Sacramento Sediment Loads at NODOS Diversions

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RECLAMATION
Managing Water in the West

Technical Report No. SRH-2011-22

Sediment Loads at Tehama-Colusa, Glen-Colusa, and Delevan Diversions

Mid Pacific Region
NODOS Investigation Report

U.S. Department of the Interior
Bureau of Reclamation

June 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

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Mid Pacific Region
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1 Introduction

The current Tehama-Colusa (TC) Canal, Glenn-Colusa (GC) Canal, and the proposed New Delevan Pipeline will be used to convey water to the proposed Sites Reservoir. The TC Canal accepts water from the Red Bluff Pumping Plant at RM 243.0. The GC accepts water from the Glen-Colusa Irrigation District Diversion at RM 206.2. The New Delevan Pipeline will be a new diversion point for the proposed Sites Reservoir and will be located near Colusa at RM 158.5. This report estimates the sedimentation loads diverted into these three canals under the alternatives defined in the North-of-the-Delta Off-stream Storage (NODOS) Administrative Draft Environmental Impact Report/Study (ADEIR/S) and Feasibility Study (FS). Daily stream flows and diversions under the alternatives were developed by CH2MILL (2011) and these were defined as:

- Existing Conditions (Existing)
- No Action Alternative (NoAction)
- NODOS Alternative A (AltA)
- NODOS Alternative B (AltB)
- NODOS Alternative C (AltC)

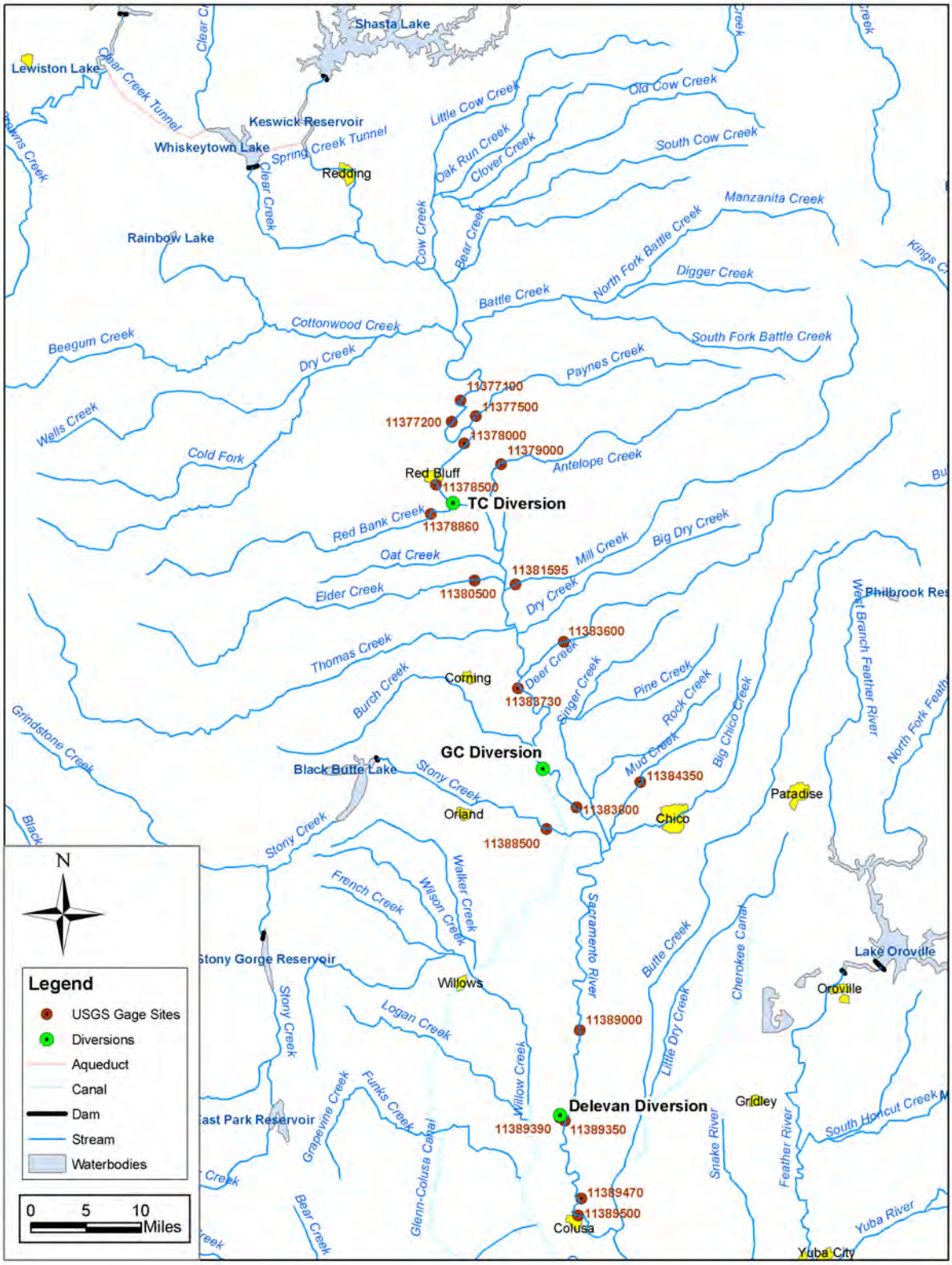

Figure 1-1. Site map of the Sacramento River between Red Bluff and Colusa.

2 Sediment Loads

2.1 Suspended Sediment Data

A total of eight US Geological Survey (USGS) gages are located in the study area, of which, seven provided sediment data for the study. The locations along with the USGS gage numbers are shown in Table 2-1. The periods of suspended sediment collection are listed in Table 2-2.

Table 2-1. USGS gage descriptions and locations in the study area.

Gage #	Description	Latitude	Longitude
11377100	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA	-122.186664	40.288488
11377200	SACRAMENTO R AT BEND BRIDGE NR RED BLUFF CA	-122.223054	40.264043
11378500	SACRAMENTO R A RED BLUFF CA	-122.181663	40.231822
11383730	SACRAMENTO R A VINA BRIDGE NR VINA CA	-122.093041	39.909324
11383800	SACRAMENTO R NR HAMILTON CITY CA	-121.995535	39.751548
11389000	SACRAMENTO R A BUTTE CITY CA	-121.994141	39.457662
11389390	SACRAMENTO R OPPOSITE MOULTON WEIR CA	-122.031086	39.343220
11389500	SACRAMENTO R A COLUSA CA	-122.000250	39.214056

Table 2-2. Location of USGS Suspended Sediment Gages and sample collection periods.

Gage #	River Mile	Sample collection period	Used for diversion
11377100	RM 260.2	1977-1983, 1996-2000	TC Canal at Red Bluff (RM 243.0)
11377200	RM 257.7	1967-1970	
11378500	RM 250.2	1956-1966	
11383730	RM 218.3	2000 (only 6 samples)	Not enough data for GC Canal at Hamilton City
11383800	RM 199.3	1977-1979	
11389000	RM 168.5	1977-1980	New Delevan Pipeline (RM 158.5)
11389390	RM 158.0	1956-1980,1995-2002	
11389500	RM 143.5	No data	

2.2 Sediment Rating Curves

The sediment rating curves were developed in two steps. First, the average concentrations were calculated in different flow bins. Then, the following function was fit to the average concentration:

$$C = aQ^b$$

C is the concentration in mg/l,
Q is the Sacramento River flow in cfs.

In most cases, a single power function did not fit the data and different values of a and b were used to fit different ranges of flow. If not enough data was available at a given site, then the information was interpolated from surrounding stream gage information.

2.2.1 Rating Curve at Red Bluff

Gages 11377100, 11377200, and 11378500 were used to develop the rating curves for TC Canal at Red Bluff. To develop regression equations that represent the average concentration in the Sacramento River, the average concentration in various flow bins was first computed. The average concentration for various flow bins is shown in Figure 2-2. There is a break in the slope of the relationship between concentration and discharge at between 10,000 to 20,000 cfs. Therefore, because of the break in slope, a single power fit was not able to fit this data because it would under-predict concentrations at low flows and over-predict the concentrations at high flows. Therefore, three different sets of coefficients were used: a_1 and b_1 for flows less than 10,000 cfs, a_2 and b_2 for flows between 10,000 cfs and 20,000 cfs, and a_3 and b_3 for flows greater than 20,000 cfs. The coefficients a_3 and b_3 for the flow bin greater than 20,000 cfs were derived by minimizing the sum of the squares between the observed and computed concentrations. The coefficients a_2 and b_2 for the 10,000 cfs to 20,000 cfs flow bin were derived by best fitting b_2 and calculating a_2 so that C is a continuous function at a flow of 20,000 cfs. The same procedure was used for the flow bin below 10,000 cfs. All regression coefficients are summarized in Table 2-3.

Separate regressions were performed on the data from 1956 to 1970, 1977 to 1983, and 1996 to 2000. Results indicate there has been a significant decline in suspended sediment loads since the 1950s, but this is partly an artifact of the gage being moved. The sample location was moved upstream from Red Bluff to Bend Bridge in 1967, and moved again to above Bend Bridge in 1977. The Bend Bridge site is upstream of a few tributaries such as Dibble and Payne Creeks and therefore the sediment supplied from these tributaries would affect the Red Bluff site and not the Bend Bridge site. However, it is likely that there is also a decline in suspended loads in time because the gage has been at the same location since 1977 and there is still a significant decrease in suspended loads at this one gage location since 1977 based upon the regression lines drawn in Figure 2-2. The concentrations based upon the 1996 to 2000 data are approximately 2.8 times less than concentrations for the same flow based upon the 1977 to 1983 data. However, there is much more data from 1977 to 1983 than from 1996 to 2000. A USGS study by Wright and Schoellhamer (2004) calculated that the suspended sediment loads delivered to the San Francisco Bay by the Sacramento River decreased by about one-half from 1950 to 2001. Because there is not enough overlapping data between the two sites it is difficult to determine how much of the decline in sediment loads is due to the site move versus the temporal trend in

sediment loads. At this stage of analysis, we recommend using the regression coefficients derived from all the data and perform more detailed analyses of sediment load trends at the next phase of analysis.

To determine if there is a seasonal influence on sediment concentrations, additional regressions were performed on the data grouped by months of November to January, February to May, and June to October from 1996-2000 (see Figure 2-3) and using the date from 1956 to 2000 (see Figure 2-4). The highest concentrations occur from November to January during most of the flow rates, and the summer concentrations are significantly less. The concentration in the late winter and spring (February to May) are also less than the winter (October to January) concentrations. It is probable that the winter flows act as flushing flows and are typically dominated by the tributary flows, which inject more sediment into this reach than do releases from Shasta Dam. As with the regression for 1996 to 2000 data not grouped by month,the sediment concentrations were lower than that derived from all the data from 1956 to 2000.

Table 2-3. Regression coefficients used to fit suspended sediment data.

Flow Bin (cfs)	**< 10,000**		**10,000 to 20,000**		**> 20,000**	
Coefficient	**Coefficient Values for various data groups**					
	a_1	b_1	a_2	b_2	a_3	b_3
All Data	3.68E-05	1.50	2.32E-10	2.80	0.34	0.67
1956-1970	6.06E-05	1.50	3.82E-10	2.80	0.55	0.67
1977-1983	2.84E-05	1.50	1.79E-10	2.80	0.26	0.67
1996-2000	1.07E-03	1.00	6.76E-11	2.80	9.81E-02	0.67
1996-2000 Nov to Jan	2.09E-10	2.80	5.25E-08	2.20	2.00E-01	0.67
1996-2000 Feb to May	9.70E-02	0.60	0.56	0.41	4.30E-02	0.67
1996-2000 June to Oct	0.58	0.30	9.24E-08	2.00	5.00E-02	0.67
1956-2000 Nov to Jan	3.69E-10	2.80	3.69E-10	2.80	0.54	0.67
1956-2000 Feb to May	2.21E-05	1.50	1.39E-10	2.80	2.02E-01	0.67
1956-2000 June to Oct	2.58E-02	0.67	2.58E-02	0.67	2.58E-02	0.67

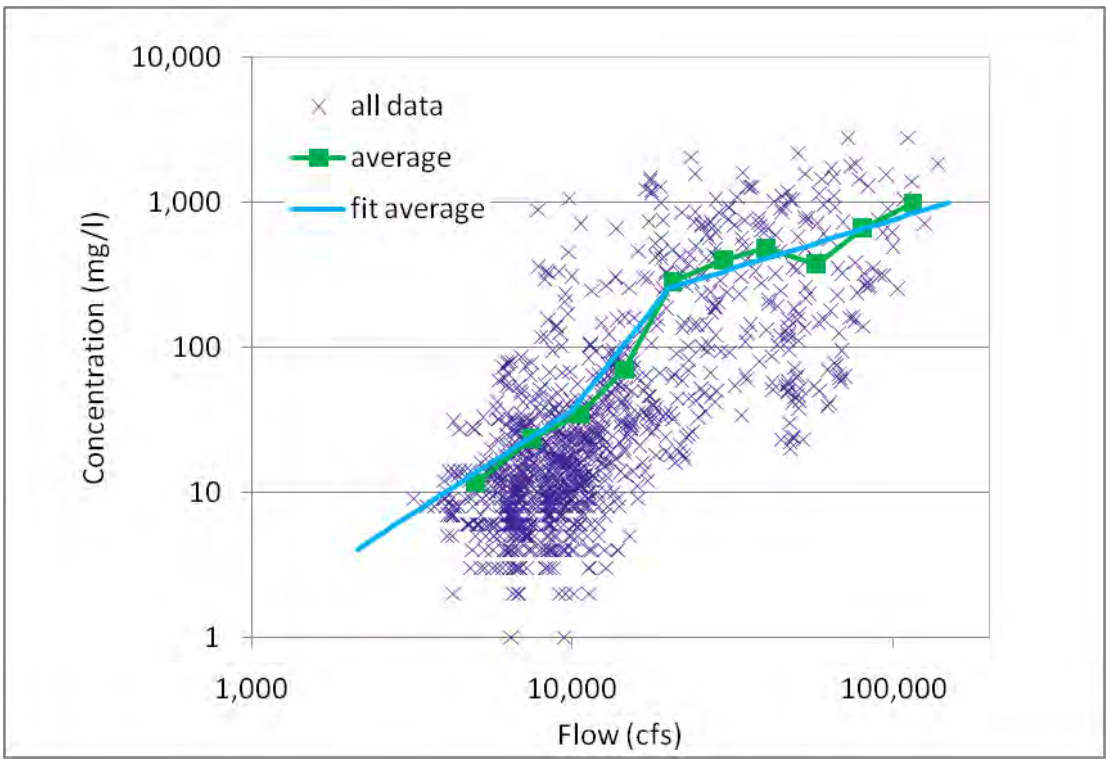

Figure 2-1. All suspended sediment data collected by USGS gages near Red Bluff Diversion. Regression fits are shown as solid lines and data is given as points.

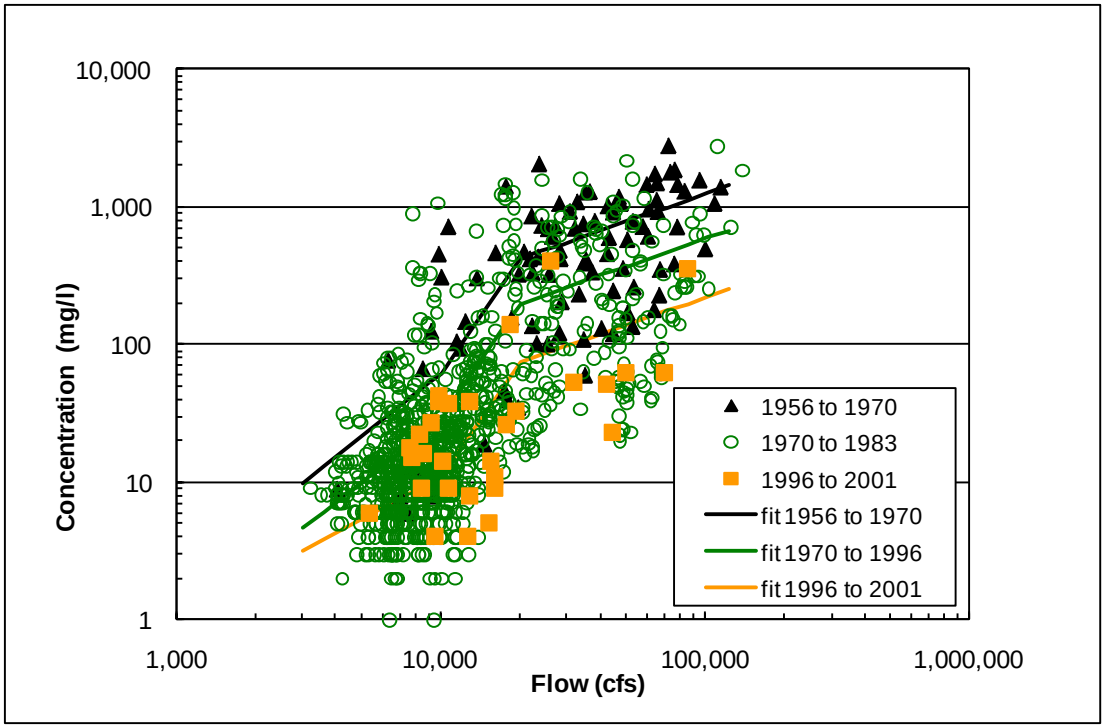

Figure 2-2. USGS suspended sediment data by various time periods. Regression fits are shown as solid lines and data is given as points.

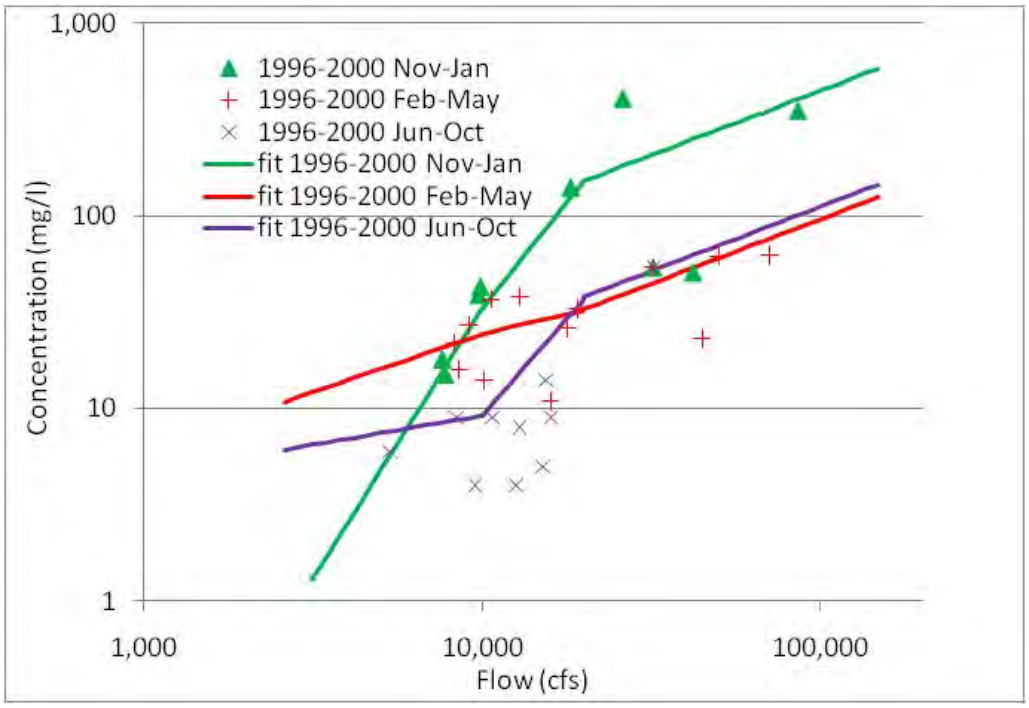

Figure 2-3. 1996 to 2000 suspended sediment data given by time of year collected. Regression fits are shown as solid lines and data is given as points.

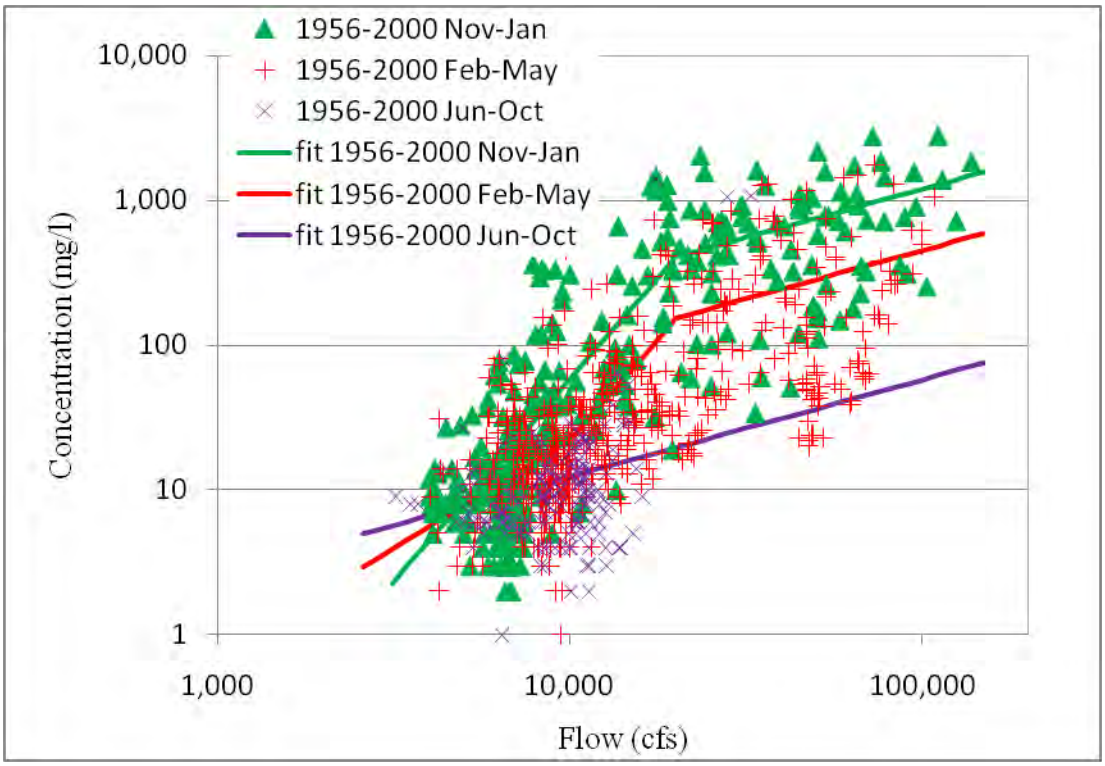

Figure 2-4. 1956 to 2000 suspended sediment data given by time of year collected. Regression fits are shown as solid lines and data is given as points.

2.2.2 Rating Curve near the New Delevan Pipeline

Gages 11389000 (SACRAMENTO R A BUTTE CITY CA , RM 158) and 11389390 (SACRAMENTO R OPPOSITE MOULTON WEIR CA, RM 168.5) were used to develop the rating curves for the new Delevan Pipeline (RM 158.5). The Butte City gage operated from 1977-1980, while the Moulton Weir gage operated from 1956 to 1980 and from 1995 to 2002. The difference in sediment loads at these two gages are not considered significant because there are no major tributaries between these gages.

Similar to the situation at Red Bluff, a single value for both a and b could not completely describe the data. Therefore, two different sets of coefficients were used; a_1 and b_1 for flows less than 14,500 cfs, coefficient a_2 and b_2 for flows greater than 14,500 cfs. The coefficients a_2 and b_2 for the flow bin greater than 14,500 cfs were derived by minimizing the sum of the squares between the observed and computed concentrations. Then the coefficients a_1 and b_1 for flow less than 14,500 cfs were derived by best fitting b_1 and calculating a_1 so that C is a continuous function at a flow of 14,500 cfs. All regression coefficients are summarized in Table 2-4..

Regressions were performed on the data from 1972 to 1980, and 1996 to 2000 (see Figure 2-6). There has been a significant decline in suspended sediment loads from 1996. Based on the fit of the regression equations, the average sediment loads have decreased by more than a factor of 2 at a flow rate of 10,000 cfs. However, there is limited data at flows greater than about 50,000 cfs and therefore it is difficult to determine trends in the concentrations for high flows. This trend of decrasing sediment concentration is consistent with the previously described data at Red Bluff and the Wright and Schoellhamer (2004) study.

Regressions were also performed on the data grouped by months of November to January, February to May, and June to October from 1996-2000 (see Figure 2-7). For flows higher than 15,000 cfs, the highest concentrations occur from November to January. For flow less than 15,000 cfs, the highest concentrations occur in the summer from June to October and high flow seldom occur during this period. Regressions were also performed on the data grouped by months of November to January, February to May, and June to October using all data from 1972-2000 (see Figure 2-7). For most of the flows from 8,000 to 80,000 cfs, the highest concentrations occur from November to January.

Table 2-4. Regression coefficients used to fit the suspended sediment data near the New Delevan Pipeline.

Flow Bin (cfs)	< 14,500		14,500 to 57,500		> 57,500	
Coefficient	Coefficient Values for various data groups					
	a_1	b_1	a_2	b_2	a_3	b_3
All Data	9.84E-05	1.50	4.52E-02	0.86	4.52E-02	0.86
1972-1980	6.80E-06	1.80	0.16	0.75	0.16	0.75
1996-2000	2.04E-03	1.10	3.00E-04	1.30	3.00E-04	1.30
1996-2000 Nov to Jan	1.83E-04	1.37	2.66E-05	1.57	0.49	0.67
1996-2000 Feb to May	1.17E-04	1.41	5.00	0.30	0.09	0.67
1996-2000 Jun to Oct	7.75E-02	0.68	7.75E-02	0.68	-	-
1972-2000 Nov to Jan	1.02E-07	2.25	0.41	0.66	0.41	0.66
1972-2000 Feb to May	1.71E-04	1.374	1.71E-04	1.374	1.71E-04	1.374
1972-2000 Jun to Oct	7.75E-02	0.68	7.75E-02	0.68	-	-

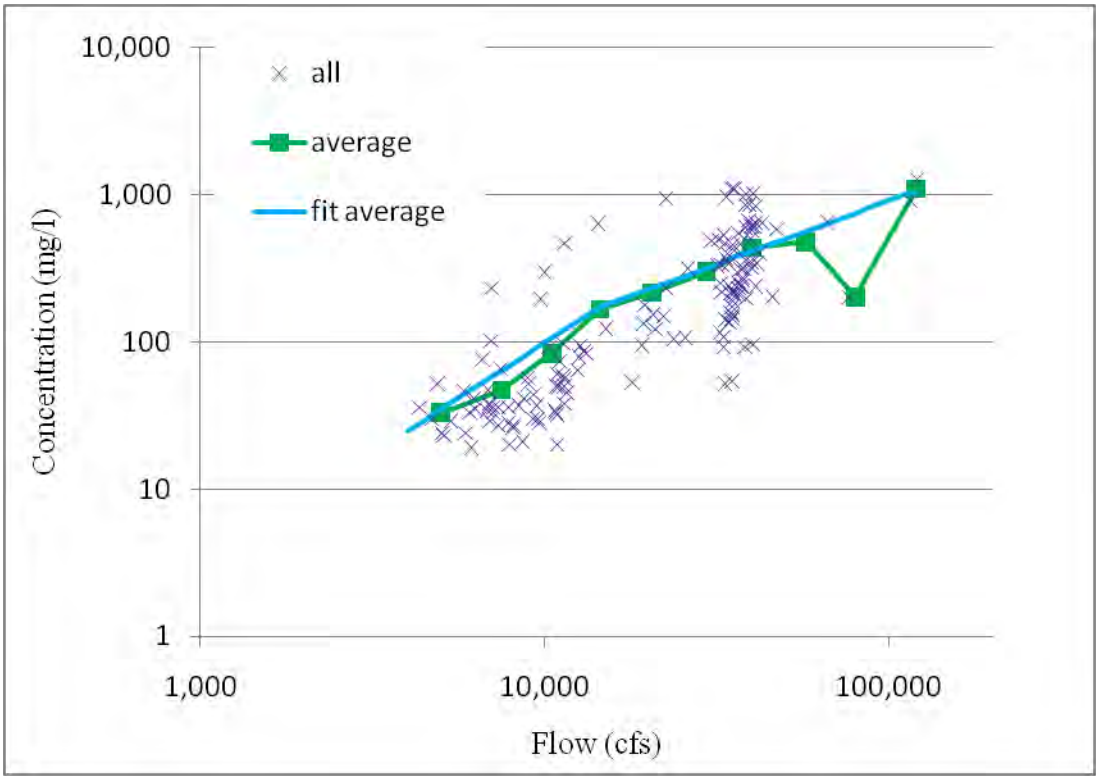

Figure 2-5. All suspended sediment data collected by USGS gages near the New Delevan Pipeline. Fits are shown as solid lines and data is given as points.

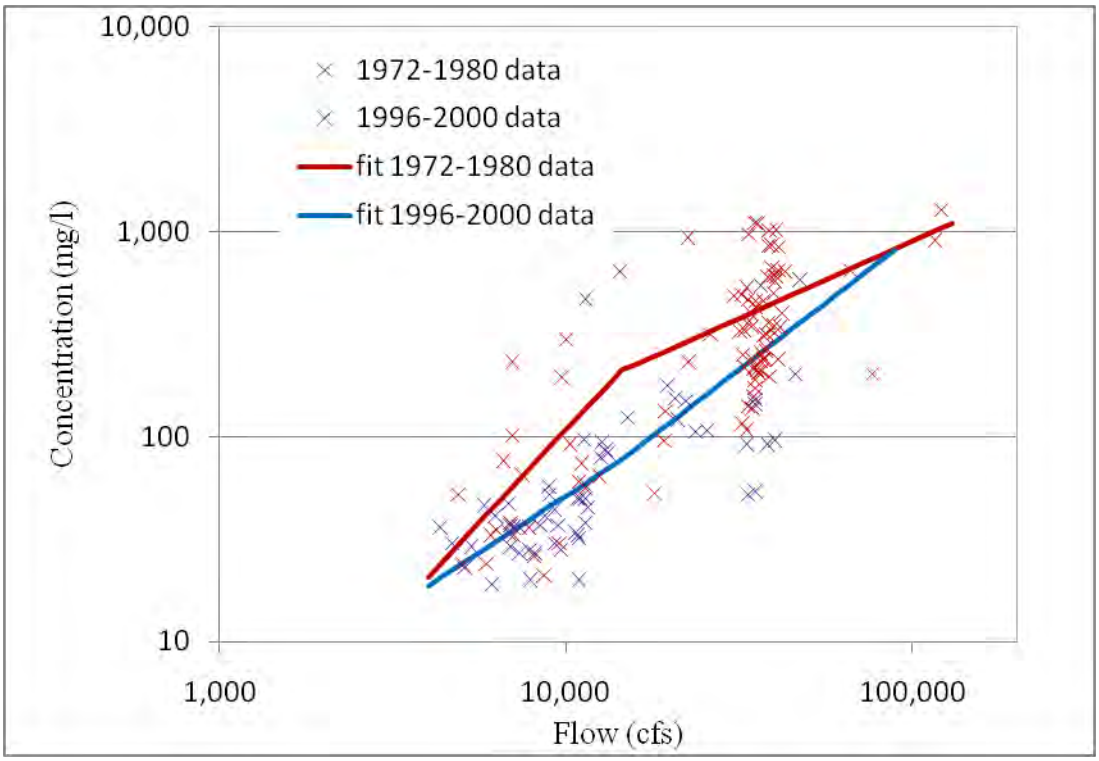

Figure 2-6. USGS suspended sediment data near the New Delevan Pipeline by various time periods. Fits are shown as solid lines and data is given as points.

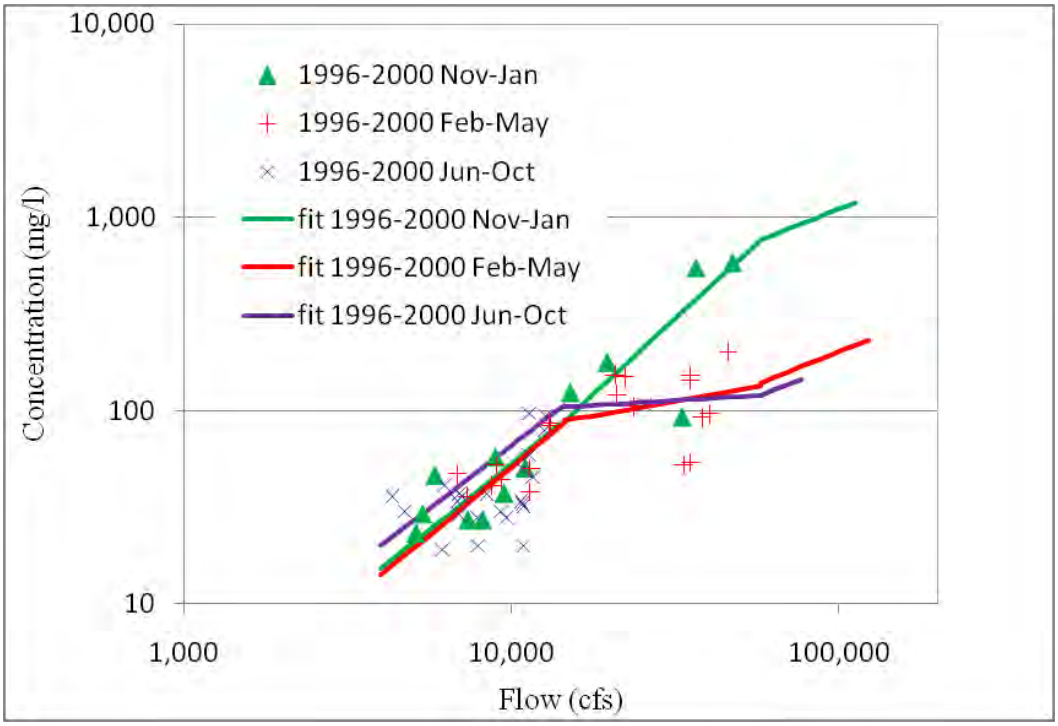

Figure 2-7. 1996 to 2000 suspended sediment data near the New Delevan Pipeline given by time of year collected. Fits are shown as solid lines and data is given as points.

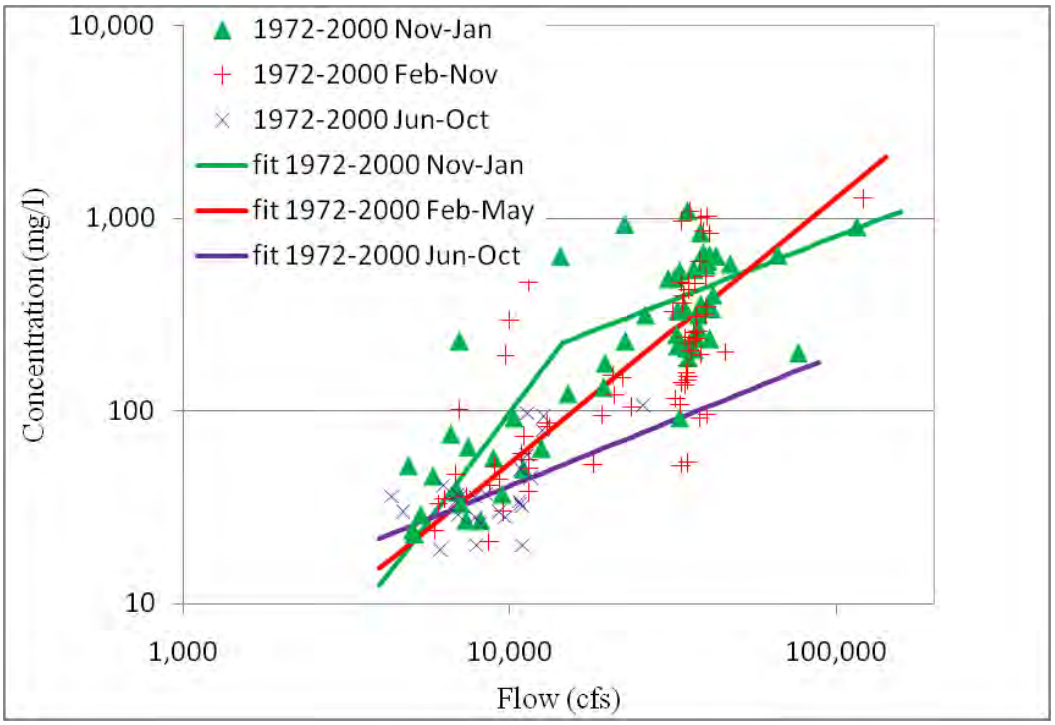

Figure 2-8. 1972 to 2000 suspended sediment data near the New Delevan Pipeline given by time of year collected. Fits are shown as solid lines and data is given as points.

2.2.3 Rating Curve near GC Canal

Gages 11383730 and 11383800 were used to develop the rating curves for the GC Canal. Two different sets of coefficients were used; coefficients a_1 and b_1 for flows less than 10,000 cfs, and coefficients a_2 and b_2 for flows greater than 10,000 cfs. The coefficients a_2 and b_2 for the flow bin greater than 10,000 cfs were derived by minimizing the sum of the squares between the observed and computed concentrations. Then the coefficients a_1 and b_1 for flow less than 10,000 cfs were derived by best fitting b_1 and calculating a_1 so that C is a continuous function at a flow of 10,000 cfs. All regression coefficients are summarized in Table 2-5.

Separate regressions were performed on the data from 1977 to 1979, and 2000 (see Figure 2-10). The amount of available data was insufficient to develop a reasonable rating curving for 2000 data. However, the limited data did indicate a potential decline in suspended sediment loads since 1979.

Because the data is limited at these gages, the suspended sediment concentrations at Hamilton City were assumed to be the average of the concentrations near Red Bluff upstream and near Delevan downstream to compute the annual sediment loads delivered to the canal.

Table 2-5. Regression coefficients used to fit the suspended sediment data near the GC Canal.

Flow Bin (cfs)	< 10,000		>= 10,000	
Coefficient	Coefficient Values for various data groups			
	a_1	b_1	a_2	b_2
All Data	8.00E-11	3	2.00E-04	1.4
1977-1979	8.00E-11	3	2.00E-04	1.4
2000	No data	No data	1.3E+02	0

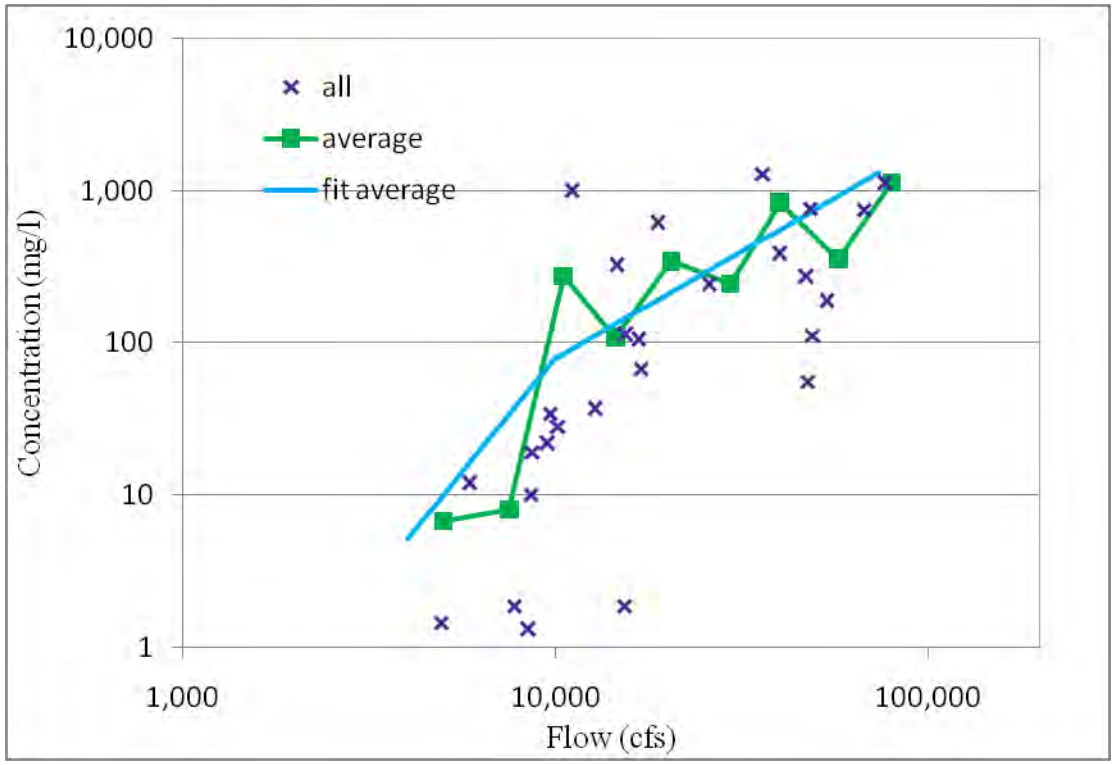

Figure 2-9. All suspended sediment data collected by USGS gages near the GC Canal. Fits are shown as solid lines and data is given as points.

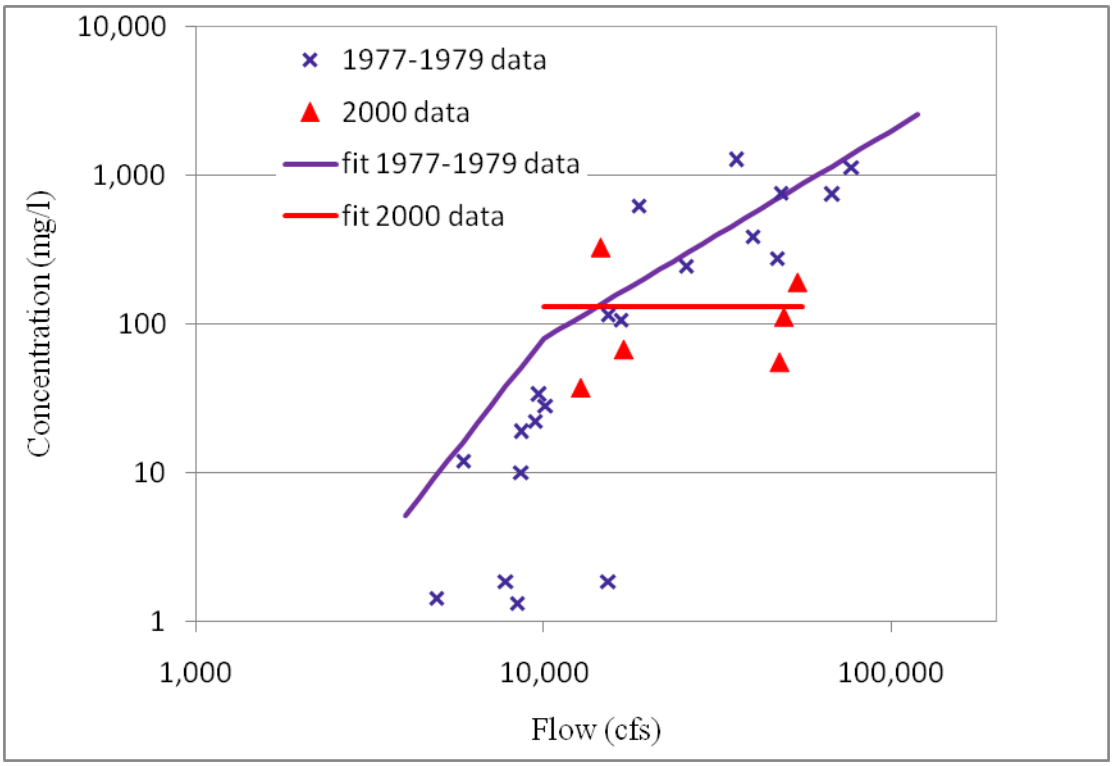

Figure 2-10. USGS suspended sediment data near the GC Canal by various time periods. Fits are shown as solid lines and data is given as points.

2.3 Sediment Loads

Daily flows from 10/1/1921 to 9/30/2003 were provided in a HEC-DSS format as described in CH2MHILL (2011). These flows were simulated using the Sacramento River daily operations model (USRDOM) under the existing conditions (Existing), future No Action Alternative (NoAction), and the proposed NODOS program alternative operations, identified as Alternative A (AltA), Alternative B (AltB), and Alternative C (AltC). Cumulative flows in the Sacramento River at Red Bluff, Hamilton City, and Colusa from the simulation are displayed in Figure 2-11 to Figure 2-13, respectively. Diversion flows to TC Canal, GC, and the New Pipeline are displayed in Figure 2-14 to Figure 2-16, respectively.

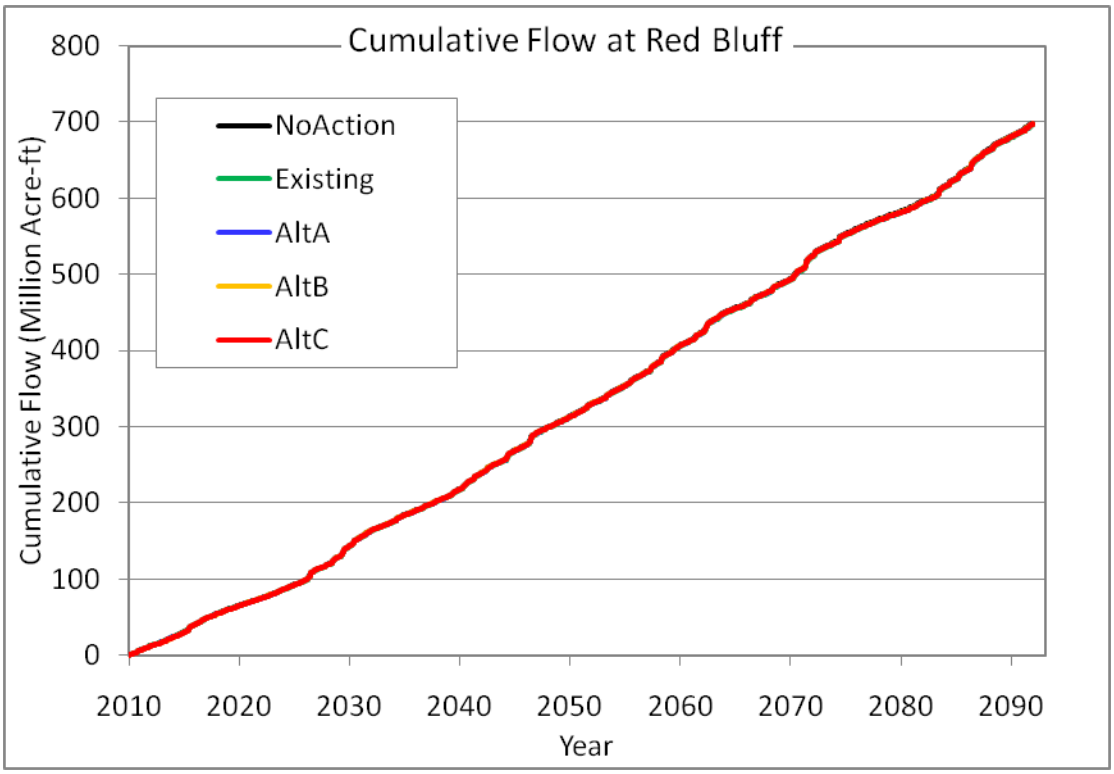

Figure 2-11. Cumulative flow in Sacramento River at Red Bluff.

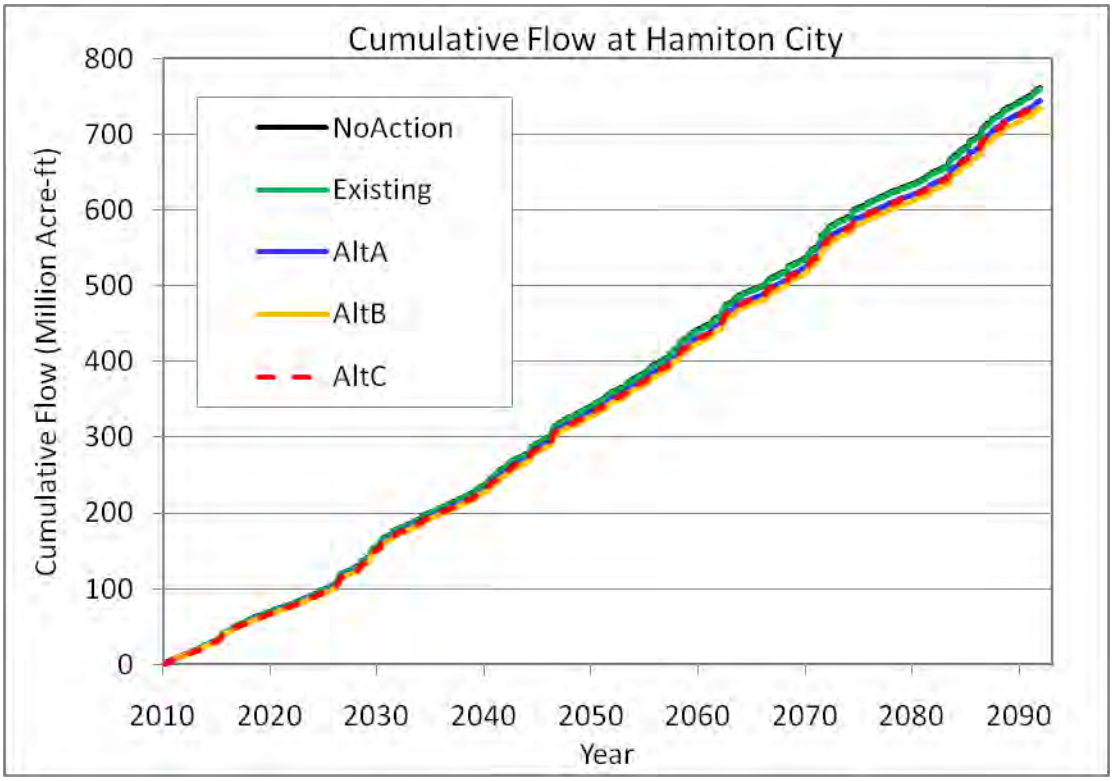

Figure 2-12. Cumulative flow in Sacramento River at Hamilton City.

