Distance to **Existing** Levee	Length of Site	Change in Bank Energy Index[1]	Levee Erosion Threat Ranking
					(ft)	(ft)		(ft)	(ft)	(%)	
215	514775	Some Veg	No	Unclear	1276	165	7.7	10	1949	121	Check
216	508794	Some Veg	No	No	501	157	3.2	10	972	114	Check
217	507644	Some Veg	No	No	644	212	3.0	10	799	187	Check
218	506265	Light Veg	No	No	490	175	2.8	10	655	210	Check
219	505349	Veg	No	Unclear	369	140	2.6	20	914	183	Low
220	502614	Bare to Light Veg	No	Yes	681	167	4.1	10	718	154	High
221	502026	Bare to Light Veg	No	No	0	220	0.0	10	312	159	Check
222	501471	Light Veg	No	No	474	395	1.2	15	1134	143	Low
223	500616	Bare to Light Veg	No	No	1081	160	6.8	30	717	76	Low
224	499745	Some Veg	No	No	422	142	3.0	10	1193	119	Check
225	497737	Veg	No	Unclear	292	450	0.6	50	713	118	Low
226	497178	Veg	No	No	557	187	3.0	20	941	64	Low
227	495752	Some Veg	No	Yes (small)	0	227	0.0	10	1026	106	Check
228	494541	Some Veg	No	No	0	193	0.0	10	738	195	Low
229	491812	Veg	No	No	329	186	1.8	25	393	96	Low
230	491812	Veg	No	No	268	178	1.5	30	323	117	Low
231	490882	Light Veg	No	No	0	182	0.0	5	510	149	High
232	489900	Veg	No	No	340	217	1.6	10	513	137	Low
233	489900	Veg	No	No	0	217	0.0	20	352	137	Low
234	488185	Veg	No	Unclear	475	200	2.4	5	1457	167	Check
235	486414	Veg	No	Unclear	299	117	2.6	5	481	93	High
236	485851	Veg	No	No	272	155	1.8	10	899	108	Low
237	484767	Some Veg	No	Yes	305	151	2.0	5	861	137	High
238	484437	Some Veg	No	Unclear	0	183	0.0	5	737	71	Check
239	482399	Light Veg	No	Unclear	296	100	3.0	10	1078	71	Low
240	481666	Light Veg	No	No	688	151	4.5	5	425	132	Check
241	480974	Some Veg	No	Unclear	731	173	4.2	10	1105	159	Low
242	479440	Some Veg	No	No	615	118	5.2	5	1388	163	Check
243	478427	Veg	No	No	0	231	0.0	25	769	75	Low
244	478427	Light Veg	No	Unclear	578	231	2.5	5	769	75	Check
245	475615	Some Veg	No	No	918	173	5.3	5	2100	94	Low
246	474411	Light Veg	No	No	784	231	3.4	5	2006	98	Low
247	470917	Veg	No	No	439	218	2.0	25	713	87	Low
248	469289	Some Veg	No	No	557	203	2.7	10	1534	100	Low
249	465182	Bare to Light Veg	No	No	570	262	2.2	5	2045	37	Check
250	463075	Bare to Light Veg	No	No	1099	363	3.0	5	667	15	Check
251	462074	Light Veg	No	Yes (small)	1408	273	5.1	5	1297	24	Check
252	495605	Bare to Light Veg	No	No	0	240	0.0	5	1346	44	Low
253	458383	Bare to Light Veg	No	Unclear	0	625	0.0	5	1468	21	Low
254	456233	Bare to Light Veg	No	No	0	324	0.0	90	890	-18	Low

[1] Based on estimated **Interim** flows.

7. To provide a semi-quantitative comparison of the relative erosion hazard and the approximate cost to mitigate the hazard among the alternatives, the sites were ranked as having either “high” or “low” erosion potential under project conditions, based on a combination of the change in BEI value and the relative amount of existing vegetative cover on the affected bank as shown on the most recent (2008) aerial photographs. Similar to the procedure used in Tt-MEI (2010b), many of the sites were classified as “check” indicating that sufficient information is not available at this time to confidently ascertain the erosion-resistance of the bank vegetation and soils. To facilitate ranking of the alternatives, the “check” sites were treated as having erosion potential intermediate between the low and high sites. For purposes of quantifying the relative risk at the sites, weighting factors were assigned to the low, check and high risk sites of 0.25, 0.5 and 1.0, respectively. These factors are intended to represent the relative potential that substantial lateral erosion could occur at the site under project conditions that could impact a levee that is in relatively close proximity to the bank line (i.e., approximately 25 percent chance at the low risk sites, 50 percent chance at the check sites and nearly certain at the high-risk sites).

8. In assessing the erosion potential rankings, it is important to keep in mind that they are based, in part, on an assessment of the existing vegetative cover, as shown on the 2008 aerial photographs. With the additional flow that will occur in the reach, it is anticipated that a substantial riparian corridor will develop along the margins of the channel under restoration conditions. Based on the evaluation completed by MEI and EDAW (2009), the riparian corridor will develop between equivalent Friant Dam releases of 350 and 1,500 cfs, with the entire zone initially consisting of relatively thick, brushy plants (e.g., willows) with high roughness and erosion resistance. Eventually, the upper portion of this zone will mature and thin, with an associated decrease in hydraulic roughness. In areas where the bank slopes are sufficiently flat to permit the vegetation to establish, the erosion potential will decrease substantially. Where the banks are very steep (typically the outsides of eroding bends), the vegetation may not establish to the indicated density due to the instability of the slope. Although many of the identified erosion potential sites are on the outsides of bends, the anticipated changes in the riparian corridor should reduce the erosion potential. Because of the overall uncertainty in these conclusions, the changes in erosion potential have not been explicitly considered in the analysis, and the results are, therefore, conservative.

9. Since erosion at many of the identified sites would not present a hazard unless it actually cut into the levee section or damaged other infrastructure, and could provide positive ecological benefits by allowing natural adjustment of the channel, high erosion potential does not necessarily imply that the area should be protected. To account for the potential for erosion to negatively impact the levees, the minimum distance from the proposed levees under each alignment to the channel bank at each site was measured and categorized (**Table 2**). For purpose of this analysis, it was assumed that any locations where the existing bankline is within one channel width of the proposed levee would fall into the high hazard category, sites between 1 and 2 channel widths would be medium hazard and sites where the levees are more than two channel widths from the bankline would be low hazard. Similar to the erosion potential analysis, these categories were assigned weighting factors of 1.0, 0.5, and 0.25, respectively.

10. The approximate cost to install erosion protection at each of the identified sites was estimated using the Remedial Alternative Cost Estimate Report (RACER) tool that was developed for DWR’s Nonurban Levee Evaluation (NULE) study for rock revetment. The

relative cost of mitigating potential lateral erosion problems under each alternative was then estimated by multiplying the estimated cost of the protection by the erosion potential and proximity weighting factors described above (**Table 3**). Based on this analysis, the cost of providing lateral erosion protection for Fresno Slough Dam FP1 is highest (~$2.3M), and the lowest cost occurs for Settlement Alignment IAFP5 (only about $130,000) (**Figure 13**). As expected, the FP1 levee alignments will likely require the most protection because of the narrower levee setback corridor, and the Fresno Slough Dam and Compact Alignment require more protection than the Settlement alignment because some of the sites are located downstream from the Settlement Alignment Control Structure. It is recommended that these costs be used as the basis for the lateral erosion rankings in the Geomorphology section of the Alternative Evaluation Matrix.

STABLE CHANNEL DESIGN

As a general rule, it can be assumed that the cross sections in a fully-adjustable, alluvial channel will adjust so that the bankfull capacity is consistent with the effective discharge[3]. The size and capacity to which the main channel in Reach 2B will eventually adjust in response to the full restoration flows was assessed based on a combination of effective discharge analysis and results from the above sediment continuity analysis. The effective discharge was estimated based on the existing conditions bed material transport capacity rating curves and the baseline and project-conditions flow records discussed above using the procedures recommended by Biedenharn et al. (2000).

Integration of the bed material transport capacity rating curves for Subreach 2B.1 through 2B.4, that are near the head, or upstream from, the normal backwater influence of Mendota Dam, over the baseline-conditions mean daily flow duration curve (Figure 11) indicates a clear mode in the incremental bed material transport capacity rating curve, and thus, the effective discharge, at 1,500 cfs (**Figure 14**). Similar curves developed using the project-conditions flow duration curve show a significant (and typically, the highest) mode at 250 cfs, followed by a number of additional modes, the most significant of which is at 1,800 cfs (**Figure 15**). The 250 cfs mode corresponds to the sustained base flow releases under restoration conditions, and almost certainly does not represent a flow to which the overall main channel will adjust. Consistent with the riparian vegetation analysis by MEI and EDAW (2009), a low elevation, vegetated berm will probably develop at about this level under restoration conditions.

Based on the typical ground elevations at the outside toe of the existing interior levees, the existing bankfull capacity in the absence of the local levee would average about 1,600 cfs in Subreaches 2B.3 and 2B.4, the portion of the reach near the head, or upstream from, the normal backwater influence of Mendota Dam, and about 2,000 cfs between San Mateo Avenue and the CCBP Bifurcation Structure (Subreaches 2B.1 and 2B.3) (**Figure 16**).[4] These results

[3] Wolman and Miller (1960) defined the effective discharge as the discharge that carries the most sediment over a long period of time, and their analysis suggested that the effective discharge is a relatively frequent event that corresponds to approximately the bankfull discharge. Although much work has been done to validate and refine the concept over the roughly five decades since the original paper (e.g., Emmett and Wolman, 2001; Biedenharn, et al, 2000; Nash, 1994; Costa, 1995; Andrews, 1980), the basic concept remains the same, and it is now well accepted by fluvial geomorphologists and river engineers.

[4] It is interesting to note that the bankfull capacity in Reach 2B prior to much of the upstream flow regulation was about 2,500 cfs, based on a preliminary hydraulic analysis by Tt-MEI using the 1914 California Debris Commission maps. The 1914 mapping also indicates that the channel planform in Reach 2B is essentially the same today as it was nearly 100 year ago. The existing channel is, thus, only marginally smaller than it was in 1914.

indicate that, in absence of channel degradation, the channel capacity may increase slightly downstream from San Mateo Avenue from the current ~1,500 cfs to about 1,600 cfs. Upstream from San Mateo Avenue, the existing bankfull capacity is greater than the effective discharge under project-conditions; thus, enlargement of the main channel cross sections is not anticipated.

Based on the above sediment continuity analysis, the Reach 2B is expected to be slightly aggradation under full restoration conditions if the proposed structures are constructed with the invert elevations that have been proposed in the feasibility-level designs; thus, the channel bed is expected to remain at about the same elevation or increase by a small amount. With the average bed at about the same elevation under restoration conditions, the channel in Subreaches 2B.3 and 2B.4 may widen by a small amount to accommodate the higher effective discharges. Assuming the bed remains at about the same level and the bankfull depth remains the same, the channel would need to widen by 15 to 20 feet to accommodate the additional approximately 200 cfs. This increase is only about 5 to 7 percent of the existing width, and likely within the uncertainty bands on the analysis

This analysis indicates that the size of the main channel in Reach 2B will not change significantly from its existing size under full restoration conditions if the bifurcation structure for the Compact or Settlement Alignments and San Mateo Avenue are constructed at the elevations proposed in the feasibility-level design. The degradation that will occur in Subreaches 2B.3 and 2B.4 under the Fresno Slough Dam alternative due to the lower baselevel control provided by the Mendota Dam Sill will increase the channel capacity downstream from San Mateo Avenue, and the changes associated with the degradation will most likely overshadow any changes that would occur due to the changes in flow and the effects of those changes on the effective discharge.