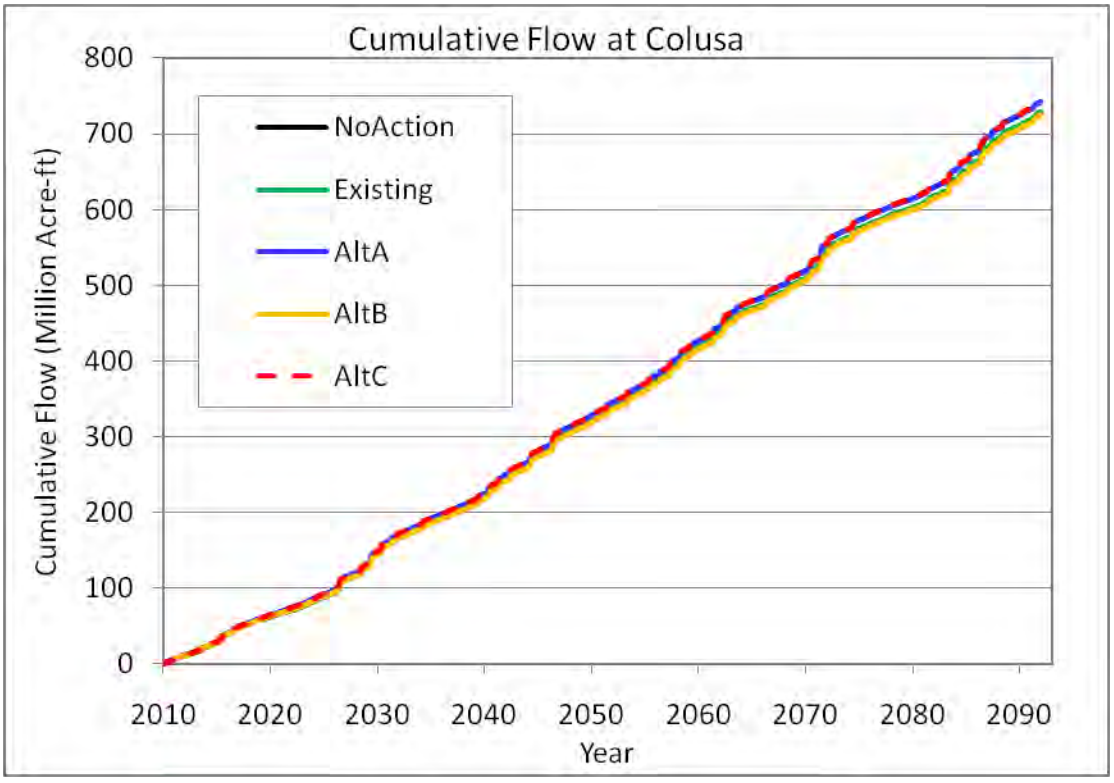

Figure 2-13. Cumulative flow in Sacramento River at Colusa.

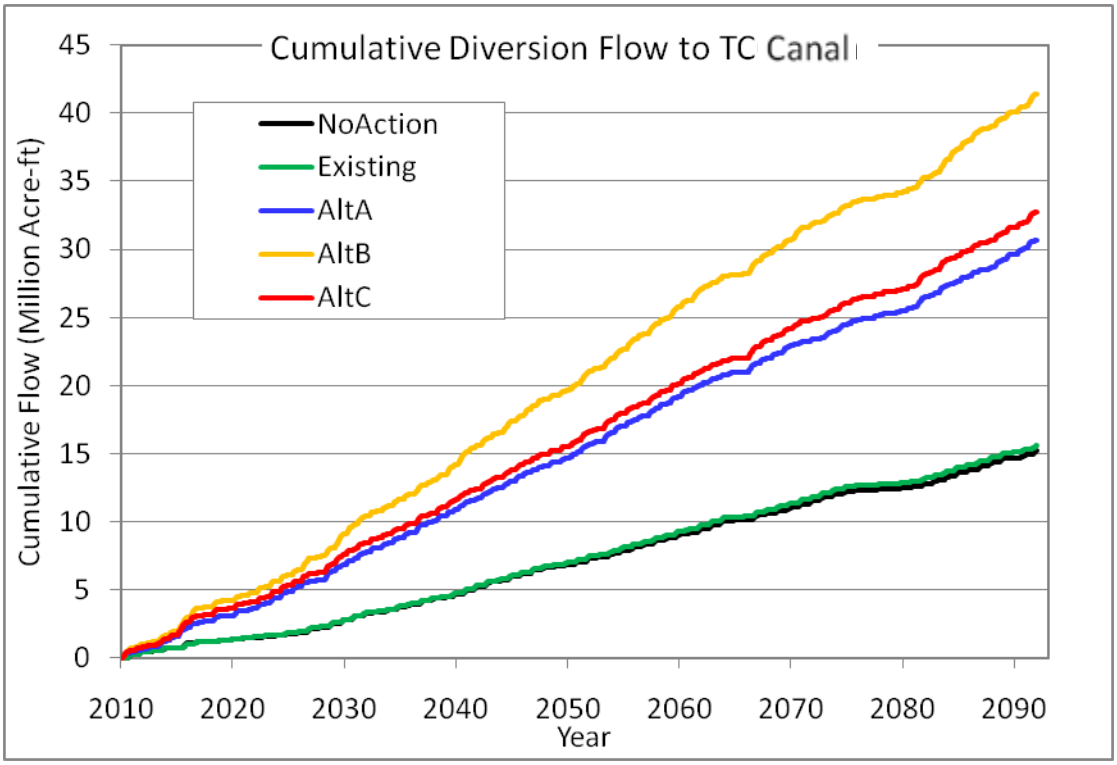

Figure 2-14. Cumulative diversion flow to TC canal.

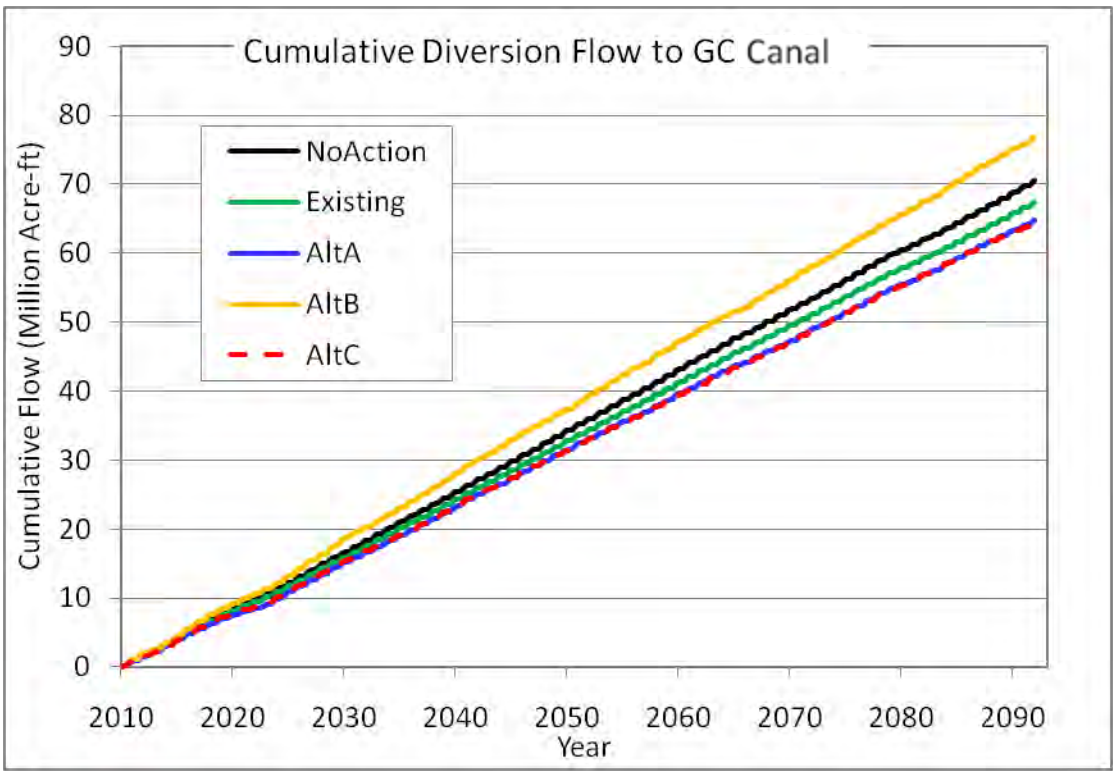

Figure 2-15. Cumulative diversion flow to GC canal.

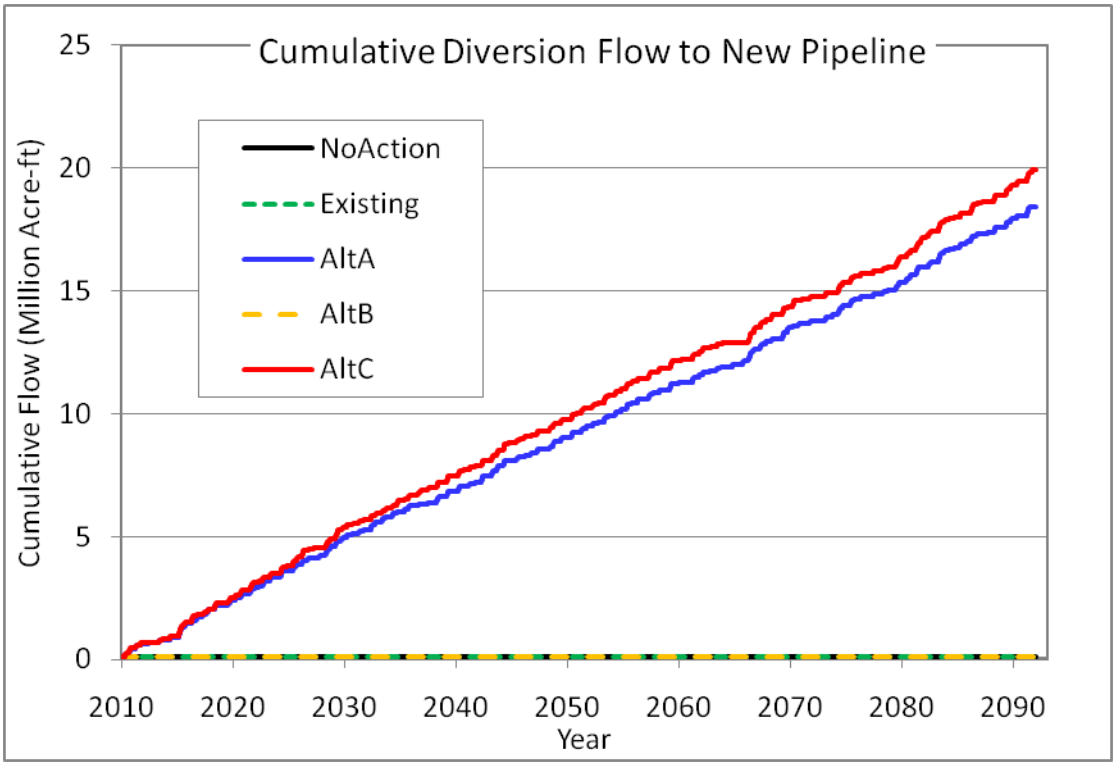

Figure 2-16. Cumulative diversion flow to the New Pipeline.

The total sediment volume delivered into the canal was calculated using the following function:

$$W_s = A\Delta t \sum_{t=1}^{n} C_s Q_d$$

Where W_s = sediment load in tons (1 ton=2000 pound dry sediment),

Δt = seconds in a day $= 3600 \times 24$,

C_s = suspended sediment concentration (mg/l) calculated with the total flow rate at that location,

Q_d = flow diversion (m^3),

n = total days simulated,

A = conversion constant from (gram to English tons) = 1/1.0E6*1000/0.4536/2000

The total sediment loads were predicted using two sets of rating curves. Figure 2-17 to Figure 2-19 show the predicted total sediment loads using sediment data from 1996 to 2000. Figure 2-20 to Figure 2-22 display the predicted total sediment loads using sediment data from 1956 to 2000. The daily flows from 10/1/1921 to 9/30/2003 were used to predict the sediment loads from 10/1/2010 to 9/29/2092.

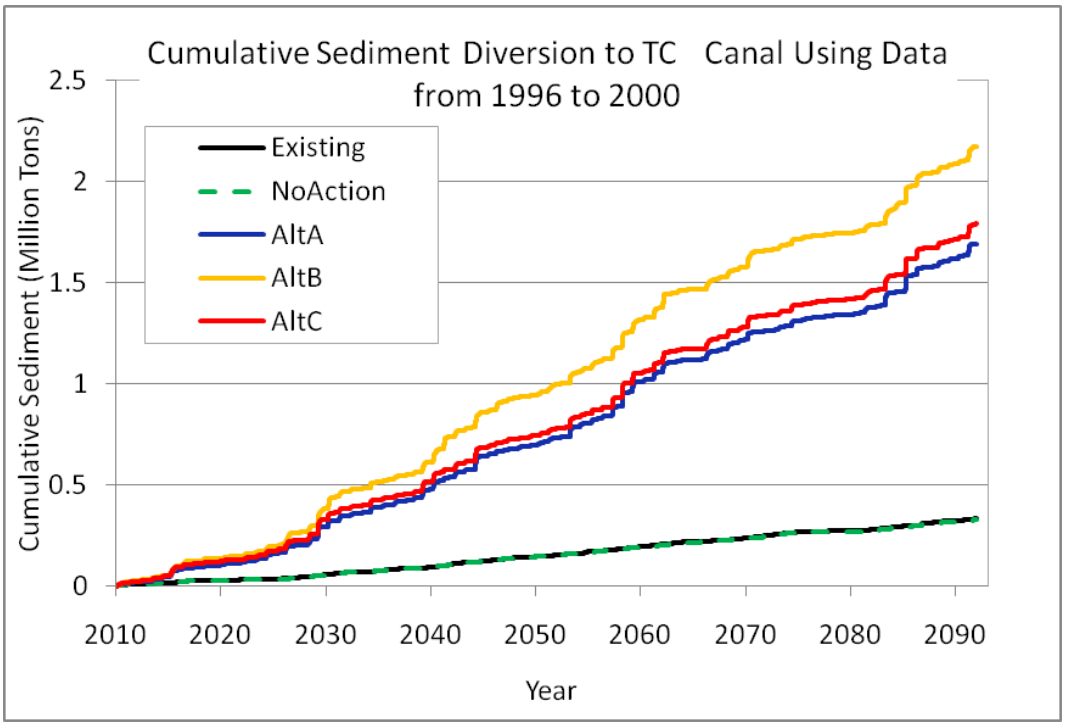

Figure 2-17. Sediment load delivered into TC Canal at Red Bluff using data from 1996 to 2000. 1 ton = 2000 pound dry sediment.

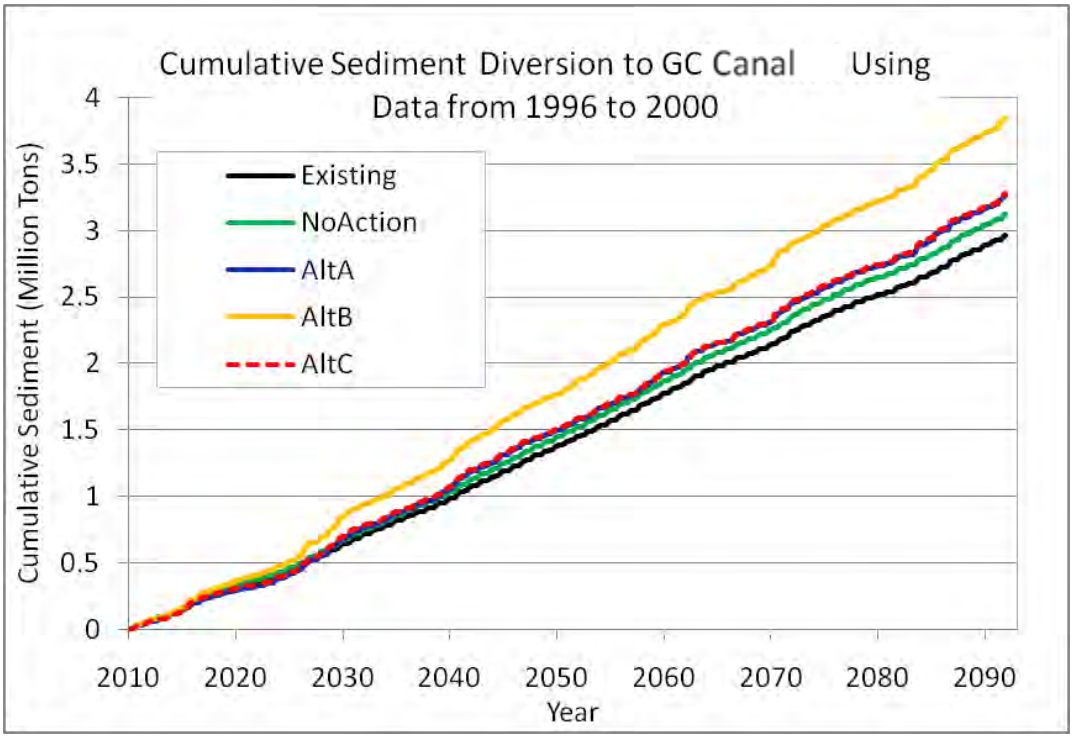

Figure 2-18. Sediment load delivered into GC Canal at Hamilton City using data from 1996 to 2000. 1 ton = 2000 pound dry sediment.

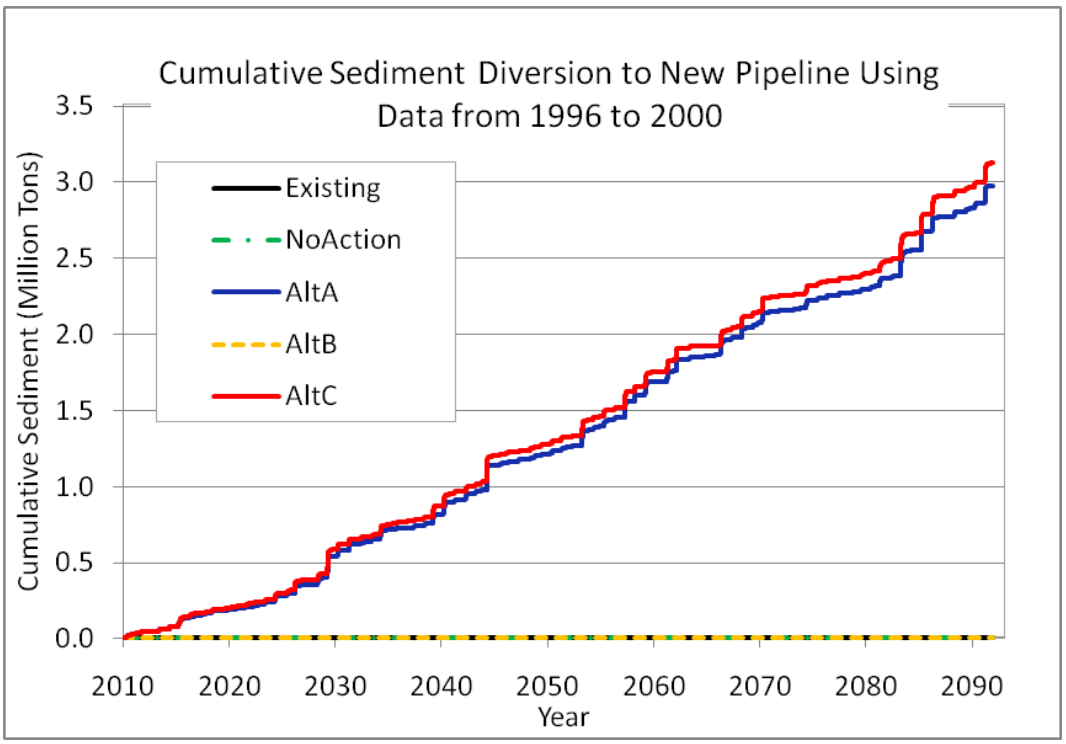

Figure 2-19. Sediment load delivered into the New Delevan Pipeline at Colusa using data from 1996 to 2000. 1 ton = 2000 pound dry sediment.

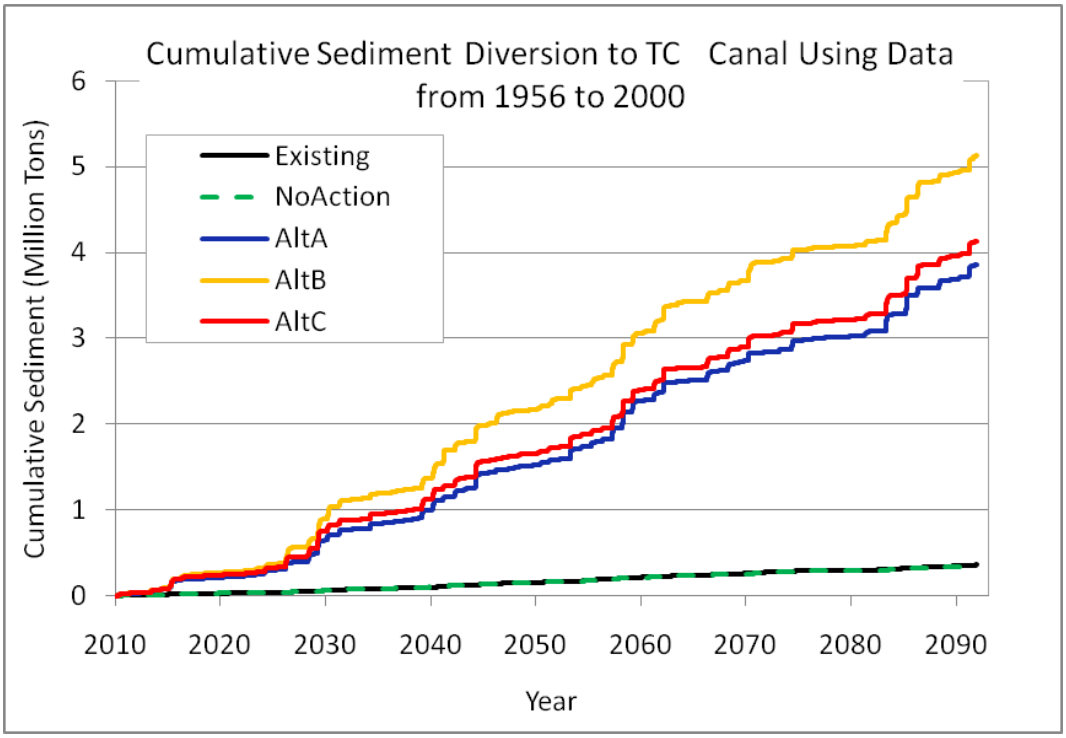

Figure 2-20. Sediment load delivered into TC Canal at Red Bluff using data from 1956 to 2000. 1 ton = 2000 pound dry sediment.

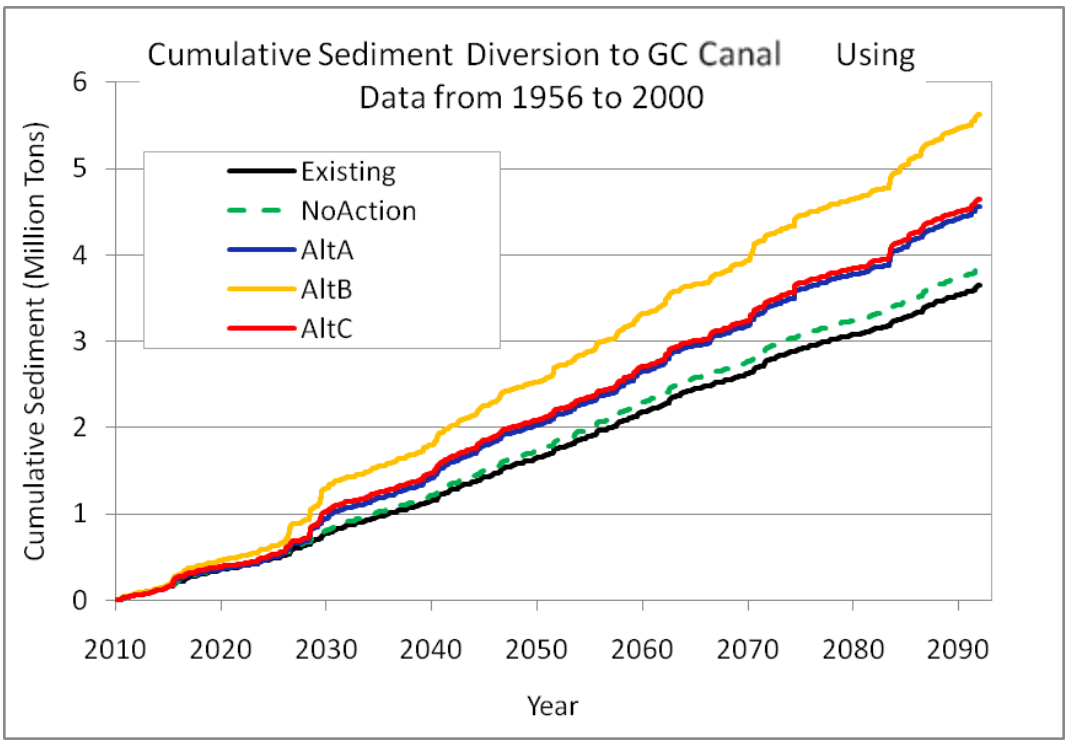

Figure 2-21. Sediment load delivered into GC Canal at Hamilton City using data from 1956 to 2000. 1 ton = 2000 pound dry sediment.

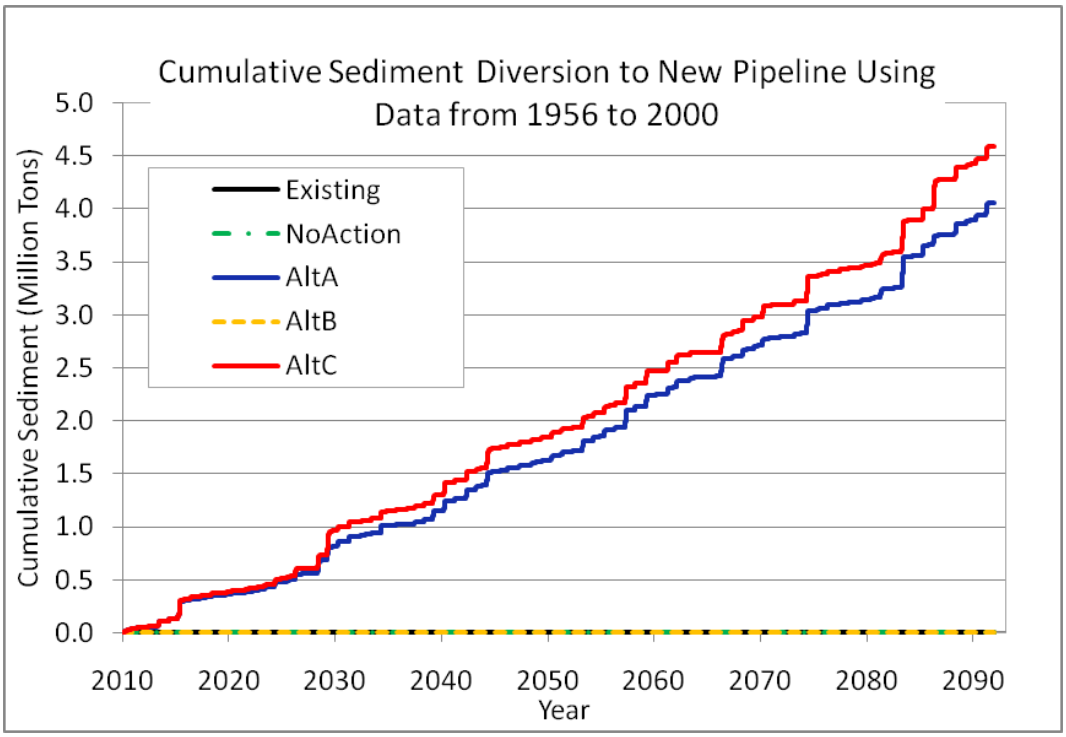

Figure 2-22. Sediment load delivered into the New Delevan Pipeline at Colusa using data from 1956 to 2000. 1 ton = 2000 pound dry sediment.

Results show the predicted sediment loads are lower using the sediment rating curves derived from the 1996 to 2000 data. At this stage of analysis, we suggest using the estimated sediment loads using all the sediment data because it is a more conservative estimate and further analysis of the decreasing sediment load trends should be performed. However, the projections using the more recent data are also presented to give a lower estimate of sediment loads that may occur in the future.

All three proposed NODOS program alternative operations deliver more water to the TC Canal than Existing Conditions and No Action Alternative, and Alt B delivers the most. The sediment load delivered to the TC Canal is approximately 10 times greater under the NODOS program alternatives than under the No Action Alternative. The large increase in the TC canal sediment loads is due to the fact that the NODOS Alternatives divert more water and during the winter season when sediment concentrations are much higher.

AltB also delivers more water to GC Canal than Existing and NoAction conditions, and AltA and AltC deliver less water to GC Canal than Existing and NoAction conditions. However, all NODOS alternatives deliver more sediment to the GC canal because more of the diversion occurs during winter flow periods when the sediment concentrations are higher.

The New Delevan Pipeline at Colusa only delivers water under the proposed alternative AltA and AltC conditions, and AltC delivers more water than AltA.

A summary of the predicted annual sediment loads for each alternative are presented in Table 2-6.

Table 2-6. Estimated Annual Sediment Loads at Three Diversions.

	Using all data			**Using 1996-2000 data**		
	Annual Sediment Loads (tons)			**Annual Sediment Loads (tons)**		
Condition	TC Canal	GC Canal	New Pipeline	TC Canal	GC Canal	New Pipeline
Existing	4,000	44,000	0	4,000	36,000	0
NoAction	4,000	47,000	0	4,000	38,000	0
AltA	47,000	56,000	49,000	21,000	40,000	36,000
AltB	62,000	69,000	0	27,000	47,000	0
AltC	50,000	57,000	56,000	22,000	40,000	38,000

Note: 1 ton of sediment = 2000 pound dry sediment

3 Conclusions

Suspended sediment rating curves were estimated based on suspended sediment concentrations at seven USGS gages. Average annual sediment loads for the TC Canal, GC Canal, and New Delevan Pipeline were estimated based on the sediment rating curves and diversion and flow rates under Existing, NoAction, AltA, AltB, and AltC conditions as simulated in the USRDOM model (CH2MHILL, 2011). The sediment load analysis results are summarized as follows:

- Annual sediment loads delivered into the TC Canal is estimated to be 4,000, 4,000, 47,000, 62,000, and 50,000 tons under Existing, NoAction, AltA, AltB, and AltC conditions, respectively.
- The Annual sediment loads delivered into the GC Canal is estimated to be 44,000, 47,000, 56,000, 69,000 and 57,000 tons under Existing, NoAction, AltA, AltB, and AltC conditions, respectively.
- The Annual sediment loads delivered into the New Delevan Pipeline is estimated to be 0, 0, 49,000, 0, and 56,000 tons under Existing, NoAction, AltA, AltB, and AltC conditions, respectively.

References

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Attachment A. USGS suspended sediment data

Table A-1. USGS suspended sediment data at sites near Red Bluff.

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/3/1977	5550	14	210
11377100	3/3/1977	5550	14	210
11377100	3/7/1977	6820	10	184
11377100	3/11/1977	6910	12	224
11377100	3/15/1977	6970	12	226
11377100	3/19/1977	6200	18	301
11377100	3/23/1977	6040	16	261
11377100	3/27/1977	6090	14	230
11377100	3/30/1977	5930	12	192
11377100	4/1/1977	6310	10	170
11377100	4/4/1977	6240	9	152
11377100	4/7/1977	6260	11	186
11377100	4/7/1977	6400	8	138
11377100	4/7/1977	6560	7	124
11377100	4/8/1977	6790	9	165
11377100	4/11/1977	7520	12	244
11377100	4/14/1977	8810	14	333
11377100	4/19/1977	9580	11	285
11377100	4/21/1977	9470	10	256
11377100	4/26/1977	10000	14	378
11377100	4/29/1977	10000	12	324
11377100	5/2/1977	10300	11	306
11377100	5/4/1977	10200	11	303
11377100	5/4/1977	10200	6	165
11377100	5/5/1977	9760	5	132
11377100	5/6/1977	8430	6	137
11377100	5/6/1977	8430	6	137
11377100	5/6/1977	8430	6	137
11377100	5/7/1977	8380	7	158
11377100	5/10/1977	9160	11	272
11377100	5/14/1977	7750	24	502
11377100	5/18/1977	7400	14	280
11377100	5/22/1977	7400	14	280
11377100	5/27/1977	7630	16	330

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	5/31/1977	7350	12	238
11377100	6/1/1977	7050	8	152
11377100	6/1/1977	6980	6	113
11377100	6/1/1977	6790	6	110
11377100	6/5/1977	8190	12	265
11377100	6/9/1977	8750	10	236
11377100	6/14/1977	9420	12	305
11377100	6/19/1977	10400	12	337
11377100	6/22/1977	10500	11	312
11377100	7/5/1977	10800	14	408
11377100	7/5/1977	10700	9	260
11377100	7/8/1977	10700	20	578
11377100	7/16/1977	10700	24	693
11377100	7/22/1977	11200	22	665
11377100	7/27/1977	10600	16	458
11377100	7/30/1977	10800	23	671
11377100	8/1/1977	10800	12	350
11377100	8/1/1977	10800	13	379
11377100	8/1/1977	10700	24	693
11377100	8/5/1977	10300	26	723
11377100	8/13/1977	8260	20	446
11377100	8/27/1977	7110	12	230
11377100	9/3/1977	6400	6	104
11377100	9/6/1977	6020	8	130
11377100	9/6/1977	5950	13	209
11377100	9/10/1977	5250	13	184
11377100	9/17/1977	6460	21	366
11377100	9/21/1977	4970	27	362
11377100	9/24/1977	4770	6	77
11377100	9/30/1977	4460	14	169
11377100	10/8/1977	3530	8	76
11377100	10/15/1977	3200	9	78
11377100	10/22/1977	3710	8	80
11377100	10/29/1977	5360	14	203
11377100	11/1/1977	5530	14	209
11377100	11/1/1977	5770	15	234
11377100	11/1/1977	5770	12	187
11377100	11/1/1977	5810	16	251
11377100	11/2/1977	5890	15	239

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	11/3/1977	5960	13	209
11377100	11/4/1977	5930	12	192
11377100	11/5/1977	6000	12	194
11377100	11/7/1977	5960	11	177
11377100	11/8/1977	5850	10	158
11377100	11/9/1977	5870	10	158
11377100	11/12/1977	5510	9	134
11377100	11/12/1977	5510	9	134
11377100	11/13/1977	5490	10	148
11377100	11/15/1977	5450	8	118
11377100	11/23/1977	7850	361	7650
11377100	11/25/1977	5580	20	301
11377100	11/28/1977	4860	11	144
11377100	11/28/1977	4790	12	155
11377100	11/29/1977	4630	9	113
11377100	11/29/1977	4300	8	93
11377100	11/30/1977	4200	8	91
11377100	11/30/1977	4200	8	91
11377100	11/30/1977	4270	7	81
11377100	12/1/1977	4220	13	148
11377100	12/1/1977	4220	8	91
11377100	12/1/1977	4220	7	80
11377100	12/1/1977	4220	9	103
11377100	12/1/1977	4220	8	91
11377100	12/1/1977	4220	9	103
11377100	12/2/1977	4170	7	79
11377100	12/3/1977	4070	5	55
11377100	12/4/1977	4040	8	87
11377100	12/5/1977	4070	7	77
11377100	12/6/1977	4040	8	87
11377100	12/7/1977	4100	10	111
11377100	12/8/1977	3980	9	97
11377100	12/9/1977	3980	12	129
11377100	12/10/1977	4070	7	77
11377100	12/11/1977	4120	14	156
11377100	12/11/1977	4150	7	78
11377100	12/12/1977	4610	14	174
11377100	12/13/1977	4440	27	324
11377100	12/14/1977	18100	517	25300

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	12/14/1977	18900	985	50300
11377100	12/14/1977	18900	561	28600
11377100	12/15/1977	24100	1560	102000
11377100	12/15/1977	18800	1270	64500
11377100	12/15/1977	17600	1200	57000
11377100	12/15/1977	17600	1160	55100
11377100	12/15/1977	16900	1230	56100
11377100	12/15/1977	16600	302	13500
11377100	12/16/1977	8420	326	7410
11377100	12/16/1977	7810	885	18700
11377100	12/17/1977	30700	766	63500
11377100	12/17/1977	19200	748	38800
11377100	12/18/1977	9780	1060	28000
11377100	12/19/1977	6220	54	907
11377100	12/20/1977	5270	33	470
11377100	12/21/1977	4880	28	369
11377100	12/22/1977	6990	32	604
11377100	12/22/1977	9310	66	1660
11377100	12/23/1977	33900	1600	146000
11377100	12/24/1977	9500	232	5950
11377100	12/25/1977	6930	48	898
11377100	12/26/1977	5850	42	663
11377100	12/27/1977	6440	32	556
11377100	12/28/1977	7450	78	1570
11377100	12/30/1977	7140	74	1430
11377100	12/31/1977	5790	37	578
11377100	1/1/1978	5400	14	204
11377100	1/2/1978	5380	17	247
11377100	1/3/1978	9070	331	8110
11377100	1/3/1978	8300	334	7490
11377100	1/3/1978	8200	293	6490
11377100	1/3/1978	7980	118	2540
11377100	1/4/1978	6920	86	1610
11377100	1/4/1978	7860	46	976
11377100	1/5/1978	17500	1460	69000
11377100	1/6/1978	13700	660	24400
11377100	1/7/1978	9470	206	5270
11377100	1/7/1978	8900	141	3390
11377100	1/8/1978	8280	118	2640

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	1/9/1978	50500	2160	295000
11377100	1/10/1978	38800	278	29100
11377100	1/10/1978	35900	1260	122000
11377100	1/10/1978	27600	685	51000
11377100	1/10/1978	28000	616	46600
11377100	1/10/1978	26300	705	50100
11377100	1/10/1978	24200	500	32700
11377100	1/11/1978	15000	256	10400
11377100	1/11/1978	14700	100	3970
11377100	1/12/1978	14500	161	6300
11377100	1/12/1978	13600	306	11200
11377100	1/13/1978	19600	334	17700
11377100	1/13/1978	24100	854	55600
11377100	1/14/1978	30800	916	76200
11377100	1/15/1978	69600	730	137000
11377100	1/15/1978	46000	934	116000
11377100	1/16/1978	53000	1570	225000
11377100	1/16/1978	89300	765	184000
11377100	1/17/1978	58700	1140	181000
11377100	1/18/1978	26700	566	40800
11377100	1/19/1978	44900	1100	133000
11377100	1/20/1978	25300	314	21400
11377100	1/20/1978	22000	59	3510
11377100	1/21/1978	19100	230	11900
11377100	1/24/1978	15400	80	3330
11377100	1/25/1978	12500	69	2330
11377100	1/25/1978	11800	26	828
11377100	1/26/1978	10400	56	1570
11377100	1/26/1978	9100	24	590
11377100	1/27/1978	8580	45	1040
11377100	1/28/1978	7990	36	777
11377100	1/29/1978	7710	38	791
11377100	1/30/1978	7470	25	504
11377100	1/31/1978	6730	26	472
11377100	2/1/1978	5800	23	360
11377100	2/2/1978	6610	26	464
11377100	2/2/1978	6610	32	571
11377100	2/2/1978	6660	30	539
11377100	2/2/1978	7210	32	623

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/3/1978	7000	42	794
11377100	2/3/1978	6680	28	505
11377100	2/4/1978	6230	29	488
11377100	2/5/1978	6380	53	913
11377100	2/5/1978	12100	28	915
11377100	2/6/1978	18700	446	22500
11377100	2/6/1978	23700	285	18200
11377100	2/7/1978	28900	288	22500
11377100	2/7/1978	37800	722	73700
11377100	2/7/1978	53400	738	106000
11377100	2/8/1978	39800	527	56600
11377100	2/8/1978	34800	480	45100
11377100	2/9/1978	38800	636	66600
11377100	2/9/1978	33500	305	27600
11377100	2/10/1978	27900	189	14200
11377100	2/10/1978	27000	66	4810
11377100	2/11/1978	24600	142	9430
11377100	2/11/1978	24200	43	2810
11377100	2/12/1978	21200	44	2520
11377100	2/12/1978	22900	69	4270
11377100	2/13/1978	27500	200	14900
11377100	2/13/1978	26900	45	3270
11377100	2/14/1978	27200	172	12600
11377100	2/14/1978	26300	94	6680
11377100	2/15/1978	26200	142	10000
11377100	2/15/1978	26000	36	2530
11377100	2/16/1978	21100	90	5130
11377100	2/16/1978	20500	32	1770
11377100	2/17/1978	18700	66	3330
11377100	2/17/1978	17900	34	1640
11377100	2/18/1978	15100	34	1390
11377100	2/18/1978	13600	52	1910
11377100	2/19/1978	13100	62	2190
11377100	2/20/1978	12900	76	2650
11377100	2/21/1978	12700	46	1580
11377100	2/22/1978	11700	42	1330
11377100	2/23/1978	10100	36	982
11377100	2/24/1978	9930	38	1020
11377100	2/25/1978	8900	33	793

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/25/1978	8090	17	371
11377100	2/26/1978	8170	32	706
11377100	2/27/1978	9160	34	841
11377100	2/28/1978	7530	26	529
11377100	3/1/1978	7230	30	586
11377100	3/1/1978	7170	26	503
11377100	3/1/1978	7160	22	425
11377100	3/1/1978	7160	20	387
11377100	3/1/1978	7140	24	463
11377100	3/2/1978	8400	154	3490
11377100	3/2/1978	13800	155	5780
11377100	3/3/1978	17300	732	34200
11377100	3/3/1978	28600	844	65200
11377100	3/4/1978	44300	455	54400
11377100	3/4/1978	56700	388	59400
11377100	3/5/1978	50200	343	46500
11377100	3/5/1978	41000	200	22100
11377100	3/6/1978	43600	192	22600
11377100	3/6/1978	40700	212	23300
11377100	3/7/1978	35800	143	13800
11377100	3/7/1978	35100	126	11900
11377100	3/8/1978	60900	155	25500
11377100	3/8/1978	81000	323	70600
11377100	3/9/1978	63100	556	94700
11377100	3/9/1978	53300	479	68900
11377100	3/10/1978	54800	233	34500
11377100	3/10/1978	53300	216	31100
11377100	3/11/1978	68700	58	10800
11377100	3/11/1978	56800	404	62000
11377100	3/12/1978	50300	64	8690
11377100	3/12/1978	49300	72	9580
11377100	3/13/1978	47200	96	12200
11377100	3/13/1978	47100	125	15900
11377100	3/13/1978	47100	112	14200
11377100	3/13/1978	47000	137	17400
11377100	3/13/1978	47000	156	19800
11377100	3/13/1978	47000	120	15200
11377100	3/14/1978	43400	104	12200
11377100	3/14/1978	41700	87	9800

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/15/1978	38200	80	8250
11377100	3/15/1978	34600	64	5980
11377100	3/16/1978	30800	92	7650
11377100	3/17/1978	23000	81	5030
11377100	3/17/1978	20400	62	3420
11377100	3/17/1978	20300	35	1920
11377100	3/18/1978	16900	64	2920
11377100	3/18/1978	16500	16	713
11377100	3/19/1978	15200	30	1230
11377100	3/19/1978	14800	42	1680
11377100	3/20/1978	13300	48	1720
11377100	3/20/1978	12700	20	686
11377100	3/21/1978	11700	28	885
11377100	3/21/1978	11300	22	671
11377100	3/22/1978	12400	50	1670
11377100	3/22/1978	11900	24	771
11377100	3/23/1978	11400	18	554
11377100	3/23/1978	11500	31	963
11377100	3/24/1978	12000	17	551
11377100	3/24/1978	11600	64	2000
11377100	3/25/1978	10900	36	1060
11377100	3/25/1978	10800	36	1050
11377100	3/26/1978	10500	14	397
11377100	3/27/1978	10200	24	661
11377100	3/27/1978	10200	16	441
11377100	3/28/1978	10100	27	736
11377100	3/29/1978	9940	12	322
11377100	3/29/1978	9950	12	322
11377100	3/29/1978	9910	22	589
11377100	3/30/1978	9880	24	640
11377100	3/30/1978	9950	9	242
11377100	3/31/1978	9840	10	266
11377100	3/31/1978	10000	8	216
11377100	4/1/1978	17200	298	13800
11377100	4/2/1978	15600	159	6700
11377100	4/3/1978	12500	60	2030
11377100	4/3/1978	12400	54	1810
11377100	4/3/1978	12400	42	1410
11377100	4/3/1978	12300	47	1560

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	4/4/1978	13900	55	2060
11377100	4/5/1978	11500	244	7580
11377100	4/5/1978	10200	28	771
11377100	4/6/1978	23900	142	9160
11377100	4/6/1978	23000	44	2730
11377100	4/7/1978	19500	24	1260
11377100	4/7/1978	19200	253	13100
11377100	4/8/1978	18000	40	1940
11377100	4/9/1978	18200	38	1870
11377100	4/10/1978	17500	46	2170
11377100	4/11/1978	17000	34	1560
11377100	4/12/1978	16000	35	1510
11377100	4/13/1978	15200	28	1150
11377100	4/14/1978	16800	14	635
11377100	4/15/1978	15400	31	1290
11377100	4/16/1978	18200	28	1380
11377100	4/17/1978	18000	32	1560
11377100	4/18/1978	16700	36	1620
11377100	4/19/1978	15200	24	985
11377100	4/20/1978	18200	18	885
11377100	4/21/1978	14200	31	1190
11377100	4/22/1978	12900	16	557
11377100	4/23/1978	12400	24	804
11377100	4/24/1978	9970	16	431
11377100	4/25/1978	18100	420	20500
11377100	4/26/1978	21600	324	18900
11377100	4/27/1978	12400	32	1070
11377100	4/28/1978	12600	27	919
11377100	4/29/1978	15900	61	2620
11377100	4/30/1978	15300	67	2770
11377100	5/1/1978	15300	50	2070
11377100	5/1/1978	15300	29	1200
11377100	5/1/1978	15200	30	1230
11377100	5/1/1978	15200	27	1110
11377100	5/1/1978	15100	34	1390
11377100	5/2/1978	14700	24	953
11377100	5/3/1978	14500	20	783
11377100	5/4/1978	14000	22	832
11377100	5/5/1978	14100	14	533

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	5/6/1978	14000	8	302
11377100	5/7/1978	13800	9	335
11377100	5/8/1978	12800	20	691
11377100	5/9/1978	12700	13	446
11377100	5/10/1978	12500	16	540
11377100	5/11/1978	11600	13	407
11377100	5/12/1978	11500	13	404
11377100	5/13/1978	11500	12	373
11377100	5/14/1978	11500	33	1030
11377100	5/15/1978	11500	4	124
11377100	5/16/1978	10600	11	315
11377100	5/17/1978	10200	8	220
11377100	5/18/1978	10100	6	164
11377100	5/19/1978	9910	9	241
11377100	5/20/1978	9860	11	293
11377100	5/21/1978	9710	11	288
11377100	5/22/1978	9480	10	256
11377100	5/23/1978	8830	10	238
11377100	5/24/1978	8690	10	235
11377100	5/25/1978	8690	13	305
11377100	5/26/1978	8650	18	420
11377100	5/27/1978	8310	5	112
11377100	5/28/1978	8400	8	181
11377100	5/29/1978	8500	6	138
11377100	5/30/1978	8430	5	114
11377100	5/31/1978	8330	18	405
11377100	6/2/1978	8310	10	224
11377100	6/2/1978	8270	9	201
11377100	6/2/1978	8260	12	268
11377100	6/5/1978	8200	22	487
11377100	6/7/1978	8920	9	217
11377100	6/9/1978	9410	10	254
11377100	6/11/1978	9370	9	228
11377100	6/13/1978	9500	16	410
11377100	6/15/1978	9950	12	322
11377100	6/17/1978	10100	2	55
11377100	6/19/1978	9990	29	782
11377100	6/21/1978	9940	4	107
11377100	6/23/1978	9910	18	482

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	6/25/1978	10400	8	225
11377100	6/27/1978	10400	8	225
11377100	6/29/1978	10500	13	369
11377100	7/1/1978	10400	5	140
11377100	7/3/1978	10500	6	170
11377100	7/5/1978	10800	17	496
11377100	7/5/1978	10700	11	318
11377100	7/5/1978	10600	7	200
11377100	7/5/1978	10500	14	397
11377100	7/7/1978	10100	15	409
11377100	7/9/1978	10300	19	528
11377100	7/11/1978	10100	4	109
11377100	7/13/1978	10200	6	165
11377100	7/15/1978	11300	14	427
11377100	7/17/1978	11300	10	305
11377100	7/19/1978	11300	4	122
11377100	7/21/1978	11200	8	242
11377100	7/23/1978	11400	6	185
11377100	7/25/1978	11300	3	92
11377100	7/27/1978	11300	9	275
11377100	7/29/1978	11300	2	61
11377100	7/31/1978	11200	3	91
11377100	7/31/1978	11200	12	363
11377100	7/31/1978	11200	9	272
11377100	8/1/1978	11300	9	275
11377100	8/10/1978	11100	5	150
11377100	8/15/1978	12700	3	103
11377100	8/23/1978	9910	5	134
11377100	8/31/1978	8630	4	93
11377100	9/5/1978	8490	3	69
11377100	9/12/1978	7410	9	180
11377100	9/19/1978	6420	1	17
11377100	9/26/1978	6500	6	105
11377100	10/3/1978	6340	7	120
11377100	10/9/1978	6480	7	122
11377100	10/16/1978	6450	6	104
11377100	10/23/1978	6520	5	88
11377100	11/1/1978	5930	5	80
11377100	11/3/1978	5710	5	77

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	11/4/1978	6500	4	70
11377100	11/6/1978	6610	6	107
11377100	11/7/1978	6580	3	53
11377100	11/7/1978	6540	3	53
11377100	11/7/1978	6540	3	53
11377100	11/8/1978	6540	6	106
11377100	11/10/1978	6530	5	88
11377100	11/12/1978	6540	3	53
11377100	11/12/1978	6540	2	35
11377100	11/12/1978	6570	3	53
11377100	11/13/1978	6610	7	125
11377100	11/13/1978	6630	8	143
11377100	11/14/1978	6710	3	54
11377100	11/15/1978	6690	4	72
11377100	11/17/1978	6750	2	36
11377100	11/18/1978	6800	3	55
11377100	11/19/1978	6800	15	275
11377100	11/20/1978	7050	18	343
11377100	11/20/1978	7210	12	234
11377100	11/21/1978	7340	5	99
11377100	11/21/1978	7350	4	79
11377100	11/21/1978	7360	5	99
11377100	11/22/1978	7220	3	58
11377100	11/22/1978	7150	6	116
11377100	11/24/1978	6930	6	112
11377100	11/26/1978	6810	2	37
11377100	11/28/1978	6860	3	56
11377100	11/30/1978	6830	3	55
11377100	12/1/1978	6840	4	74
11377100	12/1/1978	6860	5	93
11377100	12/1/1978	6870	5	93
11377100	12/2/1978	6870	6	111
11377100	12/5/1978	6780	5	92
11377100	12/7/1978	6790	6	110
11377100	12/9/1978	6750	6	109
11377100	12/11/1978	6780	10	183
11377100	12/13/1978	6830	19	350
11377100	12/15/1978	6750	6	109
11377100	12/18/1978	7000	6	113

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	12/20/1978	6730	7	127
11377100	12/22/1978	6740	6	109
11377100	12/27/1978	6700	8	145
11377100	12/29/1978	6720	11	200
11377100	1/2/1979	6990	8	151
11377100	1/2/1979	6970	9	169
11377100	1/4/1979	6870	9	167
11377100	1/6/1979	5940	9	144
11377100	1/8/1979	6140	4	66
11377100	1/9/1979	8670	27	632
11377100	1/9/1979	8610	23	535
11377100	1/9/1979	8490	27	619
11377100	1/10/1979	6790	19	348
11377100	1/10/1979	6730	20	363
11377100	1/10/1979	6700	26	470
11377100	1/11/1979	23000	376	23400
11377100	1/11/1979	27600	429	32000
11377100	1/12/1979	13400	95	3440
11377100	1/12/1979	12800	52	1800
11377100	1/12/1979	25100	52	3520
11377100	1/14/1979	14000	68	2570
11377100	1/14/1979	20700	65	3630
11377100	1/15/1979	40600	660	72300
11377100	1/15/1979	38600	688	71700
11377100	1/15/1979	33600	34	3080
11377100	1/16/1979	14700	38	1510
11377100	1/16/1979	14300	53	2050
11377100	1/16/1979	13500	10	364
11377100	1/17/1979	10600	7	200
11377100	1/18/1979	8020	20	433
11377100	1/20/1979	7570	7	143
11377100	1/21/1979	7440	22	442
11377100	1/22/1979	7390	6	120
11377100	1/23/1979	7080	10	191
11377100	1/24/1979	6310	6	102
11377100	1/25/1979	6400	6	104
11377100	1/26/1979	6260	8	135
11377100	1/27/1979	6160	8	133
11377100	1/29/1979	6140	16	265

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	1/30/1979	6100	62	1020
11377100	1/31/1979	5980	11	178
11377100	1/31/1979	5840	3	47
11377100	1/31/1979	5640	4	61
11377100	2/1/1979	5580	6	90
11377100	2/2/1979	5210	16	225
11377100	2/2/1979	5210	11	155
11377100	2/2/1979	5360	5	72
11377100	2/2/1979	5320	4	57
11377100	2/3/1979	4880	4	53
11377100	2/4/1979	4800	3	39
11377100	2/5/1979	4800	14	181
11377100	2/7/1979	4380	13	154
11377100	2/9/1979	4290	14	162
11377100	2/10/1979	4220	5	57
11377100	2/11/1979	4250	2	23
11377100	2/11/1979	4270	31	357
11377100	2/13/1979	19000	409	21000
11377100	2/13/1979	22300	149	8970
11377100	2/13/1979	25400	703	48200
11377100	2/15/1979	9670	170	4440
11377100	2/15/1979	8920	138	3320
11377100	2/15/1979	8670	95	2220
11377100	2/16/1979	16700	50	2250
11377100	2/17/1979	8450	36	821
11377100	2/18/1979	8840	38	907
11377100	2/18/1979	17000	54	2480
11377100	2/19/1979	13000	92	3230
11377100	2/20/1979	9270	102	2550
11377100	2/20/1979	12100	65	2120
11377100	2/21/1979	22500	264	16000
11377100	2/21/1979	26900	241	17500
11377100	2/21/1979	29000	94	7360
11377100	2/21/1979	30200	241	19700
11377100	2/22/1979	13000	124	4350
11377100	2/22/1979	12700	265	9090
11377100	2/23/1979	17600	106	5040
11377100	2/23/1979	15200	82	3370
11377100	2/23/1979	13600	82	3010

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/24/1979	11200	84	2540
11377100	2/25/1979	7940	51	1090
11377100	2/28/1979	7210	22	428
11377100	2/28/1979	7400	15	300
11377100	3/1/1979	19600	185	9790
11377100	3/1/1979	16200	127	5560
11377100	3/1/1979	15100	100	4080
11377100	3/2/1979	9500	14	359
11377100	3/2/1979	9100	16	393
11377100	3/3/1979	7990	19	410
11377100	3/3/1979	7870	22	467
11377100	3/3/1979	7870	14	297
11377100	3/4/1979	7800	10	211
11377100	3/5/1979	7410	31	620
11377100	3/6/1979	6970	30	565
11377100	3/7/1979	6930	35	655
11377100	3/8/1979	7100	5	96
11377100	3/8/1979	7220	13	253
11377100	3/9/1979	7210	20	389
11377100	3/10/1979	6910	16	299
11377100	3/11/1979	6600	19	339
11377100	3/12/1979	6270	35	593
11377100	3/15/1979	5970	7	113
11377100	3/15/1979	5920	11	176
11377100	3/16/1979	6410	8	138
11377100	3/16/1979	7120	16	308
11377100	3/16/1979	7420	19	381
11377100	3/17/1979	7770	14	294
11377100	3/17/1979	7510	21	426
11377100	3/17/1979	7510	22	446
11377100	3/18/1979	8140	20	440
11377100	3/18/1979	7790	8	168
11377100	3/18/1979	7600	44	903
11377100	3/19/1979	10700	37	1070
11377100	3/19/1979	10400	44	1240
11377100	3/19/1979	9820	68	1800
11377100	3/21/1979	6870	50	927
11377100	3/23/1979	6830	54	996
11377100	3/24/1979	6230	21	353

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/26/1979	5890	59	938
11377100	3/26/1979	5890	32	509
11377100	3/26/1979	5870	32	507
11377100	3/27/1979	6080	73	1200
11377100	3/27/1979	6290	80	1360
11377100	3/27/1979	7430	64	1280
11377100	3/28/1979	14900	73	2940
11377100	3/28/1979	15000	71	2880
11377100	3/28/1979	15500	71	2970
11377100	3/29/1979	13600	79	2900
11377100	3/29/1979	13500	90	3280
11377100	3/29/1979	13400	34	1230
11377100	3/30/1979	13400	74	2680
11377100	4/2/1979	11100	36	1080
11377100	4/2/1979	11000	24	713
11377100	4/2/1979	11000	22	653
11377100	4/3/1979	9950	8	215
11377100	4/4/1979	7470	6	121
11377100	4/5/1979	7420	8	160
11377100	4/6/1979	7360	15	298
11377100	4/6/1979	7400	18	360
11377100	4/6/1979	7440	30	603
11377100	4/7/1979	7470	4	81
11377100	4/8/1979	7340	15	297
11377100	4/9/1979	7310	17	336
11377100	4/10/1979	6250	25	422
11377100	4/11/1979	5470	6	89
11377100	4/12/1979	5310	3	43
11377100	4/13/1979	5250	9	128
11377100	4/14/1979	5640	3	46
11377100	4/15/1979	7290	5	98
11377100	4/16/1979	7320	4	79
11377100	4/16/1979	7420	11	220
11377100	4/17/1979	7690	6	125
11377100	4/17/1979	7600	13	267
11377100	4/17/1979	7540	8	163
11377100	4/18/1979	7470	6	121
11377100	4/19/1979	7290	5	98
11377100	4/21/1979	7890	4	85

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	4/22/1979	8240	7	156
11377100	4/22/1979	8610	6	139
11377100	4/22/1979	8760	3	71
11377100	4/23/1979	10200	25	688
11377100	4/23/1979	10400	14	393
11377100	4/24/1979	13700	17	629
11377100	4/25/1979	11100	18	539
11377100	4/25/1979	11100	9	270
11377100	4/25/1979	11000	13	386
11377100	4/26/1979	9800	14	370
11377100	4/26/1979	9560	24	619
11377100	4/26/1979	9300	11	276
11377100	4/27/1979	10100	36	982
11377100	4/28/1979	9310	10	251
11377100	4/29/1979	8960	9	218
11377100	4/30/1979	8870	28	671
11377100	5/1/1979	9600	17	441
11377100	5/2/1979	9280	19	476
11377100	5/2/1979	9240	15	374
11377100	5/2/1979	9190	17	422
11377100	5/2/1979	9140	16	395
11377100	5/3/1979	8740	11	260
11377100	5/4/1979	8650	32	747
11377100	5/5/1979	9260	51	1280
11377100	5/6/1979	11900	25	803
11377100	5/6/1979	11400	37	1140
11377100	5/6/1979	10900	25	736
11377100	5/7/1979	12800	10	346
11377100	5/7/1979	12300	16	531
11377100	5/7/1979	11800	19	605
11377100	5/8/1979	9880	13	347
11377100	5/9/1979	8220	8	178
11377100	5/10/1979	8090	11	240
11377100	5/11/1979	9970	10	269
11377100	5/12/1979	9970	4	108
11377100	5/13/1979	9950	18	484
11377100	5/14/1979	9790	16	423
11377100	5/15/1979	9630	10	260
11377100	5/16/1979	9560	8	206

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	5/17/1979	9460	8	204
11377100	5/18/1979	9420	1	25
11377100	5/19/1979	9390	4	101
11377100	5/20/1979	9520	2	51
11377100	5/21/1979	9390	6	152
11377100	5/22/1979	9350	7	177
11377100	5/23/1979	9300	9	226
11377100	5/24/1979	9140	13	321
11377100	5/25/1979	9090	26	638
11377100	5/26/1979	9100	8	197
11377100	5/27/1979	9080	2	49
11377100	5/28/1979	8780	4	95
11377100	5/29/1979	8740	5	118
11377100	5/30/1979	8610	4	93
11377100	5/31/1979	9330	4	101
11377100	6/1/1979	9180	12	297
11377100	6/1/1979	9100	7	172
11377100	6/8/1979	10800	21	612
11377100	6/13/1979	10900	23	677
11377100	6/21/1979	10900	15	441
11377100	6/27/1979	12700	13	446
11377100	7/2/1979	14800	29	1160
11377100	7/3/1979	14700	53	2100
11377100	7/11/1979	14200	30	1150
11377100	7/20/1979	14200	28	1070
11377100	7/27/1979	13600	64	2350
11377100	7/31/1979	13200	39	1390
11377100	8/2/1979	13200	16	570
11377100	8/3/1979	13200	19	677
11377100	8/7/1979	12600	7	238
11377100	8/16/1979	8310	6	135
11377100	8/24/1979	8150	4	88
11377100	8/31/1979	7660	6	124
11377100	9/1/1979	7610	5	103
11377100	9/4/1979	7230	5	98
11377100	9/4/1979	7130	5	96
11377100	9/14/1979	5600	6	91
11377100	9/17/1979	5190	7	98
11377100	9/29/1979	5310	4	57

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	10/1/1979	5760	6	93
11377100	10/4/1979	5680	5	77
11377100	10/12/1979	5820	6	94
11377100	10/17/1979	5030	6	81
11377100	10/23/1979	5350	11	159
11377100	10/29/1979	4970	10	134
11377100	11/2/1979	4640	9	113
11377100	11/2/1979	4700	6	76
11377100	11/2/1979	4780	6	77
11377100	11/3/1979	4740	6	77
11377100	11/3/1979	4840	9	118
11377100	11/3/1979	5090	6	82
11377100	11/4/1979	6640	22	394
11377100	11/4/1979	6210	16	268
11377100	11/4/1979	5810	16	251
11377100	11/5/1979	6230	14	235
11377100	11/5/1979	6570	13	231
11377100	11/5/1979	6280	13	220
11377100	11/6/1979	5790	14	219
11377100	11/6/1979	5720	14	216
11377100	11/6/1979	5710	13	200
11377100	11/7/1979	5710	14	216
11377100	11/8/1979	5580	11	166
11377100	11/9/1979	5130	6	83
11377100	11/10/1979	4990	5	67
11377100	11/11/1979	4900	8	106
11377100	11/18/1979	8210	9	200
11377100	11/19/1979	7370	10	199
11377100	11/20/1979	6910	14	261
11377100	11/22/1979	6620	9	161
11377100	11/22/1979	6690	11	199
11377100	11/22/1979	6760	11	201
11377100	11/23/1979	9350	38	959
11377100	11/23/1979	8970	26	630
11377100	11/23/1979	8470	36	823
11377100	11/25/1979	8990	48	1170
11377100	11/25/1979	8820	37	881
11377100	11/25/1979	8480	42	962
11377100	11/26/1979	7680	23	477

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	11/27/1979	7270	29	569
11377100	11/28/1979	7130	29	558
11377100	11/29/1979	6970	11	207
11377100	11/30/1979	6910	9	168
11377100	12/1/1979	6860	13	241
11377100	12/2/1979	6840	14	259
11377100	12/3/1979	6780	12	220
11377100	12/3/1979	6810	10	184
11377100	12/3/1979	6810	7	129
11377100	12/4/1979	6660	10	180
11377100	12/5/1979	6610	12	214
11377100	12/6/1979	6620	5	89
11377100	12/7/1979	6620	11	197
11377100	12/8/1979	6520	11	194
11377100	12/9/1979	6470	8	140
11377100	12/10/1979	6420	4	69
11377100	12/11/1979	6330	5	85
11377100	12/12/1979	6330	4	68
11377100	12/13/1979	6350	5	86
11377100	12/14/1979	6280	7	119
11377100	12/15/1979	6280	7	119
11377100	12/16/1979	6310	8	136
11377100	12/17/1979	6260	6	101
11377100	12/18/1979	6350	8	137
11377100	12/19/1979	6350	12	206
11377100	12/19/1979	6370	9	155
11377100	12/19/1979	6370	6	103
11377100	12/20/1979	6400	18	311
11377100	12/20/1979	6420	6	104
11377100	12/20/1979	6520	10	176
11377100	12/21/1979	7320	7	138
11377100	12/22/1979	7110	11	211
11377100	12/22/1979	7020	14	265
11377100	12/24/1979	48700	1030	135000
11377100	12/24/1979	44900	858	104000
11377100	12/24/1979	54200	773	113000
11377100	12/26/1979	14000	81	3060
11377100	12/26/1979	13800	75	2790
11377100	12/26/1979	13400	74	2680

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	12/26/1979	12900	63	2190
11377100	12/27/1979	10800	33	962
11377100	12/28/1979	9820	23	610
11377100	12/30/1979	13300	76	2730
11377100	1/2/1980	12300	47	1560
11377100	1/2/1980	12000	38	1230
11377100	1/2/1980	11900	36	1160
11377100	1/13/1980	33700	563	51200
11377100	1/13/1980	34000	509	46700
11377100	1/17/1980	50200	154	20900
11377100	1/17/1980	50700	111	15200
11377100	1/30/1980	14400	42	1630
11377100	1/31/1980	14200	42	1610
11377100	2/1/1980	13000	41	1440
11377100	2/1/1980	12800	22	760
11377100	2/2/1980	11800	21	669
11377100	2/3/1980	16200	21	919
11377100	2/4/1980	12300	16	531
11377100	2/5/1980	11500	26	807
11377100	2/6/1980	11300	27	824
11377100	2/7/1980	11000	42	1250
11377100	2/7/1980	10900	26	765
11377100	2/8/1980	11000	21	624
11377100	2/9/1980	10900	24	706
11377100	2/10/1980	10300	19	528
11377100	2/11/1980	9190	23	571
11377100	2/12/1980	9100	20	491
11377100	2/13/1980	8820	16	381
11377100	2/14/1980	8920	17	409
11377100	2/14/1980	8870	17	407
11377100	2/14/1980	8820	18	429
11377100	2/15/1980	8950	18	435
11377100	2/15/1980	9000	17	413
11377100	2/15/1980	9050	17	415
11377100	2/20/1980	93700	312	78900
11377100	2/20/1980	84700	264	60400
11377100	2/21/1980	92800	620	155000
11377100	2/21/1980	83400	282	63500
11377100	2/21/1980	83300	261	58700

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/21/1980	83300	261	58700
11377100	2/21/1980	81600	264	58200
11377100	2/21/1980	77000	237	49300
11377100	2/22/1980	68000	61	11200
11377100	2/22/1980	67900	65	11900
11377100	2/22/1980	75600	152	31000
11377100	2/23/1980	67700	125	22800
11377100	2/23/1980	66400	75	13400
11377100	2/23/1980	65700	78	13800
11377100	2/24/1980	63100	41	6990
11377100	2/24/1980	62500	39	6580
11377100	2/24/1980	62400	70	11800
11377100	2/28/1980	73000	160	31500
11377100	2/28/1980	74900	162	32800
11377100	2/28/1980	68900	95	17700
11377100	2/29/1980	52400	23	3250
11377100	2/29/1980	51000	43	5920
11377100	2/29/1980	50700	38	5200
11377100	3/1/1980	49100	24	3180
11377100	3/1/1980	48700	42	5520
11377100	3/1/1980	48400	24	3140
11377100	3/2/1980	47700	22	2830
11377100	3/2/1980	47700	20	2580
11377100	3/2/1980	47500	30	3850
11377100	3/3/1980	47000	55	6980
11377100	3/3/1980	46900	49	6210
11377100	3/3/1980	46900	50	6330
11377100	3/3/1980	46900	58	7350
11377100	3/4/1980	49300	45	5990
11377100	3/5/1980	51200	52	7190
11377100	3/5/1980	58700	50	7920
11377100	3/5/1980	56600	54	8250
11377100	3/6/1980	50400	47	6400
11377100	3/6/1980	45900	54	6690
11377100	3/6/1980	41900	57	6450
11377100	3/7/1980	28100	50	3790
11377100	3/8/1980	25700	48	3330
11377100	3/9/1980	24700	33	2200
11377100	3/10/1980	23700	26	1660

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/11/1980	23100	25	1560
11377100	3/12/1980	22400	17	1030
11377100	3/13/1980	22200	18	1080
11377100	3/14/1980	21700	21	1230
11377100	3/16/1980	22600	24	1460
11377100	3/17/1980	21500	19	1100
11377100	3/18/1980	20300	18	987
11377100	3/19/1980	17200	12	557
11377100	3/21/1980	14600	13	512
11377100	3/22/1980	12600	12	408
11377100	3/23/1980	10500	14	397
11377100	3/24/1980	9770	9	237
11377100	3/25/1980	9560	8	206
11377100	3/26/1980	9540	8	206
11377100	3/27/1980	9280	7	175
11377100	3/28/1980	9140	7	173
11377100	3/29/1980	9020	6	146
11377100	3/30/1980	8870	12	287
11377100	3/31/1980	8990	22	534
11377100	4/1/1980	9880	25	667
11377100	4/1/1980	9930	20	536
11377100	4/1/1980	9930	20	536
11377100	4/1/1980	9980	22	593
11377100	4/2/1980	9960	19	511
11377100	4/3/1980	9750	15	395
11377100	4/4/1980	9780	15	396
11377100	4/4/1980	9780	15	396
11377100	4/4/1980	9860	15	399
11377100	4/5/1980	11100	11	330
11377100	4/6/1980	10000	14	378
11377100	4/7/1980	9190	22	546
11377100	4/8/1980	8930	17	410
11377100	4/9/1980	8840	10	239
11377100	4/10/1980	8750	8	189
11377100	4/11/1980	8660	10	234
11377100	4/12/1980	8590	7	162
11377100	4/13/1980	8420	14	318
11377100	4/14/1980	8110	10	219
11377100	4/15/1980	8290	12	269

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	4/16/1980	8100	14	306
11377100	4/17/1980	8110	20	438
11377100	4/19/1980	8870	17	407
11377100	4/19/1980	8820	19	452
11377100	4/20/1980	8950	26	628
11377100	4/21/1980	9680	19	497
11377100	4/22/1980	9280	16	401
11377100	4/23/1980	8840	15	358
11377100	4/24/1980	8320	10	225
11377100	4/25/1980	8280	8	179
11377100	4/26/1980	8500	7	161
11377100	4/27/1980	8160	4	88
11377100	4/28/1980	8110	13	285
11377100	4/29/1980	8400	7	159
11377100	4/30/1980	8560	11	254
11377100	5/1/1980	8560	12	277
11377100	5/1/1980	8560	9	208
11377100	5/1/1980	8510	8	184
11377100	5/2/1980	8610	8	186
11377100	5/3/1980	9280	9	226
11377100	5/4/1980	9290	10	251
11377100	5/5/1980	9400	9	228
11377100	5/7/1980	9330	10	252
11377100	5/9/1980	9430	15	382
11377100	5/9/1980	9590	16	414
11377100	5/12/1980	8970	14	339
11377100	5/14/1980	8740	9	212
11377100	5/16/1980	7830	10	211
11377100	5/19/1980	7640	9	186
11377100	5/21/1980	8420	9	205
11377100	5/23/1980	8350	9	203
11377100	5/26/1980	8390	4	91
11377100	5/28/1980	8280	3	67
11377100	5/30/1980	8130	4	88
11377100	6/2/1980	8470	4	91
11377100	6/3/1980	8480	9	206
11377100	6/3/1980	8480	7	160
11377100	6/4/1980	8560	14	324
11377100	6/4/1980	8560	8	185

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	6/4/1980	8560	6	139
11377100	6/5/1980	8790	16	380
11377100	6/5/1980	8790	14	332
11377100	6/5/1980	8790	13	309
11377100	6/9/1980	10600	6	172
11377100	6/11/1980	10800	21	612
11377100	6/13/1980	11600	22	689
11377100	6/16/1980	12500	28	945
11377100	6/18/1980	13900	4	150
11377100	6/20/1980	13800	4	149
11377100	6/23/1980	12100	8	261
11377100	6/25/1980	12100	5	163
11377100	6/27/1980	12000	10	324
11377100	7/3/1980	11300	20	610
11377100	7/9/1980	11200	10	302
11377100	7/18/1980	12200	9	296
11377100	7/23/1980	12100	6	196
11377100	7/30/1980	11300	4	122
11377100	8/2/1980	11000	12	356
11377100	8/2/1980	11000	8	238
11377100	8/6/1980	10400	8	225
11377100	8/7/1980	10500	6	170
11377100	8/21/1980	9070	4	98
11377100	8/29/1980	8250	3	67
11377100	9/4/1980	7880	25	532
11377100	9/10/1980	6910	9	168
11377100	9/10/1980	6910	23	429
11377100	9/18/1980	6470	80	1400
11377100	9/23/1980	6590	10	178
11377100	9/28/1980	6400	7	121
11377100	11/1/1980	5190	3	42
11377100	11/3/1980	6330	65	1110
11377100	11/7/1980	6350	3	51
11377100	11/13/1980	6230	4	67
11377100	12/2/1980	6640	6	108
11377100	1/6/1981	6070	3	49
11377100	1/29/1981	25200	228	15500
11377100	1/29/1981	25200	228	15500
11377100	2/3/1981	7180	12	233

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/2/1981	6900	9	168
11377100	4/1/1981	17100	27	1250
11377100	4/1/1981	17100	27	1250
11377100	5/4/1981	10900	7	206
11377100	11/3/1981	4430	8	96
11377100	11/19/1981	8190	55	1220
11377100	11/30/1981	17400	32	1500
11377100	12/22/1981	49100	186	24700
11377100	2/4/1982	12600	15	510
11377100	4/5/1982	27800	42	3150
11377100	5/4/1982	20900	16	903
11377100	11/3/1982	8900	5	120
11377100	12/1/1982	19500	19	100
11377100	12/22/1982	49100	186	24700
11377100	12/23/1982	58300	148	23300
11377100	1/3/1983	10800	8	233
11377100	3/4/1983	99300	619	166000
11377100	5/2/1983	26400	105	
11377100	3/8/1996	32100	54	
11377100	4/24/1996	8560	16	
11377100	5/30/1996	15900	11	
11377100	6/27/1996	12600	4	
11377100	7/11/1996	15100	5	
11377100	8/29/1996	12900	8	
11377100	9/20/1996	9500	4	
11377100	11/22/1996	7780	15	
11377100	12/12/1996	42200	51	
11377100	1/3/1997	86400	355	
11377100	2/20/1997	10600	37	
11377100	3/20/1997	8300	22	
11377100	4/22/1997	9140	27	
11377100	5/30/1997	10100	14	
11377100	6/25/1997	15400	14	
11377100	7/23/1997	16000	9	
11377100	8/21/1997	10700	9	
11377100	9/17/1997	8390	9	
11377100	10/22/1997	5330	6	
11377100	11/19/1997	9900	43	
11377100	12/10/1997	7620	18	

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	1/14/1998	18300	141	
11377100	2/18/1998	70700	63	
11377100	3/18/1998	12900	38	
11377100	4/9/1998	19200	33	
11377100	5/14/1998	17800	26	
11377100	1/19/2000	9790	39	
11377100	1/20/2000	26100	410	
11377100	2/20/2000	44700	23	
11377100	2/21/2000	50000	62	
11377200	2/2/1967	52800	135	19200
11377200	4/27/1967	33100	232	20700
11377200	1/15/1968	44600	910	110000
11377200	2/21/1968	35200	412	39200
11377200	12/10/1968	28200	418	31800
11377200	1/3/1969	9130	125	3080
11377200	1/12/1969	53000	780	112000
11377200	1/12/1969	60500	608	99300
11377200	1/13/1969	78000	710	150000
11377200	1/23/1969	66700	228	41100
11377200	1/31/1969	34900	60	5650
11377200	2/6/1969	43000	595	69100
11377200	3/1/1969	44600	245	29500
11377200	12/19/1969	50500	575	78400
11377200	12/20/1969	48600	356	46700
11377200	12/21/1969	65200	1110	195000
11377200	1/10/1970	43000	322	37400
11377200	1/16/1970	95900	898	233000
11377200	1/17/1970	69200	322	60200
11377200	1/21/1970	90600	311	76100
11377200	1/24/1970	111000	2770	830000
11377200	1/26/1970	103000	253	70400
11377200	1/27/1970	138000	1830	682000
11377200	1/27/1970	125000	715	241000
11377200	2/2/1970	80200	139	30100
11377200	2/17/1970	27700	190	14200
11378500	11/2/1956	8590	17	394
11378500	12/11/1956	6980	8	151
11378500	1/21/1957	6270	77	1300
11378500	2/18/1957	4010	9	97

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11378500	2/28/1957	22000	137	8140
11378500	3/26/1957	7640	13	268
11378500	4/18/1957	9750	452	11900
11378500	5/14/1957	11800	94	3000
11378500	6/10/1957	9400	10	254
11378500	7/29/1957	9350	8	202
11378500	9/17/1957	7430	6	120
11378500	10/13/1957	27900	1050	79100
11378500	11/14/1957	26900	725	52700
11378500	12/29/1957	18400	156	7750
11378500	1/10/1958	22100	331	19800
11378500	1/26/1958	64200	1720	298000
11378500	1/31/1958	53400	261	37600
11378500	2/4/1958	76000	384	78800
11378500	2/12/1958	108000	1050	306000
11378500	2/22/1958	99600	493	133000
11378500	3/22/1958	42600	1010	116000
11378500	3/30/1958	34600	389	36300
11378500	4/10/1958	40300	131	14300
11378500	1/9/1959	30600	920	76000
11378500	2/16/1959	83200	1290	290000
11378500	9/19/1959	17500	1400	66200
11378500	2/8/1960	73400	1770	351000
11378500	2/9/1960	34400	748	69500
11378500	3/6/1960	23900	729	47000
11378500	12/1/1960	65900	918	163000
11378500	1/30/1961	21900	853	50400
11378500	1/31/1961	47700	1050	135000
11378500	2/1/1961	23200	431	27000
11378500	2/2/1961	35000	1270	120000
11378500	2/11/1961	38000	782	80200
11378500	12/1/1961	31900	694	59800
11378500	12/21/1961	13600	304	11200
11378500	2/15/1962	65400	1480	261000
11378500	2/16/1962	28500	204	15700
11378500	3/6/1962	59800	1440	233000
11378500	3/9/1962	17300	46	2150
11378500	10/12/1962	32600	1080	95100
11378500	11/27/1962	12300	147	4880

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11378500	12/3/1962	21600	418	24400
11378500	12/17/1962	42400	455	52100
11378500	2/1/1963	46900	1170	148000
11378500	2/10/1963	25300	690	47100
11378500	2/13/1963	25500	322	22200
11378500	5/22/1963	14500	19	744
11378500	11/12/1963	8240	10	222
11378500	1/21/1964	60800	957	157000
11378500	1/21/1964	26200	607	42900
11378500	11/11/1964	8480	67	1530
11378500	12/20/1964	9980	308	8300
11378500	12/21/1964	10600	713	20400
11378500	12/21/1964	16000	462	20000
11378500	12/21/1964	20500	469	26000
11378500	12/22/1964	72300	2750	537000
11378500	12/23/1964	114000	1380	425000
11378500	12/23/1964	94800	1550	397000
11378500	12/23/1964	78200	1440	304000
11378500	12/25/1964	57800	715	112000
11378500	12/27/1964	67100	350	63400
11378500	12/29/1964	50600	170	23200
11378500	12/30/1964	44600	120	14500
11378500	1/1/1965	27900	121	9120
11378500	1/2/1965	25200	101	6870
11378500	1/3/1965	37200	335	33600
11378500	1/8/1965	63700	179	30800
11378500	1/10/1965	34500	109	10200
11378500	1/21/1965	22900	102	6310
11378500	2/9/1965	19500	35	1840
11378500	4/2/1965	11400	103	3170
11378500	4/9/1965	36400	1280	126000
11378500	11/15/1965	23400	2030	128000
11378500	11/16/1965	11400	105	3230
11378500	11/18/1965	19600	323	17100
11378500	1/5/1966	76300	1840	379000
11378500	2/1/1966	17700	40	1910
11378500	2/6/1966	28000	481	36400
11378500	3/2/1966	8050	12	261

Table A-2. USGS suspended sediment data at sites near Hamilton City.

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load, (tons/d)
11383730	1/19/2000	12800	37	
11383730	1/19/2000	17000	67	
11383730	1/20/2000	14600	326	
11383730	2/20/2000	47500	55	
11383730	2/21/2000	48900	111	
11383730	2/21/2000	53500	190	
11383800	5/11/1977	8600	10	232
11383800	5/12/1977	9700	34	890
11383800	6/8/1977	5890	12	191
11383800	11/30/1977	4930		19
11383800	12/15/1977	35900	1280	124000
11383800	1/10/1978	11100	1010	30300
11383800	1/18/1978	48300	758	98900
11383800	2/8/1978	76500	1130	233000
11383800	2/10/1978	40000	388	41900
11383800	3/8/1978	47000	275	34900
11383800	3/22/1978	15300		76
11383800	3/22/1978	15400	115	4780
11383800	4/27/1978	16700	106	4780
11383800	6/27/1978	7770		61
11383800	8/1/1978	8440		30
11383800	1/16/1979	25800	244	17000
11383800	2/14/1979	67500	749	137000
11383800	2/15/1979	18800	620	31500
11383800	3/7/1979	10100	28	764
11383800	4/4/1979	9500	22	564
11383800	5/15/1979	8640	19	443

Table A-3. USGS suspended sediment data at sites near Colusa.

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389000	11/3/1977	5120	24	332
11389000	12/16/1977	21000	933	52900
11389000	1/4/1978	10400	92	2580
11389000	1/11/1978	69700	648	122000
11389000	1/12/1978	31700	532	45500
11389000	1/17/1978	119000	906	291000
11389000	4/20/1978	16900	53	2420
11389000	6/1/1978	7870	36	765
11389000	7/5/1978	8090	26	568
11389000	12/27/1978	19800	231	12300
11389000	1/16/1979	37500	611	61900
11389000	2/15/1979	45900	498	61700
11389000	3/8/1979	11400	56	1720
11389000	4/5/1979	9360	30	758
11389000	5/16/1979	8650	21	490
11389000	12/27/1979	19800	231	12300
11389000	1/24/1980	43000	201	23300
11389000	2/20/1980	122000	1270	418000
11389000	4/1/1980	11000	60	1780
11389500	12/19/1972	30600	486	40200
11389500	12/20/1972	32100	492	42600
11389500	1/11/1973	32500	249	21900
11389500	1/12/1973	35100	1100	104000
11389500	1/13/1973	39200	667	70600
11389500	1/15/1973	34300	342	31700
11389500	1/16/1973	32700	331	29200
11389500	1/17/1973	38400	846	87700
11389500	1/19/1973	41000	645	71400
11389500	1/20/1973	42000	400	45400
11389500	1/22/1973	37900	315	32200
11389500	1/23/1973	37400	239	24100
11389500	1/24/1973	36700	209	20700
11389500	1/26/1973	34800	213	20000
11389500	1/27/1973	32700	218	19200
11389500	2/6/1973	33500	466	42200
11389500	2/8/1973	38300	598	61800

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389500	2/9/1973	37200	310	31100
11389500	2/10/1973	35300	223	21300
11389500	2/12/1973	36600	232	22900
11389500	2/13/1973	36600	256	25300
11389500	2/15/1973	38600	196	20400
11389500	2/16/1973	37200	238	23900
11389500	2/17/1973	35100	172	16300
11389500	2/28/1973	35300	428	40800
11389500	3/1/1973	37700	260	26500
11389500	3/2/1973	35900	206	20000
11389500	3/3/1973	34800	157	14800
11389500	3/5/1973	34500	136	12700
11389500	3/6/1973	33200	108	9680
11389500	3/7/1973	34400	240	22300
11389500	3/8/1973	33600	141	12800
11389500	3/9/1973	32300	116	10100
11389500	11/14/1973	38500	357	37100
11389500	11/15/1973	35600	212	20400
11389500	11/16/1973	35200	189	18000
11389500	11/17/1973	37800	270	27600
11389500	11/20/1973	41000	237	26200
11389500	2/11/1975	31700	327	28000
11389500	2/13/1975	33700	969	88200
11389500	2/13/1975	35700	1090	105000
11389500	2/14/1975	40400	1020	111000
11389500	2/14/1975	41100	836	92800
11389500	3/11/1975	35300	457	43600
11389500	3/12/1975	34100	398	36600
11389500	3/12/1975	33800	365	33300
11389500	3/20/1975	39300	855	90700
11389500	3/21/1975	40000	346	37400
11389500	1/20/1977	6920	38	710
11389500	1/26/1977	7080	33	631
11389500	2/23/1977	5890	24	382
11389500	3/20/1977	7000	101	1910
11389500	3/22/1977	6060	33	540
11389500	4/26/1977	6300	35	595
11389500	11/4/1977	4890	52	687
11389500	12/17/1977	14300	636	24600

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389500	1/3/1978	7460	65	1310
11389500	1/11/1978	40500	601	65700
11389500	1/19/1978	40100	572	61900
11389500	2/8/1978	38600	1010	105000
11389500	3/7/1978	39900	319	34400
11389500	4/19/1978	19200	95	4930
11389500	5/17/1978	9730	194	5100
11389500	1/9/1979	12500	64	2160
11389500	1/17/1979	26100	315	22200
11389500	2/15/1979	11400	467	14400
11389500	2/15/1979	37100	459	46000
11389500	3/6/1979	11100	74	2220
11389500	4/6/1979	10000	297	8020
11389500	11/6/1979	6600	76	1350
11389500	12/26/1979	41500	340	38100
11389500	1/3/1980	19400	133	6970
11389500	1/16/1980	42900	638	73900
11389500	2/28/1996	35200	151	
11389500	3/20/1996	20700	153	
11389500	4/2/1996	13000	86	
11389500	5/16/1996	8980	52	
11389500	6/17/1996	11300	59	
11389500	7/16/1996	10900	32	
11389500	8/14/1996	11600	45	
11389500	9/25/1996	9270	30	
11389500	10/9/1996	7080	36	
11389500	11/14/1996	5820	46	
11389500	12/4/1996	7340	27	
11389500	12/16/1996	33200	92	
11389500	1/4/1997	47400	579	
11389500	2/12/1997	23700	105	
11389500	3/13/1997	8700	41	
11389500	4/16/1997	6840	47	
11389500	5/20/1997	7350	36	
11389500	6/3/1997	8420	37	
11389500	7/31/1997	10800	33	
11389500	8/18/1997	7870	28	
11389500	9/25/1997	6930	29	
11389500	10/21/1997	4340	36	

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389500	11/13/1997	5100	23	
11389500	12/9/1997	19600	177	
11389500	1/13/1998	36600	545	
11389500	2/11/1998	45900	202	
11389500	3/17/1998	22200	149	
11389500	4/8/1998	35100	144	
11389500	5/13/1998	21000	121	
11389500	6/10/1998	25600	107	
11389500	7/29/1998	12700	94	
11389500	8/12/1998	12600	79	
11389500	9/16/1998	11300	97	
11389500	10/21/1998	6250	41	
11389500	11/12/1998	8920	57	
11389500	12/29/1998	11000	50	
11389500	1/20/1999	15100	123	
11389500	2/17/1999	33500	52	
11389500	3/11/1999	35100	54	
11389500	4/8/1999	13200	83	
11389500	5/6/1999	11400	50	
11389500	6/3/1999	10800	50	
11389500	7/20/1999	9670	28	
11389500	8/17/1999	6820	34	
11389500	9/9/1999	6920	37	
11389500	10/21/1999	4710	30	
11389500	11/4/1999	5340	29	
11389500	12/10/1999	9470	37	
11389500	1/13/2000	8140	27	
11389500	2/23/2000	38200	92	
11389500	3/10/2000	40200	96	
11389500	4/12/2000	11400	38	
11389500	5/19/2000	9290	44	
11389500	6/15/2000	10700	34	
11389500	7/19/2000	10900	20	
11389500	8/18/2000	7890	20	
11389500	9/14/2000	6130	19	

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Bedload Analysis of NODOS

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RECLAMATION
Managing Water in the West

Technical Report No. SRH-2011-23

Sacramento River Bedload Analysis of NODOS Alternatives

Mid Pacific Region
NODOS Investigation Report

U.S. Department of the Interior
Bureau of Reclamation

June 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

Technical Report No. SRH-2011-23

Sacramento River Bedload Analysis of NODOS Alternatives

Mid Pacific Region
NODOS Investigation Report

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1 Introduction

The Sedimentation and River Hydraulics Group at the Technical Service Center (TSC) of the Bureau of Reclamation has been tasked, at the request of the Mid Pacific Regional Office, to provide analysis to support the North of Delta Off-Stream Storage (NODOS) Administrative Draft Environmental Impact Report/Study (ADEIR/S) and Feasibility Study (FS).

CH2MILL (2011) developed model simulations for the NODOS ADEIR/S and FS. The modeling simulations that were completed were labeled as:

- Existing Conditions
- No Action Alternative
- NODOS Alternative A
- NODOS Alternative B
- NODOS Alternative C

The purpose of the analysis was to investigate sediment transport capacity rates and a sediment budget for the existing conditions and alternative scenarios. This report provides results of sediment bedload analysis in the mainstem of the Sacramento River from Keswick Dam to Colusa. The Sacramento River from Shasta Reservoir to Colusa Weir is divided into 15 reaches, identified numerically from 23 (upstream) to 9 (downstream). Reaches 1 through 8 cover from Colusa Weir to RM80 and are not included in this analysis. Figure 1-1 through Figure 1-3 locates the reaches.

This report does not analyze suspended load in the Sacramento River, only the bed load, which consists primarily of gravel sized sediment (2 mm to 64 mm).

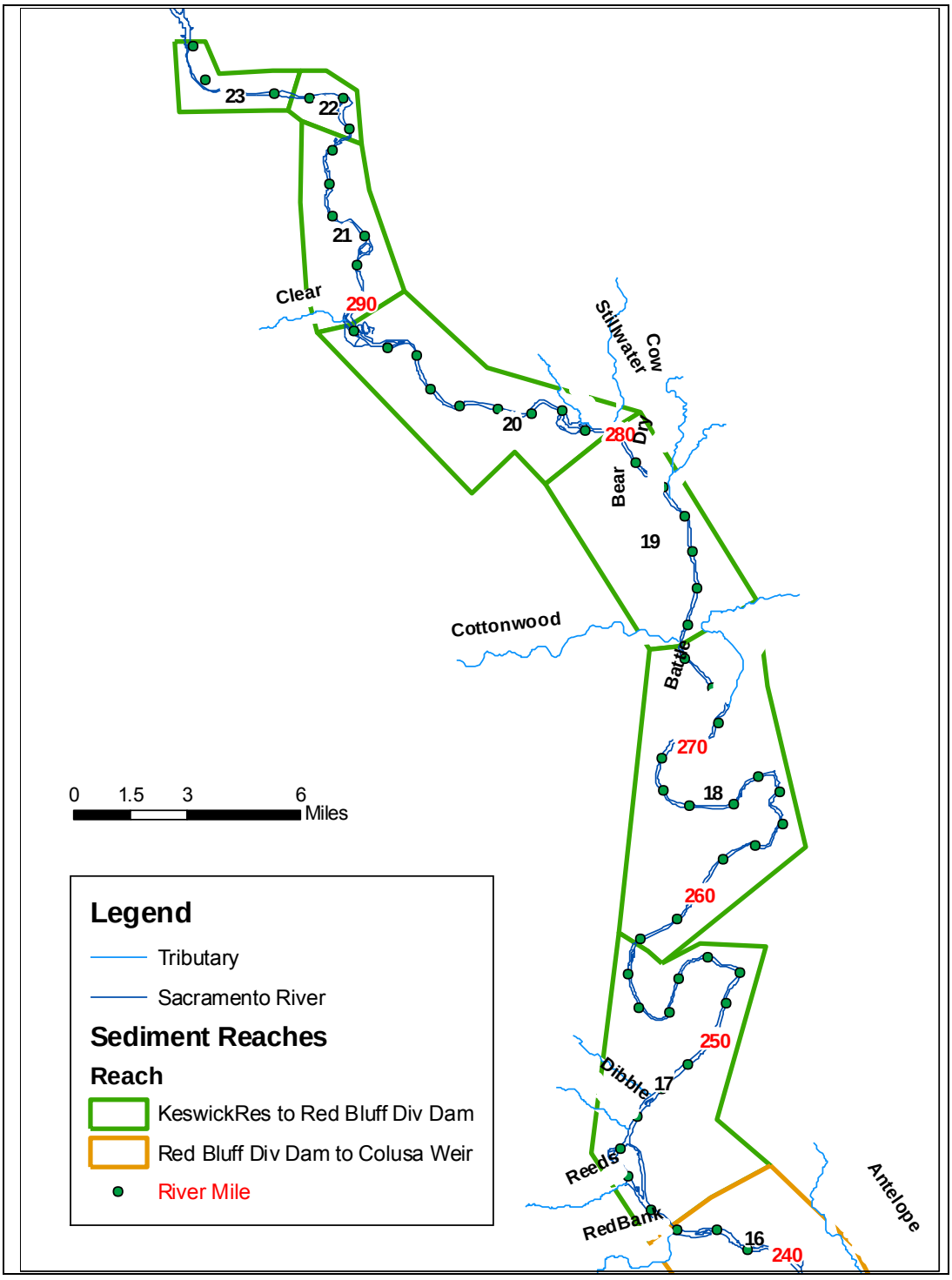

Figure 1-1. Reaches 23 - 17 with tributaries.

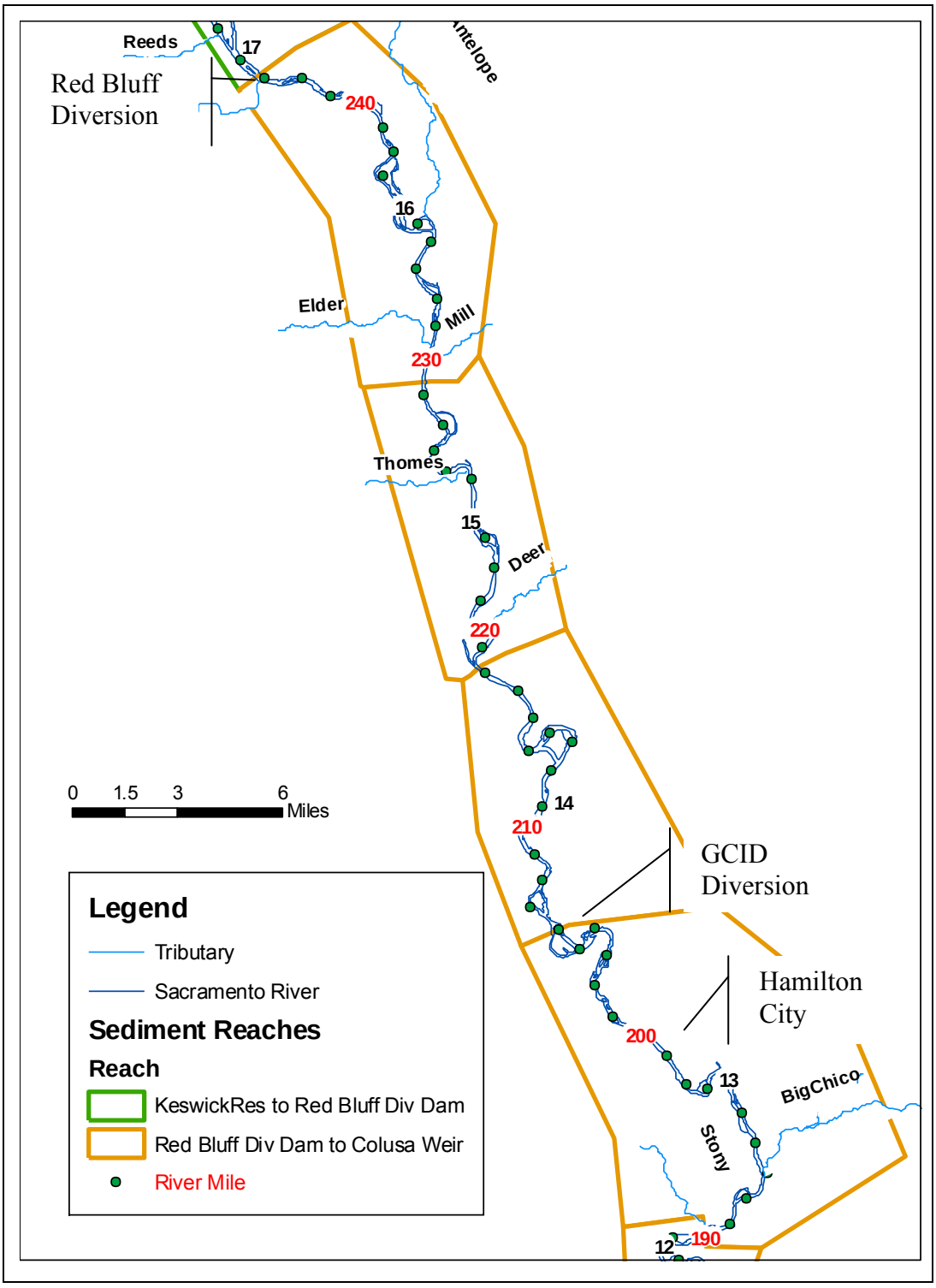

Figure 1-2. Reaches 16 - 13 with tributaries.