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Table 2 Summary of potential lateral erosion sites in Reach 2B under full restoration conditions

Site	Representative Cross Section ID/Station	Bank Cover	Existing Bank Protection	Erosion Since 1998	Bend Radius	Bankful Top Width	Rc/Tw	Length of Site[1]	Min Distance to Existing Levee	Minimum Distance to Proposed Levee (feet)[2]								
					(ft)	(ft)		(ft)	(ft)	Settlement FP1	Settlement FP2	Settlement FP3	Settlement FP4	Settlement FP5	Compact FP1	Compact FP5	FSD FP1	FSD FP5
215	514775	Some Veg	No	Unclear	1276	165	7.7	1500	10	50	50	50	200	200	50	200	50	200
216	508794	Some Veg	No	No	501	157	3.2	972	10	300	330	330	330	330	300	330	300	330
217	507644	Some Veg	No	No	644	212	3.0	799	10	300	400	400	470	470	300	470	300	470
218	506265	Light Veg	No	No	490	175	2.8	655	10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
219	505349	Veg	No	Unclear	369	140	2.6	914	20	920	920	920	1600	1600	920	1600	920	1600
220	502614	Bare to Light Veg	No	Yes	681	167	4.1	718	10	400	400	400	1400	2250	400	2250	400	2250
221	502026	Bare to Light Veg	No	No	0	220	0.0	312	10	400	1100	1100	1900	1900	400	1900	400	1900
222	501471	Light Veg	No	No	474	395	1.2	1134	15	300	375	375	740	1500	300	1500	300	1500
223	500616	Bare to Light Veg	No	No	1081	160	6.8	717	30	300	850	850	1500	1600	300	1600	300	1600
224	499745	Some Veg	No	No	422	142	3.0	1193	10	300	300	300	n/a	n/a	300	n/a	300	n/a
225	497737	Veg	No	Unclear	292	450	0.6	713	50	300	680	680	2800	2800	300	2800	300	2800
226	497178	Veg	No	No	557	187	3.0	941	20	300	320	320	350	1600	300	1600	300	1600
227	495752	Some Veg	No	Yes (small)	0	227	0.0	1026	10	420	1150	1150	n/a	n/a	420	n/a	420	n/a
228	494541	Some Veg	No	No	0	193	0.0	738	10	320	320	320	320	n/a	320	n/a	320	n/a
229	491812	Veg	No	No	329	186	1.8	393	25	350	n/a	n/a	n/a	n/a	350	n/a	350	n/a
230	491812	Veg	No	No	268	178	1.5	323	30	350	n/a	n/a	n/a	n/a	350	n/a	350	n/a
231	490882	Light Veg	No	No	0	182	0.0	510	5	400	750	750	n/a	n/a	400	n/a	400	n/a
232	489900	Veg	No	No	340	217	1.6	513	10	375	490	490	1550	1650	375	1650	375	1650
233	489900	Veg	No	No	0	217	0.0	352	20	400	490	490	1550	1650	400	1650	400	1650
234	488185	Veg	No	Unclear	475	200	2.4	1457	5	350	350	350	750	2800	350	2800	350	2800
235	486414	Veg	No	Unclear	299	117	2.6	481	5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
236	485851	Veg	No	No	272	155	1.8	899	10	300	750	750	750	2400	300	2400	300	2400
237	484767	Some Veg	No	Yes	305	151	2.0	861	5	300	820	820	820	1900	300	1900	300	1900
238	484437	Some Veg	No	Unclear	0	183	0.0	737	5	435	n/a	n/a	n/a	n/a	435	n/a	435	n/a
239	482399	Light Veg	No	Unclear	296	100	3.0	1078	10	300	n/a	n/a	n/a	n/a	300	n/a	300	n/a
240	481666	Light Veg	No	No	688	151	4.5	425	5	300	300	300	1000	n/a	300	n/a	300	n/a
241	480974	Some Veg	No	Unclear	731	173	4.2	1105	10	300	440	440	630	1740	300	1740	300	1740
242	479440	Some Veg	No	No	615	118	5.2	1388	5	330	330	330	1150	3000	330	3000	330	3000
243	478427	Veg	No	No	0	231	0.0	769	25	250	350	350	n/a	n/a	250	n/a	250	n/a
244	478427	Light Veg	No	Unclear	578	231	2.5	769	5	420	n/a	n/a	n/a	n/a	420	n/a	420	n/a
245	475615	Some Veg	No	No	918	173	5.3	2100	5	50	50	50	200	200	50	200	50	200
246	474411	Light Veg	No	No	784	231	3.4	2006	5	400	900	900	900	900	400	900	400	900
247	470917	Veg	No	No	439	218	2.0	713	25	n/a	n/a	n/a	n/a	n/a	100	100	100	100
248	469289	Some Veg	No	No	557	203	2.7	1534	10	n/a	n/a	n/a	n/a	n/a	100	100	100	100
249	465182	Bare to Light Veg	No	No	570	262	2.2	2045	5	n/a	n/a	n/a	n/a	n/a	10	n/a	10	n/a
250	463075	Bare to Light Veg	No	No	1099	363	3.0	667	5	n/a	n/a	n/a	n/a	n/a	10	440	10	440
251	462074	Light Veg	No	Yes (small)	1408	273	5.1	1297	5	n/a	n/a	n/a	n/a	n/a	10	10	10	10
252	495605	Bare to Light Veg	No	No	0	240	0.0	1346	5	n/a	n/a	n/a	n/a	n/a	10	10	10	10
253	458383	Bare to Light Veg	No	Unclear	0	625	0.0	1468	5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	10	450
254	456233	Bare to Light Veg	No	No	0	324	0.0	890	90	n/a	n/a	n/a	n/a	n/a	n/a	n/a	10	10

[1] Site 215 modified from Tt-MEI (2010b) analysis to represent upstream right bank at the neck of the meander bend.
[2] n/a indicates bend would be unlikely to impact levees, even after significant lateral migration due to levee and channel alignment.

Tabble 3. Sumnmary of risk rating factors and costs for protecting erosion sites under the various Mendota Bypass and levee setback alternatives.

Site	Full Restoration	Total Cost						Proximity Rating					Weighted Cost								
Site	Full Restoration Levee Erosion Threat Ranking	FP1	FP2	FP3	FP4	FP5	Erosion Potential Factor	FP1	FP2	FP3	FP4	FP5	IAFP1	IAFP2	IAFP3	IAFP4	IAFP5	Compact FP1	Compact FP5	FSD FP1	FSD FP5
215	High						1	1	1	1	0.5	0.5	$ 35,538	$ 35,538	$ 35,538	$ 35,538	$ 35,538	$ 35,538	$ 35,538	$ 35,538	$ 35,538
216	Check	$402,453	$ 402,453	$402,453	$289,896	$ 289,896	0.5	0.5	0.3	0.3	0.3	0.25	$ 100,613	$ 50,307	$ 50,307	$ 36,237	$ 36,237	$ 100,613	$ 36,237	$ 100,613	$ 36,237
217	Check	$233,385	$ 233,385	$233,385	$ 87,611	$ 87,611	0.5	0.5	0.5	0.5	0.3	0.25	$ 58,346	$ 58,346	$ 58,346	$ 10,951	$ 10,951	$ 58,346	$ 10,951	$ 58,346	$ 10,951
218	High						1											$ -	$ -	$ -	$ -
219	Low						0.25	0.3	0.3	0.3	0.3	0.25						$ -	$ -	$ -	$ -
220	High	$209,783	$ 209,783	$209,783			1	0.3	0.3	0.3	0.3	0.25	$ 52,446	$ 52,446	$ 52,446			$ 52,446	$ -	$ 52,446	$ -
221	Check	$106,212	$ 106,212	$106,212			0.5	0.5	0.3	0.3	0.3	0.25	$ 26,553	$ 13,277	$ 13,277			$ 26,553	$ -	$ 26,553	$ -
222	Low	$662,398	$ 662,398	$662,398	$146,019		0.25	1	1	1	0.5	0.25	$ 165,599	$ 165,599	$ 165,599	$ 18,252		$ 165,599	$ -	$ 165,599	$ -
223	Low	$174,522	$ 174,522	$174,522	$ 60,860		0.25	0.5	0.3	0.3	0.3	0.25	$ 21,815	$ 10,908	$ 10,908	$ 3,804		$ 21,815	$ -	$ 21,815	$ -
224	Check	$609,642	$ 383,345	$383,345			0.5	0.3	0.3	0.3			$ 76,205	$ 47,918	$ 47,918			$ 76,205	$ -	$ 76,205	$ -
225	Low						0.25	1	0.5	0.5	0.3	0.25						$ -	$ -	$ -	$ -
226	Low	$320,867	$ 320,867	$320,867	$ 85,219		0.25	0.5	0.5	0.5	0.5	0.25	$ 40,108	$ 40,108	$ 40,108	$ 10,652		$ 40,108	$ -	$ 40,108	$ -
227	Check	$424,936					0.5	0.5	0.3	0.3			$ 106,234					$ 106,234	$ -	$ 106,234	$ -
228	Low	$269,633	$ 269,633	$269,633	$269,633		0.25	0.5	0.5	0.5	0.5		$ 33,704	$ 33,704	$ 33,704	$ 33,704		$ 33,704	$ -	$ 33,704	$ -
229	Low	$229,757					0.25	0.5					$ 28,720					$ 28,720	$ -	$ 28,720	$ -
230	Low	$188,913					0.25	0.5					$ 23,614					$ 23,614	$ -	$ 23,614	$ -
231	Check	$148,885	$ 148,885	$148,885			0.5	0.3	0.3	0.3			$ 18,611	$ 18,611	$ 18,611			$ 18,611	$ -	$ 18,611	$ -
232	Low	$249,848	$ 249,848	$249,848			0.25	0.5	0.3	0.3	0.3	0.25	$ 31,231	$ 15,616	$ 15,616			$ 31,231	$ -	$ 31,231	$ -
233	Low	$171,340	$ 171,340	$171,340			0.25	0.5	0.3	0.3	0.3	0.25	$ 21,417	$ 10,709	$ 10,709			$ 21,417	$ -	$ 21,417	$ -
234	Check	#########	$ 625,373	$625,373			0.5	0.5	0.5	0.5	0.3	0.25	$ 267,907	$ 156,343	$ 156,343			$ 267,907	$ -	$ 267,907	$ -
235	High						1											$ -	$ -	$ -	$ -
236	Low	$372,446	$ 372,446	$372,446	$372,446		0.25	0.5	0.3	0.3	0.3	0.25	$ 46,556	$ 23,278	$ 23,278	$ 23,278		$ 46,556	$ -	$ 46,556	$ -
237	High	$502,709	$ 502,709	$502,709	$292,038		1	0.5	0.3	0.3	0.3	0.25	$ 251,355	$ 125,677	$ 125,677	$ 73,009		$ 251,355	$ -	$ 251,355	$ -
238	Check	$466,241					0.5	0.3					$ 58,280					$ 58,280	$ -	$ 58,280	$ -
239	Low	$340,818					0.25	0.3					$ 21,301					$ 21,301	$ -	$ 21,301	$ -
240	Check	$206,792	$ 158,237	$158,237			0.5	0.5	0.5	0.5	0.3		$ 51,698	$ 39,559	$ 39,559			$ 51,698	$ -	$ 51,698	$ -
241	Low	$361,512	$ 361,512	$361,512	$361,512		0.25	0.5	0.3	0.3	0.3	0.25	$ 45,189	$ 22,595	$ 22,595	$ 22,595		$ 45,189	$ -	$ 45,189	$ -
242	Check	$574,773	$ 134,594	$134,594			0.5	0.3	0.3	0.3	0.3	0.25	$ 71,847	$ 16,824	$ 16,824			$ 71,847	$ -	$ 71,847	$ -
243	Low	$337,139	$ 153,438	$153,438			0.25	0.5	0.5	0.5			$ 42,142	$ 19,180	$ 19,180			$ 42,142	$ -	$ 42,142	$ -
244	Check	$103,534					0.5	0.5					$ 25,884					$ 25,884	$ -	$ 25,884	$ -
245	Low	$664,561	$ 664,561	$664,561	$379,749	$ 379,749	0.25	1	1	1	0.5	0.5	$ 166,140	$ 166,140	$ 166,140	$ 47,469	$ 47,469	$ 166,140	$ 47,469	$ 166,140	$ 47,469
246	Low	$365,162					0.25	0.5	0.3	0.3	0.3	0.25	$ 45,645					$ 45,645	$ -	$ 45,645	$ -
247	Low	$ 12,172				$ 347,332	0.25	1				1								$ 219,097	$ 1,217
248	Low	$876,389				$ 4,869	0.25	1				1								$ 147,227	$ 481,834
249	Check	$294,454				$ 963,667	0.5	1				1								$ 1,217	$ 66,946
250	Check	$ 2,434				$ 267,785	0.5	1				0.5								$ 1,278	$ 1,278
251	Check	$ 2,556				$ 2,556	0.5	1				1									
252	Low						0.25	0				0								$ 669	
253	Low	$ 2,677					0.25	1				0									
254	Low						0.25	0				0								$ 1,825	$ 1,825
247	Low	$ 7,301				$ 7,301	0.25	1				1						$ 1,825	$ 1,825.24		
248	Low	$613,579				$ 3,409	0.25	1				1						$ 153,395	$ 852.19		
249	Check	$254,451				$ 832,749	0.5	1				1						$ 127,226	$ 416,374.60		
250	Check	$ 1,460				$ 160,621	0.5	1				0.5						$ 730	$ 40,155.19		
251	Check	$ 1,826				$ 1,826	0.5	1				1						$ 913	$ 913.24		
												Total Weighted Cost	**$ 1,935,000**	**$ 1,123,000**	**$ 1,123,000**	**$ 315,000**	**$ 130,000**	**$ 2,219,000**	**$ 590,000**	**$ 2,306,000**	**$ 683,000**