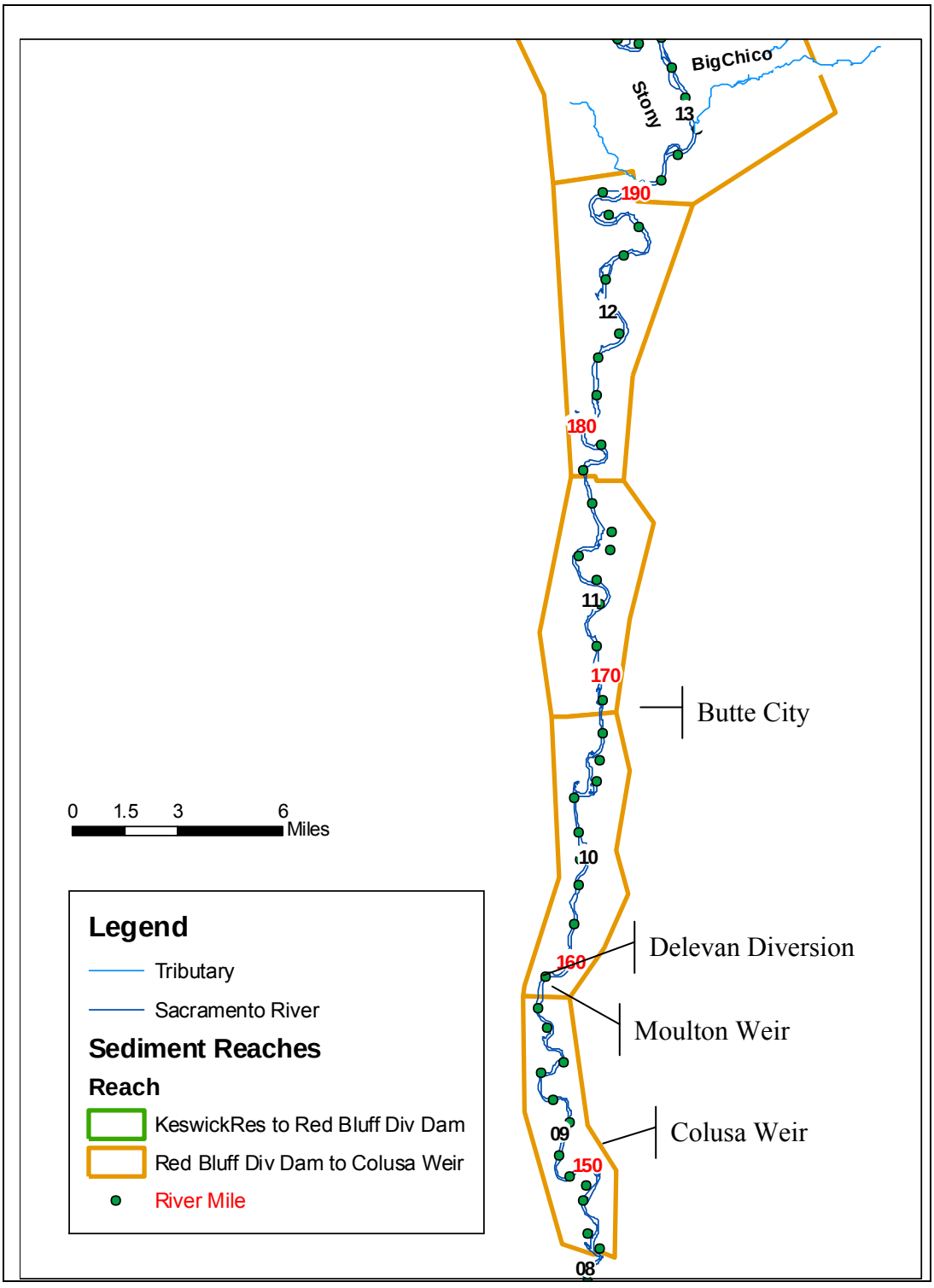

Figure 1-3. Reaches 12 - 9 with tributaries.

2 Alternative Analysis

The bedload sediment transport of five NODOS alternatives are compared to each other using sediment transport functions. The supporting data and methodology of the sediment computations are described in Reclamation (2011).

The analysis first compares the annual flow volumes and flow duration curves by reach. Then the transport capacity in tons/year for material greater than 2 mm is estimated, followed by the calculation of a sediment budget.

2.1 Annual Flow Volume

A hydrologic model (USRDOM) was developed for the Sacramento River where flow calculations were conducted at nodes (CH2MHILL, 2011). The nodes most appropriate to the 15 reaches defined above were assigned as is shown in Table 2-1. Reach 23 is the upstream-most reach and 09 is the most downstream reach.

Table 2-1. Hydrologic model nodes applied by reach.

Reach	River Miles	USRDOM ID
23	302 - 298.5	200-KESWICKDAM
22	298.5 - 295.6	197-ACID-DIV
21	295.6 - 289.3	197-ACID-DIV
20	289.3 - 280.1	195-CLEARCKINF
19	280.1 - 273.4	188-BEAR-ASHIN
18	273.4 - 257.8	185-BATTLECKIN
17	257.8 - 243	182-BENDBR-GAG
16	243 - 229.4	175-RDBLFDIVDA
15	229.4 - 218.3	162-THOMESCKIN
14	218.3 - 206	160-DEERCKINF
13	206 - 190	150-GCC-DIV
12	190 - 177.9	140-ORDFERRY
11	177.9 - 168.6	140-ORDFERRY
10	168.6 - 158.5	135-BUTTE-CITY
09	158.5 - 145.9	128-NODOS-DIV

As can be seen in Table 2-1, reaches 22 and 21 share a common hydrology, as do reaches 12 and 11; all other reaches have a unique hydrology. The hydrologic model covers a simulation period of approximately 82 years. An average annual volume of water was calculated for each reach and compared across the different alternatives. Figure 2-1 presents the difference in annual flow volume, measured in million acre feet (MAF). Figure 2-1 indicates little difference in annual flow volume between the alternatives upstream of Red Bluff Diversion Dam (Reaches 23 – 17) as well as for the river between Moulton and Colusa Weirs (Reach 9). For the river between Red Bluff Diversion Dam and Moulton Weir (Reaches 16 – 10), the following conditions in the annual flow volume are noted:

- Existing and No Action alternatives are comparable;
- Alternative A and Alternative C are comparable to each other and are less than the annual flow volume for Existing/No Action, and;
- Alternative B is lower than that of Alternative A and Alternative C.

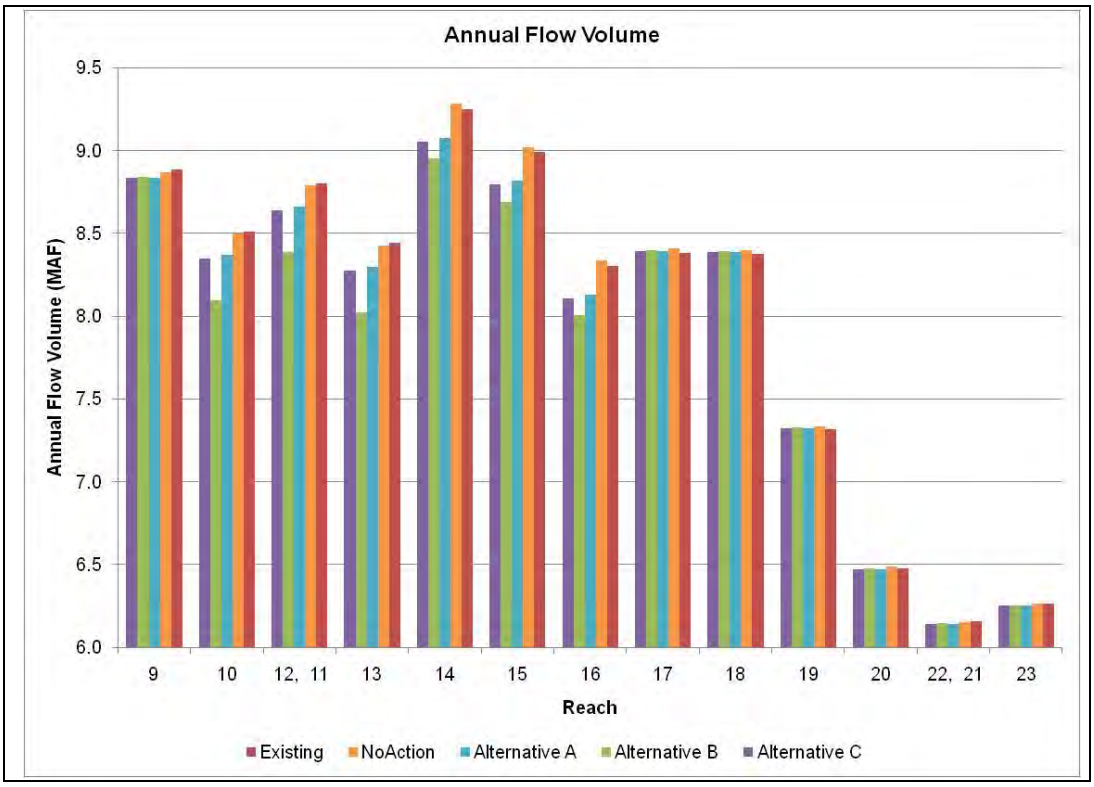

Figure 2-1. Comparison of annual flow volume for alternatives in analysis.

2.2 Flow Duration Curves

Along with total flow volume, flow rate frequency will affect sediment transport capacity; low flow transports much less sediment than high flow for the same flow volume. Existing flow duration curves (FDC) for Reaches 20, 17, 16, 13, and 10 are presented (Figure 2-2 through Figure 2-11). Because the FDCs are very similar between the alternatives, the differences in the FDCs are also presented. The reaches selected here are qualitatively representative of the reaches not presented. For instance, the existing FDC (and the discharge for the alternatives relative to existing) for reaches 23 through 19 are described by the FDC for Reach 20. Reach 17 is representative of reach 18. Reach 16 is representative for reaches 15 and 14. Reach 10 represents the characteristics for reaches 12, 11, and 9. Entire FDCs along with just the portion for flow non-exceedances greater than .99 are displayed due to the large variation in flows as the non-exceedance approaches 1.

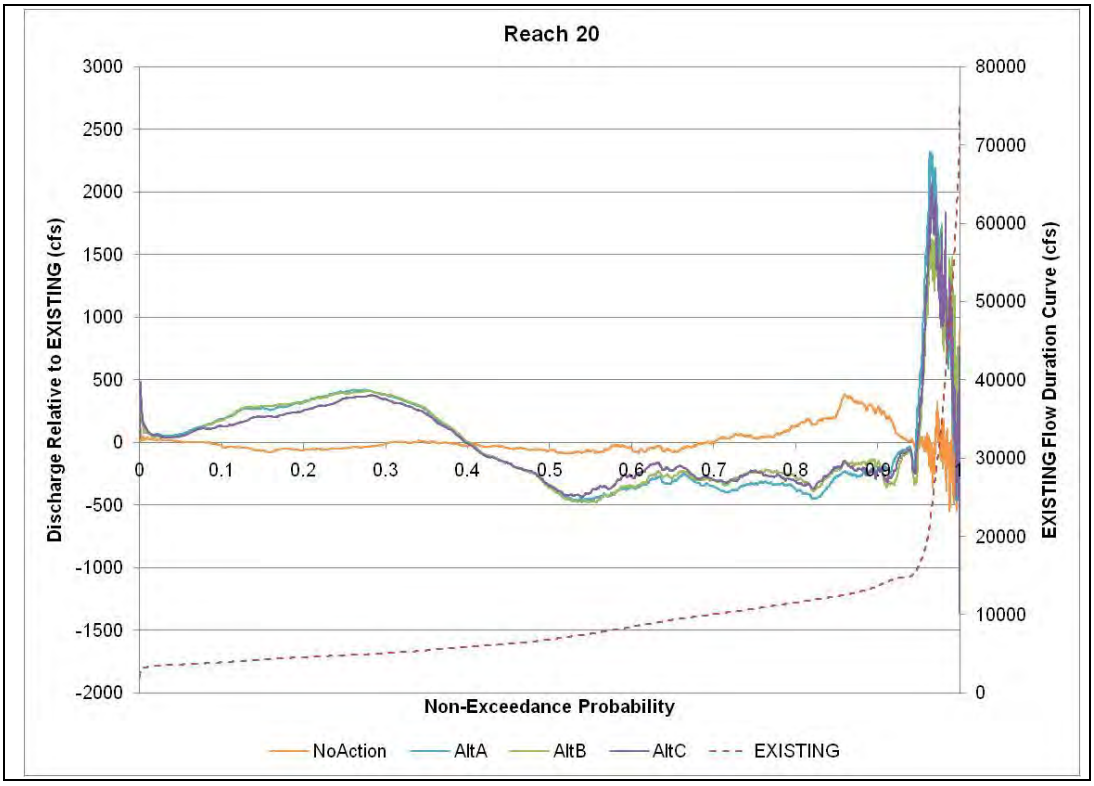

Figure 2-2. Average FDC for Reach 20, along with deviation of the alternatives from existing.

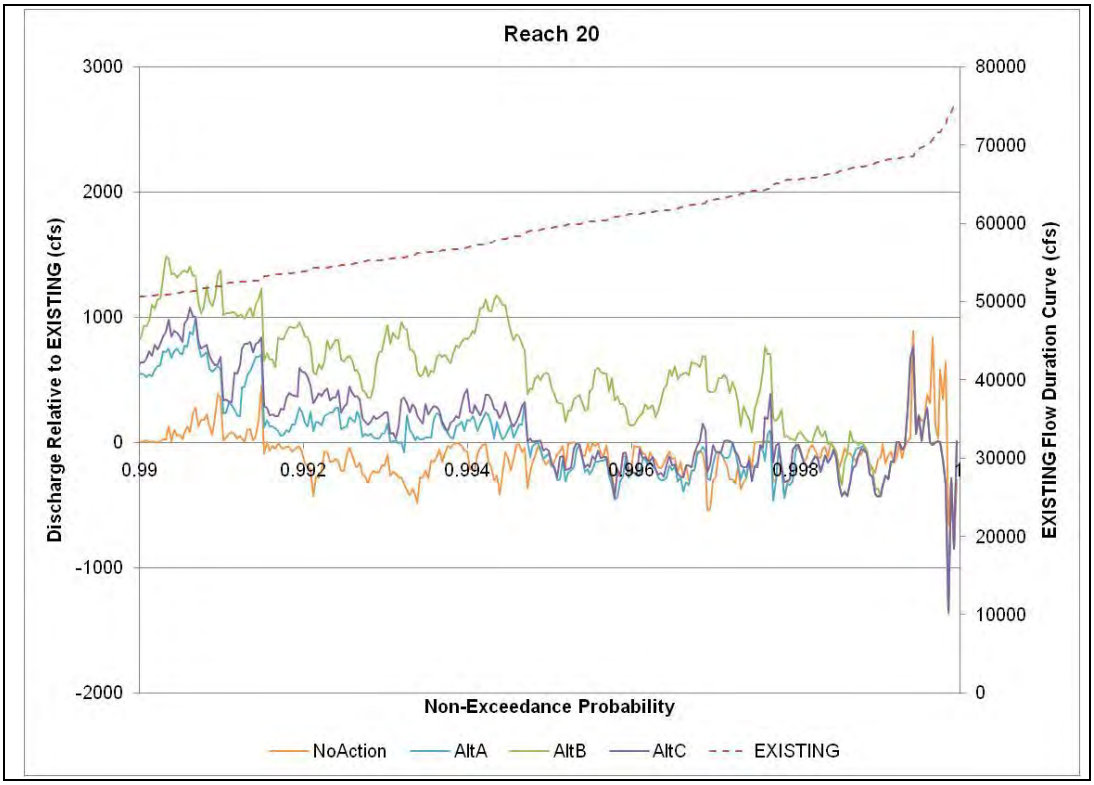

Figure 2-3. Average FDC (non exceedance > 0.99) for Reach 20, along with deviation of the alternatives from existing.

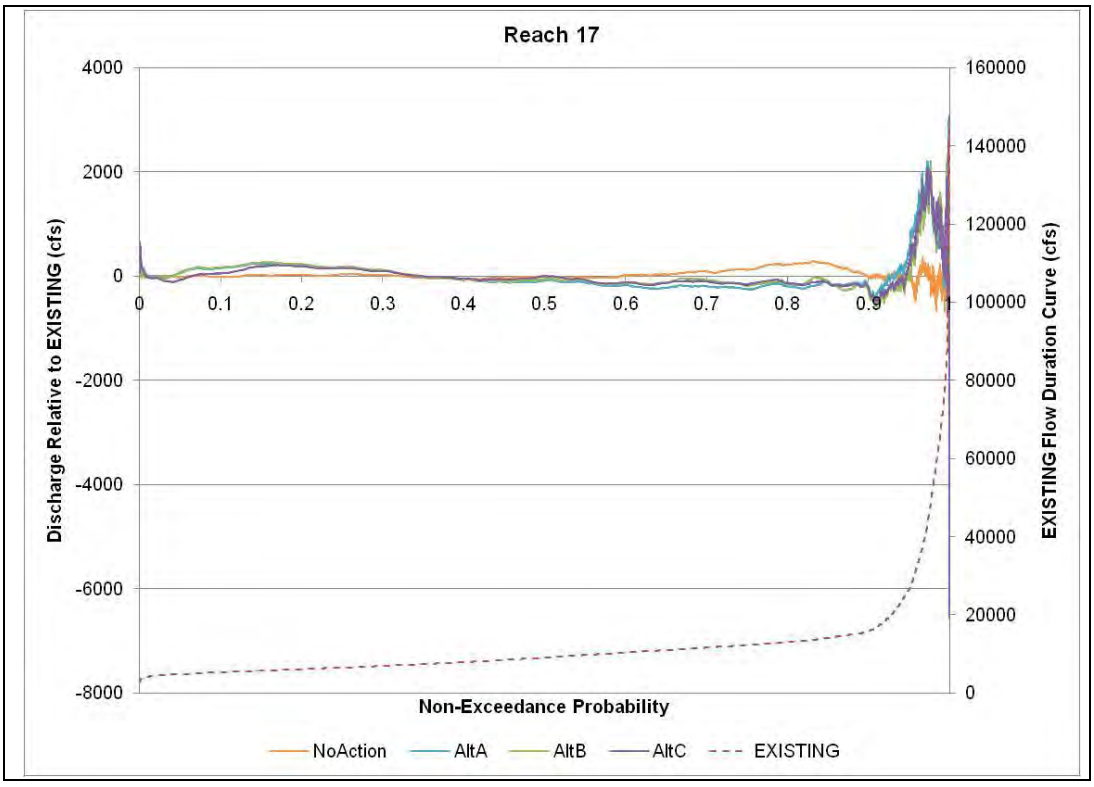

Figure 2-4. Average FDC for Reach 17, along with deviation of the alternatives from existing.

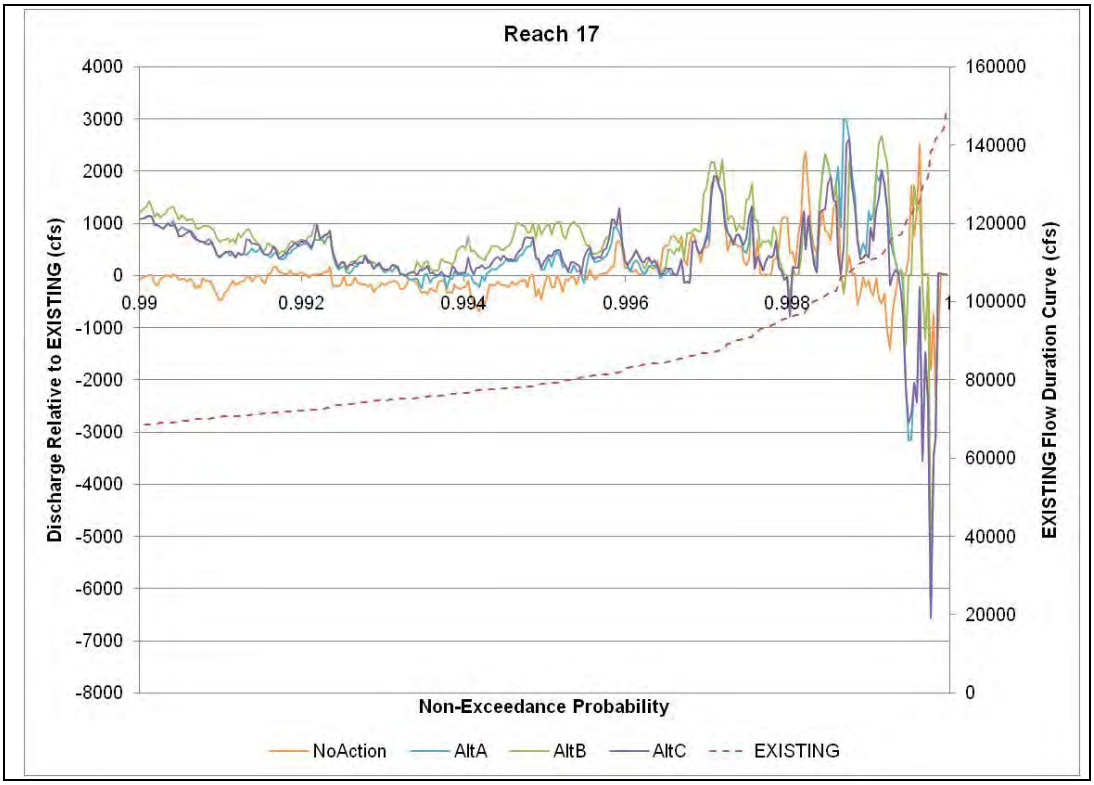

Figure 2-5. Average FDC (non exceedance > 0.99) for Reach 17, along with deviation of the alternatives from existing.

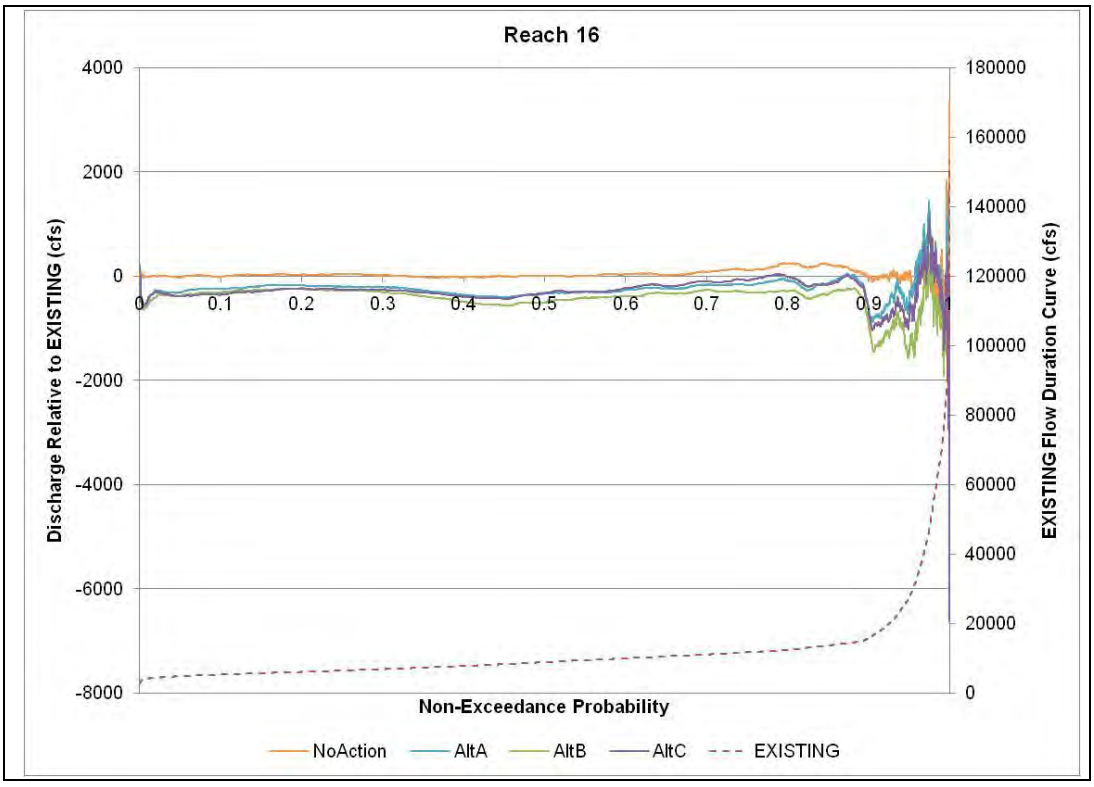

Figure 2-6. Average FDC for Reach 16, along with deviation of the alternatives from existing.

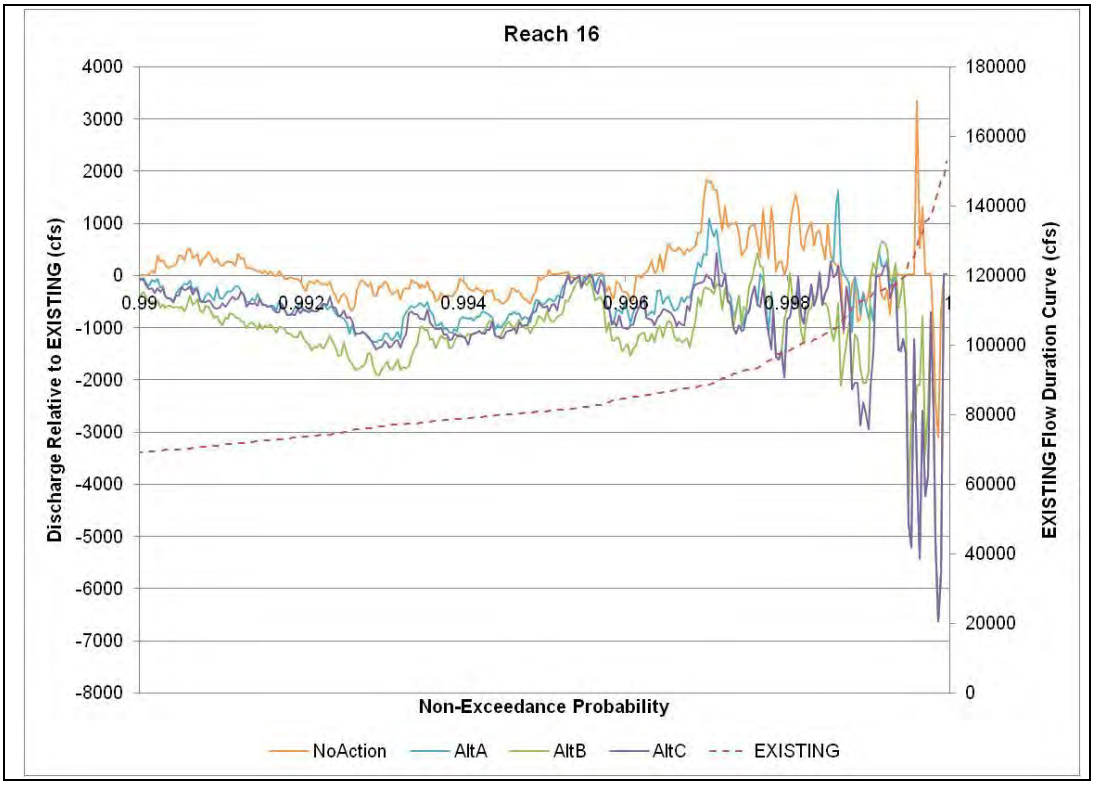

Figure 2-7. Average FDC (non exceedance > 0.99) for Reach 16, along with deviation of the alternatives from existing.

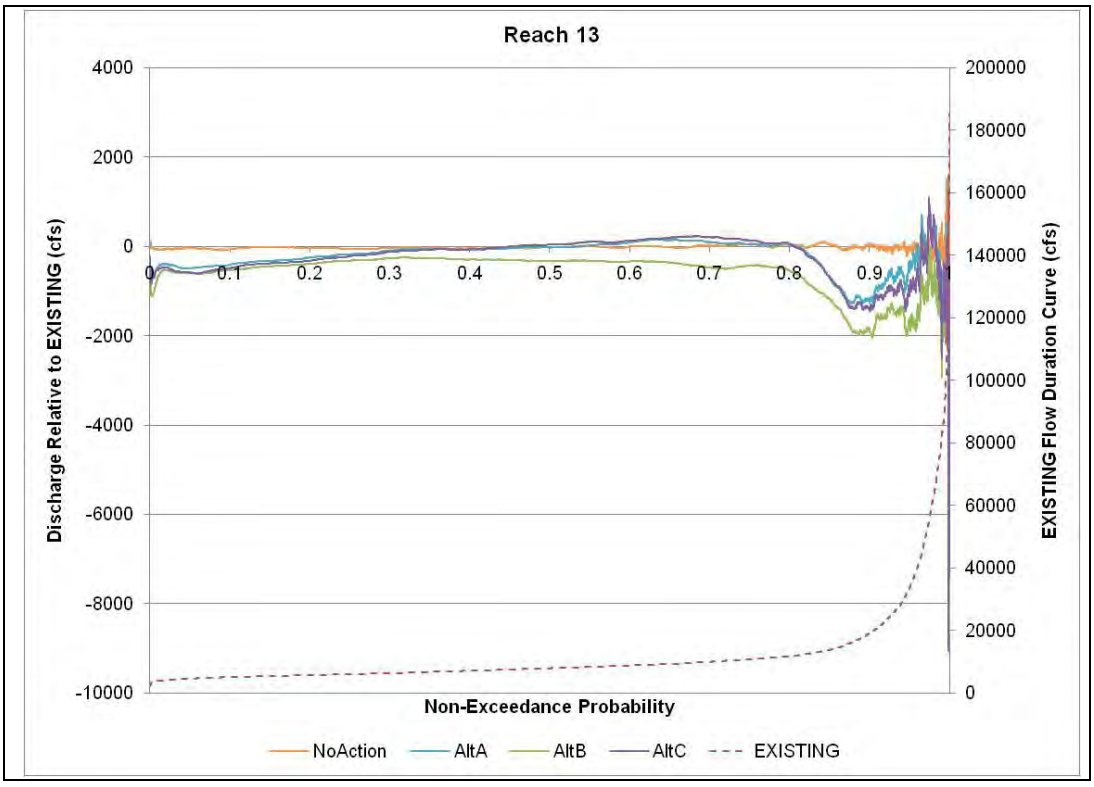

Figure 2-8. Average FDC for Reach 13, along with deviation of the alternatives from existing.

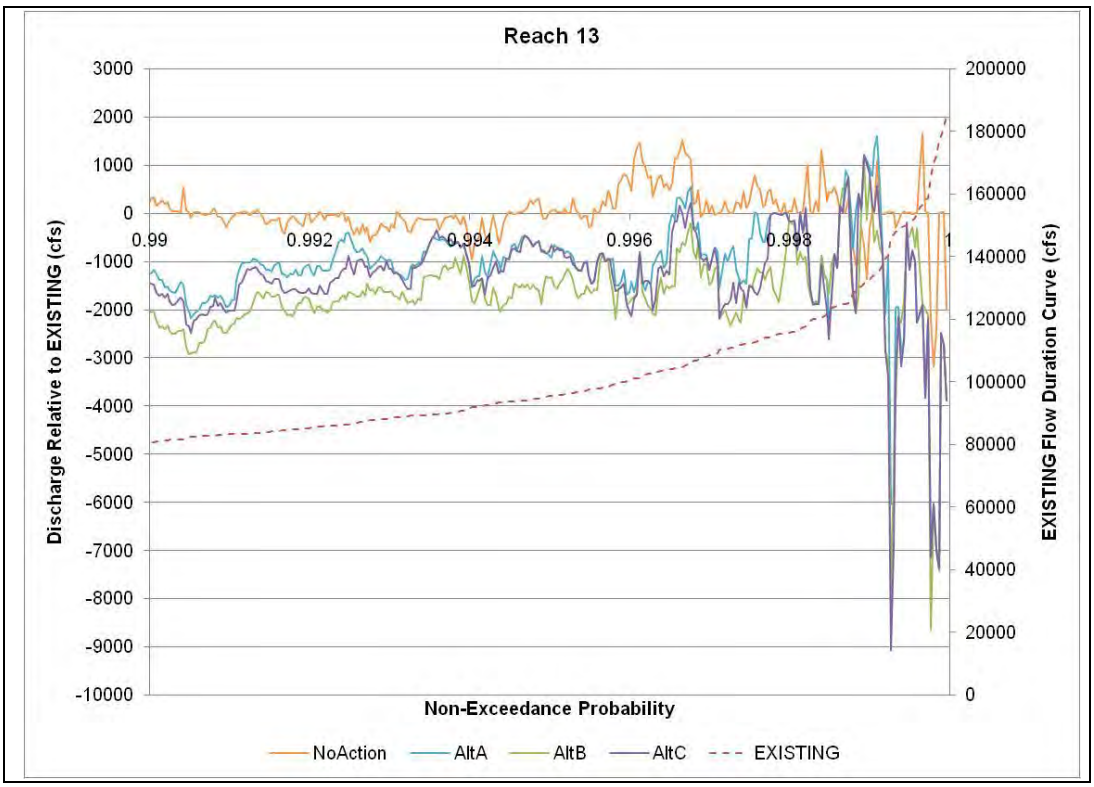

Figure 2-9. Average FDC (non exceedance > 0.99) for Reach 13, along with deviation of the alternatives from existing.

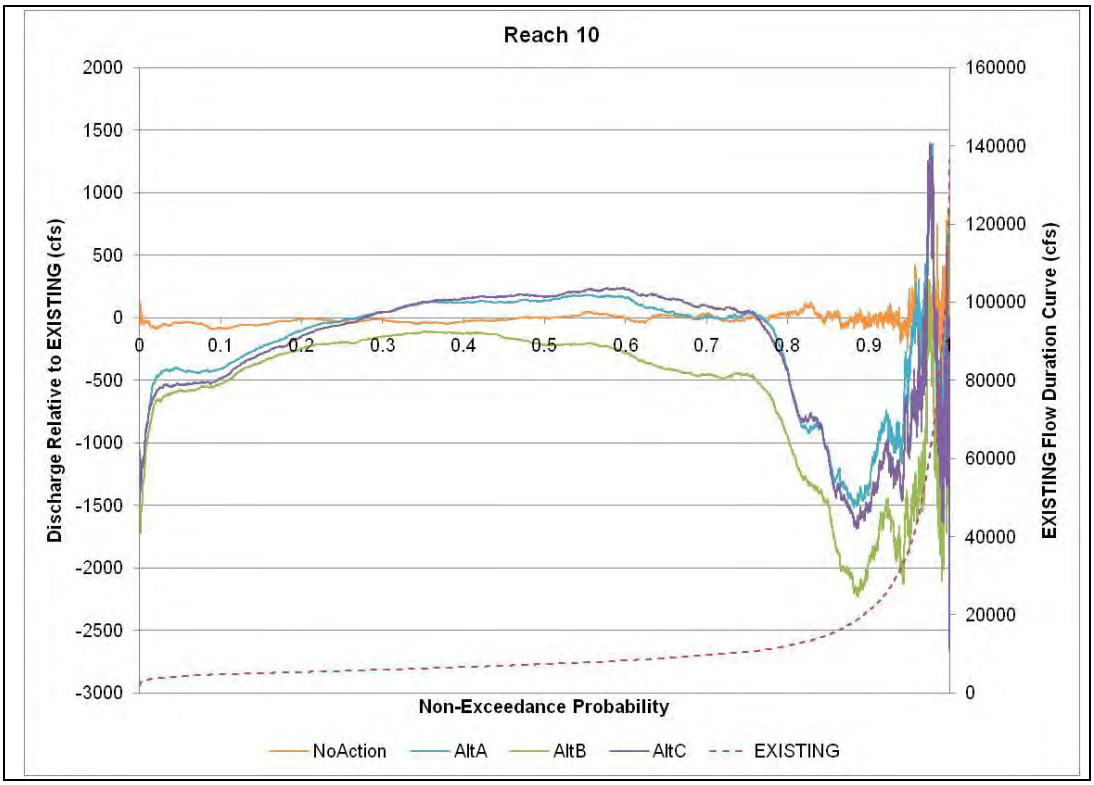

Figure 2-10. Average FDC for Reach 10, along with deviation of the alternatives from existing.

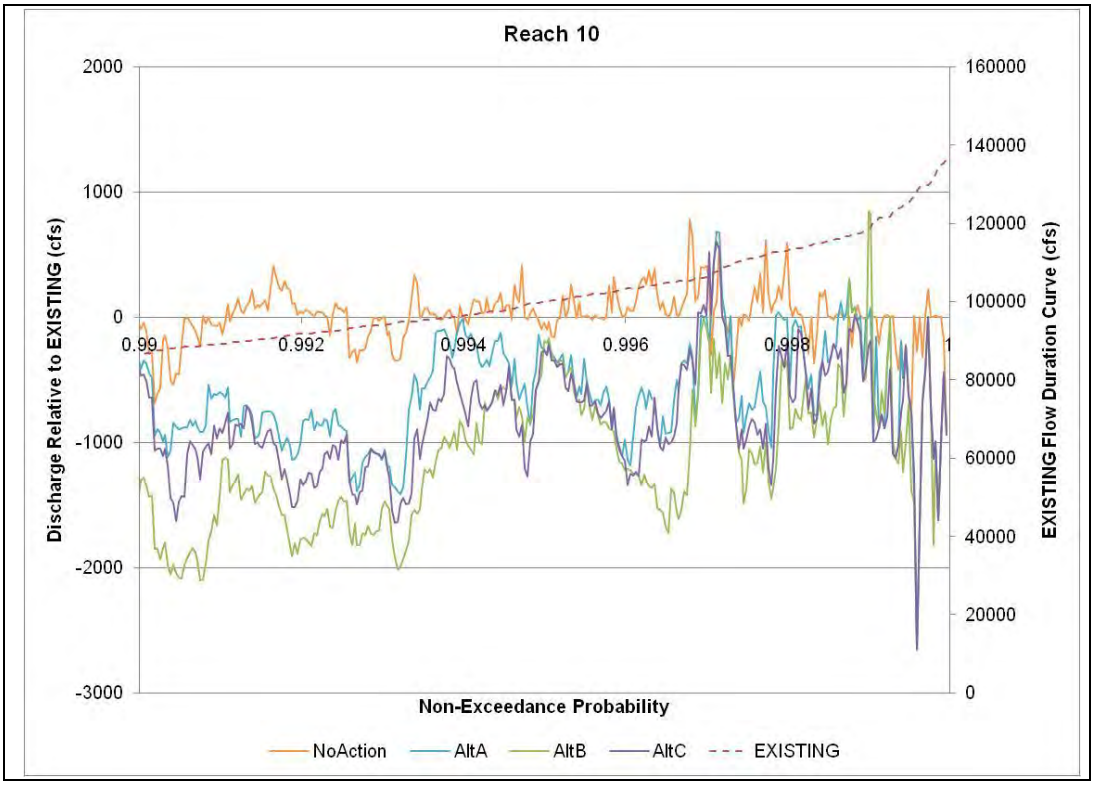

Figure 2-11. Average FDC (non exceedance > 0.99) for Reach 10, along with deviation of the alternatives from existing.

2.3 Hydraulics and Bed Material

Reach-averaged channel hydraulic properties were developed in HEC-RAS as discussed in Reclamation (2011). The bed material used to estimate sediment transport capacity is also the same as presented in Reclamation (2011).

2.4 Sediment Transport

Three sediment transport equations are used to estimate the transport capacity by reach; Parker (1990), Wilcock and Crowe (2003) and Meyer-Peter-Müller (1948). Parker and Wilcock and Crowe are utilized by applying the respective default reference shear stress and hiding factor. In addition, the reference shear stress is increased and decreased by 25% for both equations, and no sensitivity is performed on hiding factor. The Meyer-Peter-Müller (MPM) equation does not have adjustable reference shear stresses or hiding factors. An entire grain size distribution is used for both Parker and for Wilcock and Crowe, as this information is necessary in terms of particle hiding. For MPM, the median grain size is used to represent the grain size distribution as the phenomenon of hiding is not represented in this equation. Table 2-2 presents the transport scenarios (combination of equation, reference shear stress, and hiding factor) that were performed on the Sacramento River.

Table 2-2. Transport scenarios (equation and coefficients) used in this analysis.

Transport Scenario	Reference Shear Stress	Hiding Factor
Parker0.75DefaultDefault	0.0290	0.905
Parker1.00DefaultDefault	0.0386	0.905
Parker1.25DefaultDefault	0.0483	0.905
WilcockCrowe0.75DefaultDefault	0.0158	0.330
WilcockCrowe1.00DefaultDefault	0.0210	0.330
WilcockCrowe1.25DefaultDefault	0.0263	0.330
Meyer-Peter-Müller	N/A	N/A

Figure 2-12 presents the annual transport capacity (tons/year) by reach for Wilcock and Crowe, which is considered a realistic estimate of transport rates in the Sacramento based on knowledge of the system and professional judgment. Plots for all of the other scenarios presented in Table 2-2 can be found in Appendix A. The most important inference from the sensitivity analysis and the plots in Appendix A is that sediment transport results for the Sacramento River are much more sensitive to transport equation and reference shear stress than to the alternative being considered. The Parker equation estimates practically no bedload transport for Reaches 23 to 15, and then again for Reaches 10 and 9 (Figure A-1, Figure A-2, Figure A-3). The Wilcock and Crowe equations estimate much more transport for all reaches (Figure 2-12, Figure A-4, Figure A-6). The MPM equation is relatively similar to the Parker equation in that is predicts almost no transport in Reaches 23 to 15, and then again in Reaches 10 and 9 (Figure A-7). For the purpose of comparing alternatives, the Wilcock and Crowe equation is deemed the most appropriate based on knowledge of the system and

professional judgement. The bedload transport capacity upstream of Red Bluff diversion are increased from existing conditions by 2 to 6% for Alternative A, B, and C (Reaches 23 to 17). This is because the high flows in this reach are increased slightly under these alternatives (see Figure 2-3).

From Red Bluff to the GCID diversion (Reaches 16 to 14), the bedload transport capacity is decreased from existing conditions for Alternatives A, B, and C. Alternative B is decreased by approximately 4%, while Alternatives A and C are decreased by 2%. The slight decrease is due to the increased diversion rates at the Red Bluff Diversion during the high flow periods. Alternative B has higher rates of diversion and therefore the impact of Alternative B is greater.

From GCID to Delevan diversion (Reaches 13 to 10), the bedload transport capacity is decreased from existing conditions by 2 to 4% for Alternatives A and C, and 6 to 10% for Alternative B.

Downstream of the Delevan diversion, the bedload transport capacities are decreased from existing conditions by 4 to 6 % for Alternative A and C and 10 to 12 % for Alternative B.

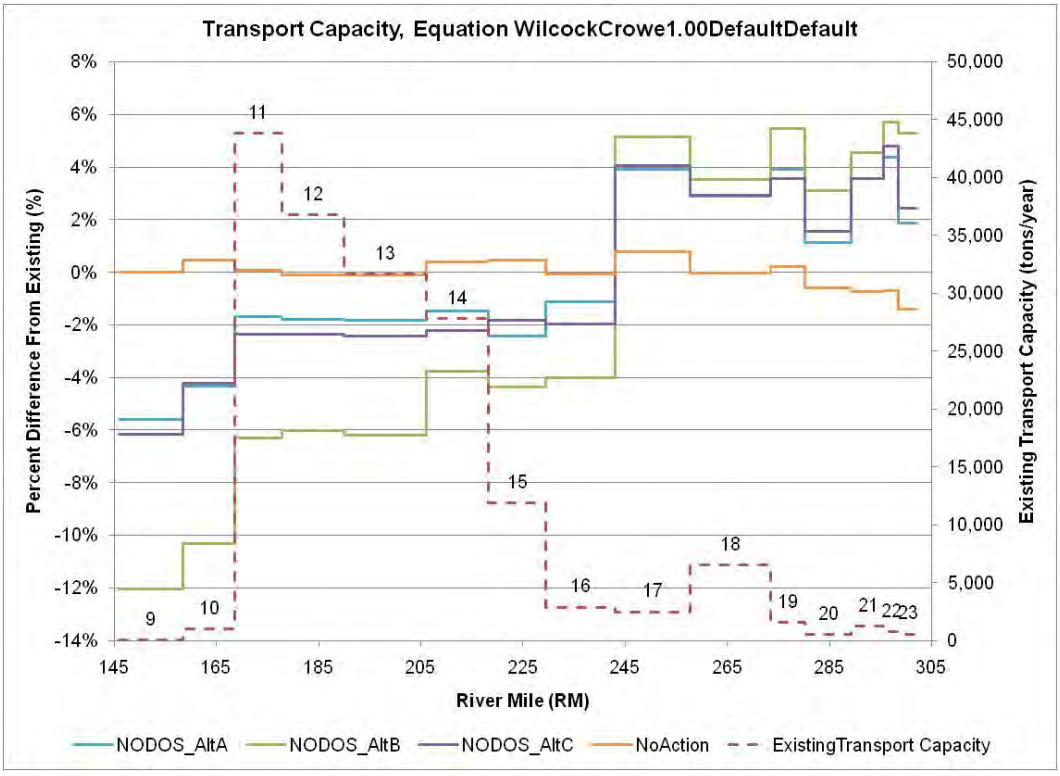

Figure 2-12. Transport capacity for Wilcock and Crowe (100% reference shear), and percent difference from existing for alternatives.

2.5 Sediment Budget

A sediment budget for the river reaches was developed with inputs to a reach being comprised of the sediment from the upstream reach and the sediment being supplied by the tributaries. See Reclamation (2011) for more information on the tributaries to the Sacramento that were identified and modeled for sediment purposes. Figure 2-13 and Figure 2-14 present the annual tributary loads for the same transport scenarios as presented in Table 2-2. There is significant uncertainty in the estimates for the tributary sediment loads, and the estimates given in Figure 2-13 and Figure 2-14 are considered to be preliminary estimates not verified by field data. Bed load data on each individual stream would be required to improve the estimates. However, because the NODOS alternatives do not impact the tributary inputs of sediment, the relative differences between the alternatives can be compared with greater confidence. The inclusion of the tributary loads is done to compute an "order of magnitude" sediment budget for the mainstem of the Sacramento River. These estimates of tributary loads could be further refined if additional analysis of the sediment budget is warranted.

Table 2-3 presents the tributaries in upstream to downstream order by reach assignment for the sediment budget.

Figure 2-15 presents a plot of the reach-averaged sediment budget for existing hydrology for Wilcock and Crowe (default parameters), with select location identifiers presented for reference. Values in the sediment transport budget of less than 10,000 ton/yr are not considered significant to the overall budget. Over a 10 mile reach, this annual load would equate to less than 0.1 inches/yr.

Three sediment budgets were developed using a consistent equation (Wilcock and Crowe, Parker, Meyer-Peter-Müller) for all reaches of and for all tributaries to the Sacramento River. The specific characteristics of a given tributary may suggest that a different equation be more appropriate than the one used for the mainstem Sacramento. However, the different alternatives being considered have no bearing on sediment hydrology or sediment delivery to the mainstem; so the comparison between alternatives is more pertinent than the absolute loads delivered by the tributaries. For simplicity, the results from a consistent transport equation – in this case Wilcock and Crowe – are used to derive the following general observations. The sediment budgets developed using Parker and Meyer-Peter-Müller can be found in Appendix B.

Reaches 23 – 17 are in relative equilibrium based on the sediment budget estimates. Reaches 23 to 20 are armored because of the lack of sediment supply, and the bed material in these reaches is relatively immobile. Reach 19 is downstream of several tributaries, but the annual sediment transport capacity of the bedload is likely less than 10,000 tons/yr based upon the sediment transport results presented in Figure 2-12. This is considered a low value relative to the size of the Sacramento River. Reaches 18 and 17 are slightly degradational and aggradational respectively. However, the annual rates of degradation and aggradation are less than 7,000 tons/yr and not considered significant.

Cottonwood Creek enters the Sacramento River in the upstream portion of Reach 18 and introduces a substantial amount of gravel sized sediment so that this reach is somewhat more mobile than upstream reaches. The predicted bedload transport capacity rates through the reach increase up to 7,000 tons/yr (Figure 2-12) The estimated sediment input to the reach is less than 7,000 tons/yr leading to a prediction of erosion (Figure 2-15). The predicted degradation caused by this deficit is less than 5,000 tons/yr and not substantial.

Reach 17 is just upstream of Red Bluff Diversion Dam and may be affected by the presence of this structure.

Reach 16 is just downstream of Red Bluff Diversion Dam and is slightly aggradational, but the rates are not considered significant.

Reach 15 is slightly degradational. Again, however, the rates are small and not significant.

Reaches 14 experiences the most degradation of all the reaches. This is a function of the total volume of annual water flowing through this reach (Figure 2-1).

Reaches 13, 12, and 11 show varying degrees of degradation but the rates are small and generally not considered significant.

Reach 10 is highly depositional. This reach is downstream of the bypass system, which typically removes flow from the top of the water column and leaves the bedload in the river. This reach may be the only reach of the Sacramento River that will demonstrate measurable amounts of deposition. The high flows transported through the main stem of the Sacramento are significantly decreased by the bypass system, thereby directly decreasing the sediment transport capacity rates in the main stem.

Reach 9 shows relative equilibrium. Most of the deposition is expected to occur in Reach 10 so that the reaches below are closer to equilibrium.

Figure 2-16 compares the resulting sediment budget by alternative for material greater than 2 mm using the Wilcock and Crowe transport equation. Within most reaches, the alternatives change the sediment budget by less than 5% from existing conditions, which is not considered significant to the sediment budget. Reach 22 shows high percent differences for the alternatives; however the calculated transport is so low that these percent differences still reflect an equilibrium conditions. The greatest differences from existing conditions are noted for Alternative B in Reaches 9 to 13, where there is a more substantial decrease in transport rates. Of these reaches, only Reach 10 exhibited a significant lack of equilibrium as discussed above. Even though the transport rates are decreased for alternatives A, B, and C in Reaches 9 to 13, the bedload sediment balance is not considerably altered because less sediment is entering these reaches from the upstream.