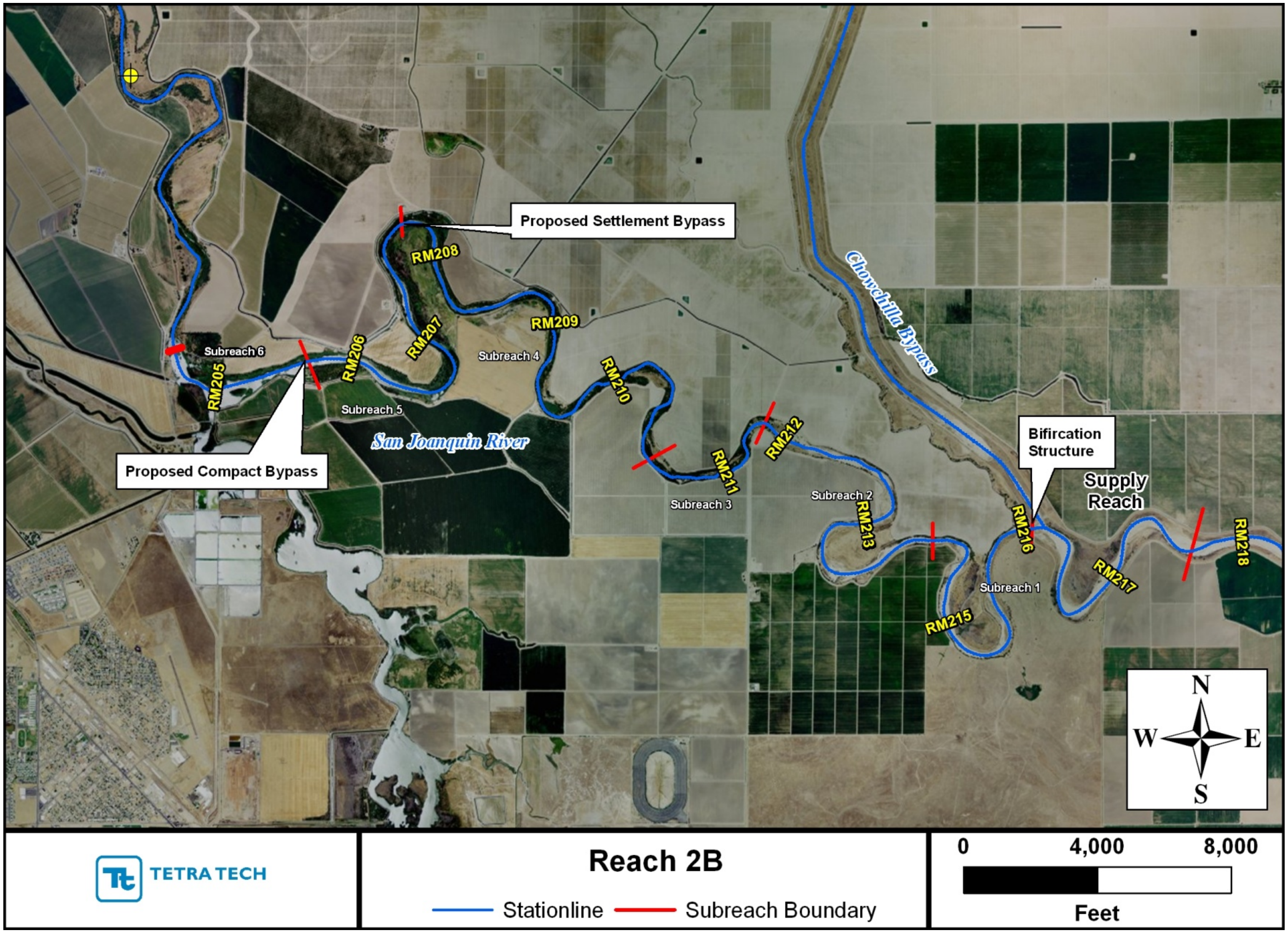

Figure 1. Planview of San Joaquin River Reach 2B showing the subreach delineations used for the vertical stability analysis.

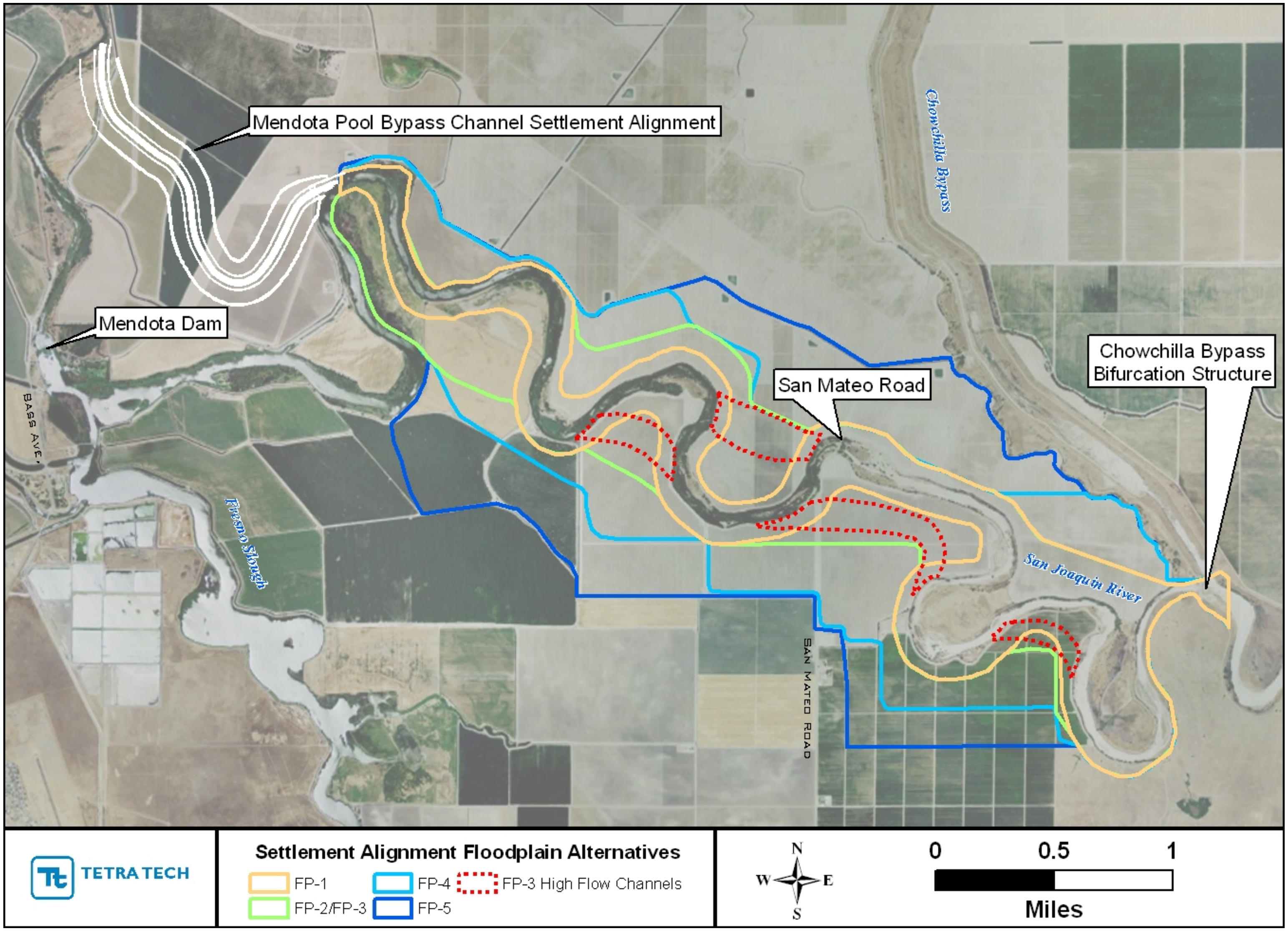

Figure 2a. Planview of Reach 2B showing the various levee setback alternatives associated with the Mendota Pool Bypass Channel Settlement Alignment.

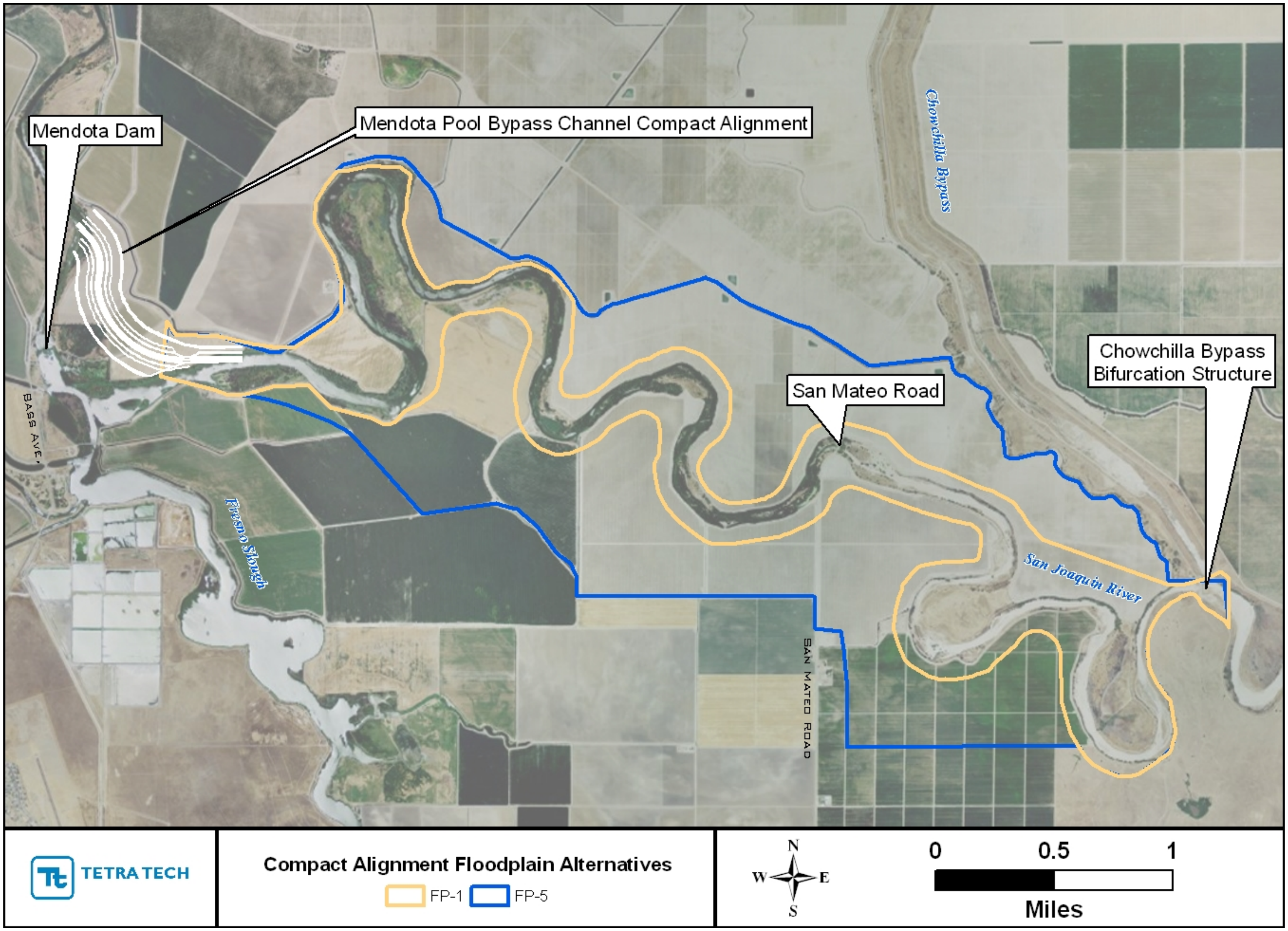

Figure 2b. Planview of Reach 2B showing the various levee setback alternatives associated with the Mendota Pool Bypass Channel Compact Alignment.

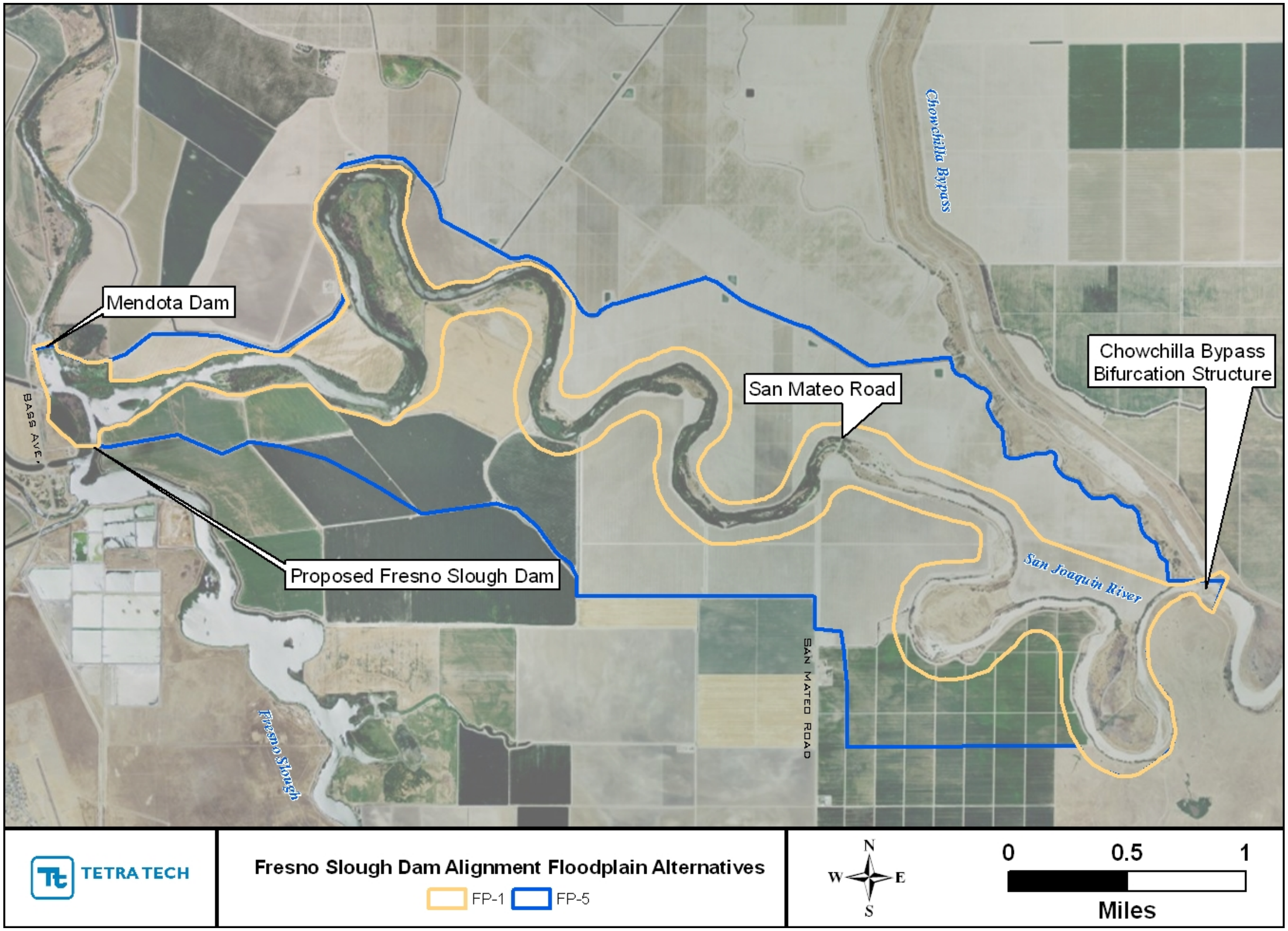

Figure 2c. Planview of Reach 2B showing the various levee setback alternatives associated with the Fresno Slough Dam Alternative.

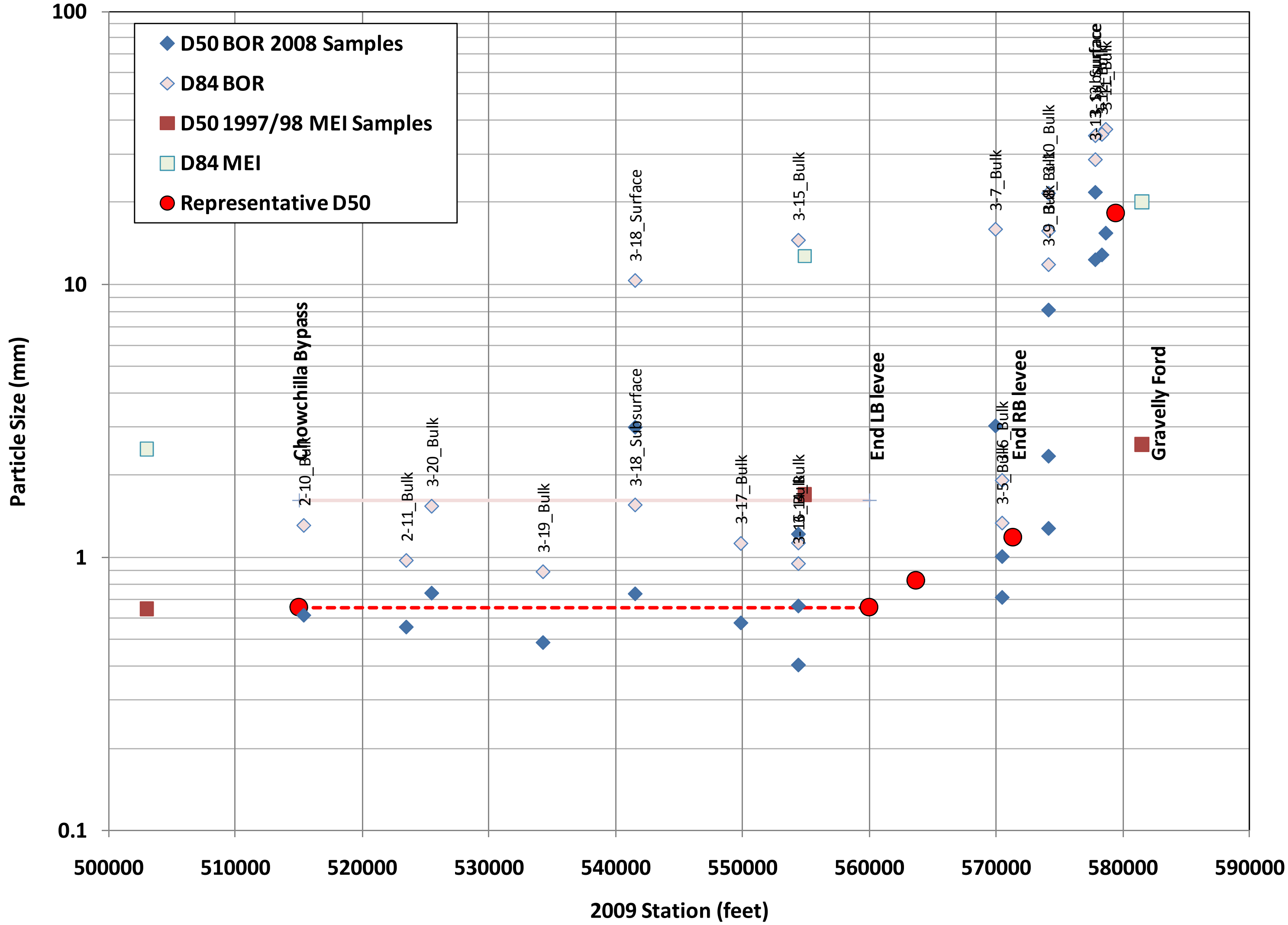

Figure 3. Median (D_{50}) and D_{84} sizes of bed material samples collected in Reach 2A by Reclamation in 2008 and in Reach 2B by Mussetter Engineering, Inc. in 1998.