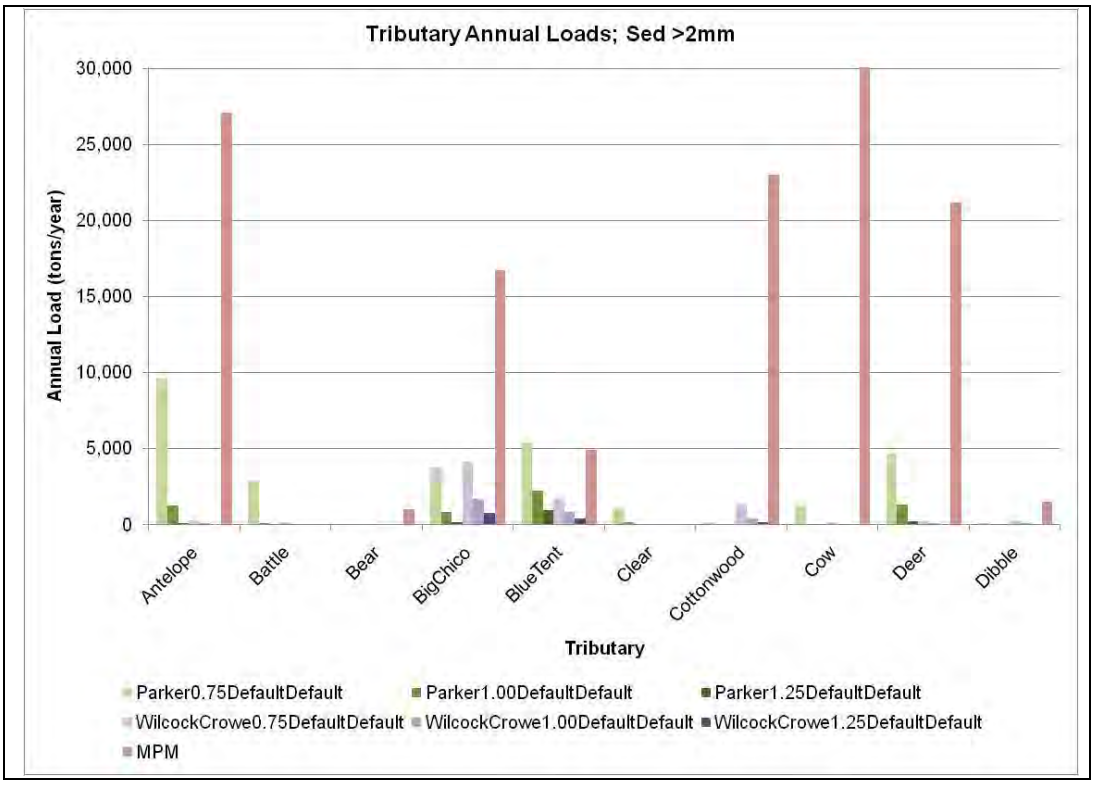

Figure 2-13. Tributary transport capacity sensitivity for first 10 alphabetically.

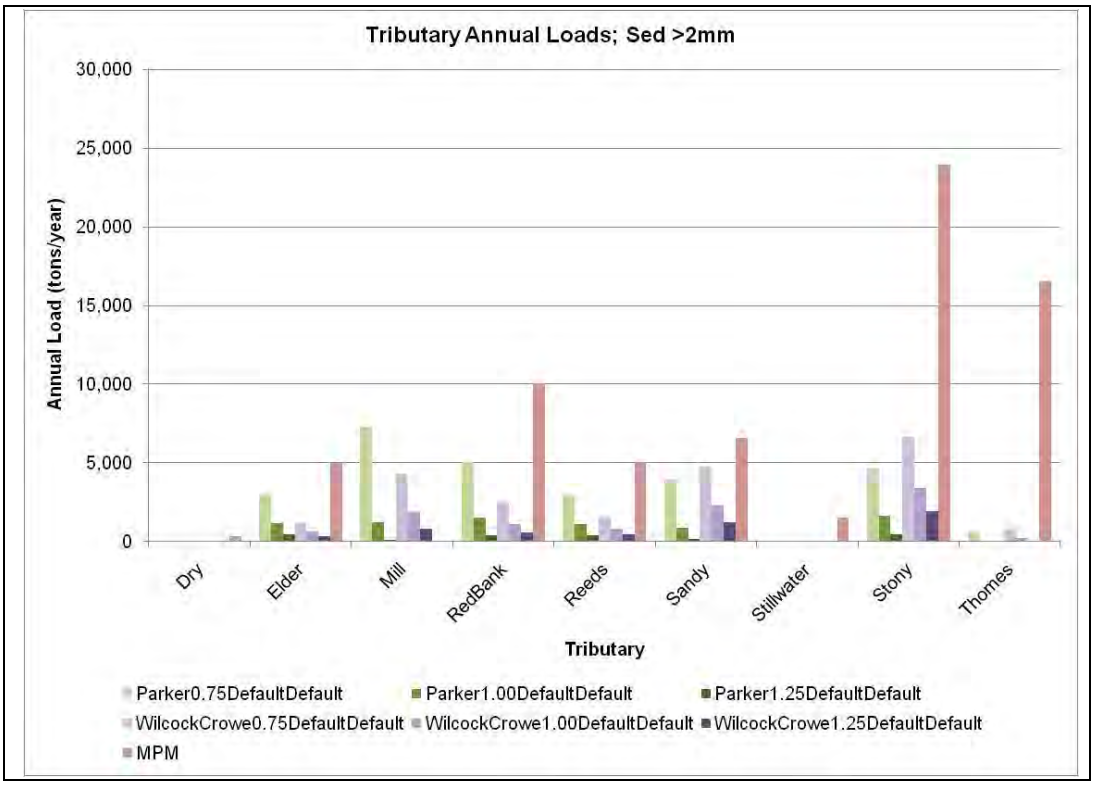

Figure 2-14. Tributary transport capacity sensitivity for last 9 alphabetically.

Table 2-3. Tributary reach assignments for sediment budget.

Reach	Upstream Tributary	Tributary	Tributary	Downstream Tributary
23	--	--	--	--
22	--	--	--	--
21	--	--	--	--
20	--	--	Clear	--
19	Stillwater	Cow	Dry	Bear
18	--	--	Cottonwood	Battle
17	--	--	Blue Tent	Dibble
16	--	Reeds	Red Bank	Antelope
15	--	Elder	Mill	Thomes
14	--	--	--	Deer
13	--	--	--	--
12	--	Sandy	Big Chico	Stony
11	--	--	--	--
10	--	--	--	--
9	--	--	--	--

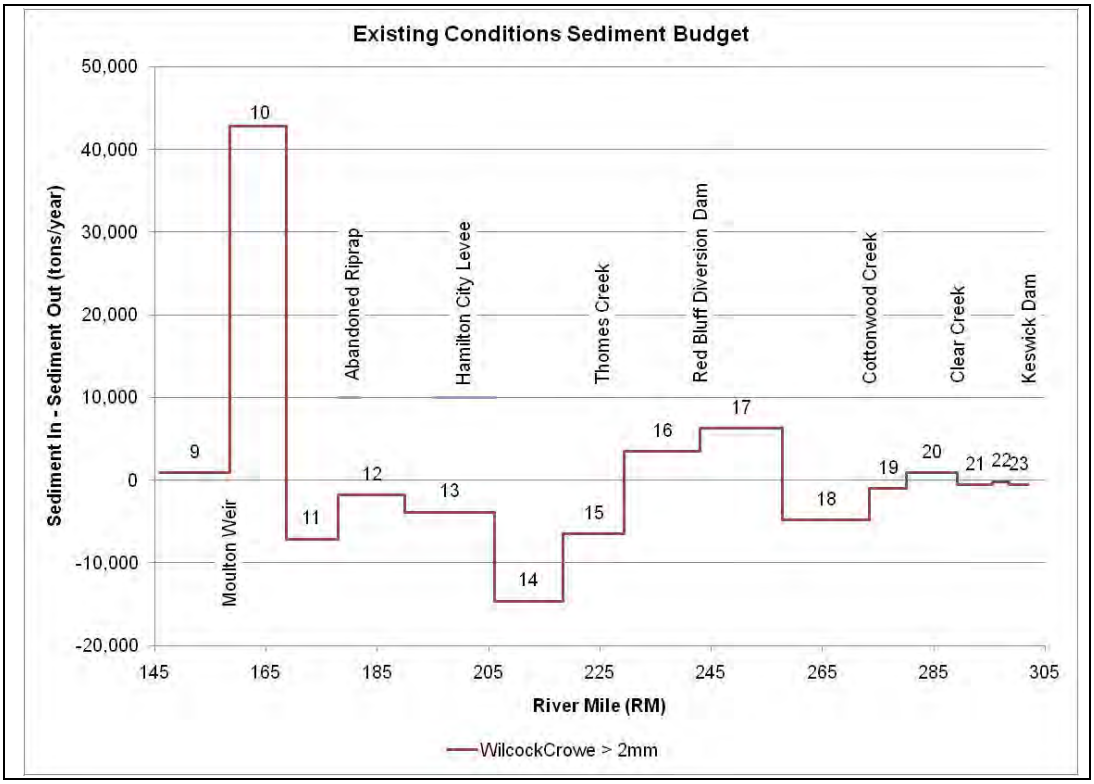

Figure 2-15. Sediment budget (existing hydrology) for material greater than 2mm using Wilcock and Crowe with default parameters.

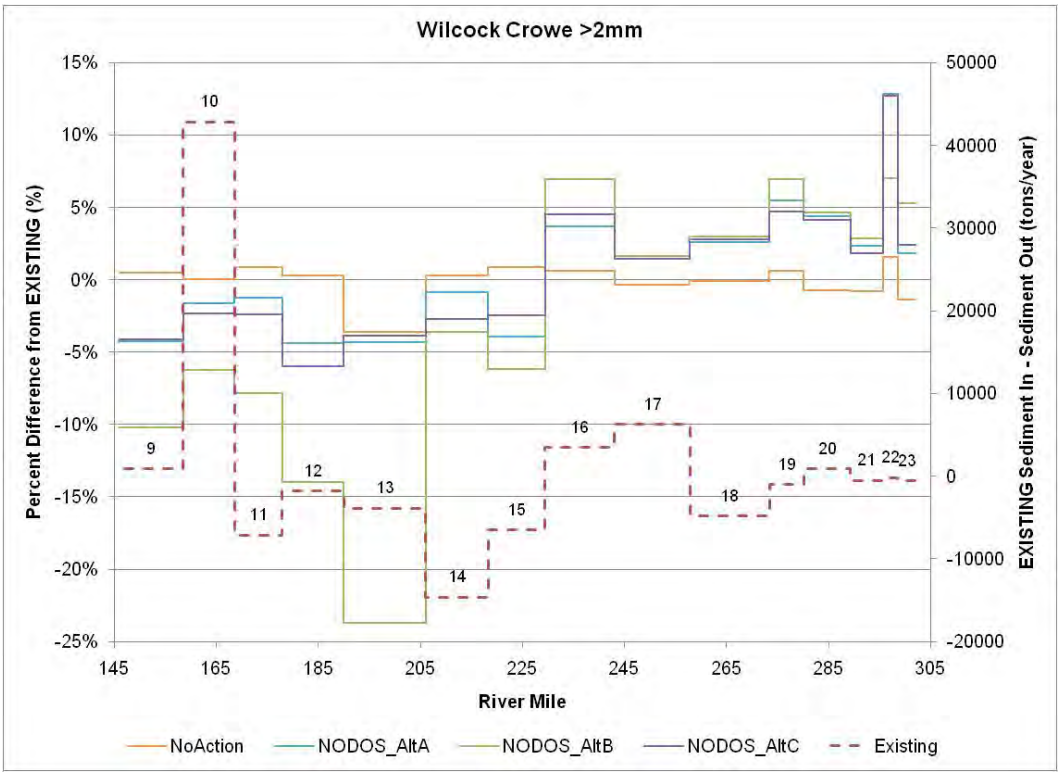

Figure 2-16. Percent difference in sediment budget for No Action and Alternatives A, B, C, relative to Existing.

3 Conclusions

The bed load in the Sacramento River and its tributaries was computed under the NODOS alternatives analysis.

The NODOS alternatives generally do not significantly affect the annual flow duration curves by more than a few percent and therefore do not significantly affect the bed load sediment balance in the Sacramento River. However, because of the increase in diversion rates from the Sacramento River, there are small effects of the alternatives on the bedload sediment transport that can be quantified. The quantitative predictions presented in this section are based upon the results of the sediment analysis using the Wilcock and Crowe equation. Results using other equations, presented in the appendices, do no influence the conclusions of this investigation.

The bedload transport capacity upstream of Red Bluff diversion are increased from existing conditions by 2 to 6% for Alternative A, B, and C (Reaches 23 to 17) using the Wilcock and Crowe equation. This is because the high flows through these reaches are increased slightly under these alternatives (see Figure 2-3; the flow duration curves for Reaches 23-17 are all fairly represented by flow duration curve for Reach 20).

From Red Bluff to the GCID diversion (Reaches 16 to 14), the bedload transport capacity is decreased from existing conditions for Alternatives A, B, and C.

Alternative B is decreased by approximately 4%, while Alternatives A and C are decreased by 2%. The slight decrease is due to the increased diversion rates at the Red Bluff Diversion during high flow periods. Alternative B has higher rates of diversion, and therefore the impact of Alternative B is greater.

From GCID to Delevan diversion (Reaches 13 to 10), the bedload transport capacity is decreased from existing conditions by 2% for Alternatives A and C, and 6% for Alternative B.

Downstream of the Delevan diversion, the bedload transport capacities are decreased by 4 to 6 % by Alternative A and C and 10 to 12 % by Alternative B.

Most reaches in the Sacramento are not experiencing measurable erosion or deposition, except for Reach 10 in the vicinity of Moulton Weir, which is experiencing aggradation. The NODOS alternatives do not significantly affect the aggradation that will continue into the future in Reach 10. However, this aggradation may impact the NODOS project because the Delevan Diversion is located in this reach. Alternative methods for reducing deposition, such as dredging of river sediment, may be necessary to maintain a sufficient flow depth for diversion.

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A Sensitivity Analysis of Sediment Transport Equations and Reference Shear Stresses

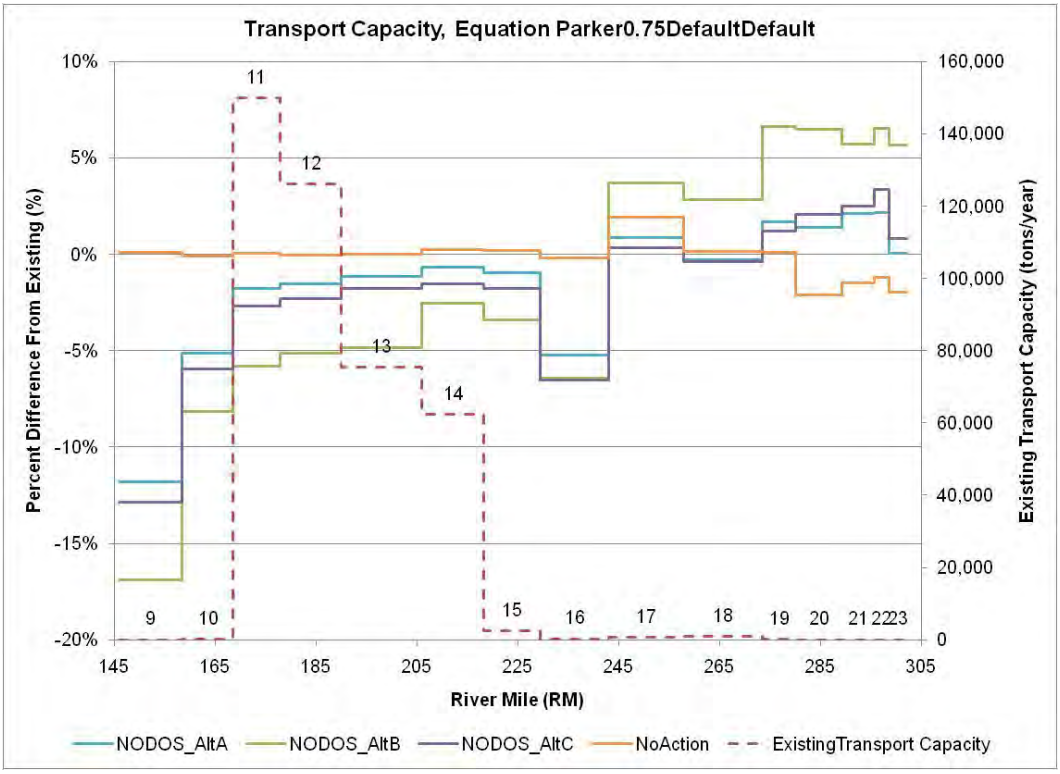

Figure A-1. Transport capacity for Parker (75% reference shear), and percent difference from existing for alternatives.

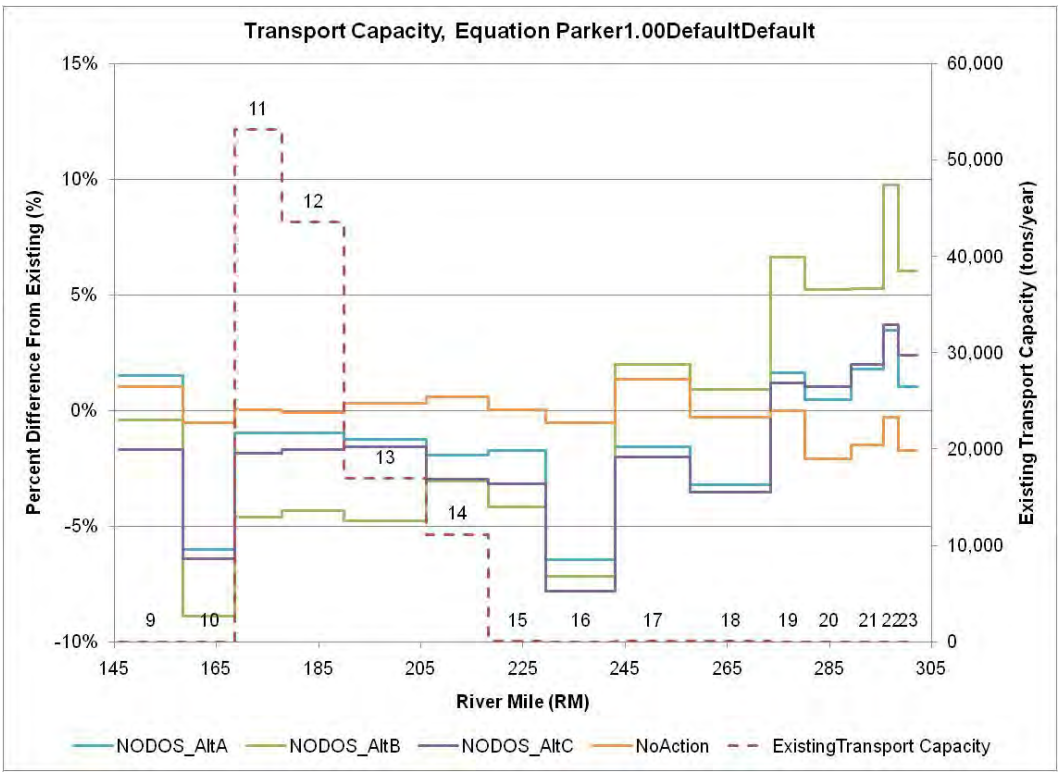

Figure A-2. Transport capacity for Parker (100% reference shear), and percent difference from existing for alternatives.

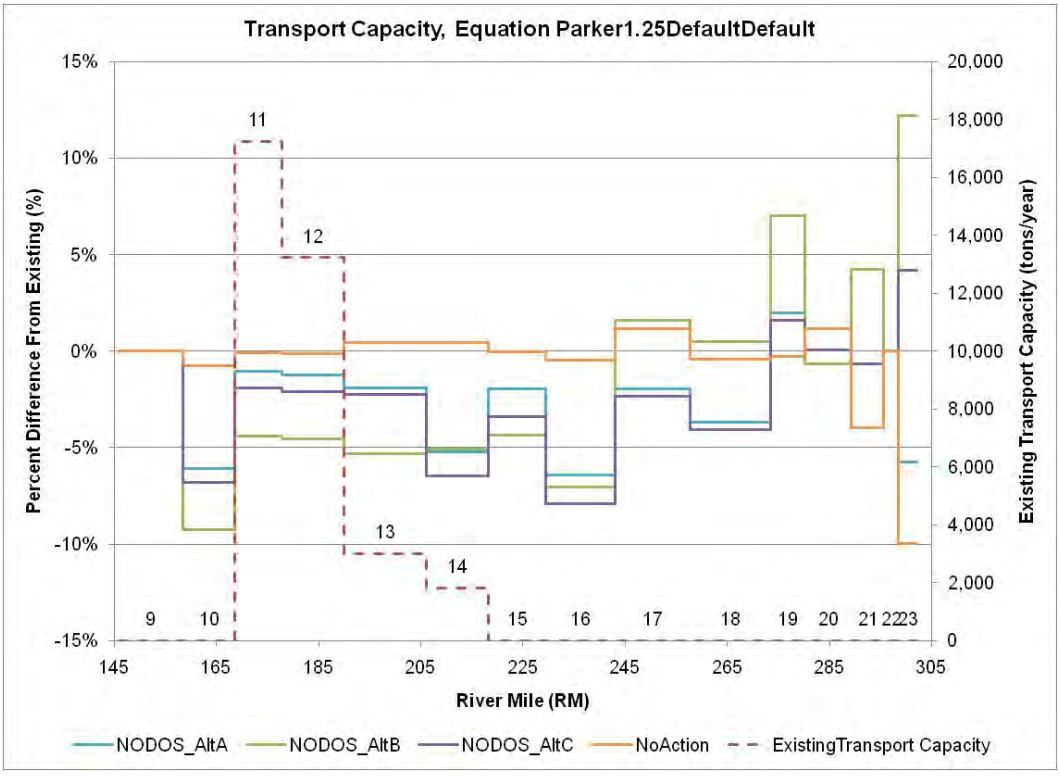

Figure A-3. Transport capacity for Parker (125% reference shear), and percent difference from existing for alternatives.

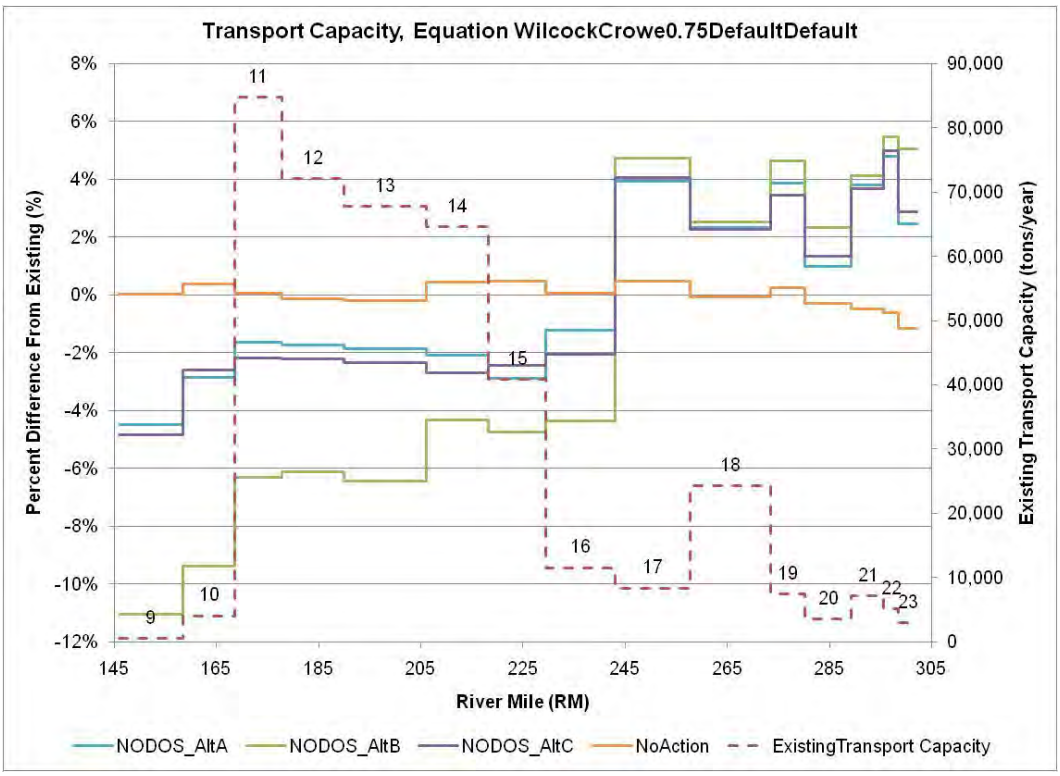

Figure A-4. Transport capacity for Wilcock and Crowe (75% reference shear), and percent difference from existing for alternatives.

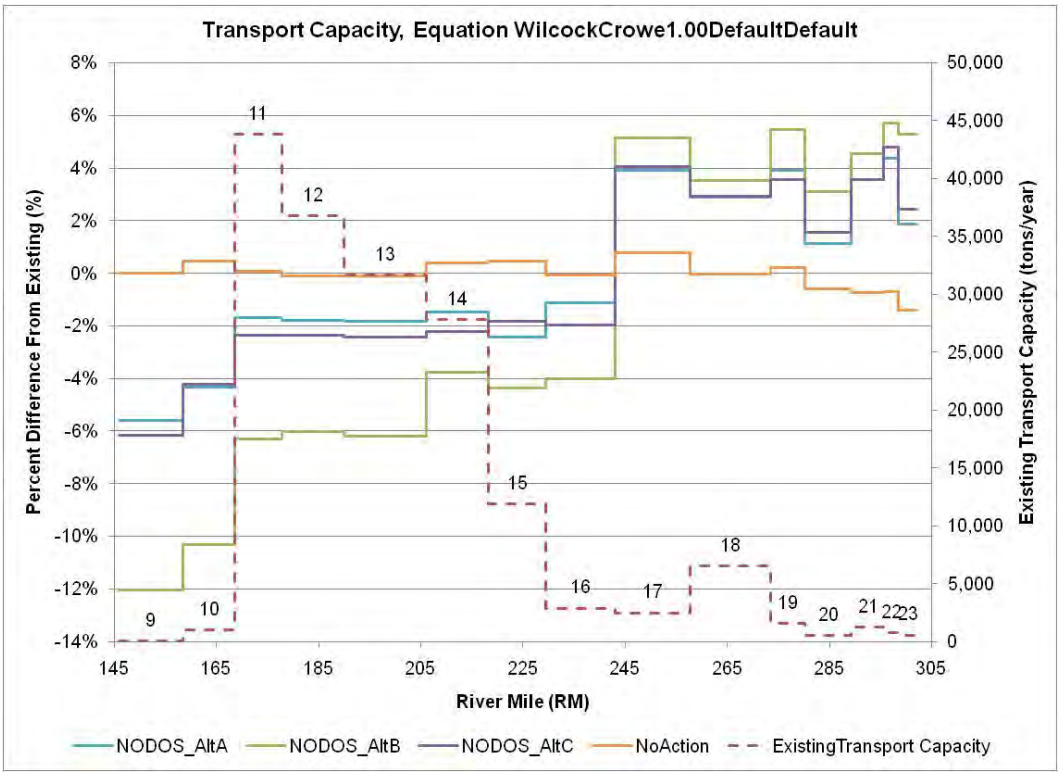

Figure A-5. Transport capacity for Wilcock and Crowe (100% reference shear), and percent difference from existing for alternatives.

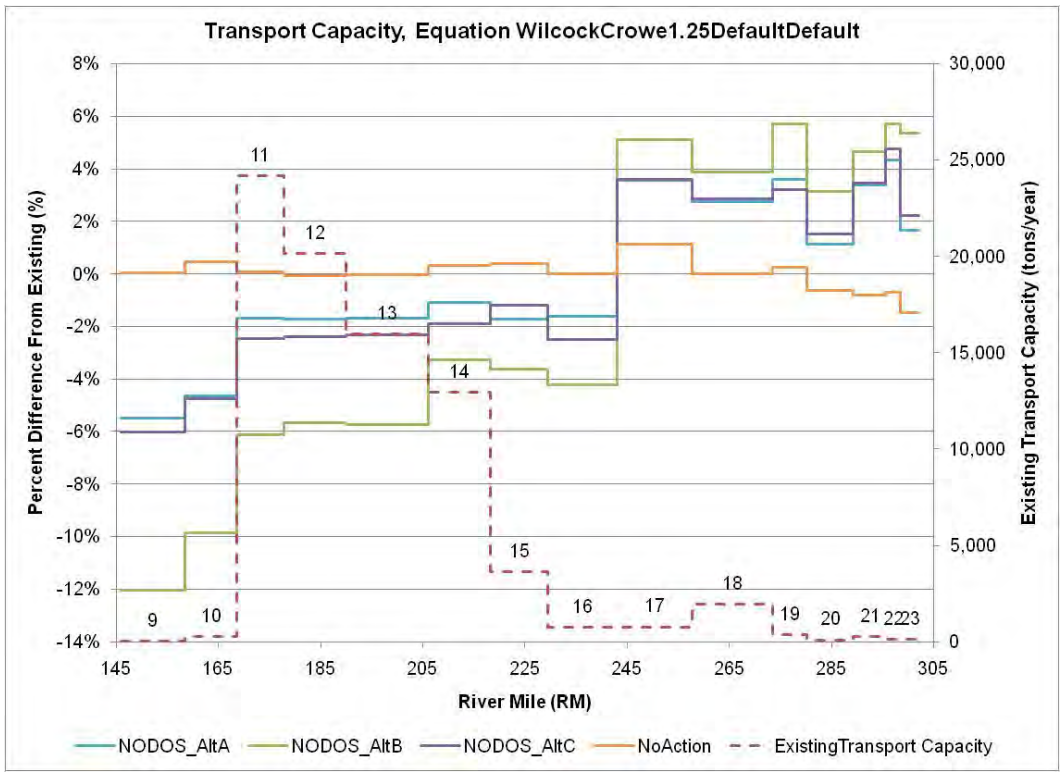

Figure A-6. Transport capacity for Wilcock and Crowe (125% reference shear), and percent difference from existing for alternatives.

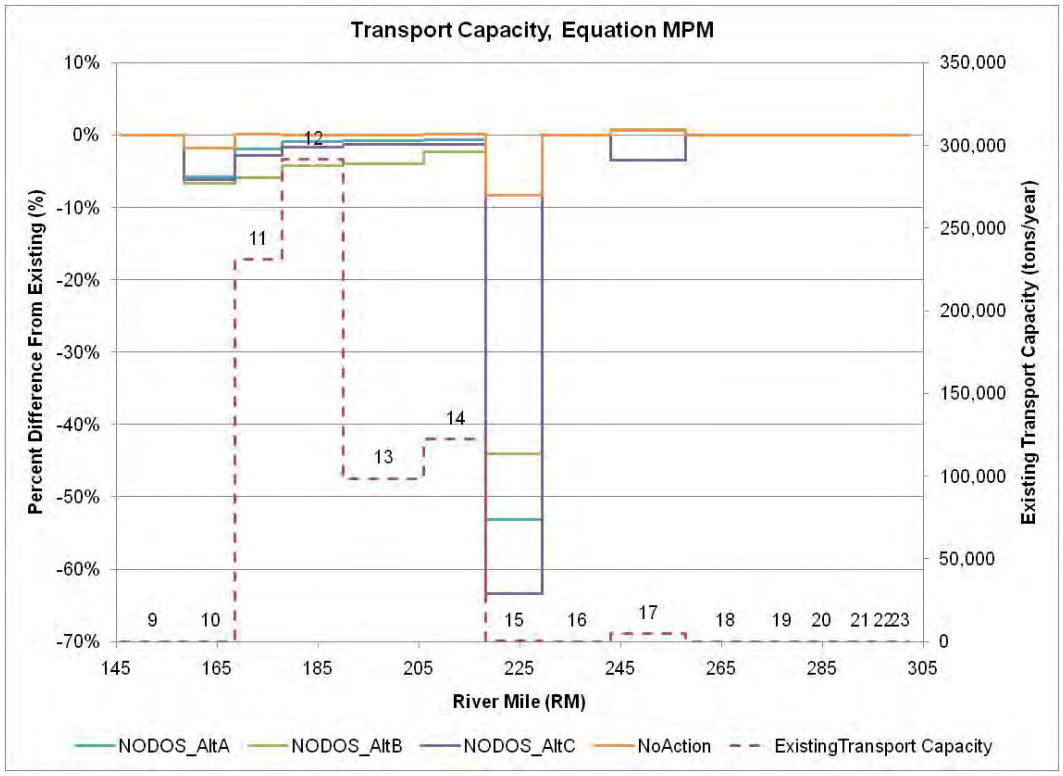

Figure A-7. Transport capacity for Meyer-Peter-Müller, and percent difference from existing for alternatives.

B Sediment Budget for Existing Conditions Comparing Three Transport Equations

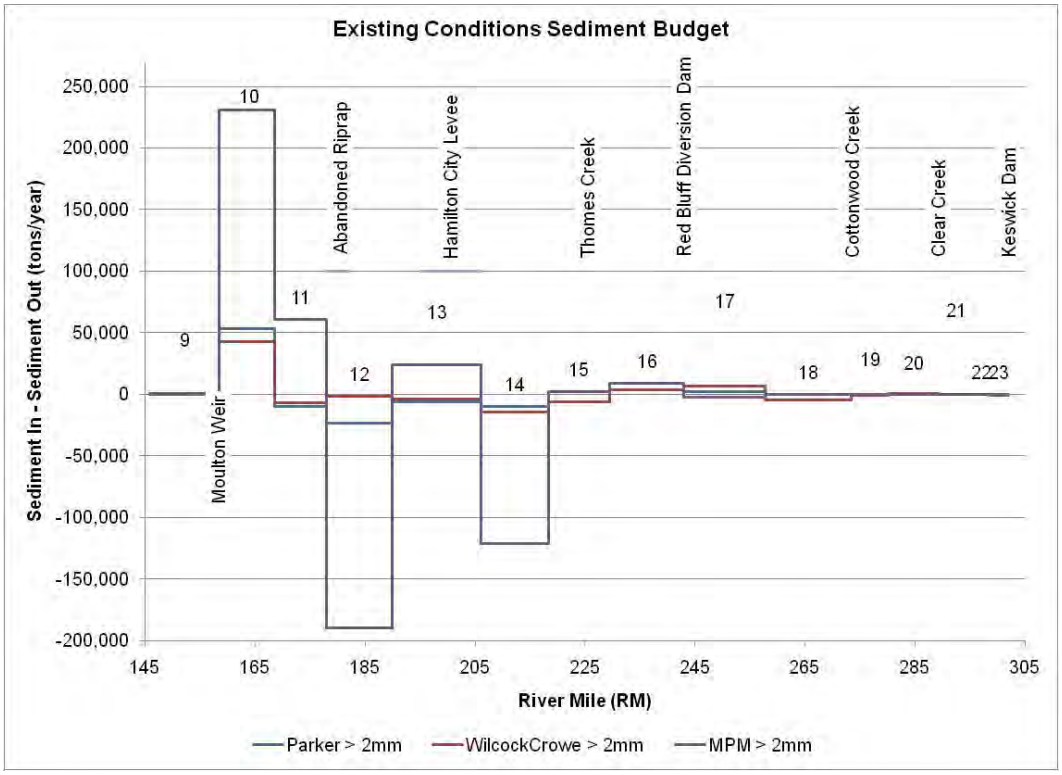

Figure B-1Sediment budget (existing hydrology) for material greater than 2mm using Parker and Wilcock and Crowe (both with default parameters) and Meyer-Peter-Müller.

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Vegetation Analysis of NODOS

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RECLAMATION
Managing Water in the West

Technical Report No. SRH-2011-27

Vegetation Analysis of the Sacramento River NODOS Flow Alternatives using SRH-1DV

Mid Pacific Region
NODOS Investigation Report

U.S. Department of the Interior
Bureau of Reclamation

December 2011

Mission Statement

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

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Table of Contents

Executive Summary

As part of the Sacramento River NODOS Alternatives Investigation, the impacts on vegetation from alternative flow management plans are evaluated and compared using SRH-1DV, a numerical modeling tool developed by the Bureau of Reclamation. The model simulates the establishment, growth, and mortality of vegetation, in addition to computing hydraulics and ground water surface in the riparian zone near the river. The simulation tracks daily vegetation changes through eight decades of flow records, within the 107 river miles of study area. This alternatives analysis tool is well suited for tracking complex, interrelated processes, and reporting on subtle differences in results. The analysis focuses on vegetation, specifically 4 desirable native vegetation types: cottonwood, mixed forest, Gooding's black willow, and narrow leaf willow. A series of model calibrations were conducted previous to this application of SRH-1DV.

Five flow management alternatives are proposed: No Action, Existing Conditions, Alternative A, Alternative B, and Alternative C. The No Action and Existing Conditions alternatives are similar with the largest winter peak flow values. Flow is shaved from the declining limb of the winter hydrograph to increase the summer flows of Alternatives A, B and C. The No Action and Existing Conditions Alternatives, and sometimes Alternative B, have the lowest summer flows. Alternative B uses the smallest volume of flow.

The model predicts general vegetation trends of: minimal increase in mixed forest (4%); some increase in cottonwood (28%); and the largest increases in Gooding's black willow (45%) and narrow leaf willow (56%). These values are averaged from the flow regimes of all five alternatives.

Productive areas for plants were most often located in the bends of the Sacramento River where sand bar processes, bend migration processes, and multiple remnant or active secondary channels have space in the flood plain to develop, Cottonwood plants were more abundant at meander bends and locations with periodic bare sand bars. Narrow leaf willow abundance was also related to active meander bends where multiple channels, both active secondary or inactive remnant channels remain. Straight and confined sections of river with a single-thread channel provided less area for riparian vegetation to establish.

There are only small differences in vegetation cover between alternatives but the results simulated for 82 years point to preferred alternatives for cottonwood, mixed forest, Gooding's black willow and narrow leaf willow. No single alternative is best for all vegetation types as shown in Table ES. Cottonwood is a desirable plant for habitat, yet often has declining numbers due to the implementation of flow management that reduces high peak flows. Cottonwood plants in this study are most abundant with the Existing Conditions Alternative. Mixed forest has the most coverage of the four vegetation types, and is more

abundant with Alternative A. Despite the extensive coverage, the area of mixed forest is relatively stable area with very little increase with time (4%). Gooding's black willow results were the least definitive, favoring both the No Action flow regime and Alternative B, but tolerant of all flow alternatives. Narrow leaf willow was most abundant with Alternative A or Alternative C. Both Alternatives A and C have higher summer flows during the narrow leaf willow germination and growth seasons. Alternative A produces the most coverage of all 4 vegetation types in the study area but due to the small differences in values between vegetation types, this result is only reflecting the largest coverage by mixed forest (Alternative A is the most productive flow plan for mixed forest). Desiccation accounts for most of the plant mortality in the study area, followed by inundation. Scour and competition/shading account for lesser amounts of plant removal.

Table ES. Reach Based Vegetated Width Results and General Vegetated Width Results from Table 5-10 indicating the alternative that produced the most vegetation. Numbers in parenthesis indicate number of river reaches with this alternative ranked first.

	General Area Results Flow alternative with the most vegetation (vegetated width)		Reach Based Results Flow alternative with the most vegetation (vegetated width)	
Ranking	1rst	2nd	1rst	2nd
cottonwood	**Existing**	No Action	**Existing** (4)	A (3)
mixed forest	**A**	B	**A** (8)	C & B (2)
Gooding's black willow	B	C	No Act (6)	B & A (2)
narrow leaf willow	C	A	A (5)	C, Exis, NA (2)
herbaceous	**No Action**	Existing	**No Act** (6)	B (4)

If Cottonwood is assigned a greater value, the preferred flow management plan would be the Existing Conditions Alternative. Its ranking may be due more to variation in the flows, and the maximum winter flows that produce bare bar and bank areas for cottonwood establishment. However the larger spring peak flows and summer flows of Alternative A and Alternative C appear more beneficial for narrow leaf willow and mixed forest, plants that also provide riparian habitat. Assuming the cottonwood germination period was adequately represented in these simulations, it appears that all three alternatives: Existing Conditions, Alternative A and Alternative C might be enhanced for cottonwood by scheduling the average spring peak flow to coincide more frequently with the cottonwood germination period.

Flow management is an important factor in riparian vegetation success, and was the primary focus of this study. Also emerging from the results of numerical modeling is the significance of land management at river bends. Active river

bends where old channel scars were apparent, were more productive than stable river bends as determined by the locations of large cottonwood, narrow leaf willow and Gooding's black willow populations. Stable meander bends could be targeted by removing levees, old riprap or other river bank "hard points", benching or secondary channel enhancements through mechanical means, and/or purchasing lands and land agreements to enable channel migration, continued sediment supply, and a wider active flood plain.

1 Introduction

This study was conducted as supporting information to the investigation of the Sacramento River for the Environmental Impact Study/Environmental Impact Report. Five flow alternatives are compared with respect to vegetation impacts: No Action, Existing Conditions, Alternative A, Alternative B and Alternative C. The model used for this vegetation analysis of flow alternatives is the Sedimentation and River Hydraulics One-Dimensional Sediment Transport and Vegetation Dynamics Model (SRH-1DV). The model simulates flow hydraulics, sediment transport, and vegetation establishment and survival of the Red Bluff, CA to Colusa, CA study area (Figure 1-1). SRH-1DV provides quantifiable predictions of vegetation establishment, growth, and survival for each location in the study area. Inter-related processes of flow and plant development are assessed on a daily basis. SRH-1DV cannot provide the detailed predictions of a multidimensional model; however, this one-dimensional (1D) model is capable of computing plant growth over the longitudinal extent of the study area and over an extended period of years. Complex interactions between flow and vegetation can be tracked for a more precise picture of the impacts of flow management.

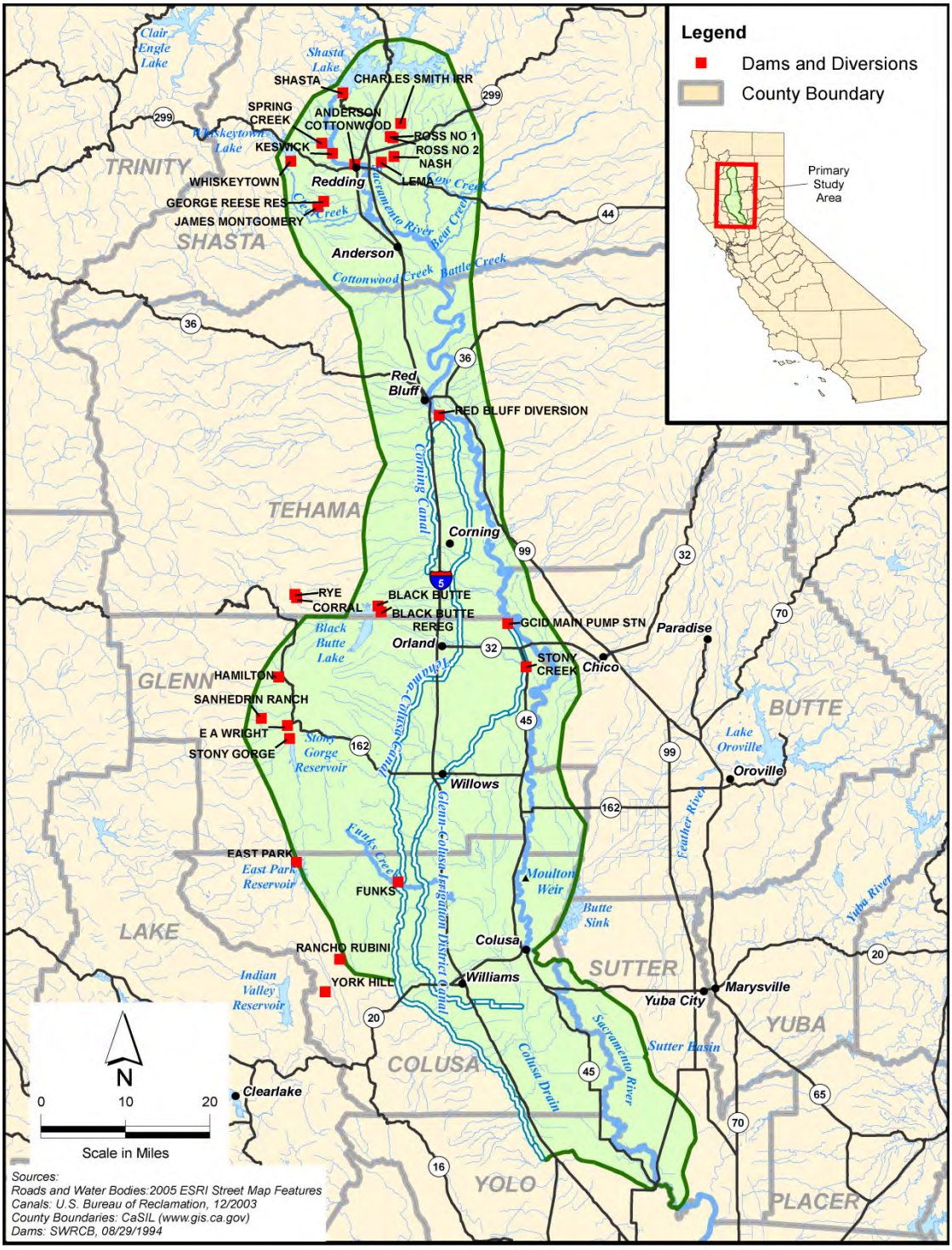

Figure 1-1. Location of study area.

2 Model Description

SRH-1DV is an extension of the Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model (SRH-1D), a 1D flow and sediment transport model developed by the Technical Service Center (TSC) (Huang and Greimann, 2007and 2010). SRH-1DV was written to include ground water and vegetation simulation.

The flow module of SRH-1DV can compute steady or unsteady water surface profiles. SRH-1DV is a cross section based model comparable to the Hydrologic Engineering Centers River Analysis System (HEC-RAS) model, as it uses similar hydraulic computation methods. There is also a sediment module that can compute sediment transport capacity and resulting vertical bed changes using several different transport functions. The results of previous sediment studies for the Sacramento River are presented in Reclamation (2011), and indicate that deep bend pools in the actively meandering Sacramento River make it difficult for accurate representation of sediment transport with a one-dimension model. Therefore, to focus only on the interactions of flow and vegetation, the sediment transport computations are not activated in this vegetation application. More detail of the numerical solution of the flow model, sediment transport algorithms, and channel representation can be found in Huang and Greimann (2007 and 2010).

SRH-1DV requires cross sectional data, similar to other 1D hydraulic models. Both the Sacramento District of the USACE and the CDWR supplied the geometry data. Cross sections were obtained from integrating bathymetric boat survey data at wetted locations and photogrammetry surveys of dry terrain. Both surveys occurred in 1997 (USACE 2002). USACE cross sections were spaced approximately one-quarter mile apart and extended from river mile (RM) 143 to RM 215. CDWR cross sections had more variable spacing and were included in the model from RM 215 to RM 250. The study area extends from Colusa to Red Bluff, CA, a distance of 107 miles. Daily flows were developed by CH2MHILL (2011) using USDRDOM to represent a range of alternatives for the EIS evaluation. Eighty-two years of data are analyzed in these simulations. The development of the sediment input files and the vegetation input files are described in Reclamation (2011). Vegetation mapping from 1999 is input as initial conditions of the 82 year simulation.

2.1 Groundwater Module

Groundwater elevation is a critical factor in the survival of riparian vegetation and is predicted in the model from the computed water surface in the river. The ground water module within SRH-1DV is a cross-section based saturated flow model. Ground water levels are a function of the river water elevation and a soil permeability coefficient. The module solves for the ground water levels, and assumes no ground water interaction between cross sections. Therefore, the

ground water solutions obtained from SRH-1DV will only be applicable near the river, i.e., generally within the alluvial soils of the floodplain. The boundary conditions imposed in the model are:

1. A known water surface elevation wherever the water surface intersects the cross section

2. No flux boundary conditions at the cross section end points

The user can enter separate saturated hydraulic conductivities for the left and right overbanks. It is also possible to enter a known flux or fixed water surface boundary condition, but this was not done for the presented simulations. Soil type and permeability can be specified by cross section or specified by polygon. This feature was also not used for this study.

2.2 Vegetation Establishment Module

In addition to surface flow and groundwater elevations, the establishment, growth and mortality of vegetation are tracked within 3 modules. The Establishment Module simulates germination due to air dispersal assuming an unlimited supply of seed. Established plants can also expand to adjacent points through lateral spread of roots.

2.2.1 Air Dispersal

If air dispersal is being simulated, a plant is assumed to germinate if there is available space, available seeds and moist soil. The “available space” criterion is met if no other vegetation is present at that location that would outcompete the plant. At every point in a cross-section, a plant type can establish if all of the following conditions are met:

- an older plant of the same type is not already growing at that point;
- competition rules for other established plants do not prevent germination;
- the plant type is tolerant of existing shade conditions at that location.

For example, if there are five plant-types in the model, all five plant types can potentially establish at a single point at one time. However, an older plant and a new plant of the same type cannot grow at the point. Also, all competition stipulations between plant types and shading conditions for that plant type must be met at that location. Plants specified as non-tolerant of shade cannot establish when the canopy of a plant at the same or adjacent point is shading the point. Competition, shading and multiple plant types were model developments added after initial development work with cottonwood.

The “available seeds” criterion determines whether or not seeds are available to germinate. Start and end days for seed germination are user specified. The date

must be between the start and end date for seed germination for a plant to establish. It is assumed that an unlimited number of seeds are available between the start and end dates, regardless of the presence or absence of mature plants.

The "moist soil" criterion determines if the soil has enough soil moisture for the seed to begin germination. For each plant type, the user enters a distance above the ground water table within which germination is allowed. Also, the user enters a specified number of days. This accounts for the time that the soil remains moist after the river stage recedes.

2.2.2 Lateral Root Spread

Narrow leaf willow and similar plants can be identified in the vegetation input file as able to expand through lateral growth of roots. These plants can colonize closely spaced adjacent points in the cross section or even closely spaced adjacent cross sections. Before plants can spread laterally to an adjacent point or cross section, root growth must exceed 50 percent of the distance between points. Lateral spread to an adjacent cross section is rare since cross section spacing is commonly greater than extension of the plant roots for the period considered. Lateral root spread rate is specified for each plant type in the input file.

2.3 Vegetation Growth Module

The Growth Module calculates vertical growth of the root (depth), stalk (height), and canopy (width). User-specified growth rates for the roots, stalks, and canopy are based upon the month and age of the plant; that is, a growth rate can be assigned for each month of the first year, and then different growth rates can be assigned for each subsequent year of plant life. Root growth is computed at the specified rates until reaching a user-specified depth with respect to the ground water table. Stalk growth and canopy width are also computed and tracked in the Growth Module until the plant reaches an assigned maximum height or width for the vegetation type.