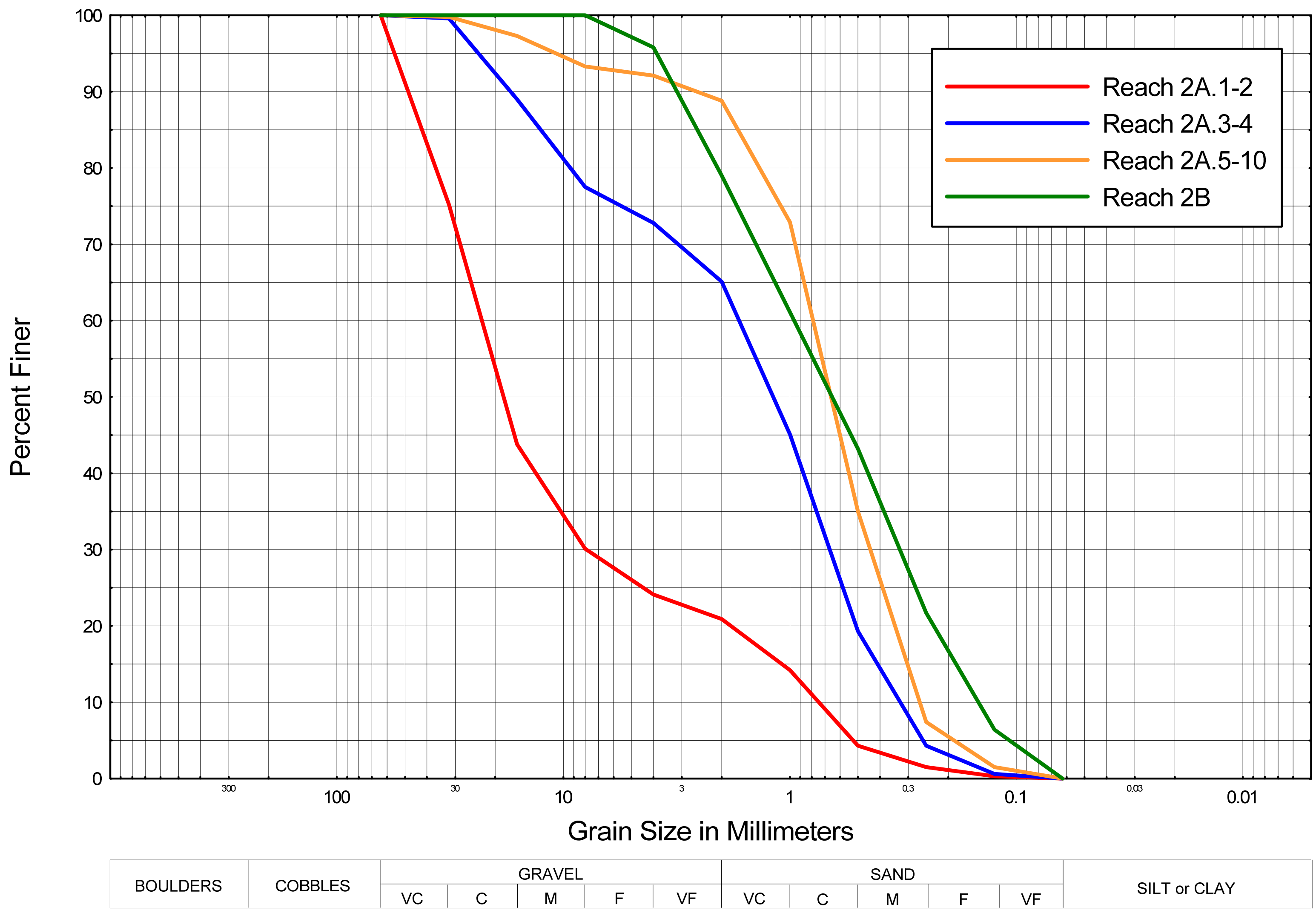

Figure 4. Representative bed-material gradations for the lower end of Reaches 2A and 2B used in the sediment-transport analysis.

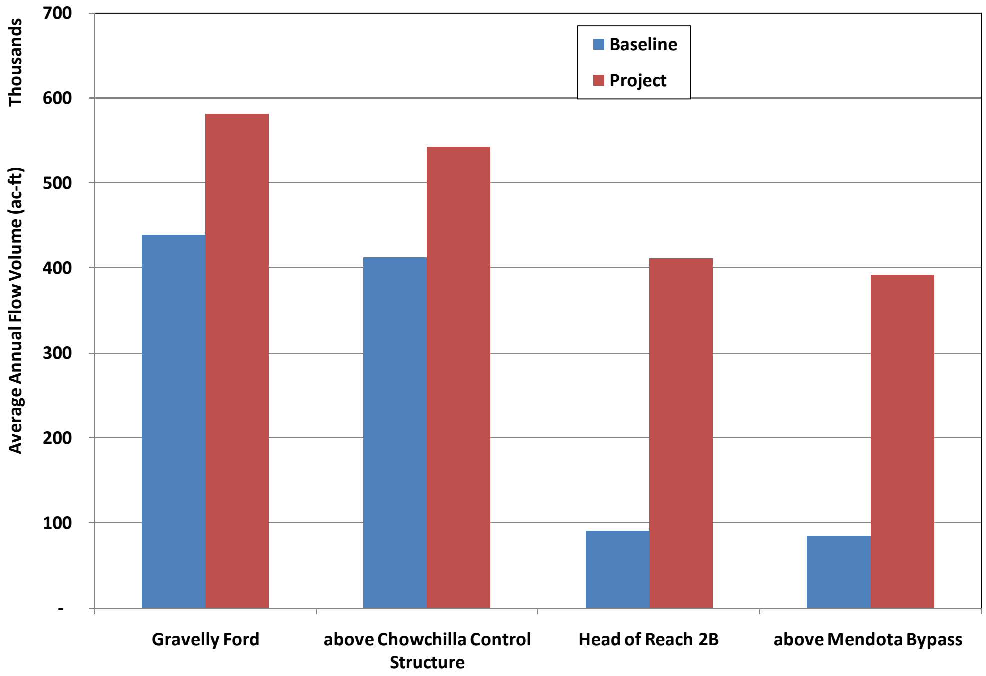

Figure 5. Average annual flow volume at various locations in Reaches 2A and 2B under baseline and project conditions based on the daily disaggregated flow records used for the analysis.

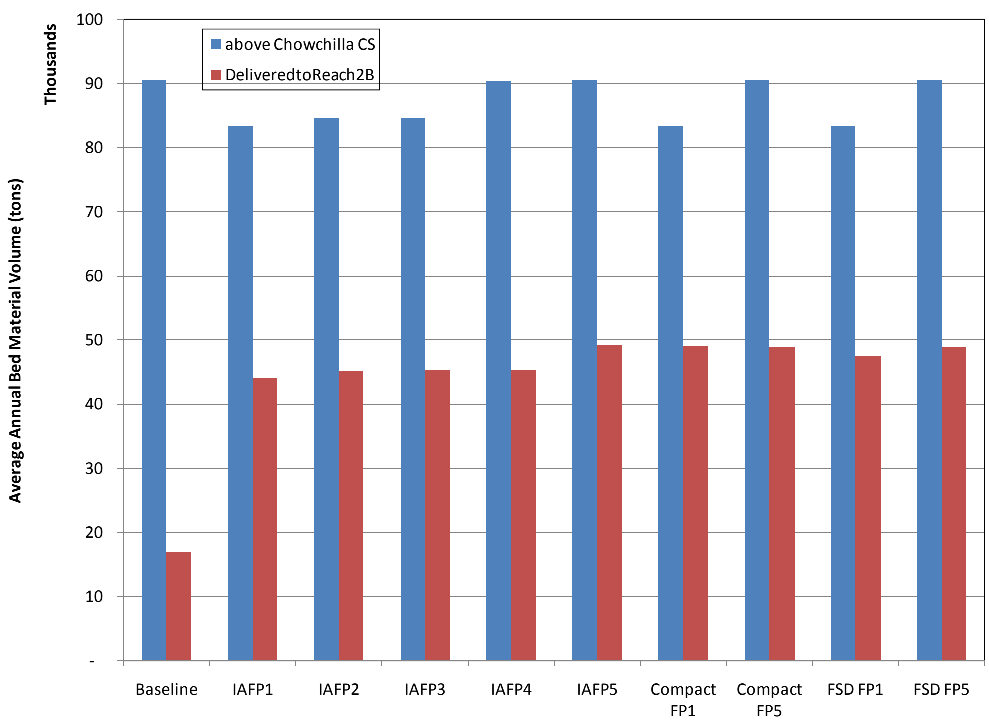

Figure 6. Average annual bed material transport capacity in the approximately 1.7-mile portion of Reach 2A just upstream from the Chowchilla Bypass Control Structure under baseline and various levee-setback and Mendota Dam Bypass Alternatives. Also shown is the estimated, average annual bed material load delivered through the Control Structure into Reach 2B.

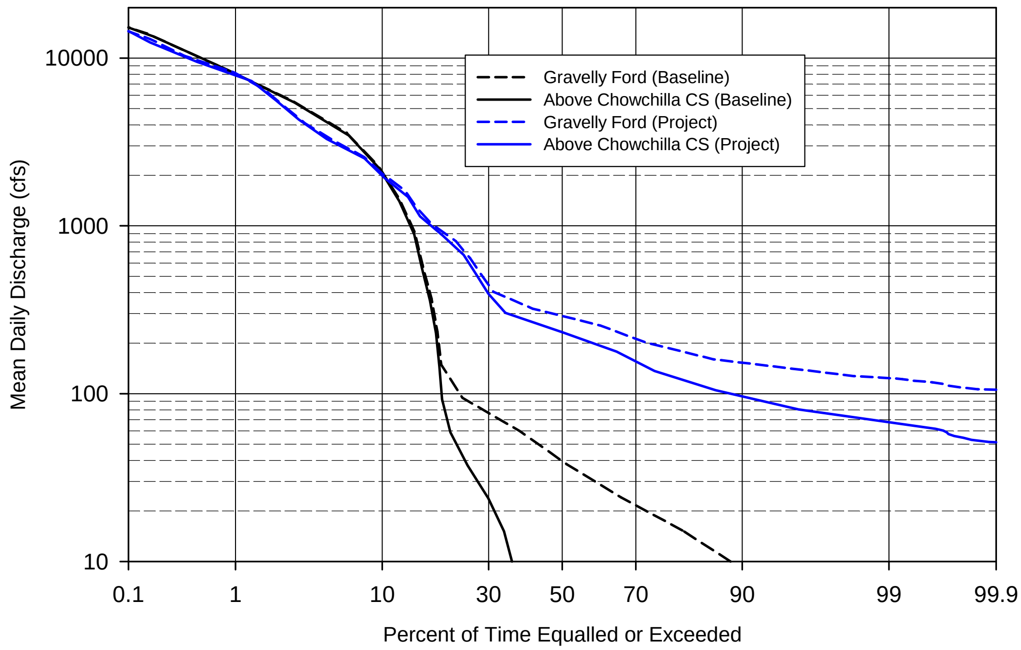

Figure 7. Mean daily flow-duration curves in the San Joaquin River at Gravelly Ford and above the Chowchilla Bypass Control Structure under baseline and project conditions, based on the 23-year record of estimated mean daily flows.