2.4 Vegetation Mortality Module

The Mortality Module calculates whether the plant survives each time step. There are multiple ways a plant may die in this study, and thus be removed from the module:

- Desiccation, if a plant experiences too much stress due to lack of water;
- Scour, if the local flow velocity at the plant becomes larger than a user-specified value;
- Inundation, if flows exceed the root crown by an assigned depth and flow duration;
- Competition, where assigned rules define the dominant plants; and
- Shading, when a susceptible plant is under the canopy of another plant.

2.4.1 Desiccation

Two methods are used to predict desiccation, both of which depend on the relative location of the root and capillary fringe. The capillary fringe is assumed to be a constant distance above the ground water elevation for a particular cross section. The ground water elevation is calculated as described in the Ground Water Module section. One method assumes that desiccation occurs when the root is separated from the capillary fringe for a user-specified number of days. The other method tracks a "water stress" variable. When the value of that variable exceeds a user-specified value, then desiccation occurs. This water stress method was developed from the Stockholm Environment Institute (SEI) laboratory studies and development of the Riparian Habitat Establishment Model (RHEM; Reclamation, 2011).

2.4.2 Time of Separation

The "time of separation" method tracks the relative elevation of the plant root and the capillary fringe. When a plant root is a user-specified distance above the capillary fringe of the water table for more than the number of days specified, the critical time of separation is reached. The critical time of separation can also be a function of the plant age. The user can vary each plant's resistance to desiccation with age.

2.4.3 Water Stress

The other method of desiccation tracks a water stress parameter, which can increase or decrease every time step depending upon whether the plant is experiencing or recovering from water stress. This method was developed based upon research on Freemont Cottonwood conducted by the SEI (Reclamation, 2011). The user enters a desiccation table of water stress values (desiccation rates) versus water table change where a negative desiccation rate indicates recovery. If the water table is declining faster than the root can grow, the desiccation rate is

positive and the plant may eventually die. However, if the water table rises or stabilizes, the desiccation rate is negative, and the plant may recover. The relationship between rate of desiccation and the water table for each plant type is a function of soil type. The program has one relationship for sand and one for gravel. Soil type for every location is specified by the cross section, or specified by the Geographic Information System (GIS) polygon in the ground water input file.

2.4.4 Scour

Removal due to scour occurs when the local scour velocity at the plant becomes larger than a user-specified value–the "critical scour velocity." This critical scour velocity value can be assigned for various ages for each plant type.

2.4.5 Inundation

Removal due to inundation occurs when flows exceed the root crown by an assigned depth and duration.

2.4.6 Competition

Competition is implemented through a matrix for each plant type, containing rules between each plant type based on plant age. For example, a new cottonwood seedling could be prevented from establishing if 3-year-old herbaceous grass, a 2-year-old invasive plant, or an agricultural plant of any age is already present at the point. Although two plant types could be established at the same point, the dominant plant could eliminate the second plant at a user-specified age. For example a 3-year-old invasive plant can eliminate any age of herbaceous grass or a 0, 1-, or 2 year-old cottonwood.

2.4.7 Shading

Plants can be prevented from growing in areas that are shaded or can experience mortality when conditions exceed their shade tolerance. A canopy growth function was added to the growth module to track locations of shade. The shaded area around each plant is determined based on age of the plant and growth rate of the canopy specified by month. During simulation, the model computes if the plant at a point is shaded by other vegetation on adjacent points. The user can enter the age at which the plant becomes shade tolerant.

2.5 Modeled Vegetation

Fremont cottonwood was the original plant simulated with the SRH-1DV model. Four plant types were added to the initial cottonwood model: mixed forest (mxf), Gooding's black willow (gbw), narrow leaf willow (nlw), and herbaceous (hb).,. These plant types combined with Fremont cottonwood (ctw) were selected to represent the range of riparian communities of the Sacramento River. A designation of managed and cultivated plants (ag), and a designation of no-grow (nogr) areas were also used to mark developed lands where growth does not occur. Some plant types represent a single species, and others represent multiple species or a community that shares similar germination, growth, and mortality characteristics.

2.5.1 Fremont cottonwood (Populus Fremontii) (ctw).

Cottonwoods are a disturbance plant that normally establish after a high flow event. They are fast growing, flood and drought tolerant woody plant found in the floodplain of the river. Areas may be categorized as cottonwood if there is a group of cottonwoods within an area populated by different species of low density.

2.5.2 Mixed forest (mxf).

This designation contains woody species that can be found in the floodplain. Normally, species in this category are less tolerant of inundation than cottonwoods. Oregon ash (Fraxinus latifolia), box elder (Acer negundo), California sycamore (Platanus racemosa), and valley oak (Quercus lobata) are included. Although these species have some differences in germination, growth, and mortality parameters, they are described using the mixed forest designation with most typical values for parameters including germination season and growth rates.

2.5.3 Gooding's black willow (Salix goodingii) -gbw

This willow is a woody riparian species that is very flood tolerant and rapidly growing.

2.5.4 Narrow leaf willow (Salix exigua) -nlw

Although parameters are based on requirements for narrow leaf willow, this category is also representative of other riparian shrubs. These plants tolerate inundation and grow roots quickly, but root depth is relatively shallow in comparison to woody species.

2.5.5 Herbaceous -hb

Herbaceous plants, also described as upland grasses, are mainly used in this model to represent low ground cover as a mechanism to prevent germination of other plants when specified. The desiccation mortality has been turned off for this vegetation type; therefore, these plants can grow in both riparian and upland areas.

2.5.6 Managed and cultivated plants -ag

A separate plant type is assigned to remove cultivated and managed lands from the computations. Unlike riparian plants, these areas are not dependent primarily on flow levels from the river and can include fields, orchards, vineyards, and pastures. A plant may be assigned as a managed and cultivated plant, but germination, growth, and removal are not simulated.

2.5.7 Developed lands -nogr

Areas that do not support native vegetation due to development are designated as no-grow areas. Like managed and cultivated plants, no plant germination, growth or removal is simulated. These areas include roads, urban development, and commercial sites.

3 Model Calibrations

The SRH-1DV Sacramento River for Red Bluff to Colusa was calibrated in a series of studies before beginning this alternatives analysis. Descriptions of the calibration studies, along with detailed information on the vegetation module, are presented in Reclamation (2011). Following development of the initial code and input files, three aspects of the model were calibrated: the flow and ground water modules, the sediment transport module, and the vegetation establishment, growth and survival module. Brief descriptions are provided below, and more detailed information can be found in Reclamation (2011).

3.1 Flow and Groundwater Module Calibrations

For calibration of the flow and ground water modules, surface and groundwater data were collected by CDWR at two sites and compared to simulated values. Manning's roughness coefficients had previously been calibrated and reported by USACE (2002). The agreement between the measured and predicted water surface elevations was excellent for the flows below 20,000 cfs, and therefore modification of the values reported in the USACE study was unnecessary.

3.2 Sediment Transport Module Calibration

Parker's (1990) surface-based bed load formula was chosen to represent sediment transport. Predicted gravel transport was compared against measured transport for a range of flows (figure 6-15). Limited bed load data are available, particularly at high flows; therefore, it is difficult to determine the accuracy of the predicted bed load transport. Reclamation (2011) also contains descriptions of bed material and active layer thickness considerations. However in this analysis of vegetation, sediment transport computations were not used. Deposition and erosion did not appear to significantly impact vegetation growth on this river with a small width to depth ratio, and there were limitations with modeling sediment movement through the deep pools of the modeled section of river.

3.3 Cottonwood Vegetation Module Calibrations

Two cottonwood calibration studies were based on CDWR field studies in 2005 and 2006 (Reclamation, 2011). CDWR monitored the establishment and growth of cottonwoods on the point bars at RM 192.5 and RM 183 in 2005, and at RM 192.5 in 2006. In addition to monitoring water stage and ground water levels described previously, seedling survival was monitored at two point bars, located at RM 183 and 192.5, during the summer of 2005. Cottonwood seedling dispersal was also monitored at RM 192 and RM 183 for several different cottonwood plants, and monitoring continued for the desiccation of the seedlings due to a

decrease in Sacramento River flow. Vegetation parameters were calibrated to match the documented mortality of cottonwood seedlings at these locations. In 2006, the authors simulated the minimum and maximum elevations of recruitment above low water elevation in both gravel and sandy soils using SRH-1DV (Reclamation, 2011).

3.4 Multiple Vegetation Calibration

A third calibration of the SRH-1DV vegetation module and establishment, growth and mortality parameters was completed using a 1999 set and a 2007 set of GIS vegetation mapping for the Sacramento River (Nelson et al.,2008; Viers and Hutchinson, 2008a, 2008b; Viers et. al, 2009). Both sets of vegetation mapping include floodplain areas adjacent to the mainstem river from RM 144 to RM 245. Changes in vegetated area between 1999 and 2007 mapping were compared to changes in vegetated area computed by SRH-1DV for the same period. This third calibration also served as a verification of Fremont cottonwood (ctw) values from the first and second calibration, and was a calibration of the more recently added vegetation types: mixed forest (mxf), Gooding's black willow (gbw), narrow leaf willows (nlw), and invasive plants similar to arundo (inv). Invasive plants (inv,) are excluded from this analysis based on irregularities in the calibration results.

4 Flow Alternatives

Flow records are the only input that varies between the five simulated alternatives (No Action, Existing Conditions, Alternative A, Alternative B and Alternative C). We examine flow records in this section to identify distinctions between alternatives. With this understanding, and some conceptual knowledge of plants and flow hydraulics, general or predictive assessments of impacts to vegetation can sometimes be made.

Construction of the flow regimes for the five alternatives begins with the same eighty-two years (1922 to 2003, USGS, 2010) of daily historical flow data. Starting from this base record, daily flow values were modified to represent a range of future management scenarios. Flow is added (tributaries) or removed (diversions) from the river at 11 locations in the simulations (Table 4-1). Subsequently there are 11 hydrographs for each alternative and 55 hydrographs are required to represent the five alternatives.

Table 4-1. Locations of Modeled Flow Changes.

Model Identification	Description	River Mile	Distance (miles)
180-PAYNESCKIN	Flow entering	249.92	7.1
175-RDBLFDIV	Red Bluff Diversion	242.82	7.82
170-ANTELOPE	Antelope Creek	235	5.45
165-MILLCKIN	Eleder Cr. + Miller Cr.	229.55	4.26
162-THOMESCK	Thomes Creek	225.29	5.82
160-DEERCKIN	Deer Creek	219.47	13.27
150-GCC-DIV	GCC Diversion	206.2	16.45
142-STONYCKI	Stony Creek	189.75	0.75
140-ORDFERRY	Ord Ferry	189	20
135-BUTTE-CI	Butter City	169	10.75
128-NODOS-DIV	Delevan Pipeline Diversion	158.25	15.25

4.1 A Comparison of Flow Alternatives in the Reach at Red Bluff Diversion and the Reach at GCC Diversion

Two sites have been selected for this initial comparison of flow alternatives: Red Bluff Diversion and GCC Diversion. These sites are immediately downstream of flow diversions and are assumed to have the most distinct flow patterns due to management actions and the least attenuation. In Figure 4-1, the average daily flow regimes for each alternative are shown for the reach downstream of the Red Bluff Diversion, and shown in Figure 4-2 for the reach downstream of the GCC Diversion. Five of a total 55 hydrographs are presented in each figure. The hydrographs are constructed from daily values averaged from 82 of the same calendar day between 1921 and 2003. Day 1 in Figures 4-1 and 4-2 is October 1, the first day of the water year.

This large river has average winter peaks of 21,000 cfs at Red Bluff Diversion and 25,000 cfs at the GCC Diversion. Flows drop to average annual low flows of 6,000 cfs to 7,000 cfs in November. Both flow hydrographs exhibit a jagged flow incline and high peak representing the winter rains. This peak declines in April, and by June the hydrograph has flattened with less distinct spikes in the flow pattern. Presumably the reduction in flow spikes in the summer flow regime indicates less influence from natural storm events. A second rise follows in late summer, also with a smoother hydrograph, and a gradual flow peak occurs near 12,000 cfs.

The flow period for April to September is shown a second time for Red Bluff and GCC in Figures 4-3 and 4-4 to more closely detect differences between alternatives during the summer months and during the estimated cottonwood germination season.

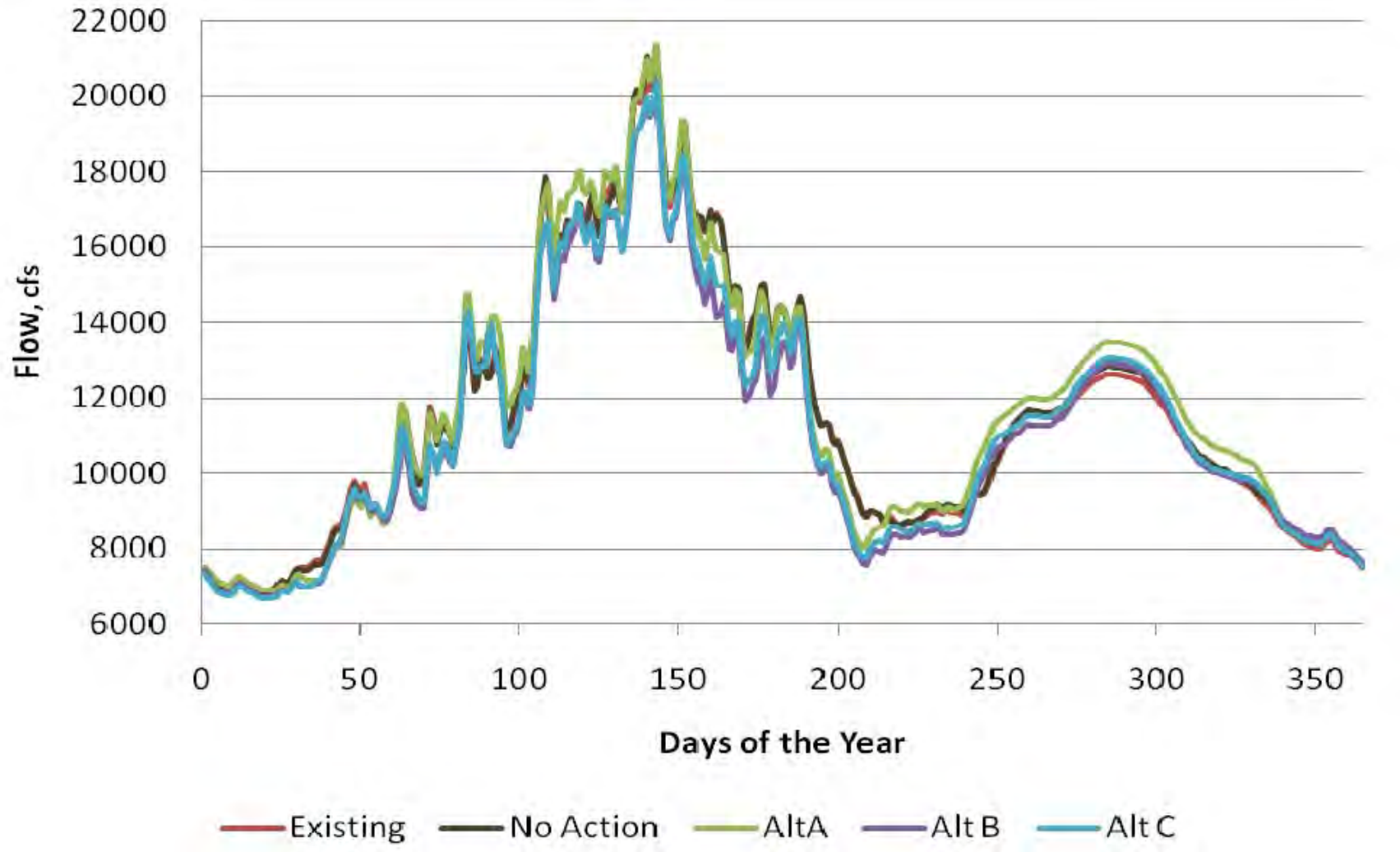

Figure 4-1. Average daily flows for each alternative in the reach downstream of the Red Bluff Diversion (RM 242.82- RM 235), computed from 82 years of simulated flows.

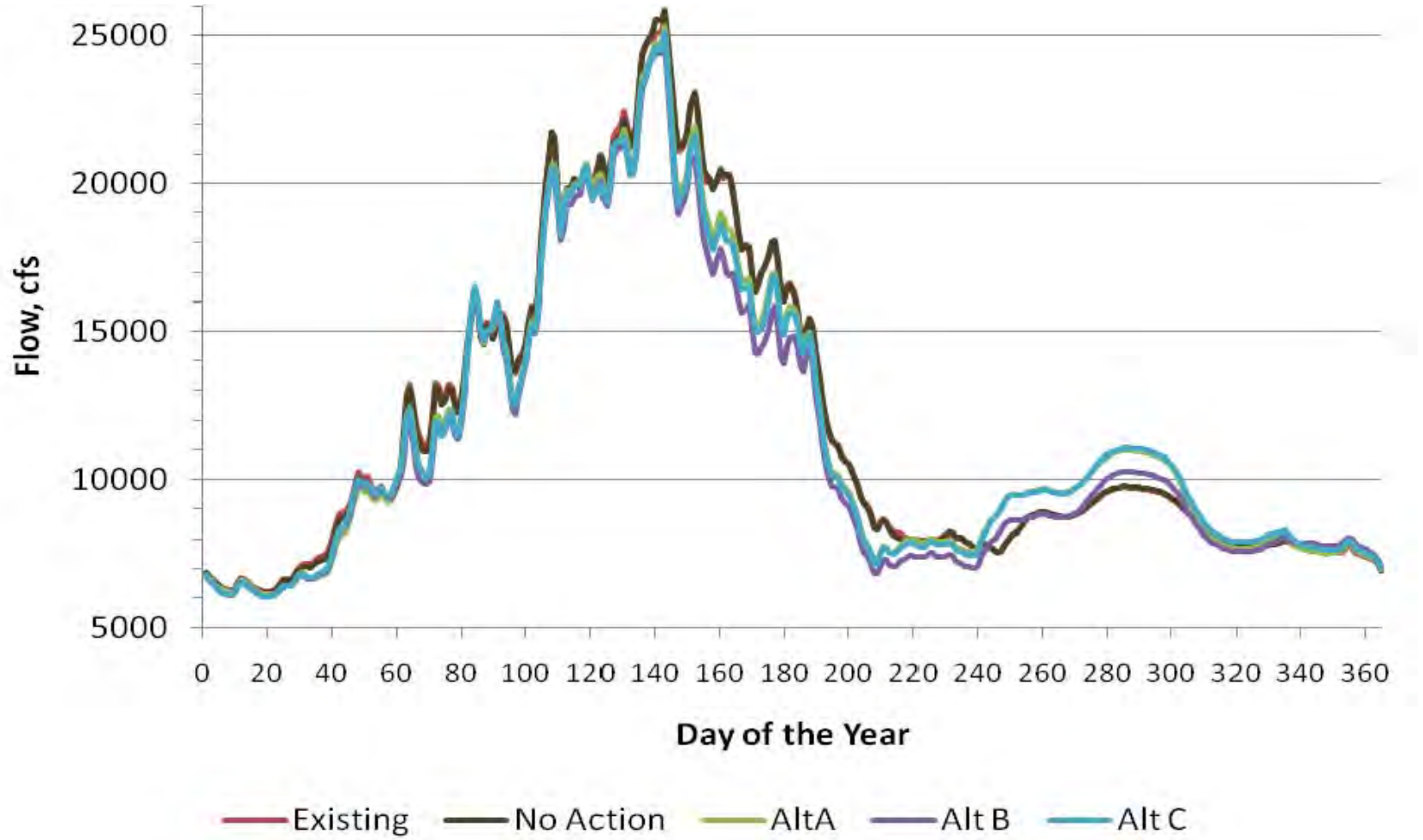

Figure 4-2. Average annual flows for each alternative in the reach downstream of the GCC Diversion (RM 206.2- RM 189.75) computed from 82 yrs of simulated flows.

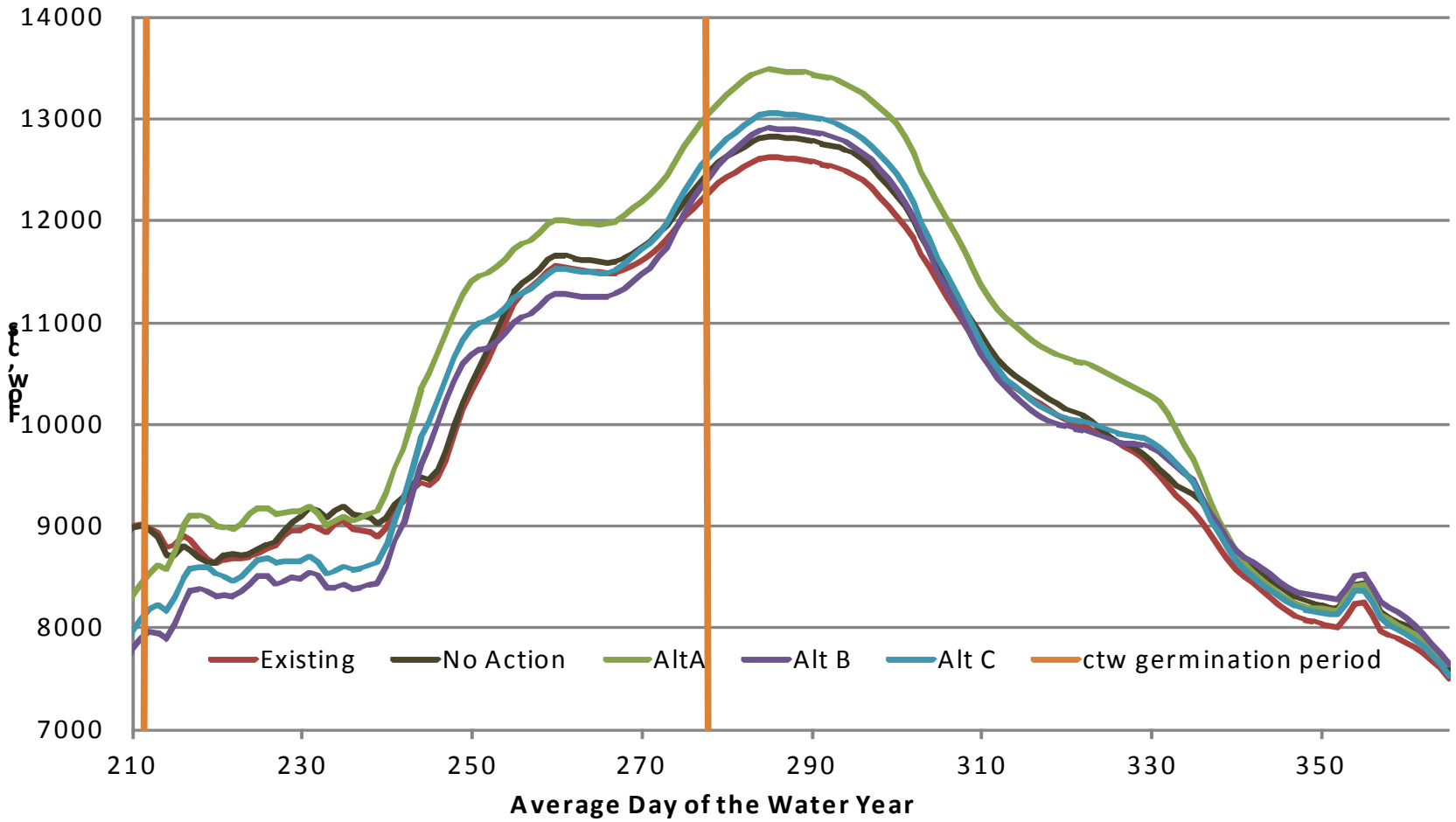

Figure 4-3. Average daily flows downstream of the Red Bluff Diversion for each alternative from April to September (210= April 28, 244 = June 1 and 365 = September 30). Average values are computed from 82 years of simulated flow data in the reach downstream of the Red Bluff Diversion (RM 242.82- RM 235). The cottonwood germination period is shown in yellow.

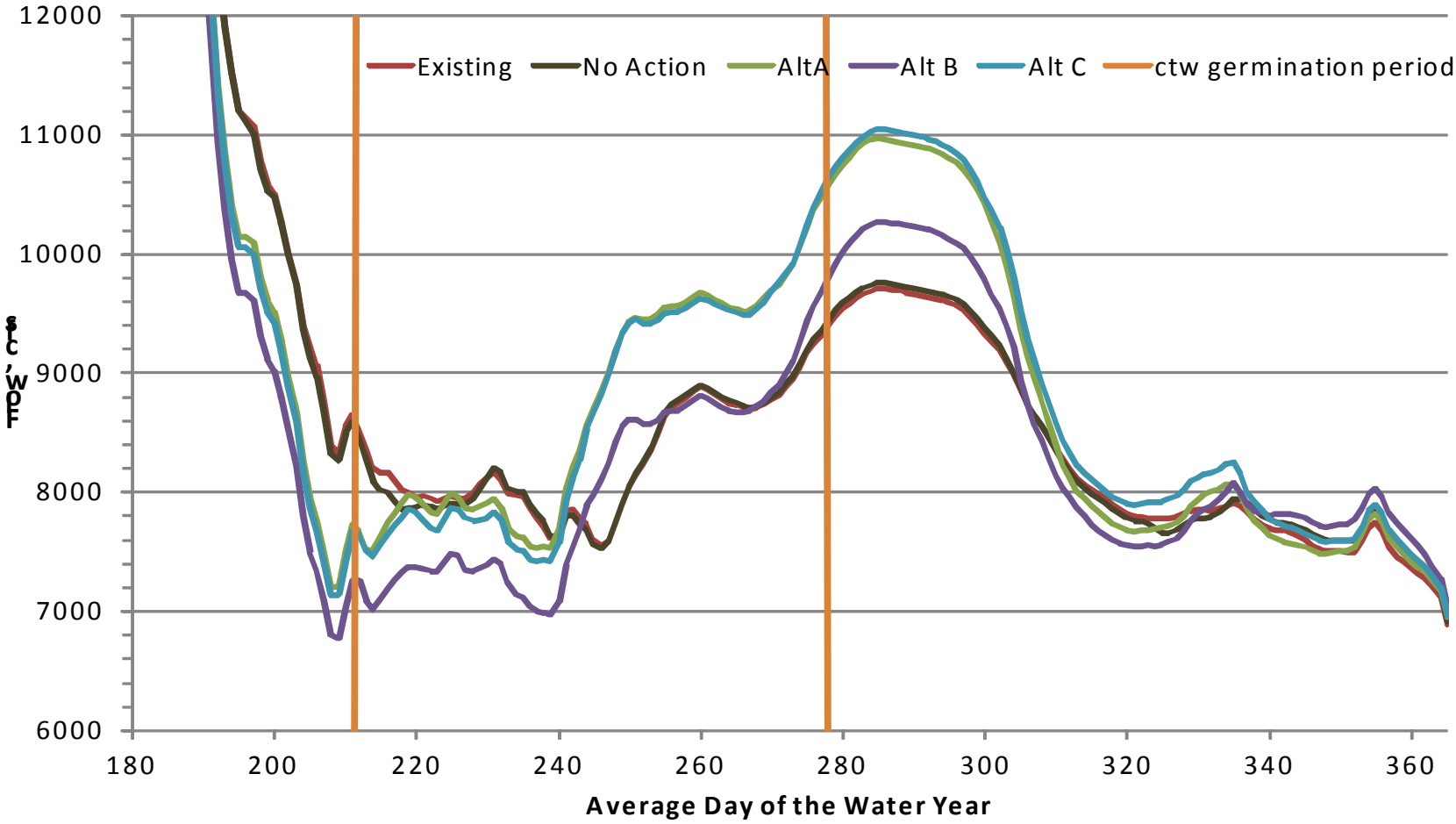

Figure 4-4. Average daily flows downstream of the GCC Diversion for each alternative from April to September (183= April 1, 244= june 1, 365 = September 30). Daily averages are based on 82 years of simulated flow data in the reach downstream of the GCC Diversion (RM 206.2- RM 189.75). The cottonwood germination period is shown in yellow.

Distinctions between flow alternatives identified in Figures 4-1 to 4-4 are:

- Existing and No Action alternatives tend to be similar;
- Existing and No Action alternatives have the largest peaks in winter at the GCC Diversion and some of the higher peaks in winter at Red Bluff Diversion;
- Existing and No Action alternatives generally have average or lower flows in summer than the A and C alternatives;
- Flows for Alternatives A and C appear to be shaved off from the declining limb of the winter hydrographs and added to the peaks of the summer hydrographs;
- Alternative B generally has the lowest flows of all alternatives with the exception of flows exceeding the No Action and Existing Alternatives for short periods during the summer peak at the GCC Diversion;
- Alternative A has the highest summer flows at the Red Bluff Diversion and the GCC Diversion;
- Alternative C has average summer flows at the Red Bluff Diversion and large summer flows, similar to Alternative A, at the GCC Diversion
- The summer peak flow for all alternatives and at both locations occurs after the estimated cottonwood germination season.

These figures represent an average year of flow. If the estimated germination period of cottonwood is correct, seeds released during an average season will be inundated in the succeeding two weeks of flow. This will reduce the establishment and survival of cottonwood seedlings. Cottonwood seedlings do not have to colonize every year to maintain good coverage, but successful colonizing is required periodically with the occurrence of high flow years. A second consideration is that the timing of the cottonwood germination period is not as specific as it appears in these graphs; cooler springs can have a later period of plant germination. However a counter to this logic, is the argument that cooler springs normally produce later runoff periods.

A concern with using an 82 year average for this analysis is the loss of timing information on peak flows and extreme low flows from year to year. Alternative B may provide the ideal peak flow for cottonwood every five years by having extreme low flows in the previous four years. Although timing information is still missing, statistics are used in the next section to pursue better descriptions of flow alternatives and their differences.

4.2 A General Comparison of Flow Alternatives

Identifying differences between flow alternatives can also be accomplished through the use of basic statistics. Daily flows have been tabulated for the 11 distinct flow locations in Table 4-1, including the Red Bluff Diversion and the GCC Diversion. As implied in a previous bullet, Alternative B at the Red Bluff Diversion and at the GCC Diversion has the smallest volume (sum) of flow, and the smallest values for mean, median and mode. Alternative B also has low minimum values (lowest at GCC Diversion, 2nd lowest at Red Bluff Diversion) in a comparison of the five alternatives.

Statistical values for the No Action and Existing alternatives at Red Bluff Diversion and GCC Diversion mainly support the bulleted item in Section 4.1 identifying a similarity between the No Action and Existing alternatives. Second and third bullets are also supported by the values in Table 4-2. Alternative A has the most flow (sum, mean and median) at the Red Bluff Diversion, but the No Action and Existing alternatives have the most flow (sum, mean median, and mode) at the GCC Diversion. The No Action and Existing alternatives also have the largest range and standard deviation at the GCC Diversion and the largest standard deviation at Red Bluff.

Table 4-2. Statistics on 82 years of daily flow simulated for each alternative at 11 locations (cfs). Shaded areas represent the highest values for each parameter.

Payn- RM 249.92					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	11,687	11,653	11,668	11,674	11,669
Median	9,107	9,117	9,047	9,070	9,117
Mode	7,540	5,608	6,069	6,832	6,744
Standard Dev.	11,130	11,125	11,271	11,261	11,262
Range	147,814	147,940	147,899	147,905	147,906
Minimum	2,915	2,765	2,828	2,821	2,821
Maximum	150,729	150,705	150,727	150,726	150,727
Sum	350,015,212	348,996,631	349,453,363	349,646,082	349,472,773

Red Bluff- RM 242.82					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	11,505	11,464	11,668	11,052	11,192
Median	8,902	8,894	9,047	8,392	8,571
Mode	5,746	10,237	6,069	5,512	6,107
Standard Dev.	11,276	11,276	11,271	11,181	11,265
Range	150,032	150,076	147,899	150,572	150,576
Minimum	2,863	2,795	2,828	2,315	2,312
Maximum	152,895	152,871	150,727	152,887	152,888
Sum	344,587,061	343,358,541	349,453,363	330,996,482	335,191,628

Antelope Cr- RM 235					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	11,687	11,646	11,407	11,233	11,374
Median	9,022	9,005	8,679	8,550	8,696
Mode	7,009	5,521	7,220	6,226	6,281
Standard Dev.	11,538	11,539	11,560	11,438	11,523
Range	152,339	152,383	152,628	152,631	152,634
Minimum	2,860	2,792	2,563	2,559	2,557
Maximum	155,199	155,175	155,191	155,190	155,191
Sum	350,031,386	348,797,539	341,647,759	336,440,732	340,637,185

Miller Cr - RM 229.55					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	12,122	12,081	11,842	11,668	11,809
Median	9,292	9,311	8,990	8,858	9,010
Mode	5,814	5,671	6,033	6,496	6,063
Std Deviation	12,099	12,101	12,115	11,990	12,078
Range	162,727	163,864	162,560	162,563	162,566
Minimum	2,894	2,830	2,951	2,946	2,944
Maximum	165,621	166,694	165,511	165,509	165,510
Sum	363,057,347	361,817,932	354,675,620	349,466,688	353,664,599

Thomes Cr - RM 225.29					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	12,453	12,411	12,173	11,999	12,139
Median	9,463	9,477	9,180	9,088	9,192
Mode	7,290	10,316	5,900	6,374	5,846
Std Deviation	12,670	12,672	12,680	12,551	12,641
Range	170,069	170,118	169,700	169,915	169,702
Minimum	2,863	2,800	3,236	3,021	3,236
Maximum	172,932	172,918	172,936	172,936	172,938
Sum	372,954,630	371,709,768	364,574,424	359,363,908	363,552,372

Deer Cr - RM 219.47					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	12,812	12,771	12,532	12,358	12,499
Median	9,689	9,705	9,392	9,316	9,399
Mode	10,589	10,672	6,488	5,840	7,948
Std Deviation	13,186	13,189	13,192	13,060	13,152
Range	182,305	183,779	176,530	176,762	176,339
Minimum	2,891	2,828	3,275	3,043	3,467
Maximum	185,196	186,607	179,805	179,805	179,806
Sum	383,726,436	382,476,626	375,347,663	370,135,679	374,325,154

GCC Diversion - RM 206.2					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	11,634	11,654	11,451	11,072	11,420
Median	7,922	7,936	7,911	7,614	7,974
Mode	5,994	5,512	5,718	5,088	8,509
Std Deviation	13,729	13,723	13,639	13,481	13,587
Range	181,080	183,036	179,565	179,712	179,580
Minimum	2,165	2,205	1,790	1,640	1,774
Maximum	183,245	185,241	181,355	181,352	181,354
Sum	348,431,206	349,051,048	342,946,333	331,614,425	342,027,363

Stoney Cr- RM 189.75					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	12,214	12,228	12,029	11,650	11,999
Median	8,010	8,016	8,059	7,759	8,118
Mode	6,813	6,169	7,062	8,406	5,000
Std Deviation	14,969	14,962	14,864	14,700	14,809
Range	190,534	191,230	190,963	191,143	190,968
Minimum	2,101	2,139	1,670	1,487	1,664
Maximum	192,635	193,369	192,633	192,630	192,632
Sum	365,797,072	366,224,640	360,277,364	348,920,195	359,367,776

ORD Ferry RM 189					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	12,136	12,151	11,956	11,578	11,926
Median	8,010	8,016	8,059	7,758	8,120
Mode	5,919	5,204	5,097	7,325	4,932
Std Deviation	14,343	14,337	14,267	14,109	14,217
Range	135,380	135,636	135,808	135,991	135,815
Minimum	2,101	2,139	1,672	1,488	1,665
Maximum	137,481	137,775	137,480	137,479	137,480
Sum	363,477,553	363,909,092	358,067,269	346,768,320	357,186,393

Butter City- RM 169					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	11,734	11,748	11,553	11,176	11,524
Median	7,412	7,410	7,549	7,197	7,581
Mode	5,383	5,880	6,501	7,749	8,717
Std Deviation	14,378	14,372	14,288	14,133	14,237
Range	133,407	134,295	134,791	134,885	134,806
Minimum	1,999	2,044	614	519	599
Maximum	135,406	136,339	135,405	135,404	135,405
Sum	351,436,836	351,846,818	346,020,169	334,729,739	345,139,367

Delevan Pipeline- RM 158.25					
	No Action	*Existing*	*Alternative A*	*Alternative B*	*Alternative C*
Mean	12,240	12,267	12,200	12,202	12,195
Median	7,744	7,728	8,187	8,183	8,251
Mode	6,575	5,239	7,998	8,508	6,183
Std Deviation	14,275	14,270	13,949	13,905	13,864
Range	110,634	111,293	110,241	110,240	110,240
Minimum	0	0	0	0	0
Maximum	110,634	111,293	110,241	110,240	110,240
Sum	366,601,326	367,410,809	365,387,395	365,463,353	365,238,258

Information from Table 4-2 is summarized in Table 4-3 and the locations with the largest values are shown in parenthesis. Both values are listed if there are two alternatives that share the same large value. Italics indicate alternatives with large values at the second greatest number of locations. In general, the Existing Alternative and the No Action Alternative have the most flow volume (sum) while the Existing Alternative has the highest peaks and highest daily flows (maximum, highest minimum, mean and medium). This table does not reflect the summer season flow patterns noted from Figures 4-3 and 4-4. During the summer months of flow delivery, Alternatives A and C have higher peak and daily flows than the Existing Alternative and the No Action Alternative. However more discharge during the winter season offsets the ability to statistically detect differences in summer flow patterns, which have greater impacts on vegetation growth. Large flows during a period of general plant dormancy increase the challenge of interpreting vegetation impacts from flow records. In other words, the maximum values shown in these flow statistics may not be the most beneficial to the vegetation if timing of the flows is not consistent with the critical establishment and growth periods of the vegetation.

Table 4-3. Alternatives with the first and second greatest values. Based on 82 years of daily flow simulated for each alternative at 11 locations (cfs) as listed in Table 4-2

Std Dev	*Range*	*Maximum*	*Highest Minimum*	*Mean*	*Median*	*Mode*	*Sum*
No Act (6)	Exis (7)	Exis (7)	Exis (4)	No Act (5)	Exis (5)	Alt B (4)	No Act (5)
Alt A (5)	*B & C (2)*	*No Act (3)*	*No Act (3)*	Exis (5)	*Alt C (4)*	*Exis (3)*	Exis (5)

.

4.3 A Spatial Examination of the Flow Hydrograph

In a second examination of the flow hydrographs, we focus on the spatial characteristics of a single alternative. There are 11 hydrographs for each alternative but only 4 hydrographs are shown in Figure 4-5. The highest peaks occur for a short distance between RM 189.75 and 189.0, and lowest peaks occur between RM 158.25 and RM 143. The highest, low-flows were noted between RM 249.9 and RM 242.82, and the lowest, low-flows were identified between RM 169 and RM 158.25. These four hydrographs (highest peaks, lowest peaks, highest low-flows, lowest low-flows) bracket the range of values for the 11 hydrographs representing Alternative A.

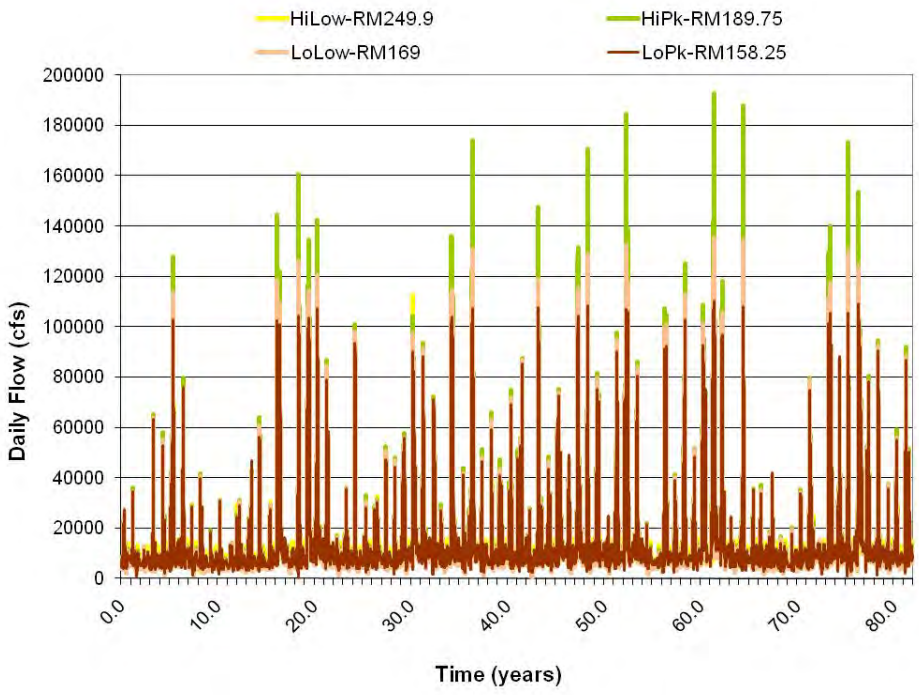

Figure 4-5. Bracketing Alternative A Flows.

Figures 4-1 to 4-4 demonstrated the temporal complexity of differences between flow alternatives. Figure 4-5 illustrates the spatial complexities of characterizing the flow alternatives. Flow complexity is generally beneficial for plant diversity, but it makes reliable predictions of vegetation response to managed flow challenging. Changes in flow patterns caused by tributary inputs and diversions result in changes to the impacts of flows on vegetation throughout the study area.

4.4 Complexities of Predicting Vegetation Vigor from the Flow Regime

There is a direct link between the presence and vigor of riparian vegetation and the pattern of water surface rise and decline in a river, most notably in the semi-arid and arid regions of the west. Riparian vegetation is dependent on the relatively shallow groundwater surface imposed by the flow regime of the stream or river system. When rainfall is sparse, vegetation with coping systems of rapid root growth invest energy in extending roots to follow the groundwater and the rapid drops in the river water surface. Plants and/or root caps require exposure to air to survive so frequent submergence or a long period of submergence can also be detrimental to plants. Subsequently riparian vegetation can be influenced by both high flows and low flows. Yet not all high flows and low flows are relevant to vegetation vigor. The flow events that occur during the germination and growth period for the vegetation of interest will have more influence than high and low flows during the dormant season of the plant.

Cottonwood plants depend on the high flows during germination seasons to create disturbance events that erode plants and deposit sediment creating bare ground, raise the groundwater surface close to the ground surface, and float seeds overbank into backwater areas. As the backwater drains, cottonwood plants that have quickly growing roots can germinate and grow in areas away from the erosive forces near the main channel. Cottonwood is expected to thrive with the alternative having the highest peak-flows, largest number of peak flow events during the germination season, and possibly a large range in water surface elevations. From Table 4-3, we could predict that the Existing flow alternative will outperform other alternatives in producing cottonwood plants.

The alternative with the highest peak (maximum), the highest low flow (minimum), the widest range in flows (standard deviation or range), the most volume (sum), and the highest typical flow (average, median or mode) can be easily selected from Tables 4-4 for each reach. If it is assumed that bigger values are beneficial to the desired vegetation (i.e. larger minimum flow, larger variations in flow, a larger average flow, and more flow), the predicted preferred alternative for each reach at this broad level of consideration would be as shown in Table 4-4. With few exceptions, the Existing Alternative has the most water and Alternative B has the least water. However timing information including the recurrence value, duration of high and low flows, or the season of occurrence, can also influence vegetation vigor and cannot be understood from these values.

Table 4-4. Preferred alternative and least desirable alternative for each reach based on the most flow and a ranking of the flow statistics. The No Action alternative is preferred at Payne due to the largest number of first place rankings at Payne (mean, mode, minimum, maximum, sum). The Existing alternative is predicted to have the poorest performance at Payne based on the largest number of low values (mean, mode, standard deviation, maximum, minimum and sum).

	Location	**Most Q**	**Least Q**
1	Payne	NoAction	Existing
2	Red Bluff Diversion	NoA&AltA	Alt B
3	Antelope Creek	NoAction	Alt B
4	Ele+Mill Cr	Exist	Alt B
5	Thomes Creek	Exist)	Alt B
6	Deer Creek	Exist	Alt B
7	GCC Diversion	Exist	Alt B
8	Stony Creek	Exist	Alt B
9	Ord Ferry	Exist	Alt B
10	Butter City	Exist	Alt B
11	Delevan Pipeline	Exist	Alt C

Lowest-low flows can trigger desiccation even in well established plants, making maximum root depth an important plant characteristic. Shrubs like willow with relatively shallow root systems colonize areas close to continuous river flow or locations with consistent and shallow ground water. Although willow plants depend on steady water delivery, these plants can also have characteristics that maximize tolerance for inundation during high flow periods. Willow is less dependent on the pattern of high flow events and may thrive with the alternative having more consistent daily flows and less low flow (drought) events during the growing season. Higher daily flows should also increase the area available for willow colonization but consistency is important for the survival of willows. . Although it often has the least flow when compared to other alternatives, Alternative B may be successful at supporting willow due to the consistency of the flow (smallest standard deviation) if low bench areas are available for colonization. Without favorable terrain, higher (larger mean and mode) consistent (smaller standard deviation) flows during the growing season are most important, but unlike cottonwood plants, occasional high flow events (maximum values) are not as important to willow The logic for both of these predictions is dependent on simplistic associations.

4.5 Summary of the Comparison between Flow Alternatives

We focused in this chapter on identifying the distinctions between flow alternatives to aid the interpretation of vegetation modeling results (presented in the next chapter). Flow hydrographs were compared temporally at two locations providing insight into variations between flow management alternatives. Flow alternatives were also compared using basic statistics at all locations that helped substantiate initial observations, and finally spatial differences between hydrographs were recognized with a bracketing of flows in one flow alternative. That investigation was then extended by attempting to predict vegetation vigor from identified distinctions between flow management plans.

Given spatial and temporal complexities of the flow hydrographs, and subtle distinctions between flow alternatives, we conclude that reliable predictions based upon flow regime alone are challenging. Additional considerations of study area size, variations in floodplain terrain, and variations in response of each plant type to dormant seasons, tolerances for desiccation and inundation, and growth patterns, make it difficult to rely on concepts of flow and plant interactions alone for meaning full predictions. In the next chapter we apply the one-dimension numerical modeling tool, SRH-1DV, to compute the differences in vegetation response between flow alternatives.

5 Analysis of Alternatives

In this chapter the computational tool SRH-1DV is used to compare the impacts of five flow alternatives on vegetation. The output from 82 years of simulation with five flow management scenarios is reviewed as summary tables and figures. Computational predictions help determine the most beneficial flow management approach for establishing and maintaining riparian vegetation

This investigation begins in section 5.1 with a general analysis of trends for each vegetation type over the 82-yr period of analysis. In section 5.2, averages of the results from the five alternatives are reviewed to determine the locations supporting the most vegetation and the reasons for the abundance. There is also a discussion in this subsection on the location where cross section spacing changes, and the odd impact from this change. In section 5.3, the alternatives comparison begins with a broad scale look and becomes more specific in section 5.4 with an inspection of each river reach. Finally in section 5.5, the types and numbers of plant mortality for each alternative are examined. A review of the mortality outcomes can contribute to our understanding of the flow impacts from each alternative.

5.1 Trends in Plant Coverage

In this section we look at changes in vegetation area across time, understanding that differences from year to year are dependent on the flow regime for each year. Flow diversion and flow discharge rates will vary with the alternatives, but the same high and low climatic events and the timing of these events are shared by all alternatives. All simulations begin with vegetation conditions in 1999 (Nelson et al., 2008; Viers and Hutchinson, 2008a, 2008b; and Viers et. al, 2009), and the channel geometry from 1997 (USACE, 2002).

A result of interest is the overall trend in coverage for each vegetation type. Vegetation coverage's for all five alternatives are presented by vegetation type in Figures 5-2 to 5-6. Each figure is constructed at the same scale. Differences between alternatives in the figures are not always clear at this scale but similarities and differences between the trends for each vegetation type can be readily identified. The trends are influenced by the calibration for multi-vegetation types (Reclamation, 2011) using mapped vegetation change from 1999 to 2007.

5.1.1 Cottonwood

A graph of acres of cottonwood coverage is presented in Figure 5-1. Differences between the alternatives are fairly minimal. Under all alternatives, cottonwood could potentially increase coverage by 2,000 acres from 5,200 to 7,200 acres (+28%) over an 82-year time period. The greatest increase in coverage occurred between the years 5 and 11 in the flow record, and also in year 16. A more

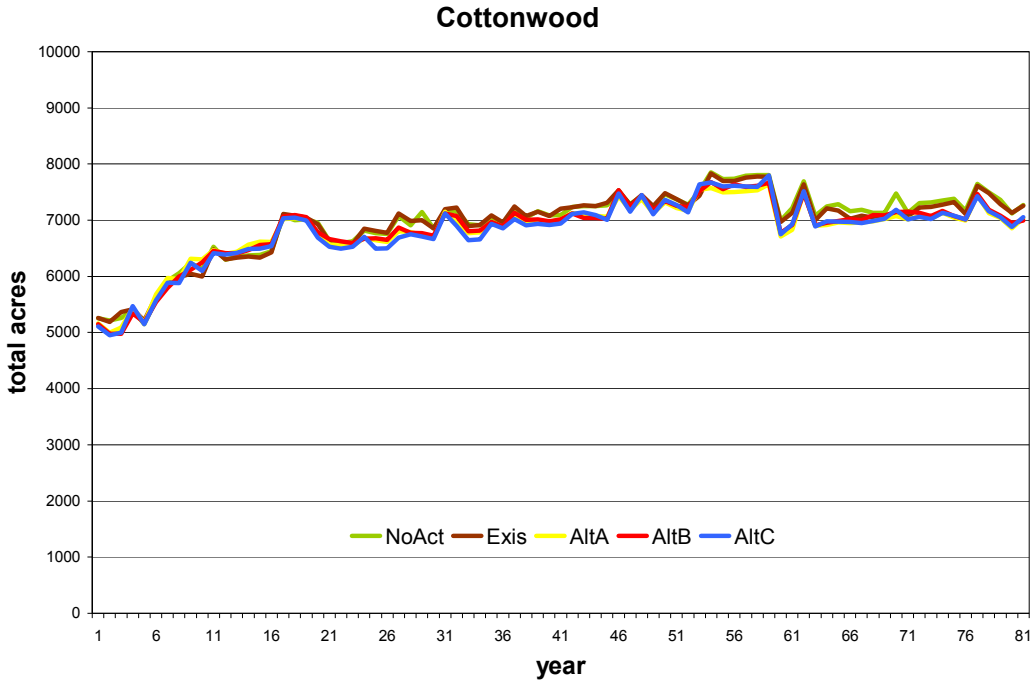

Figure 5-1. Comparison of alternatives based on cottonwood in an 82-yr simulation.

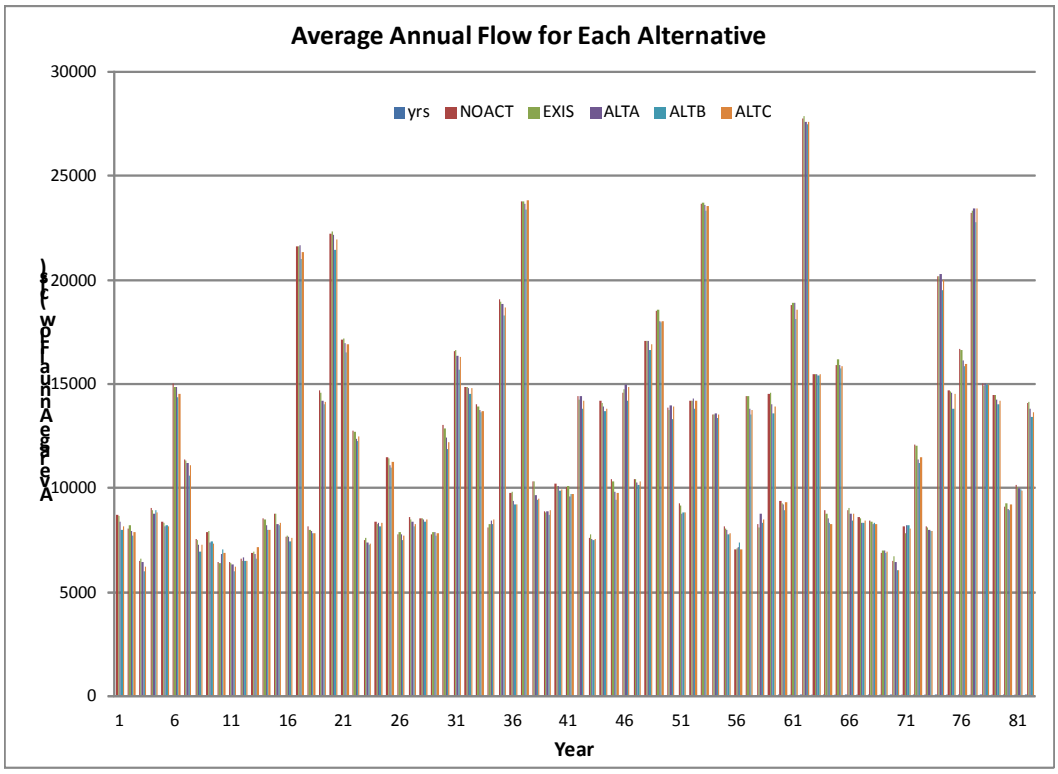

Figure 5-2. Average (11 hydrographs per alternative) annual flow

gradual increasing trend is predicted over the remaining 60 years. In year 16, flows increase coverage by 500 acres for a short period before dryer seasons reduce vegetation to a similar area of coverage projected from year 16. Shown in Figure 5-2 are the average annual flows for the same period. In year 5 (wet), 11 (dry) and 16 (wet) a correspondence can be seen between flow pattern and vegetation response.

Lower flows after year 56 reduce cottonwood cover by approximately 800 acres, and despite a spike from high flows at year 62, the previous amount of coverage (nearly 8,000 acres) is not recovered by year 82.

5.1.2 Mixed Forest

Only a small increase in coverage is predicted for mixed forest over the 82-year period modeled (Figure 5-3). Coverage increases from 7900 acres to 8200 acres (+4%), and the model predictions show a relatively consistent trend. There is a temporary increase in area in year 16 followed by a drop in year 19. At year 20, the No Action and Existing Conditions alternatives show less acreage than is present in year 1. Larger fluctuations are noted between year 45 and year 53, and an increase in mixed forest coverage is simulated between year 52 and year 58. At year 59, mixed forest coverage dropped and returned to the gradual increasing trend noticeable between years 20 and 50.

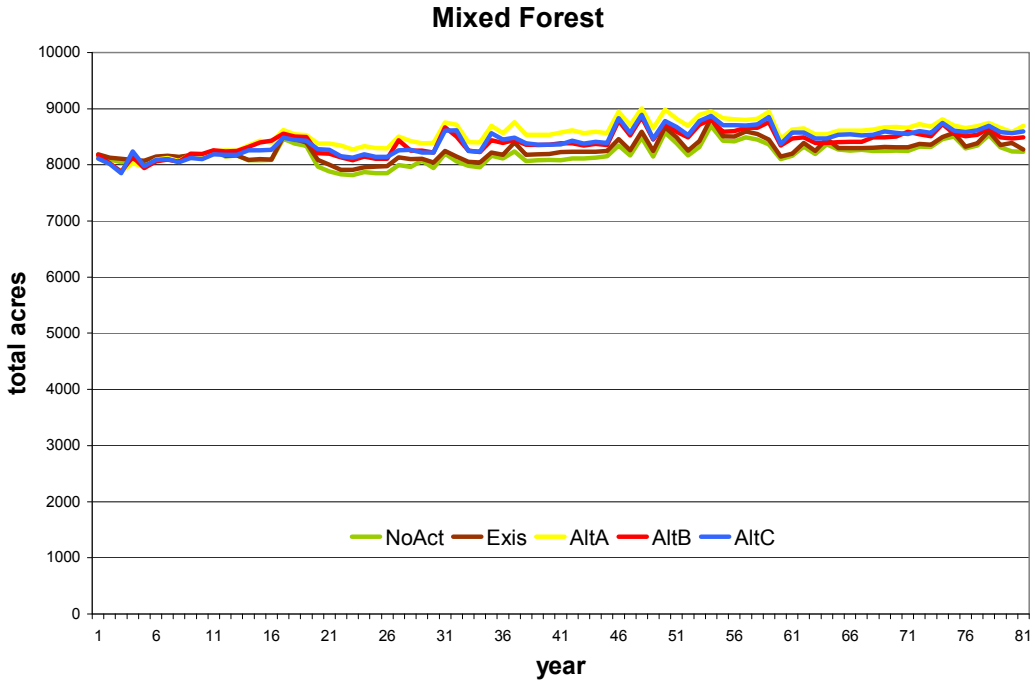

Figure 5-3. Comparison of alternatives for mixed forest across 82-yrs of flow simulation.

One explanation for the relatively stable coverage is the large extent of mature stands of mixed forest that do not vary from year to year. Changes in coverage by

senescence or disturbance events including fires or timber removal are not represented in these simulations. Established stands of mixed forest, in comparison to mixed forest seedlings, can often withstand drought and are not impacted by river flooding, the primary disturbance factors represented in the simulations. New mixed forest seedlings can begin in flood disturbed areas but are not as aggressive as cottonwood with respect to root growth rates. Therefore, the percent of mixed forest seedling coverage in new areas, when compared to the areal extent of mature mixed forest, is less.

5.1.3 Gooding's Black Willow

The Gooding's black willow coverage for all alternatives expands from approximately 2,200 acres to 4,000 acres (+45%) over the 82-year period modeled (Figure 5-4). Gooding's black willow exhibits the greatest increase in coverage between year 1 and year 17, and then increases at a lower rate after year 17. The largest increases in coverage occurred in year 16 and year 61. The larger declines in coverage occurred in years 4, 32 and 62.

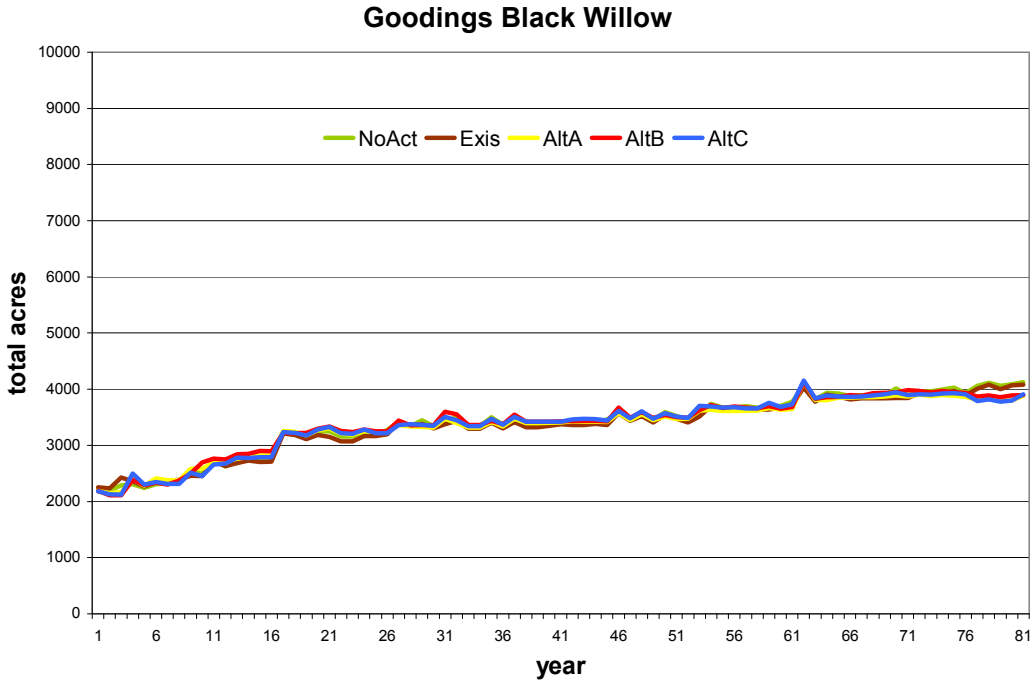

Figure 5-4. Comparison of alternatives based on Gooding's black willow in an 82-yr simulation.

5.1.4 Narrow Leaf Willow

Narrow leaf willow increased from 1,500 to 3,400 acres over the 82-year period model (Figure 5-55). This represents a 56% increase in coverage using the flow record from 1922 to 2003,. Narrow leaf willow exhibits more variation in values from year to year, and more variation in the overall trend than the other vegetation types. This is due to the relatively short root depth which restricts the plants to locations directly adjacent to the channel. Narrow leaf willow is subsequently more susceptible to changes in the water surface elevation than all other vegetation types modeled. The sharpest increases in coverage occur between year 1 and year 10, between years 15 and 18, and between years 61 and 67. The largest declines in narrow leaf willow coverage occurred in years 25 to 31 and years 67 to 72. Relatively minor trends, with no increases or decreases in coverage, occur between years 16 and 20 and again between years 31 and 35.

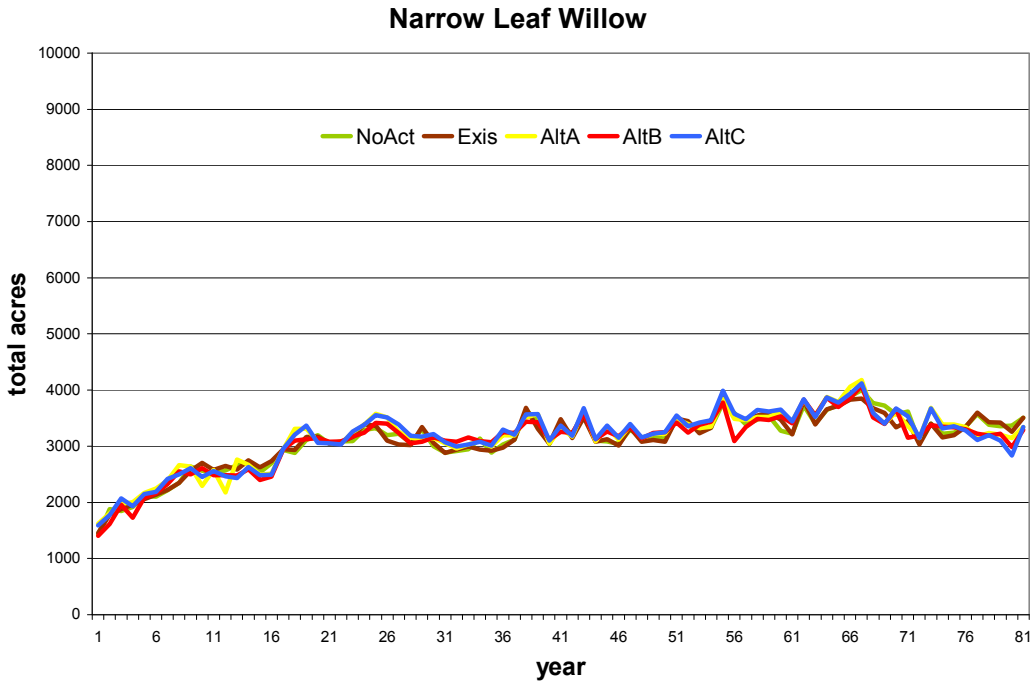

Figure 5-5. Comparison of alternatives based on narrow leaf willow in an 82-yr simulation.

5.1.5 Herbaceous

Generally coverage by herbaceous upland grasses decreases from 18,000 acres to 15,300 acres (-18%). Herbaceous grasses exhibit a trend of steep decline from year 1 to year 17, and a smaller but consistent rate of decline after years 17 (Figure 5-6).

The initial trend of a steep decline in herbaceous coverage is consistent with the initial increasing trends of coverage for cottonwood, Gooding's black willow, and narrow leaf willow. Cottonwood, Gooding's black willow, and narrow leaf willow exhibit the sharpest increasing trend from year 1 to 17 with a smaller upward trend from years 18 to 82. The downward trend of herbaceous grasses and upward trend of riparian plants are consistent. Locations of herbaceous grass establishment are not restricted by water requirements (other than low inundation tolerance) to locations near Sacramento River groundwater. This vegetation type can grow at locations that restrict riparian vegetation types (cottonwood, Gooding's black willow, and narrow leaf willow). Upland grasses also have wider seasons of establishment and can quickly colonize areas. Once well established, this vegetation type can prevent the establishment of other riparian plants until removed through erosion, inundation or competition/shading. As these plants are removed, riparian plants can establish.

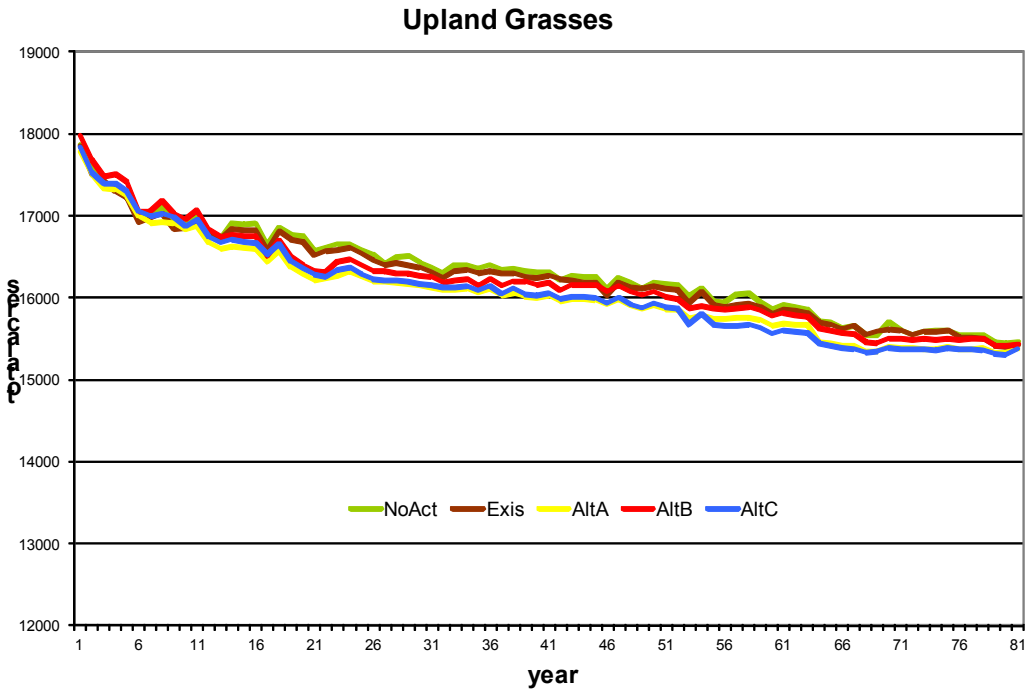

Figure 5-6. Comparison of alternatives based on herbaceous grass in an 82-yr simulation.

The break in the slope of the trend around year 17 found in the three riparian vegetation types, and found in herbaceous grasses, hypothetically could imply

both a time frame and the maximum areal extent for full riparian vegetation coverage along the Sacramento River study area. In the 17 year period, approximately 1,400 acres are likely transferred from herbaceous to riparian plants. This value is more accurate than summing riparian plant areas since multiple plants can grow at a single location, but is complicated by the fact that there are locations and periods when both riparian vegetation and grasses can coexist.

5.2 Location of Vegetation

To study plant locations, the output for all alternatives are combined and averaged for each vegetation type excluding herbaceous plants. Herbaceous plants were included as a mechanism for defining germination areas for disturbance plants and their presence is not linked to the water table. Subsequently these upland plants are ubiquitous and cover all modeled areas not submerged and not supporting riparian plants.

The results for four riparian plants (ctw, mxf, Gbw, nlw) and all alternatives are shown in Figure 5-7 and reported in Table A-1 of the Appendix. Average vegetated width at each cross section was selected as the unit of measure instead of coverage area for this location analysis. Average width is computed by summing the widths (across the channel) for each point in the cross section that supports a plant of interest. The width at each vegetated point is computed by adding half the distance to the nearest point on the left, and half the distance to the nearest point on the right. The vegetated width value for each cross section is an average of the values simulated from the five alternatives. Both Figure 5-6 and Table A-1 demonstrate relative differences in spatial coverage between vegetation types.

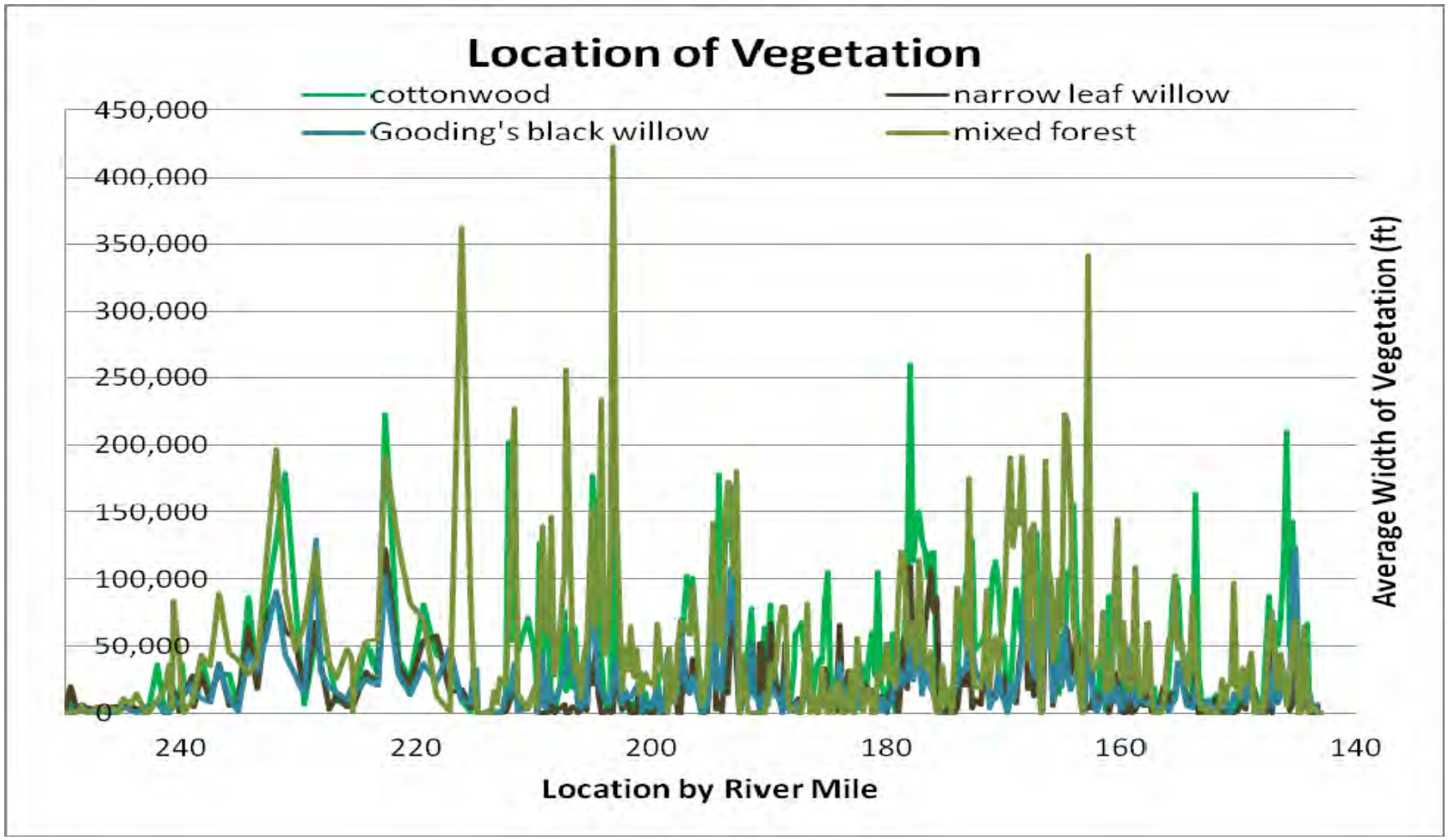

Figure 5-7. Average width of vegetation (ft) at cross sections, presented by river mile and averaged across all alternatives.

There is very little vegetation upstream of RM 240 partially due to the development near Red Bluff, but also due to the change in terrain (Figure 5-8). A wide floodplain at the Red Bluff Diversion (RM 237.45) transitions to a terrain restricted corridor at RM 243.5. Upstream of RM 240 the wide flood plain ends abruptly, and the valley geology creates a 90 degree river bend. Riparian vegetation is limited by the confined corridor upstream of RM 243. Plants are restricted to near bank locations along this section of single, stable channel,

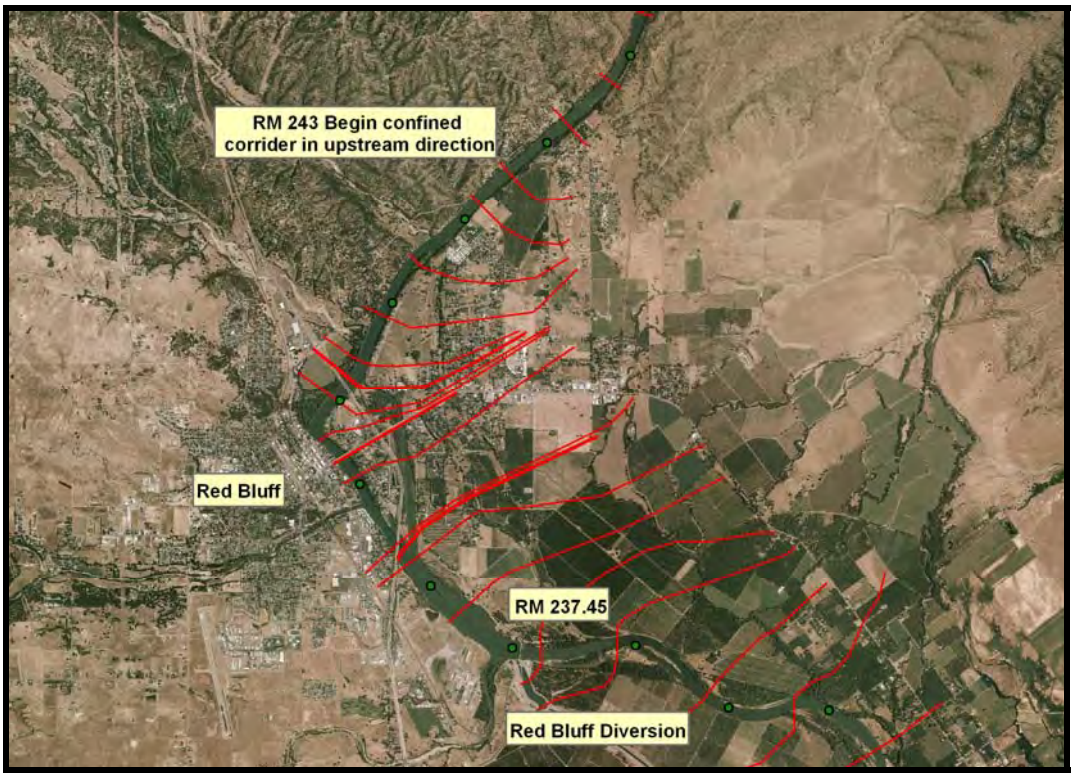

Figure 5-8. At Red Bluff. Cross sections are shown in red and reflect the flood plain width.

The cottonwood and narrow leaf willow values for vegetated width are presented a second time in Figure 5-9. Cottonwood and narrow leaf willow values spike with some periodicity. Locations where larger spikes in vegetation occur can be seen in Figures 5.10 to 5.16. All figures are oriented with north to the top of the page, and flow moves towards the south.

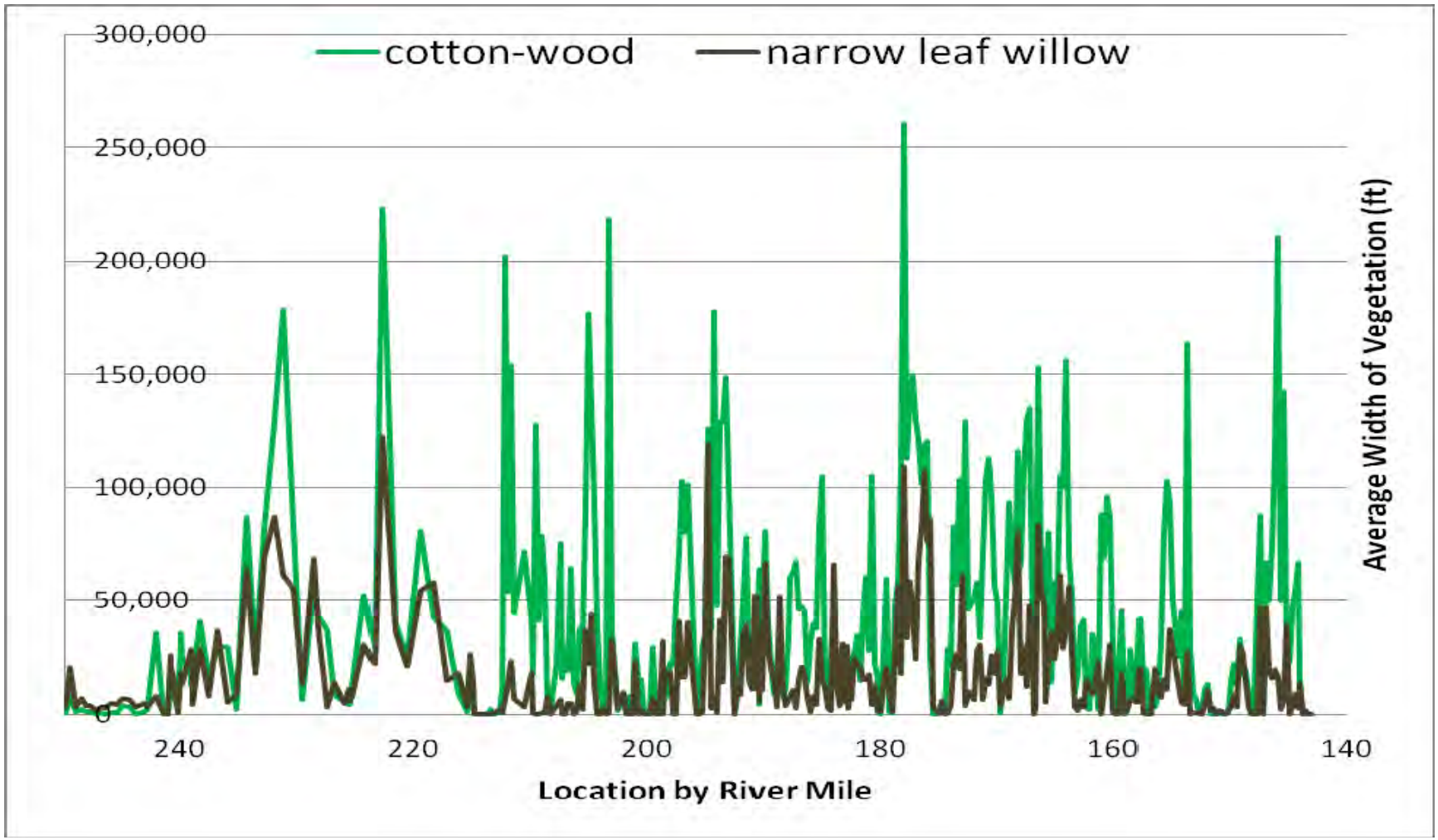

Figure 5-9. Average width for all alternatives of cottonwood plants and narrow leaf willow plants (ft) presented by river mile.

5.2.1 Locations Favored by Cottonwood Plants

Information from Table A.1, or Figure 5-9 is compared with plan view photos of the river (Figures 5-10 to 5-16). Large vegetation widths (more plants) are often found in this comparison at locations with actively shifting meander bends. The natural process of sediment-supplied bend migration creates or "disturbs" new areas. Sufficient sediment supply and the bend migration process can also create multiple channels within a cross section (complex channels). Large sand bars appear to shift in the channel with recurring high flow disturbances. Riparian plants like cottonwood, Gooding's black willow and narrow leaf willow thrive on disturbances and colonize the continuously reworked sand bars, bare of vegetation. Large sand bars in meander bends may present low bench areas where the inundation-tolerant cottonwood and willows can establish. Depending on the terrain, the back side or outside of sand bars (facing away from the main current) and side channel locations can also partially shield young cottonwood seedlings or provide areas with flows that are not as erosive as flows in the main channel. The following aerial photographs illustrate the locations where the greatest average vegetated widths of cottonwood are predicted.

Figure 5-10. RM 217.22 (2009 aerial photo). Cross sections are shown in red

Figure 5-11. RM 211 (2009 aerial photo)

Figure 5-12. RM 203.25, cross sections are shown in black.

Figure 5-13. RM 176.178 (2009 aerial photos)

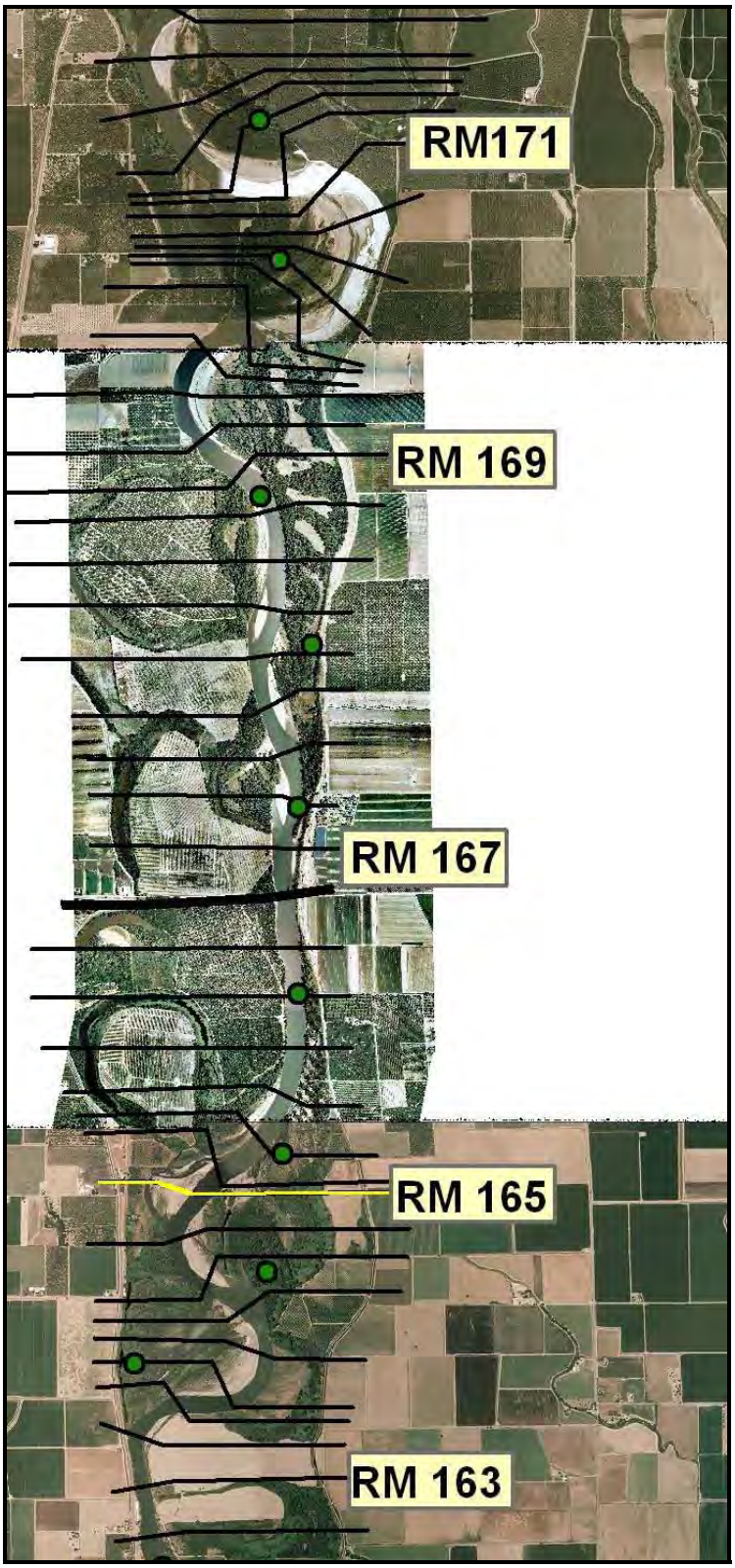

Figure 5-14. RM 171 to 163. (Combined 1999 and 2006 aerial photos). North is towards the top of the page and flow moves to the south.

Figure 5-15. RM 155.5(2009 aerial photos)

Figure 5-16. RM 146(2009 aerial photos)

5.2.2 Locations Favored by Narrow Leaf Willow Plants

Similar to cottonwood, narrow leaf willow plants are also more abundant near active meander bends. Multiple channels are created and abandoned through the development of meander bends. Inactive side channels of complex rivers can offer low surface areas closer to the groundwater surface that are suited to the shallow root depths of narrow leaf willow plants. Narrow leaf willows frequently establish on low banks adjacent to the channel, and at low points in the flood plain.

A cross section from the model (Figure 5-17) represents terrain at the meander bend near RM 165 (Figure 5-14). From left to right the terrain includes: high ground populated by mature cottonwood and mixed forest, a low bench area/scoured channel on the back of the sand bar (side away from main channel), a sand bar with herbaceous plants, the main channel, a side channel on the right, and a sloping bank with more mature cottonwood and mixed forest. Young Gooding's black willow, narrow leaf willow and cottonwood plants are colonizing the bench area/channel on the back side of the sand bar (facing away from main channel), the banks of the main channel, and the right side channel in this meander bend (plan view in Figure 5-14). The cross section in Figure 5-18 shows Gooding's black willow and cottonwood, in addition to narrow leaf willow, establishing on the low ground of a less frequently inundated side channel at RM 217.22 (plan view in Figure 5-10).

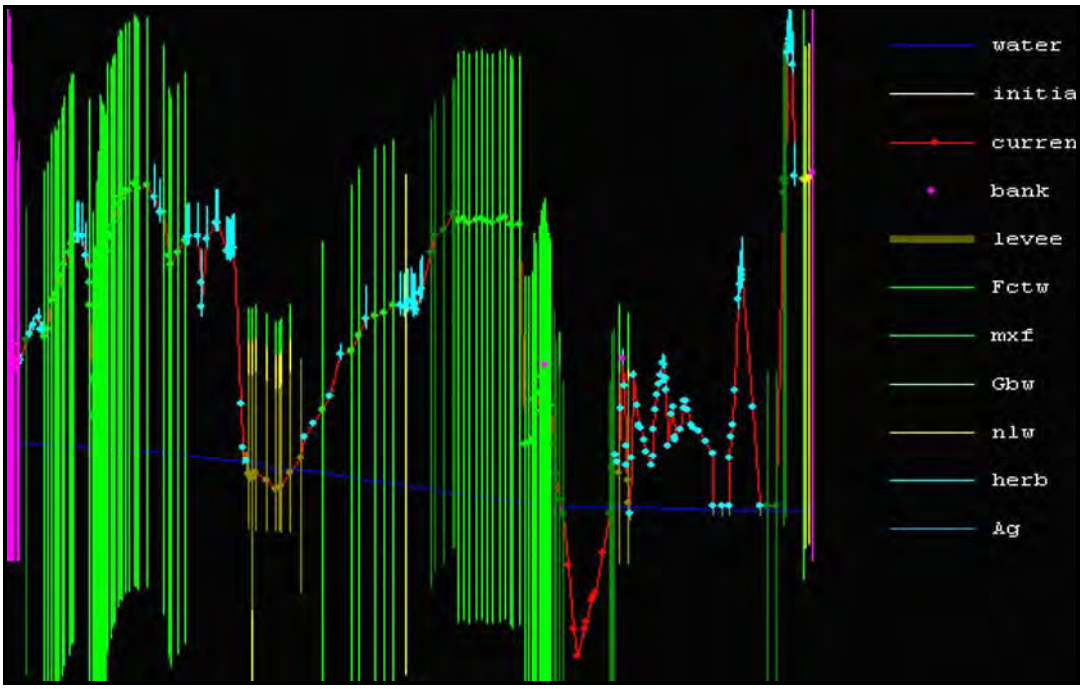

Figure 5-17. RM 165. Cross section from the model showing the terrain and the plants established at the surveyed points. Cross section is looking downstream. Lines above the river bed (river bed is red) represent plant stems and lines below the bed are roots. Multicolored stems represent more than one vegetation type established at a point and each plant type is growing at a different rate.

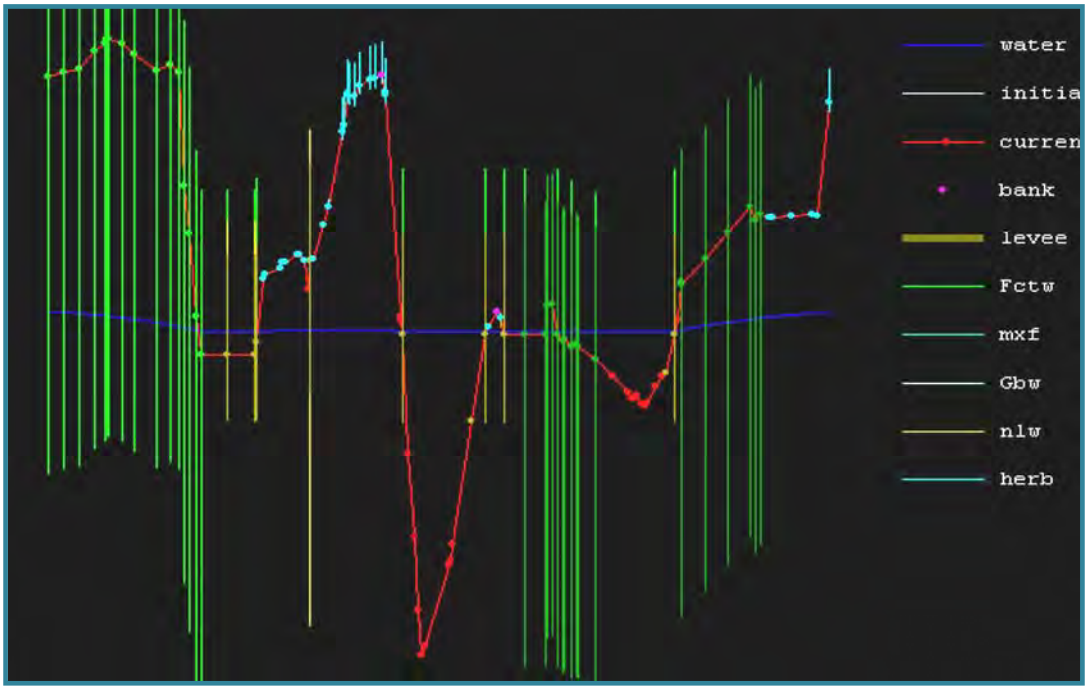

Figure 5.18- RM 217.22 cross section from the model showing terrain and plants established at the surveyed points. Cross section is looking downstream. Lines above the river bed (river bed is red) represent plant stems, while lines below the bed are roots. Multicolored stems represent more than one vegetation type established at a point and growing at different rates. Pink lines are the start of cultivated land.

5.2.3 Discussion on Cross Section Spacing

A change in cross section spacing occurs at RM215 (Figure 5-9 and Figure 5-19). Upstream of RM 215, the California Department of Water Resources cross sections are surveyed at varying spacing but average 0.55 miles and have a mode of 0.66 miles. Downstream of RM 215, the Army Corps of Engineers cross section spacing is 0.24 miles and the mode is 0.25 miles. Both sets were surveyed in 1997 (USACE, 2002). Cross section spacing has an impact on this project when the spacing between river bends is similar to the spacing between cross sections. River bend spacing in the study area ranges from 0.5 to 2+ miles. When the cross section spacing matches the spacing between river bends, the same river feature (a straight reach or a river bend) can be represented consecutively in the analysis, or skipped consecutively. This is seen more often upstream of RM 215, and specifically upstream of RM 218 where the cross section spacing is 0.75 to 1 miles, similar to river bend spacing. Downstream of RM 215, the cross section spacing ensures at least one cross section between bends in addition to a cross section at each river bend (Figure 5-19).

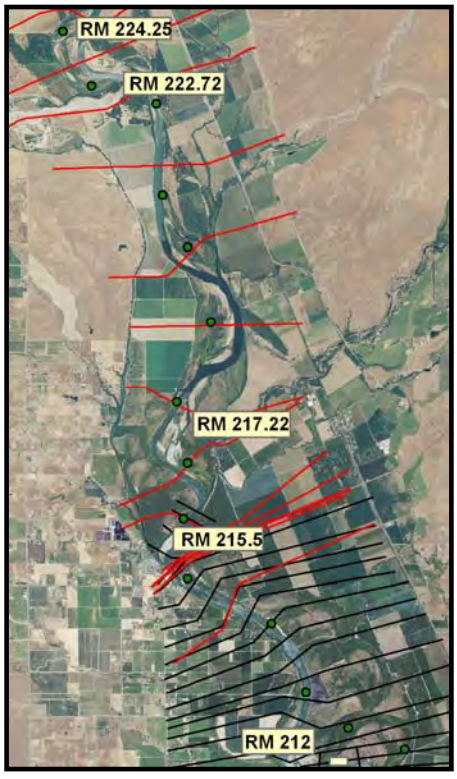

Figure 5-19. Location of change in Cross section spacing. Black sections are from COE 1997, and red sections Are from CDWR 1997(USACE 2002).

Vegetation width values are larger at the river bends, and consecutive measures from river bends only imply more vegetation at these locations. In Figures 5-7 and 5-9, vegetated width values upstream of RM 215 remain high for two- 5 to 8 mile sections of river. Although this impact will average out with an adequate number of cross sections, the results are skewed at this location. Wider cross section spacing upstream of RM 215 also magnifies the measure of vegetation cover area. Large vegetated width values from the bends are multiplied by the larger spacing values between cross sections. Even with cover area plotted by river mile (Figure 5-20), there appears to be more vegetation between RM 218 and RM 234 than at downstream locations. However, as seen in Figure 5-9, peak values for vegetative width are similar throughout the study area.

Vegetation width (ft) is used for site specific analyses in this report to limit bias introduced by a change in cross section spacing and the locations selected to represent the terrain within a specific stretch of river. Vegetation area was used as an indicator in the general trend analysis and will be used for a general plant mortality investigation in a later section.

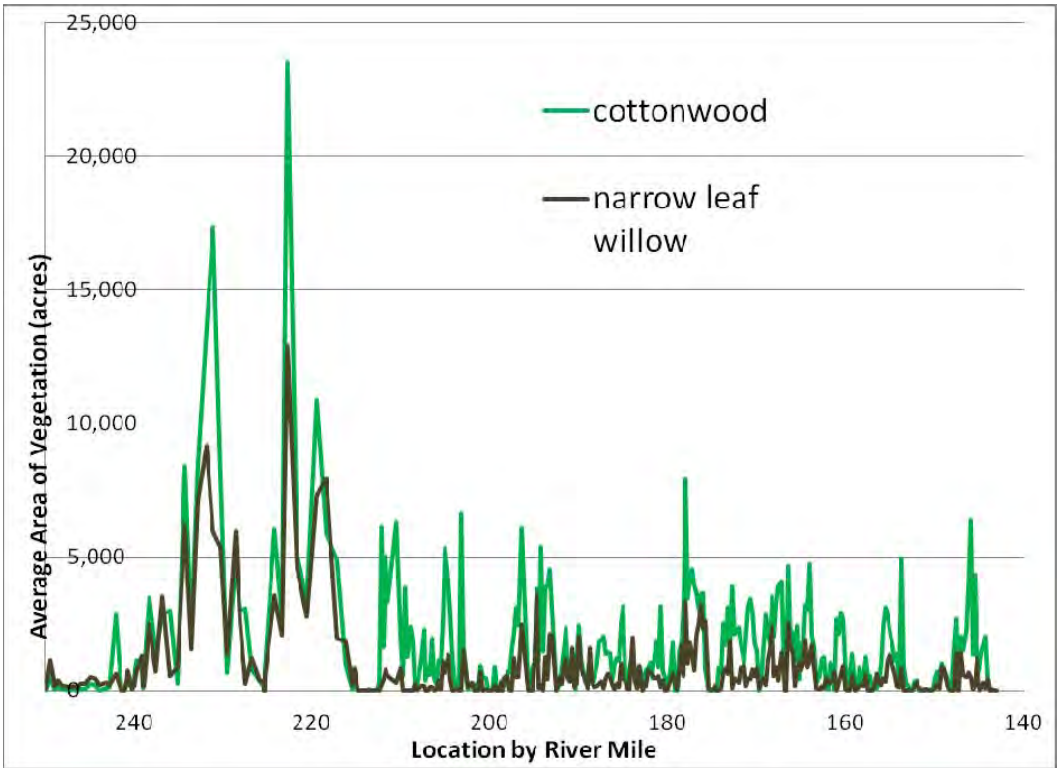

Figure 5-20. A presentation of vegetation by river mile, based on average area (acres) for all alternatives of cottonwood plants and narrow leaf willow plants. Due to a change in cross section spacing upstream of RM 218, and cross sections located more frequently at river bends, there is a false appearance of more vegetation between RM 218 and RM 234.

5.3 General Alternatives Comparison

In a comparison of vegetated width (excluding herbaceous, hb) between all alternatives, Alternative A produces the most plants when considered over an 82-year period of flow (Table 5-1). Alternative B is the second largest producer of native vegetation. Differences between alternatives are relatively small with Alternative A predicting less than one tenth of a percent more vegetated width than Alternative B. Excluding herbaceous plants, mixed forest accounts for the largest portion of vegetated width in the study area. This could be due to the large area of established mixed forest that is entered initially in the simulation from 1999 mapping.

Table 5-1. Alternatives Comparison of Vegetated Width by Feet. Total vegetated width summed from 362 cross sections and summed over 82 years for each flow alternative.

General Vegetated Width Summary Table (ft)					
	No Act	Exis	Alt A	Alt B	Alt C
ctw	14,796,635	14,817,058	14,419,225	14,547,094	14,382,215
mxf	16,552,125	16,724,967	17,292,630	17,046,868	17,061,138
Gbw	6,817,757	6,729,452	6,795,897	6,953,705	6,829,435
nlw	5,917,098	5,929,051	6,008,811	5,937,792	6,053,942
hb	36,030,217	35,880,872	35,469,145	35,738,251	35,490,585
Totals	No Act	Exis	Alt A	Alt B	Alt C
All except hb	44,083,615	44,200,527	44,516,562	44,485,459	44,326,730
ctw Gbw nlw	27,531,490	27,475,560	27,223,932	27,438,591	27,265,592
Gbw nlw	12,734,856	12,658,502	12,804,708	12,891,497	12,883,377

Table 5-2. Alternatives Comparison of Vegetated Width by Percent. Total vegetated width (summed from 362 cross sections and summed over 82 years) divided by the largest total value from the five flow alternatives.

General Vegetated Width Summary Table (Percent %)					
	No Act	Exis	Alt A	Alt B	Alt C
ctw	99.9%	100.0%	97.3%	98.2%	97.1%
mxf	95.7%	96.7%	100.0%	98.6%	98.7%
Gbw	98.0%	96.8%	97.7%	100.0%	98.2%
nlw	97.7%	97.9%	99.3%	98.1%	100.0%
hb	100.0%	99.6%	98.4%	99.2%	98.5%

5.3.1 Preferred Alternative Varies with Vegetation Type

Alternative A produces the most mixed forest (Table 5-1). If both mixed forest and herbaceous plants are excluded from the summary, the flow alternative that supports the most cottonwood, Gooding's black willow and narrow leaf willow plants is the No Action Alternative (Table 5-1), Cottonwood has the most vegetation width of the remaining vegetation types (Table 5-1), and the Existing Alternative produces the most cottonwood plants. However cottonwood produced under the No Action Alternative and under the Existing alternative differs by only one tenth of a percent (Table 5-2). If cottonwood plants are removed from the total and only the riparian indicators Gooding's willow and narrow leaf willow vegetation are considered, the most productive alternative switches from the No Action (and Existing) Alternative to Alternative B (Table 5-1). Gooding's black willow has more plants than narrow leaf willow and Alternative B is the alternative that supports the most Gooding's black willow plants. As illustrated here, the alternative favored by the vegetation type with the most plants, also ranks as the general preferred vegetation alternative when all vegetation types are considered.