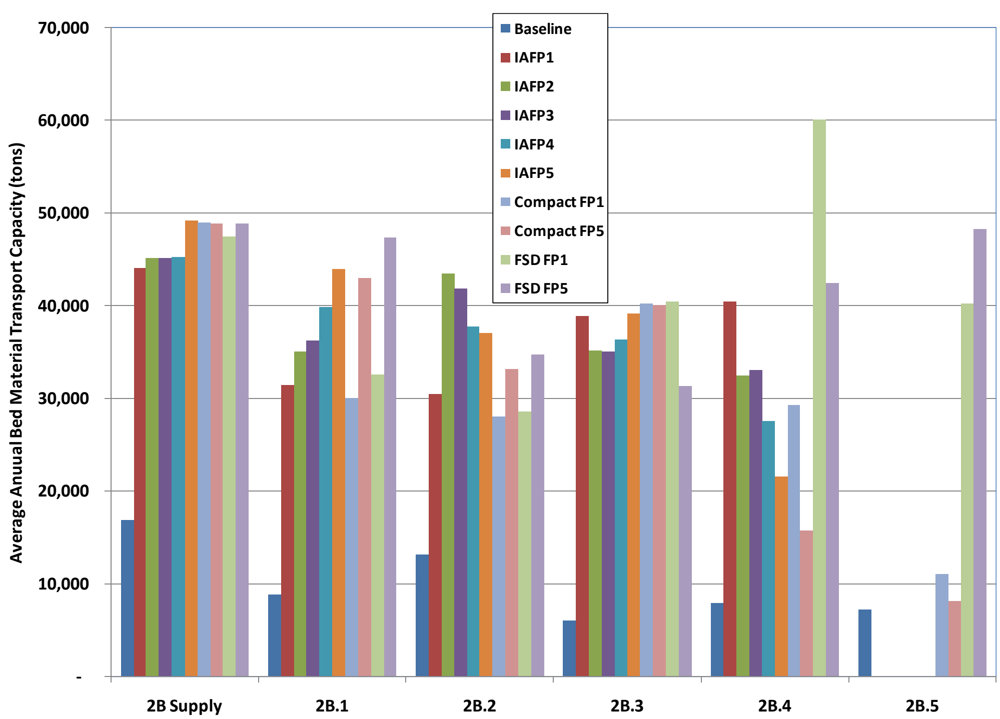

Figure 8. Average annual bed-material transport capacity in Subreaches 2B.1 through 2B.5 under baseline and project alternatives.

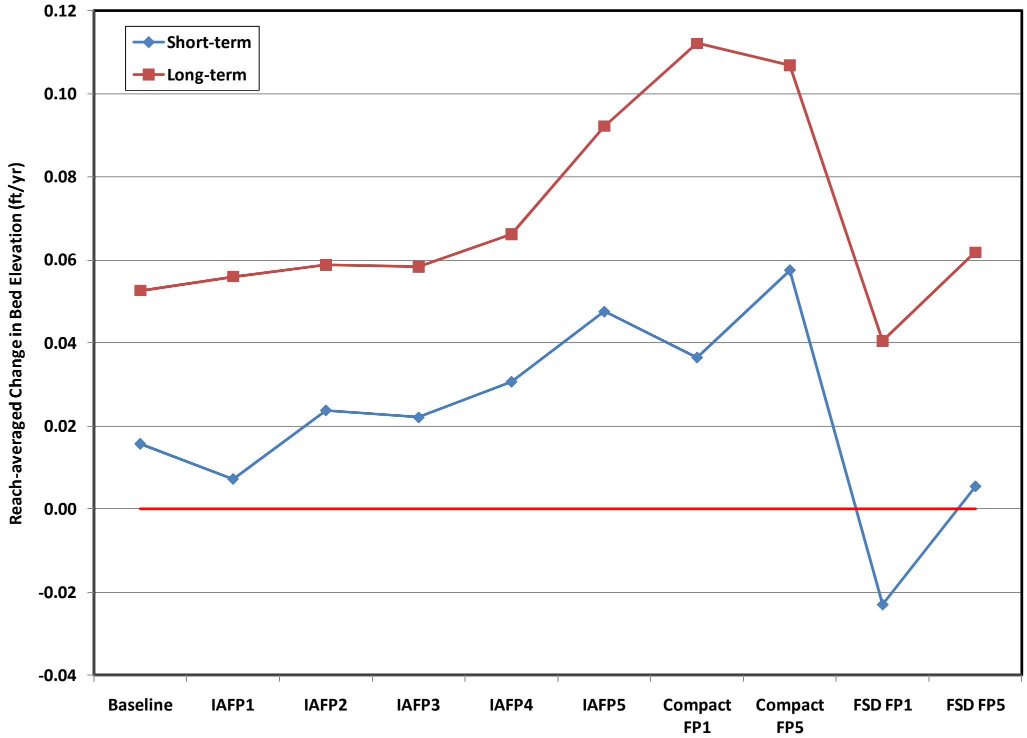

Figure 9. Average annual change in bed elevation in Reach 2B under baseline and a range of project conditions.

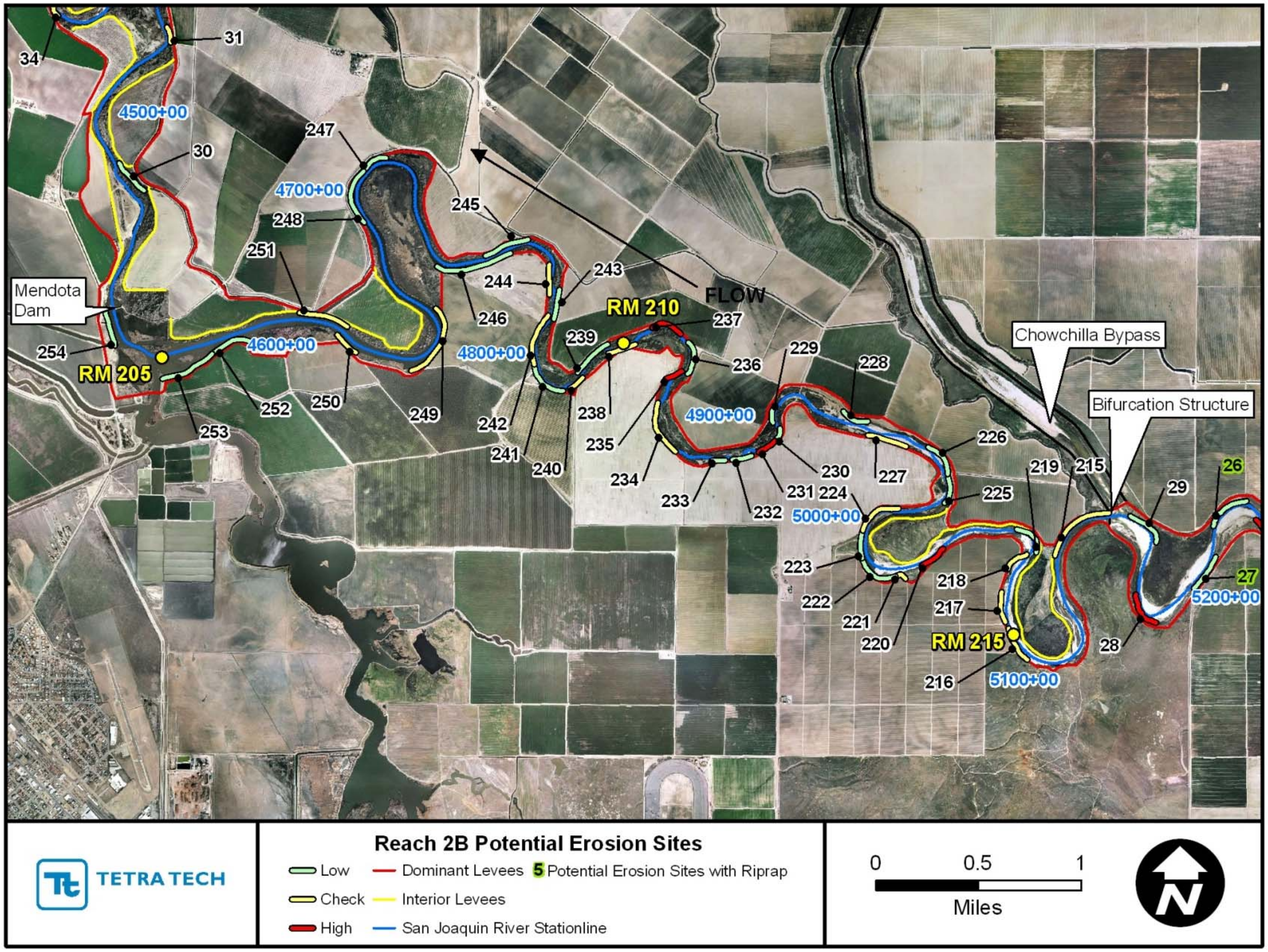

Figure 10. Aerial map showing potential lateral bank erosion sites in Reach 2B.

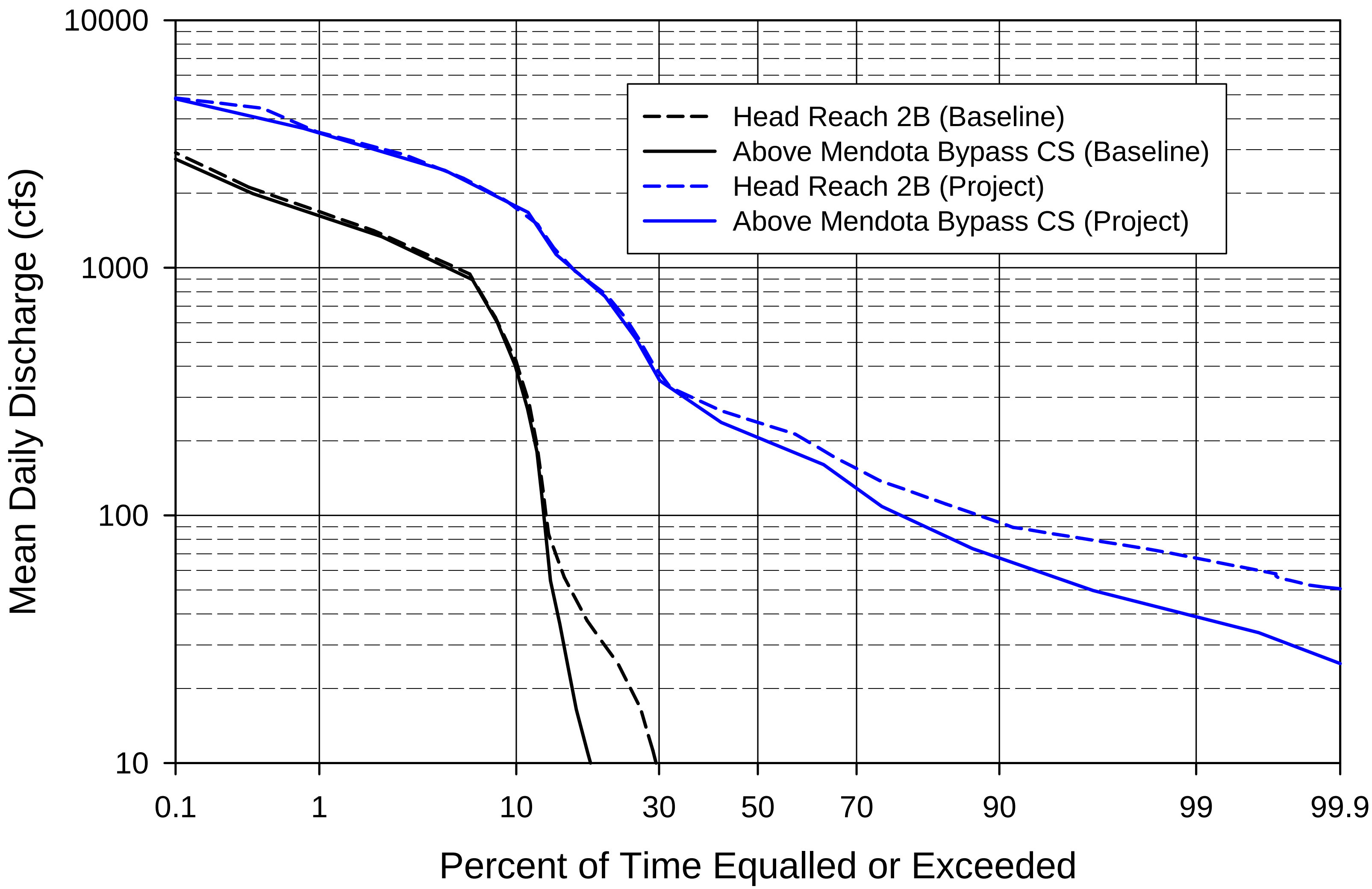

Figure 11. Mean daily flow-duration curves in the San Joaquin River at the head of Reach 2B and above the proposed Mendota Bypass Control Structure under baseline and project conditions, based on the 23-year record of estimated mean daily flows.

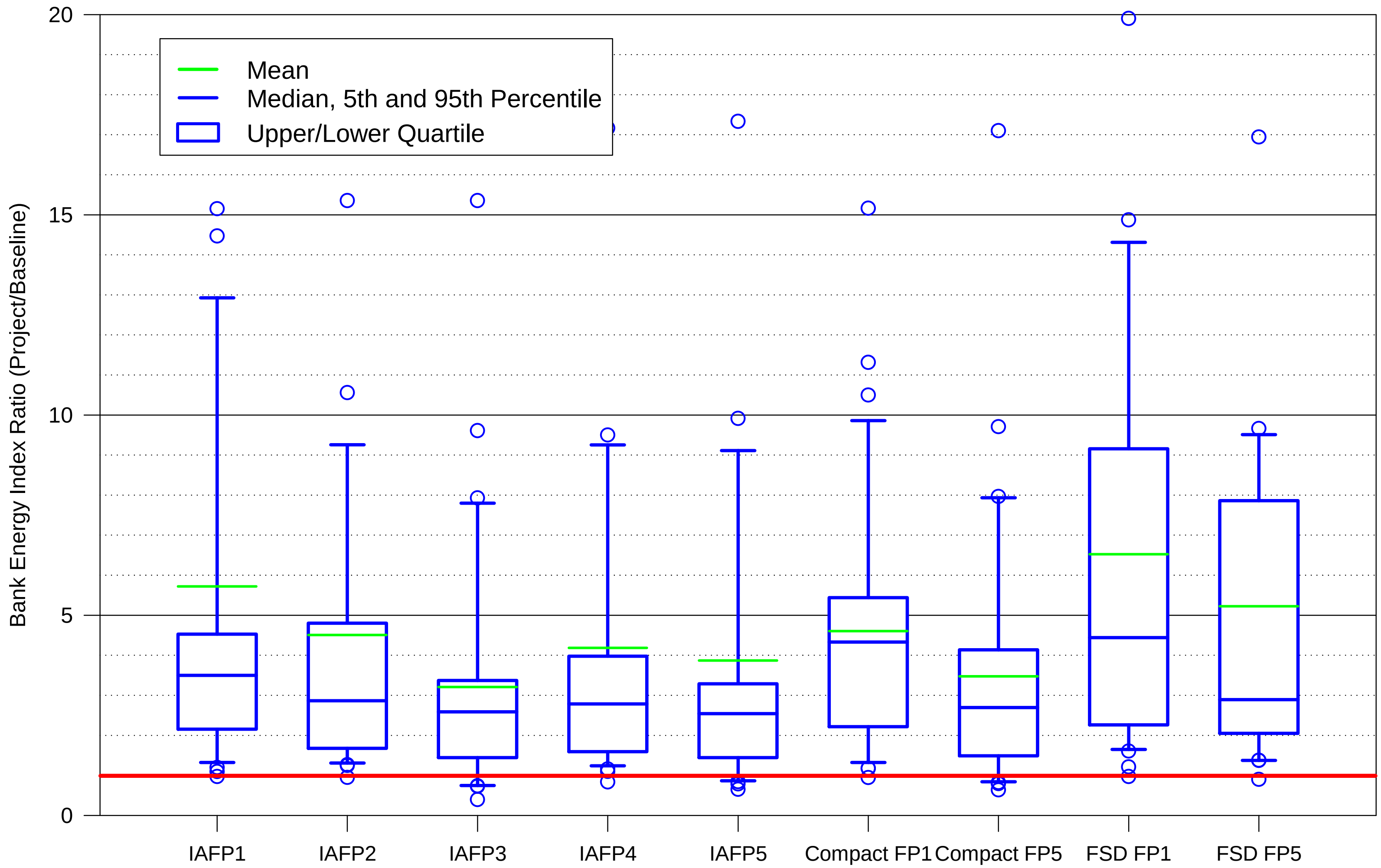

Figure 12. Statistical summary of ratio of Bank Energy Index (BEI) under project conditions to the BEI under baseline conditions for the 33 potential erosion sites in Reach 2B upstream from the proposed Mendota Bypass Channel Control Structure.

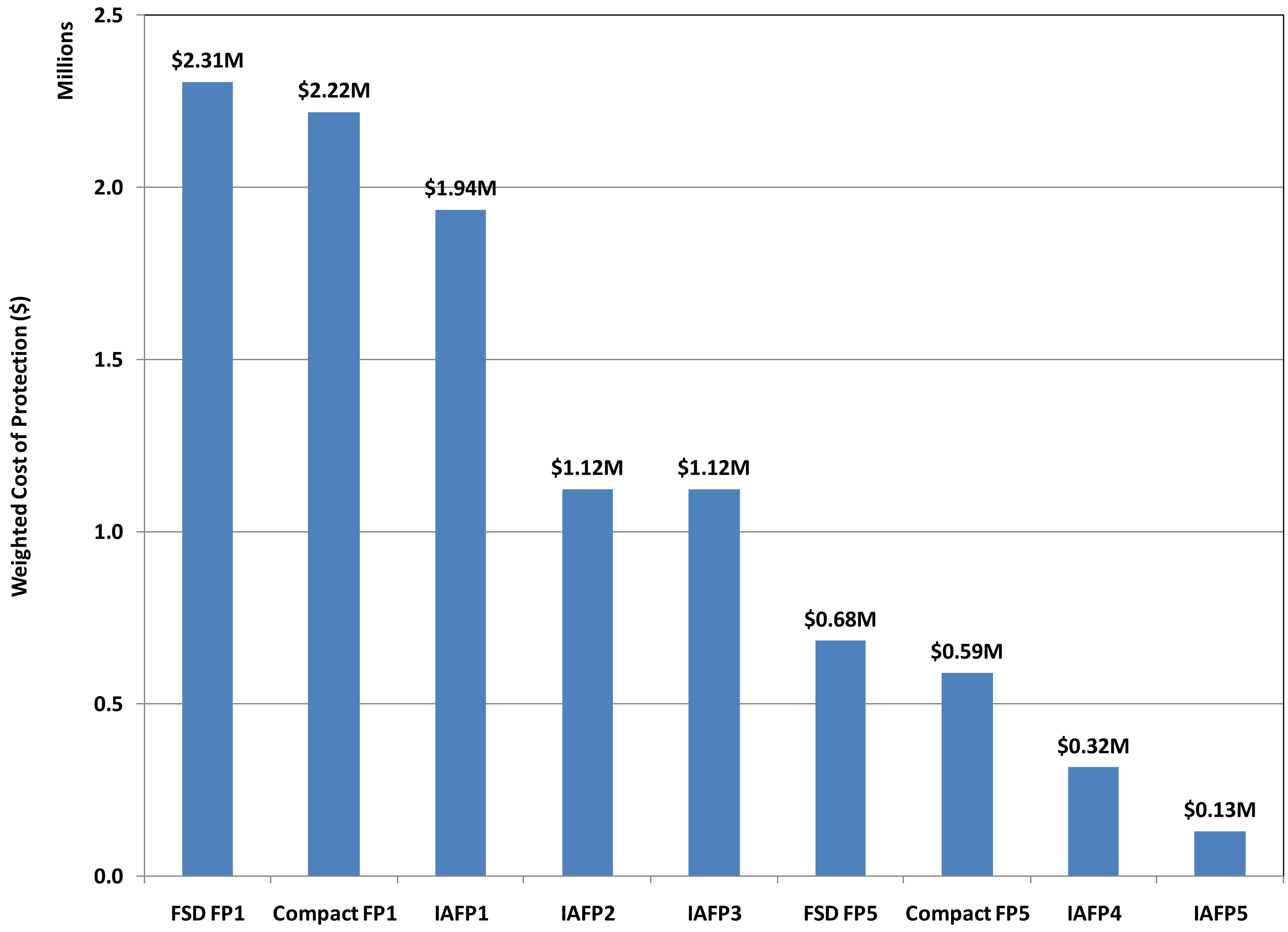

Figure 13. Estimated risk-weighted cost of providing lateral erosion protection for the range of Mendota Bypass and levee setback alternatives for Reach 2B.

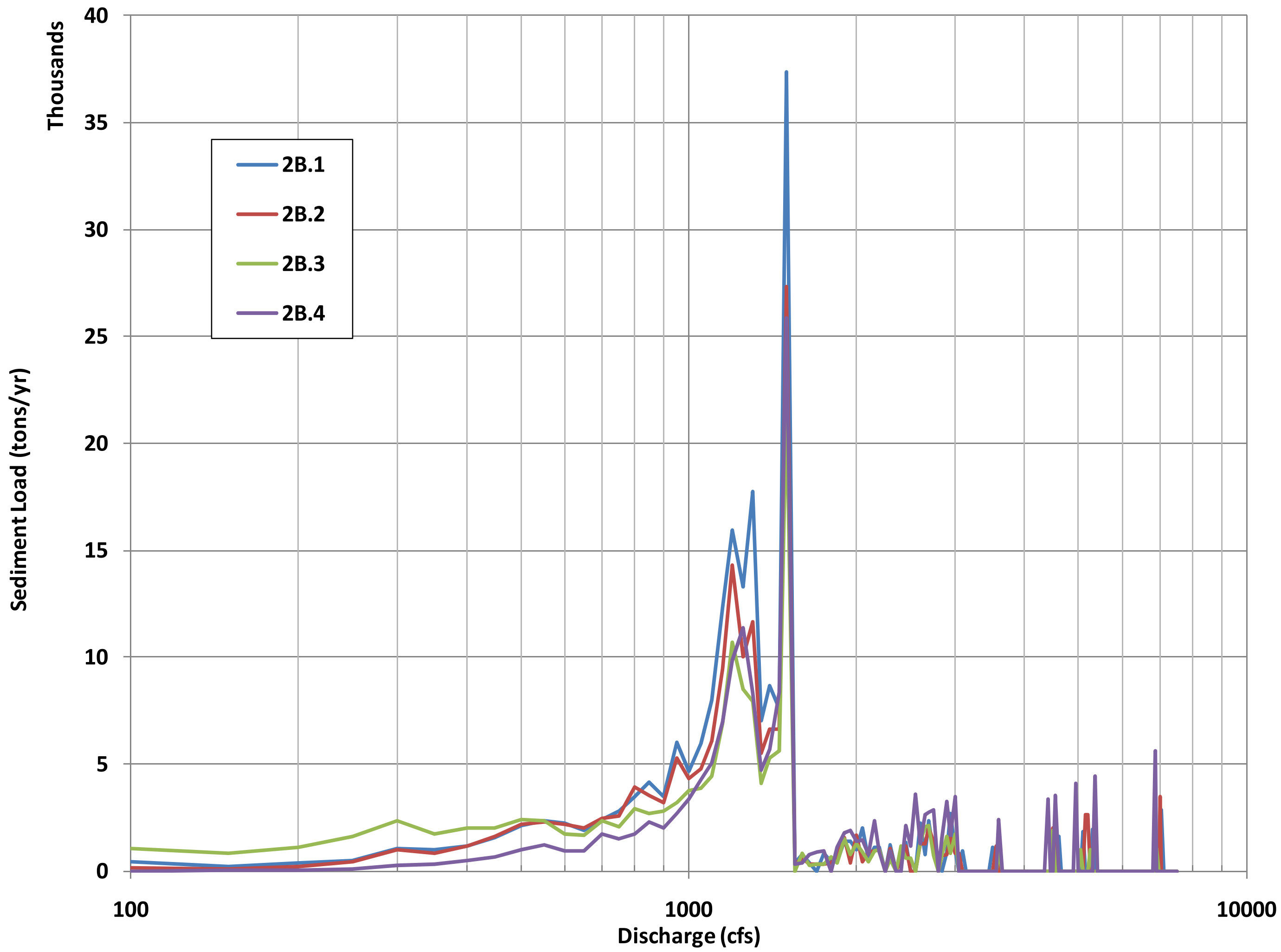

Figure 14. Average annual quantity of sediment transported by increments of flow between 100 and 8,000 cfs, based on the baseline-conditions mean day flow-duration curve and the bed-material transport capacity rating curves for each subreach.

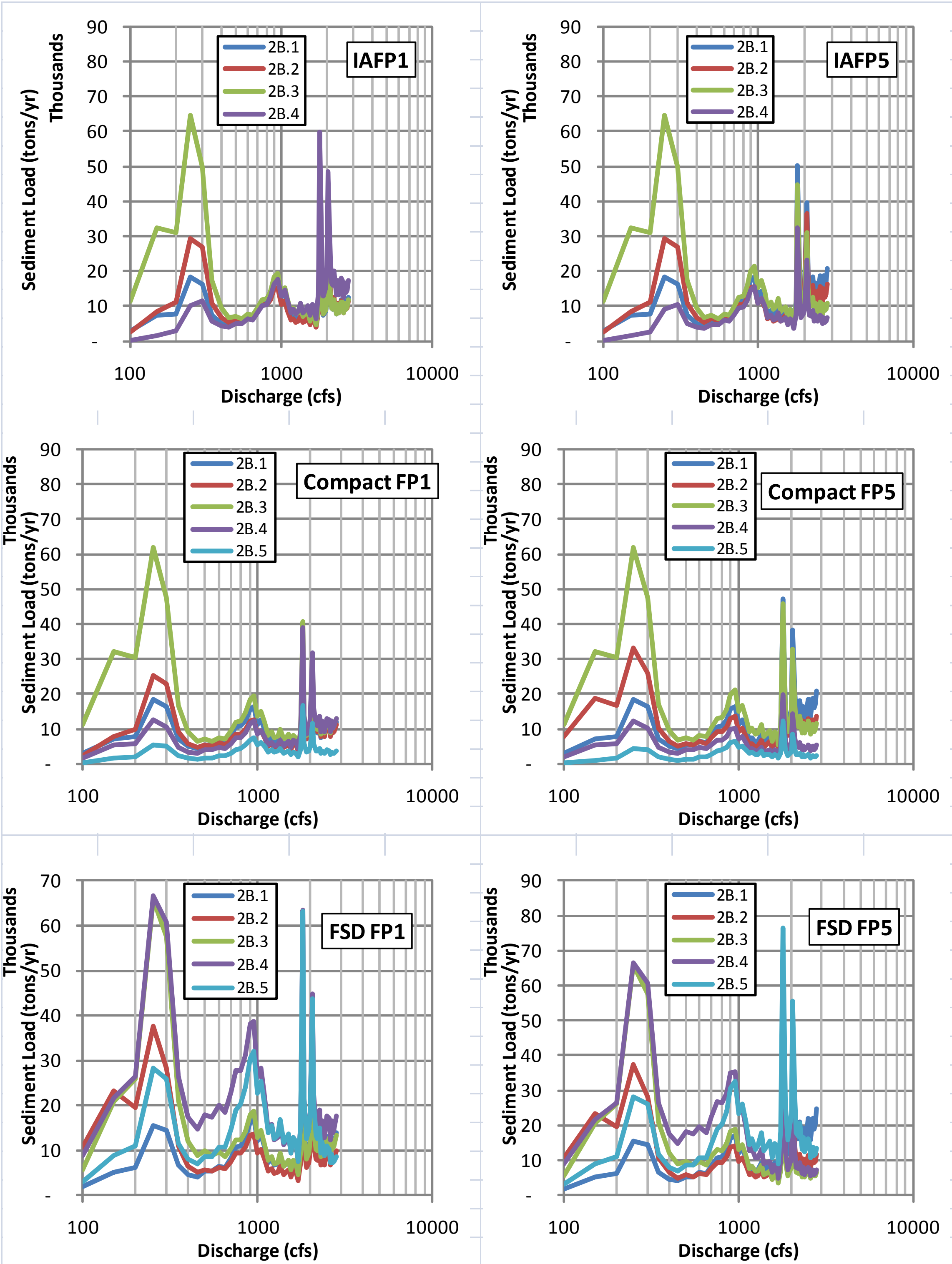

Figure 15. Average annual quantity of sediment transported by increments of flow between 100 and 8,000 cfs for the various Mendota Pool Bypass Options and the narrow (FP1) and wide (FP5) setback options, based on the project-conditions mean day flow-duration curve and the bed-material transport capacity rating curves for each subreach.

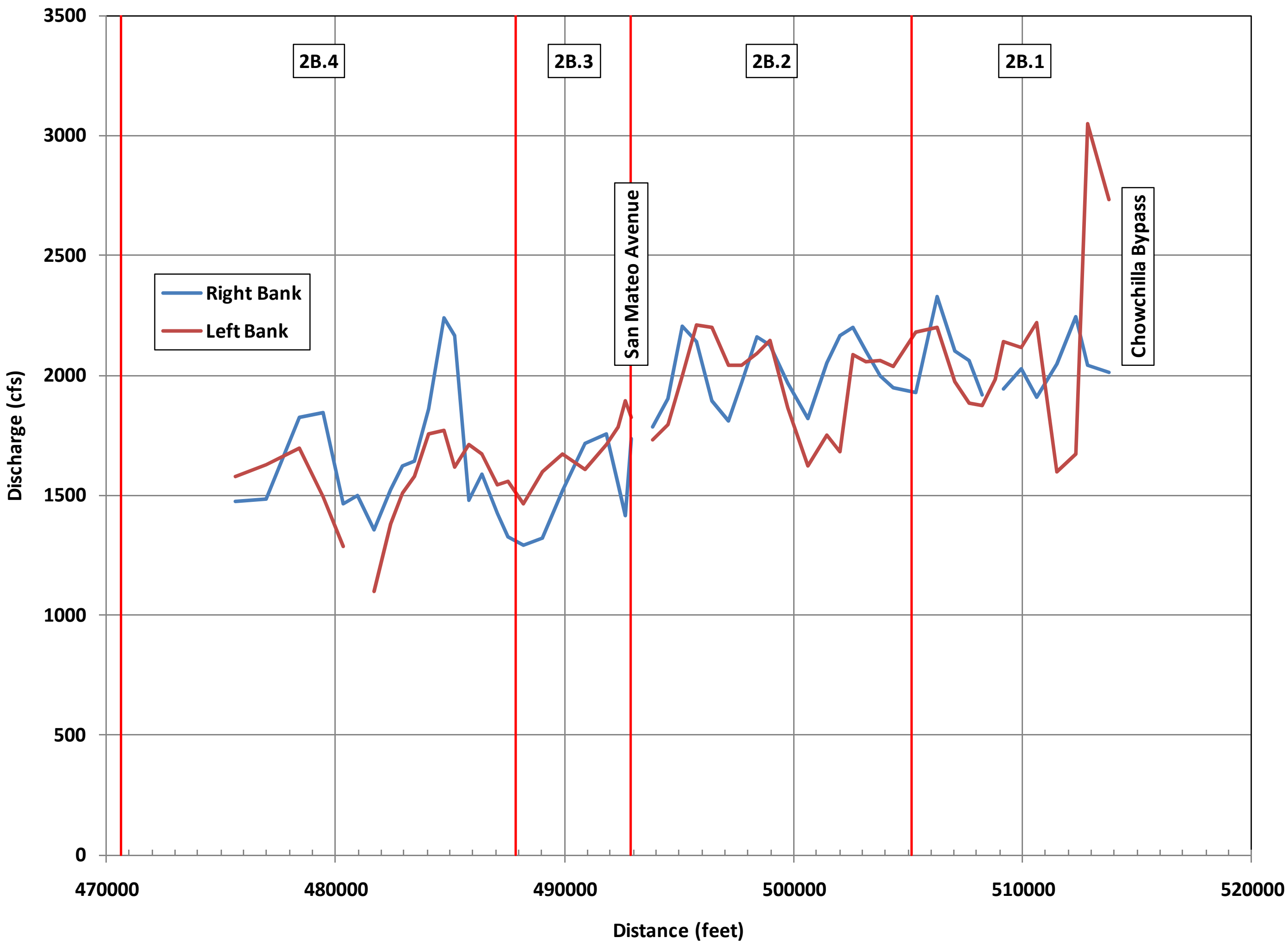

Figure 16. Bankfull discharge in the portions of Reach 2B near the head, and upstream from, the normal backwater effect of Mendota Dam, based on the ground elevations outside the interior levees.