Each vegetation type favors only one alternative (Table 5-3). Mixed forest plants are more plentiful with Alternative A flow regime; more cottonwood is produced by the Existing alternative (or the similar No Action alternative), and even the two riparian indicators, Gooding's black willow (Alternative B) and narrow leaf willow (Alternative C) favor different flow alternatives. Placing a priority on one vegetation type over another vegetation type would be a better approach to selecting a preferred flow alternative in this study, since the overall preferred alternative from the previous paragraph is only preferred by mixed forest. Cottonwood is not colonizing successfully on many managed rivers making a No Action or Existing Condition flow alternative the more practical preferred alternative for vegetation on the Sacramento River.

5.3.2 Comparing Ranking by Width versus Coverage

Table 5-3, Ranking of Alternatives based on Vegetated Width, was compared to Table 5-4, Ranking of Alternatives based on Vegetation Coverage. Differences between the two rankings are assumed to result from a change in cross section spacing that is presented in the previous section. Table 5-3 results are less biased by the spacing and are recommended over Table 5-4 results. Top ranked alternatives are the same with the exception of cottonwood. The Existing flow alternative produces more cottonwood plants and the No Action alternative is also beneficial. There is more variation between the 2nd ranked alternatives in Table 5-3 and Table 5-4.

Table 5-3. Ranking of Alternatives based on Vegetated Width. Vegetated widths are summed from 362 cross sections and summed over 82 years for each flow alternative.

General Vegetated Width Summary Table (Ranking Order)					
	1rst	2nd	3rd	4th	5th
Ctw	Exis	No Act	B	A	C
Mxf	A	B	C	Exis	No Act
Gbw	B	C	No Act	A	Exis
Nlw	C	A	B	Exis	No Act
Hb	No Act	Exis	B	C	A

Table 5-4. Ranking of Alternatives based on Vegetation Coverage. Vegetation coverage is summed from 362 cross sections and summed over 82 years for each flow alternative.

General Vegetated Area Summary Table (Ranking Order)					
	1rst	2nd	3rd	4th	5th
Ctw	NoAct	Exis	B	A	C
Mxf	A	C	B	Exis	NoAct
Gbw	B	NoAct	C	A	Exis
Nlw	C	A	NoAct	Exis	B
Hb	NoAct	Exis	B	C	A

differs from vegetated width summary

5.3.3 Discussion of General Results

There are no large variations in vegetation coverage between alternatives. The differences in vegetation coverage in these results are all within a couple percentage points and the differences within the predicted vegetation width may be within the error margin of the predictions. Despite these small margins, the results point to reasonable relationships between flow management and the response of individual riparian plants. Cottonwood is more abundant with more extreme flow events and gradual flow drawdown that allows germination and establishment of cottonwoods in high flow years. The Existing Conditions Alternative has higher winter peak flows (Maximum Flow, Table 4-3) that create more barebank and bar conditions for germination and can deposit seeds in more backwater areas.

Mixed forests are less dependent on groundwater flows and episodic flow events, and do better with the Alternative A and B flow plans. Narrow leaf willow favors Alternative A first and Alternative C second. This vegetation type is tolerant of some flooding but favors the more stable water surface because narrow leaf willow roots are shorter than the roots of cottonwood or mixed forest plants. In general, more consistent water surface elevations in Alternatives C and A support more vegetation, but are less productive for cottonwoods.

Herbaceous plants (hb) have the inverse response to riparian vegetation and riparian forests. As coverage by riparian plants increases, the coverage by herbaceous grasses decreases. Alternatives A, B, and C support more riparian plants, leaving less total acreage for herbaceous.

5.4 Alternatives Comparison by Reach

Results are also examined by location for a view of vegetation response throughout the study area. An 82-yr average of vegetation coverage (acres) for each vegetation type is presented by flow reach in Tables 5-5 to 5-9. Reach length is the distance from the named location to the downstream location. The alternative that produced the most vegetation for each reach is identified by green shading, and the alternative that produced the smallest number of acres for that reach is shaded brown.

5.4.1 Cottonwood

Cottonwood plants appear to do best in the study area with the Existing flow management plan and second best with the Alternative A flow plan. The No Action plan is the least beneficial in this reach-based analysis. None of the flow management plans are strongly favored by cottonwood, however cottonwood does well with the Existing Alternative under both the general analysis from Section 5.3 and this reach based analysis.

Table 5-5. **Cottonwood Width** comparison of alternatives by river reach. Vegetated Width (ft) = coverage area divided by length of the river reach. Shaded green alternative produced the most cottonwood width and brown alternative is the least. Rank indicates most to least productive river reach for cottonwood.

Reach	Reach length (miles)	No Action	Existing	Alt A	Alt B	Alt C	Ave. Veg. Width	Reach Rank
Payne	7.1	22	28	19	22	18	22	11
Red Bluff	7.82	241	234	249	242	247	243	10
Antelope Cr	5.45	1096	1068	1090	1099	1088	1088	1
Ele+Mill Cr	4.26	317	316	305	326	306	314	8
Thomes Cr	5.82	705	709	757	713	750	727	2
Deer Cr	13.27	515	496	503	492	508	503	6
GCC Div	16.45	586	590	554	563	559	571	5
Stony Cr	0.75	291	289	294	275	304	291	9
Ord Ferry	20	646	651	641	644	634	643	4
Butter City	10.75	712	717	725	706	715	715	3
Delevan PL	15.25	435	436	390	421	393	415	7

5.4.2 Mixed forest

Mixed forest clearly does best with Alternative A and has the smallest acres of coverage with the No Action alternative followed by the Existing Alternative. This ranking is consistent with the general analysis from section 5.3.

Table 5-6. **Mixed Forest Width** comparison of alternatives by river reach. Vegetated Width (ft) = mixed forest coverage area divided by length of the river reach. Shaded green alternative produced the most mixed forest width and brown shaded area produced the least. Rank indicates most to least productive river reach for mixed forest.

Reach	Reach length (miles)	No Action	Existing	Alt A	Alt B	Alt C	Ave. Veg. Width	Reach Rank
Payne	7.1	48	49	50	49	50	49	11
Red Bluff	7.82	383	379	397	390	393	388	9
Antelope Cr	5.45	1028	1036	1049	1022	1047	1036	3
Ele+Mill Cr	4.26	785	816	831	820	822	815	5
Thomes Cr	5.82	1030	1025	1070	1051	1068	1049	2
Deer Cr	13.27	865	863	871	862	860	864	4
GCC Div	16.45	765	767	755	755	757	760	6
Stony Cr	0.75	536	535	559	560	558	550	7
Ord Ferry	20	481	484	511	495	488	492	8
Butter City	10.75	1025	1039	1078	1051	1063	1051	1
Delevan PL	15.25	277	292	343	343	341	319	10

5.4.3 Gooding's black willow

Based on the reach analysis, Gooding's black willow has the most coverage with the No Action Alternative and the least amount of coverage with the Existing Alternative or Alternative C. These results not consistent with the general analysis presented in the previous section. Although the Existing Alternative is the least productive option in the general analysis, Alternative B is the most productive alternative.

Table 5-7. **Gooding's Black Willow Width** comparison of alternatives by river reach. Vegetated Width (ft) = Gooding's black willow coverage area divided by length of the river reach. Shaded green alternative produced the most Gooding's black willow width, brown shading indicates the least productive alternative. Rank indicates most to least productive river reach for Gooding's black willow.

Reach	Reach length (miles)	No Action	Existing	Alt A	Alt B	Alt C	Ave. Veg. Width	Reach Rank
Payne	7.1	25	19	19	19	23	21	10
Red Bluff	7.82	150	136	143	143	140	142	9
Antelope Cr	5.45	567	560	560	539	542	554	1
Ele+Mill Cr	4.26	468	468	450	459	449	459	2
Thomes Cr	5.82	352	380	394	374	415	383	4
Deer Cr	13.27	261	244	237	234	240	243	6
GCC Div	16.45	306	304	293	295	297	299	5
Stony Cr	0.75	166	133	178	157	159	159	9
Ord Ferry	20	208	202	203	227	211	210	7
Butter City	10.75	380	373	392	400	386	386	3
Delevan PL	15.25	166	178	180	176	176	175	8

5.4.4 Narrow leaf willow

Based on the reach analysis, Narrow leaf willow does best with Alternative A and has the least coverage with the Existing Alternative. The results from this reach based results do not agree with the general results as closely as the Mixed Forest reach based and general results. In the general analysis on narrow leaf willow, Alternative C had the most coverage and Alternative A was ranked second. The Existing Alternative was ranked second least productive. .

Table 5-8. **Narrow Leaf Willow Width** comparison of alternatives by river reach. Vegetated Width (ft) = narrow leaf willow coverage area divided by length of the river reach. Shaded green alternative produced the most narrow leaf willow width and brown shaded values are the least. Rank indicates most to least productive river reach for narrow leaf willow based on average values.

Reach	Reach length (miles)	No Action	Existing	Alt A	Alt B	Alt C	Ave. Veg. Width	Reach Rank
Payne	7.1	61	67	64	67	64	65	11
Red Bluff	7.82	159	155	165	162	168	162	9
Antelope Cr	5.45	694	684	674	660	667	676	1
Ele+Mill Cr	4.26	291	293	294	292	293	293	3
Thomes Cr	5.82	450	455	478	450	476	462	2
Deer Cr	13.27	191	185	190	189	188	189	8
GCC Div	16.45	213	219	212	202	215	212	7
Stony Cr	0.75	270	258	275	262	269	267	5
Ord Ferry	20	260	255	264	271	272	264	6
Butter City	10.75	289	293	294	290	291	291	4
Delevan PL	15.25	118	117	123	120	120	120	10

5.4.5 Herbaceous

The predominantly upland grasses of this herbaceous group inversely reflect the results of cottonwood, mixed forest and narrow leaf willow. The herbaceous plants do best with the No Action and Alternative B flow regimes and have the least vegetation width when flows are managed with Alternative A. Alternative A was the second most productive management plan for cottonwood and the most productive plan for mixed forest and narrow leaf willow. With the exception of Gooding's black willow, the No Action and Alternative B flow management plans were not top producers of riparian vegetation.

Table 5-9. Herbaceous comparison of alternatives by river reach. Vegetated Width (ft) = herbaceous coverage area divided by length of the river reach. Shaded green alternative produced the most herbaceous width and brown shaded values are the least. Rank indicates most to least productive river reach for herbaceous plants based on average values.

Reach	Reach length (miles)	No Action	Existing	Alt A	Alt B	Alt C	Ave. Veg. Width	Reach Rank
Payne	7.1	92	91	91	91	87	91	11
Red Bluff	7.82	484	490	472	476	474	479	10
Antelope Cr	5.45	1194	1196	1204	1218	1204	1203	6
Ele+Mill Cr	4.26	956	956	949	947	949	951	8
Thomes Cr	5.82	2079	2073	2052	2083	2053	2068	1
Deer Cr	13.27	1978	1994	1995	2003	2000	1994	2
GCC Div	16.45	1630	1626	1648	1658	1641	1641	3
Stony Cr	0.75	1245	1231	1183	1189	1174	1204	5
Ord Ferry	20	1311	1309	1274	1298	1282	1295	4
Butter City	10.75	1221	1205	1176	1201	1177	1196	7
Delevan PL	15.25	894	875	838	823	839	854	9

5.4.6 Vegetation by Reach

Rankings of most to least productive reaches of the river have been extracted from Tables 5-5 to 5-9 and are listed in Table 5-10. As discussed in section 5.2 and shown in Figure 5.6, locations with more vegetation can be associated with active meander bends where remnant channel scars, sand bars and multiple channels are present. The topography in the Payne and Red Bluff river reaches confines the flood plain at this upstream location and there is consistently less vegetation. Meander bends are distributed throughout the balance of the study area, and rankings of most to least vegetation reflect this sporadic distribution of bends. They also represent the greater channel complexity and connected floodplain terrain at some of the larger tributary confluences. Some variation in establishment and growth requirements for each plant type is also reflected in the table. However Antelope Creek, Thomes Creek and Butter City are the more productive locations in the study area due to combinations of flow regime, terrain, and established stands of vegetation.

Table 5-10. Reach ranking for each vegetation type based on most (1) to least (11) vegetated width.

Reach	ctw	mxf	Gbw	nlw	hb
Payne	11	11	10	11	11
Red Bluff	10	9	9	9	10
Antelope Cr	1	3	1	1	6
Ele + Mill Cr	8	5	2	3	8
Thomes Cr	2	2	4	2	1
Deer Cr	6	4	6	8	2
GCC Div	5	6	5	7	3
Stony Cr	9	7	9	5	5
Ord Ferry	4	8	7	6	4
Butter City	3	1	3	4	7
Delevan PL	7	10	8	10	9

5.4.7 Summary of Reach Based Alternatives Analysis

The preferred alternatives from the reach analysis are summarized in Table 5-11 for each vegetation type and compared to the preferred alternatives based on the general analysis results from Table 5-3. The ranking from the reach analysis is based on the largest number of locations where an alternative ranked first. Preferred alternatives for mixed forest (Alternative A) and herbaceous plants (No Action) are consistent. Cottonwood is most abundant with the Existing, or possibly the No Action alternative and narrow leaf willow is most abundant with Alternatives A or C. The results for Gooding's black willow are more confused. This woody species might do well with No Action, Alternative A or Alternative C alternative. Herbaceous plants are the inverse indicator of abundance in the modeled plants. Herbaceous plants do best with the No Action Alternative, making this the least beneficial flow plan when considering all vegetation except for herbaceous.

Table 5-11. Reach Based Vegetated Width Results compared to General Vegetated Width Results. Numbers in parenthesis indicate number of river reaches with this alternative ranked first.

	Results: Reach Based Vegetated Width		Results: General Area Vegetated Width	
Ranking	1rst	2nd	1rst	2nd
ctw	**Exis** (4)	A (3)	**Exis**	No Act
mxf	**A** (8)	C & B (2)	**A**	B
Gbw	No Act (6)	B & A (2)	B	C
nlw	A (5)	C, Exis, NA (2)	C	A
hb	**No Act** (6)	B (4)	**No Act**	Exis

5.5 Alternatives Comparison by Mortalities

The processes that kill or remove plants and the areas where plants have been removed are tracked in the model simulations and can provide another view of the flow management alternatives. The measure of plant mortality, mortality width is the vegetated width in a cross section that has been cleared by the death of plants. Figure 5-21 to Figure 5-24 show the mortalities for the No Action Alternative by plant type (cottonwood, mixed forest, Gooding's black willow and narrow leaf willow) and river mile. In most cases inundation or desiccation removes the most plants, and more plants are removed at locations where more plants are present. Competition/shading and erosion remove a smaller area of plants. Narrow leaf willow plants are most often removed due to desiccation (Figure 5-24). There is generally more scour erosion in the upstream half of the study area, and more competition/shading and desiccation mortality in the downstream half.

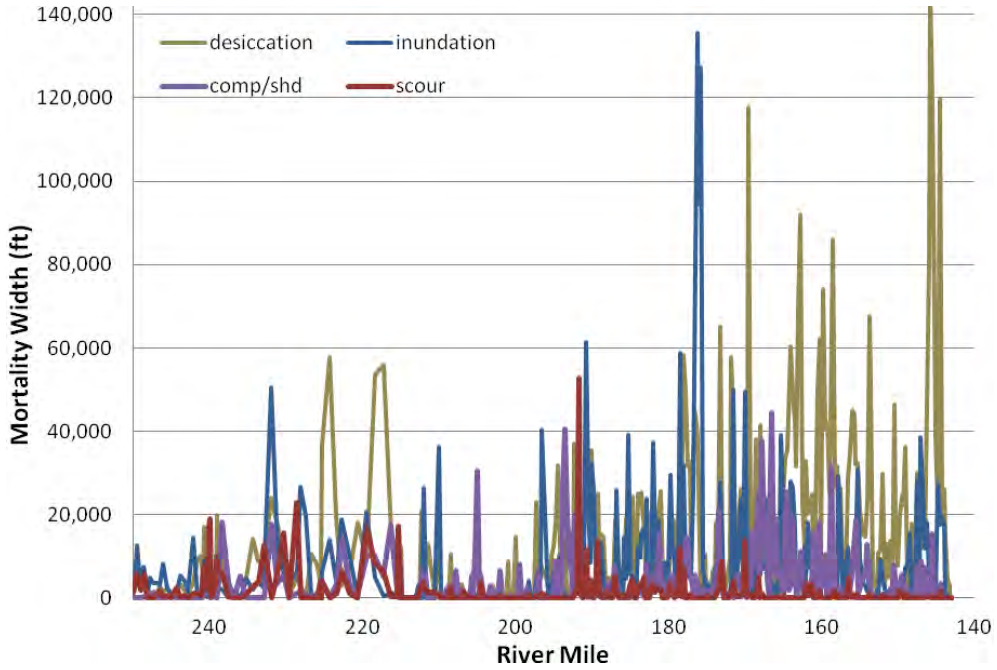

Figure 5-21. Cottonwood mortalities for the No-Action Alternative shown by cross section number.

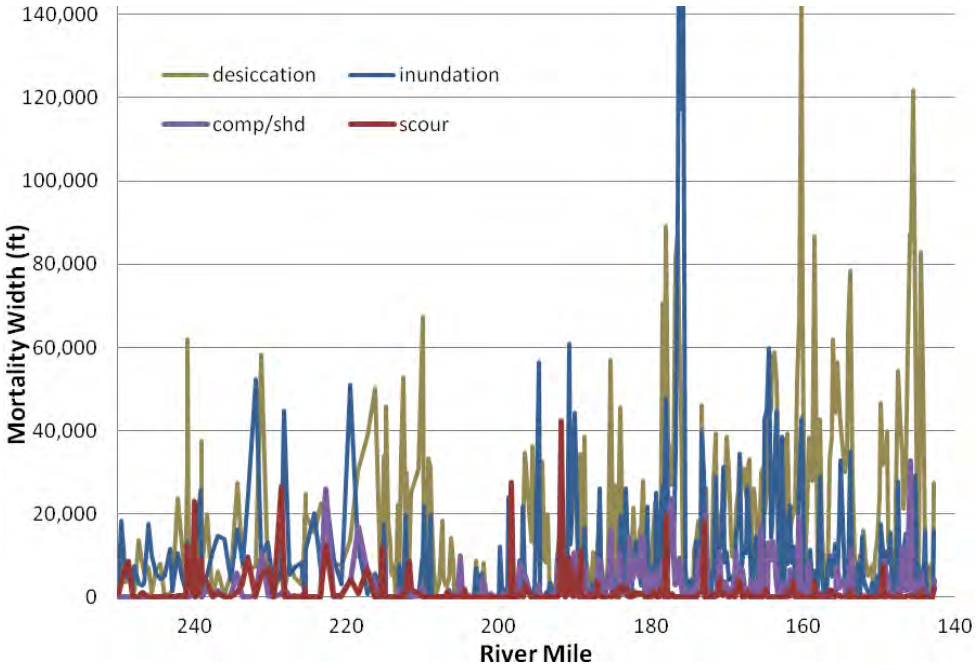

Figure 5-22. Mixed forest mortalities for the No Action alternative, shown by river mile.

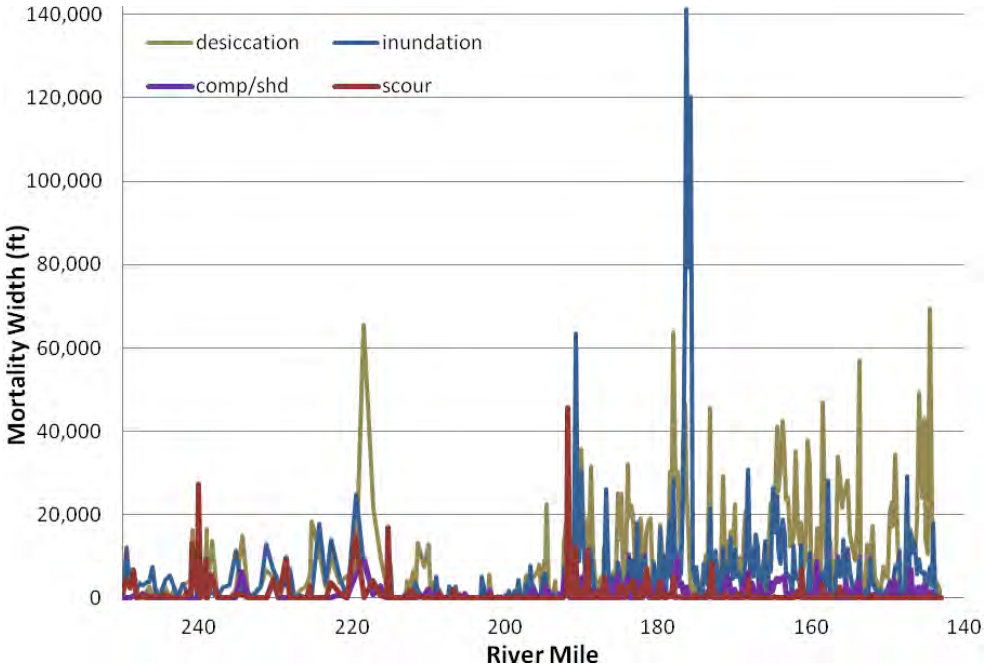

Figure 5-23. Gooding's black willow mortalities for the No Action Alternative, shown by river mile

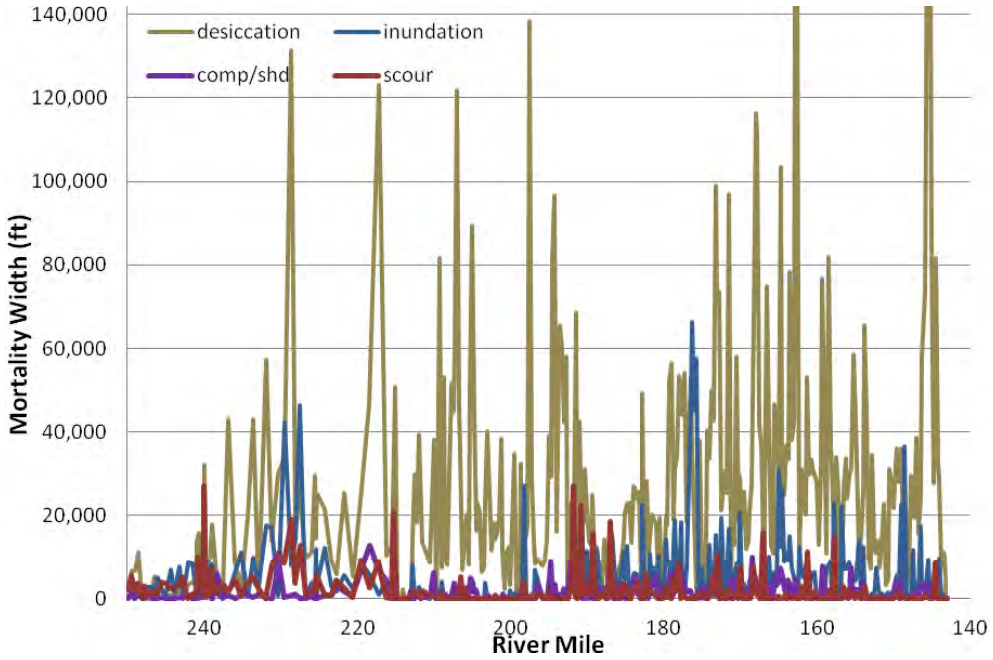

Figure 5-24. Narrow leaf willow mortalities for the No Action Alternative, shown by river mile

The mortality area from cottonwood, mixed forest, Gooding's black willow and narrow leaf willow are also summed for each type of mortality across all time steps for each alternative. The values are compared in Figure 5-25. Desiccation removes the most plants followed by inundation. Competition/shading and scour remove a similar quantity of plants. No Action and Existing Conditions alternatives behave similarly, and for the most part quantities of removal for Alternatives A, B, and C are similar. Alternatives A, B, and C have greater amounts of inundation mortality, which could be due to higher stream flows or due to plant establishment on lower surfaces in the spring and summer.

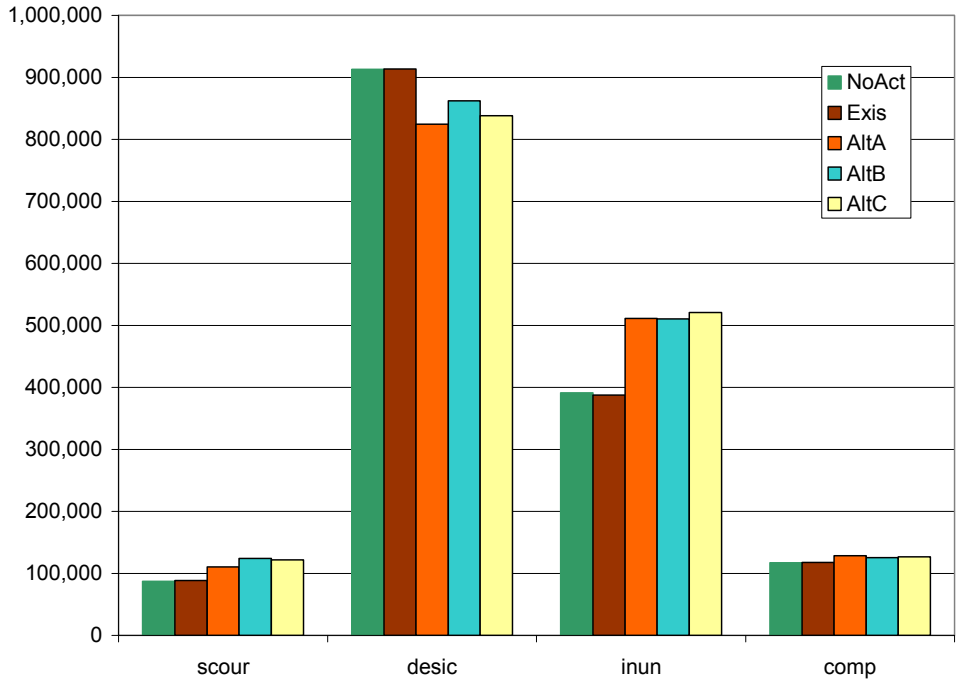

Figure 5-25. Comparison of alternatives based on the removal process: scour, desiccation, inundation and competition/shading. For each removal process, all areas from the vegetation types, cottonwood, mixed forest, Gooding's black willow and narrow leaf willow, are summed. Plant mortality area resulting from competition is combined with plant mortality area from shading.

The alternatives were also examined with respect to each vegetation type in Figure 5-26. All the mortalities were totaled for each vegetation type and each alternative. Cottonwood has less mortality with the No Action and Existing Conditions alternatives, but differences between these two alternatives are small, as are differences between Alternatives A, B, and C. Mixed forest and Gooding's black willow results are similar to cottonwood, but there is less distinction in the mixed forest results between the first two alternatives and Alternatives A, B, and C. Narrow leaf willow exhibits less mortality with Alternatives A, B, and C and has more mortality with the No Action and Existing Conditions alternative but the differences are small.

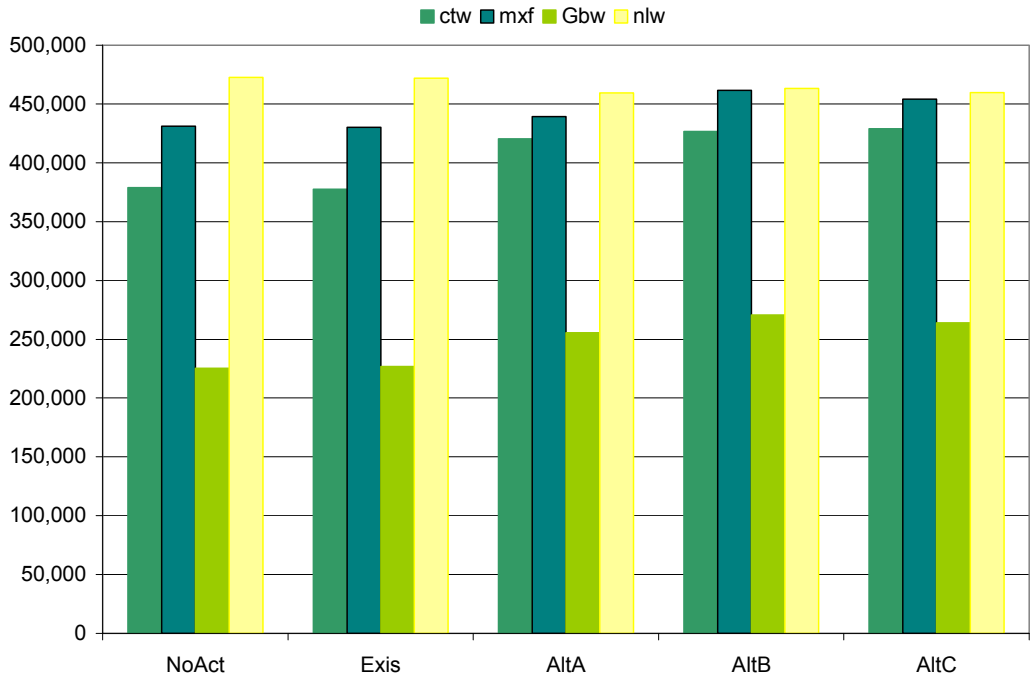

Figure 5-26. All values for types of mortality are summed for each vegetation type and each alternative.

In Figure 5-27 to 5-30, we see a comparison of the mortalities from the 5 alternatives through 82 years of simulation. The mortality values for the 4 vegetation types, cottonwood, mixed forest, Gooding's black willow, and narrow leaf willow, have been summed in these figures and represent total mortality for the vegetation. As presented previously, desiccation removes the most plants followed by inundation. Scour and competition/shading remove similar areas of plants. Again No Action and Existing alternatives are similar and Alternatives A, B, and C are similar in the quantities of plants that are removed. Figures 5-27 to 5-30 all demonstrate that the No Action and Existing Conditions Alternatives remove fewer plants through inundation, scour and competition/shading, but remove more plants through desiccation.

Mortality by desiccation, inundation, and scour increase near year 19; yet in year 63, desiccation area goes down, and inundation and scour area go up. A large increase in desiccation area also occurs in the 73rd year corresponding with small increases in inundation. Scour is the most consistent of the mortalities with small differences between alternatives throughout the 82 years of simulation implying that velocities are not largely influenced by alternatives.

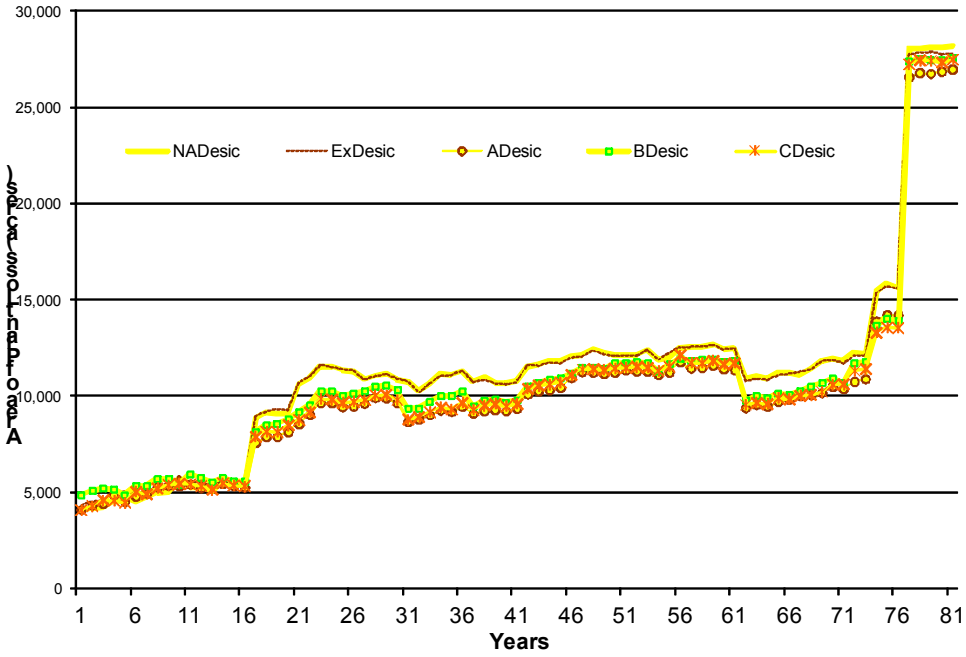

Figure 5-27. Desiccation Mortality of alternatives compared.

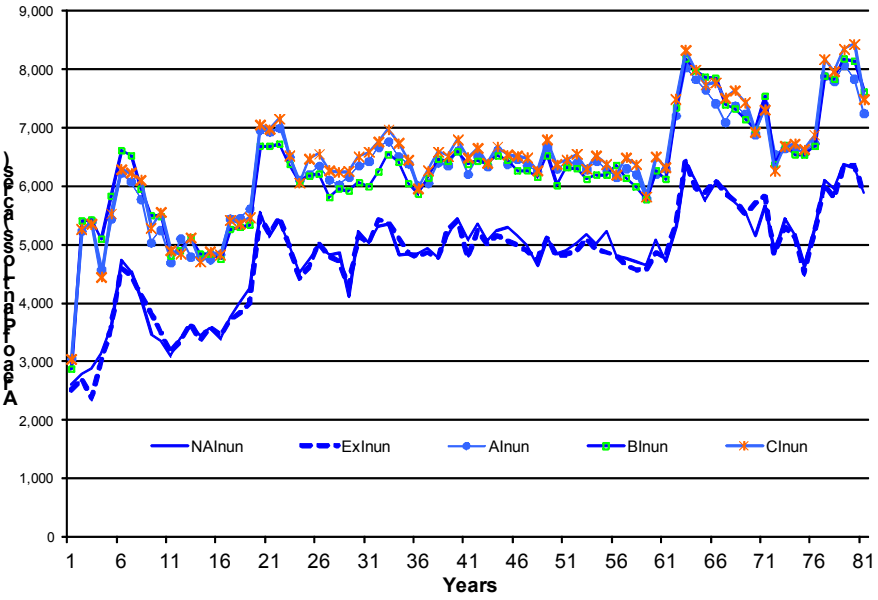

Figure 5-28. Inundation mortality of alternatives compared..

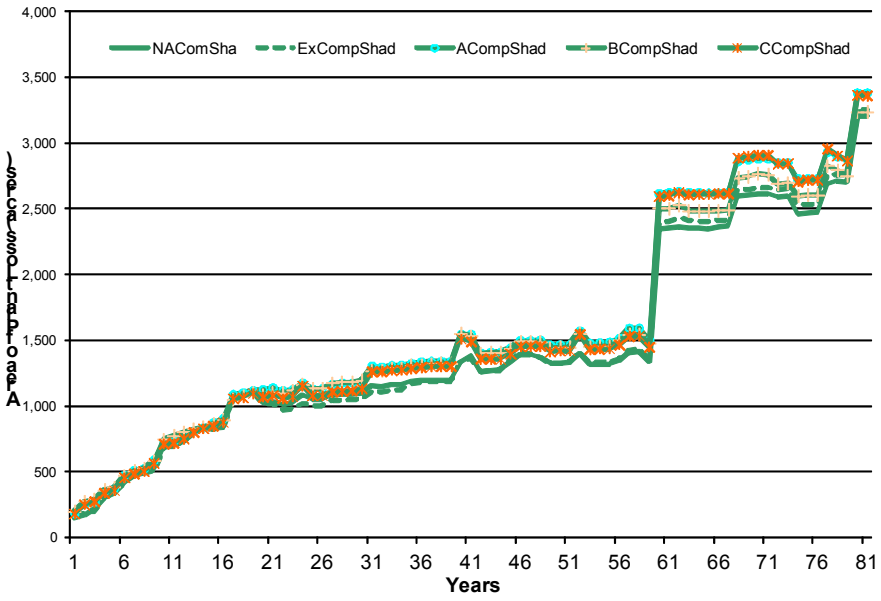

Figure 5-29. Competition and shading mortalities of alternatives compared.

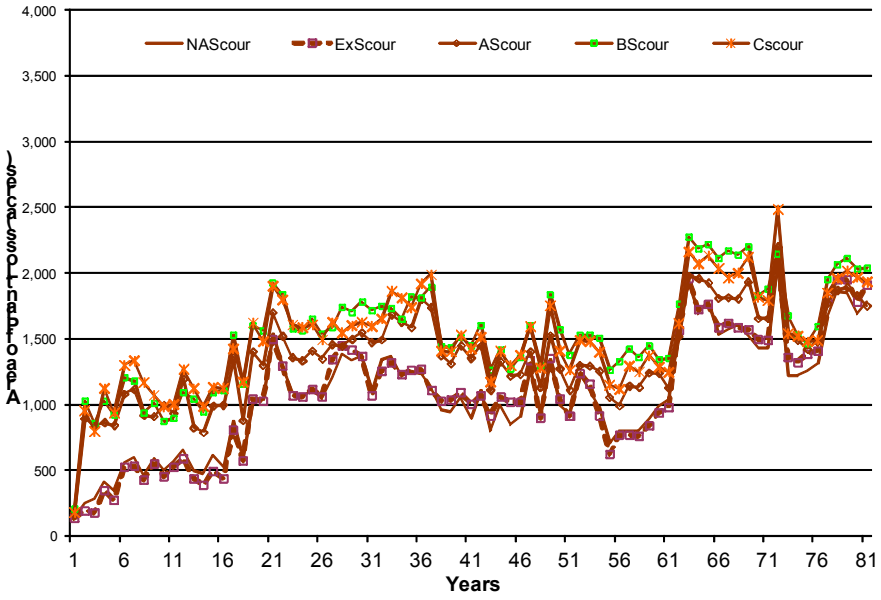

Figure 5-30. Scour mortality of alternatives compared.

6 Findings

The main question posed in this study is "What is the most beneficial flow alternative for riparian vegetation?" Five vegetation types represent the riparian communities in the study area: cottonwood, mixed forest, Gooding's black willow, narrow leaf willow, and herbaceous (upland grass). Cottonwood trees in the floodplain are often a valuable habitat feature but are declining on many managed rivers in the west. Cottonwood is given more focus in this study.

The numerical model SRH-1DV simulates 82 years of flow with five alternative management plans. A description of the model, vegetation computations, and model calibrations are presented in the initial chapters of this report. An examination of the flow management plans is presented in Chapter 4 and vegetation predictions from the SRH-1DV simulations are in Chapter 5. Findings from Chapters 4 and 5 are summarized below.

6.1 Flow Alternatives

The five flow alternatives constructed from 82 years of data, are both temporally and spatially complex. No Action and Existing alternatives are more similar than Alternatives A, B, and C. Alternative B used the smallest volume of water and often is characterized by the lowest flows. The No Action and Existing Alternatives use the most water and usually have the largest flows in winter and the smallest flows in summer. The Existing Alternative, followed by the No Action alternative, has the largest standard deviation and largest range in daily flows.

The declining limb of the winter flow hydrograph for the No Action and Existing Alternatives is shaved off to provide more flow in summer for Alternatives A, B, and C. In an average year, the cottonwood germination period ends before the summer flow peak for all alternatives immediately downstream of the Red Bluff and GCC Diversions.

6.2 Predicting Vegetation Response

An understanding of flow and vegetation processes aids reliable predictions but without an adequate tool, complex flow patterns, large study areas (107 miles) and long periods of flow (82 years) have to be largely reduced and simplified before attempting even general predictions of vegetation outcomes. In this study a computational tool is used to track these extensive and complex interactions, and the tool is based on knowledge of flow and vegetation processes.

The differences in the flow records are often subtle in this large river, and the differences in results from the model are correspondingly small. In most cases

though, the results were able to provide information on interactions between riparian vegetation and the river system and feedback on the success of the proposed flow management alternatives.

6.3 Location of Vegetation

There is very little vegetation upstream of RM 240 due to terrain, geometry and some development. For the remaining 97 miles downstream of this point, all modeled vegetation types are generally present. Cottonwood and narrow leaf willow plants in particular appear as a repeating pattern of coverage with higher concentrations of plants in actively meandering bends, and low coverage by plants in the crossover (straight) channels or at channels restricted by levees, development or other features. Within meandering bends, cottonwood is prevalent at least partially due to bare sand bar features, and coverage by narrow leaf willow is more extensive due to multiple channels from secondary and abandoned flow paths. Mixed forest can also have larger coverage at bends but has a less consistent pattern. The location and coverage of mixed forest may owe more to historical conditions (when the groves were first established), and less to the flow conditions simulated (see General Trends for mixed forest).

6.4 General Trends

Under all alternatives, increases in coverage are anticipated for the 4 main vegetation types over an 82-year period of study. When results from the five flow alternatives are averaged, mixed forest is predicted to have the smallest increase in coverage at only 4%, while cottonwood should expand by 28%. The riparian vegetation, Gooding's black willow and narrow leaf willow, are expected to have the largest increases in coverage of 45% and 56% respectively. Coverage was measured by vegetated area.

6.5 Vegetation Alternatives Comparison

The preferred vegetation alternative was considered by vegetation type based on total coverage in the study area, and based on greatest coverage in most sections of the river. Vegetated width was used as the indicator of vegetation coverage in this analysis. Each vegetation type has a unique, most beneficial alternative. There is no alternative that is most beneficial for more than one simulated vegetation type.

Alternative A is the most productive overall, but only because it is the preferred alternative for the vegetation type (mixed forest) that has the most areal coverage. If the vegetation type mixed forest and its coverage values are excluded, the most beneficial alternative for cottonwood becomes the overall preferred alternative. Cottonwood has the second largest coverage, There are relatively small

differences in the number of plants produced by flow alternatives for the same vegetation type, so these differences can be hidden in the larger values of more prevalent plants.

Table 6.1- Beneficial Alternatives

Vegetation Type	Preferred Alternative
cottonwood	Existing Conditions Alternative
mixed forest	Alternative A
Gooding's black willow	Alternative B or No Action Alternative
narrow leaf willow	Alternative C or Alternative A
herbaceous	No Action Alternative

Differences between vegetation coverage from alternative flow plans are small at a few percentage points, similar to the small differences between flow plans. These differences do not seem large enough to account for a margin of error, but in this deterministic model, the differences appear consistent with vegetation concepts and provide guidance on flow management approaches.

6.5.1 Cottonwood

In a comparison of overall predicted coverage, Alternative A produces the most total plants of the 4 main vegetation types, but produces the smallest coverage by cottonwood plants. In an examination of total coverage, the Existing Condition Alternative and occasionally the No Action Alternative produces the most cottonwood coverage. In an examination by reach, the Existing Conditions Alternative and Alternative A increases cottonwood coverage in more locations along the river. Consistent with these results, the Existing Conditions and No Action Alternatives have the least cottonwood plant mortality. In contrast, Alternative B causes the most plant mortality and desiccation removes more plants in comparison to other alternatives. Alternative B uses the smallest volume of flow and has the lowest mean value for daily flows.

Cottonwood plants were more prolific at active river bends where sand bars and low bench areas are periodically reworked through river processes. These areas provide bare ground for seedling establishment and periodically wetted surfaces close to the ground water. Timing is also an important factor in cottonwood seedling establishment. Ideally the spring peak flow should occur periodically (does not have to occur every year) within the cottonwood germination season to promote expansion of cottonwood coverage. At two locations, downstream of Red Bluff Diversion and downstream of the GCC Diversion, the average spring hydrograph peak occurs after the end of the germination season specified in the model simulations, for all alternatives.

6.5.2 Narrow leaf willow and Gooding's black willow

Narrow leaf willow did better with Alternatives A and C, which distributed more flows into secondary channels during the summer growth season. Narrow leaf willow has shallow roots in comparison to cottonwood, Gooding's black willow and mixed forest. Shallow roots restrict the plant to river banks and low benches where the water surface is brought to closer proximity with the ground surface. Locations along the river that have secondary channels or abandoned channels (frequently within active meander bends in the Sacramento River) provide at least twice as much bankline that can potentially support narrow leaf willow growth.

Gooding's black willow, the second indicator of riparian vegetation, has results with the least clear distinctions between alternatives. The Existing and No Action flow alternatives are more similar than the flow plans of Alternatives A, B, and C, yet depending on the analysis, the Gooding's black willow produced the most plants with a flow alternative from each group. Gooding's black willow did best with Alternative B, the alternative with the least summer flow, or the No Action Alternative. This may imply some tolerance to all the proposed alternatives.

6.5.3 Mixed Forest

Alternative A is clearly the preferred alternative for mixed forest although only a small percentage of new plants survive to maturity (increasing trend of only 4%). Mixed forest is the most prevalent vegetation cover in this study area.

6.5.4 Herbaceous Plants

Herbaceous plants have been included in the model as a mechanism to provide groundcover. In most cases, herbaceous plants are not analyzed because there are no requirements in the model linking herbaceous plant survival to the water table. Under this representation, they are not a riparian plant. However herbaceous plants can prevent colonization by other plants and the simulated number of herbaceous plants is inversely related to the number of plants from other vegetation types. The inverse relation makes herbaceous plants an indicator in this study and the preferred flow alternative for herbaceous plants, the No Action Alternative, becomes the least desired alternative for the other plants, possibly mixed forest plants in particular.

6.6 Concluding Remarks

None of the alternatives clearly are better for both cottonwood and the riparian vegetation indicators, narrow leaf willow and Gooding's black willow. Gooding's black willow coverage appears to be the least influenced by the different proposed flow alternatives. If an alternative is selected based on cottonwood only, the preferred flow management plan is the Existing Alternative possibly due to more variation in the flows, and the maximum winter flows that produce bare bar and

bank areas for cottonwood establishment. However the larger spring peak flows and summer flows of Alternative A and Alternative C appear more beneficial for mixed forest and narrow leaf willow. The Existing Conditions Alternative, or Alternatives C and A might be enhanced by scheduling the average spring peak flow to coincide more frequently with the cottonwood germination period. The results also confirm that more flow during the spring and summer growing season is beneficial for riparian vegetation. Riparian vegetation coverage, including cottonwood, may also be increased by promoting more migration at currently stable meander bends. This could require removing levees or other river bank "hard points", developing land agreements, and/or purchasing lands to encourage wider flood plains, multiple channels, and continued sediment supply.

The Sacramento River vegetation model (SRH-1DV) can be used in the future to test adjustments to flow alternatives and determine if changes provide effective benefits for riparian vegetation. Invasive plants can also be reviewed since a preferred alternative for native vegetation may also be a preferred alternative for invasive vegetation. This additional information is useful for weighing the true merits of the preferred alternative.

7 References

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Appendix

Table A-1. 1 of 6. Average vegetated width (ft) at each cross section of the Sacramento River, averaged from results of five flow alternatives.

River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest	River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest
249.92	542	2,987	131	1,301	235.19	2,430	8,551	1,427	39,401
249.5	8,556	20,349	1,711	352	234.34	87,239	64,073	44,539	28,813
249.01	1,183	3,247	637	207	233.6	24,806	17,531	31,278	38,456
248.59	2,146	6,683	1,424	5,274	232.88	81,970	69,088	57,387	111,633
248.12	1,192	3,789	1,429	134	231.9	129,307	87,333	91,250	196,943
247.81	1,344	3,930	2,101	432	231.15	178,968	61,374	43,209	89,782
247.31	0	1,862	808	4,158	230.3	82,786	55,312	28,382	46,954
246.79	832	3,385	2,349	2,970	229.55	6,233	12,980	13,262	67,071
246.5	98	2,451	2,363	2,313	228.59	57,301	68,734	129,881	122,408
246.04	655	4,692	7	4,666	228.11	43,376	38,170	31,245	86,630
245.57	546	4,452	929	294	227.46	37,404	2,996	19,287	37,364
245.04	3,768	6,877	4,494	10,600	226.75	8,593	13,368	15,132	26,383
244.37	3,245	6,508	1,759	6,151	225.95	5,143	4,742	9,519	47,036
243.85	274	3,202	0	14,469	225.5	4,281	10,749	19,242	41,008
243.19	1,309	4,536	4,884	55	225.43	10,725	7,143	1,105	27,930
242.82	2,191	3,339	3,979	481	225.42	4,914	5,746	837	3,784
242.08	35,912	8,073	8,324	9,964	225.37	4,980	5,990	1,958	3,403
241.52	163	389	81	16,653	225.36	8,572	7,436	4,830	1,401
241.09	83	73	55	36,341	225.29	11,855	7,408	14,081	28,206
240.9	20,712	25,978	14,523	9,394	224.25	52,388	30,819	25,291	53,402
240.89	15,656	17,112	4,460	2,873	223.38	29,409	22,128	20,209	55,162
240.69	8,665	18,913	11,016	83,520	222.72	223,131	122,301	101,473	191,434
240.23	3,447	798	6,475	41,226	221.64	40,034	36,242	29,067	125,024
240	32,312	18,059	7,165	12,238	220.63	25,459	21,055	13,342	81,445
239.99	36,018	15,519	12,793	13,127	219.47	81,117	54,589	37,274	69,820
239.81	22,704	13,561	12,734	308	218.42	42,631	58,277	24,145	12,804
239.16	22,060	28,440	22,727	9,130	217.22	37,135	14,781	48,586	1,399
239.05	12,368	22,970	15,436	7,995	216.24	9,072	17,622	10,239	362,669
239.04	14,804	26,361	18,353	19,754	215.5	1,127	3,430	7,221	88,354
238.94	16,261	4,406	17,914	12,959	215.25	13,145	26,664	31,364	30,333
238.33	41,091	29,165	10,665	43,238	215	3,180	13,869	32,237	7,650
237.54	16,239	7,917	7,795	35,506	214.83	0	0	0	0
236.88	29,650	36,869	36,301	89,407	214.82	0	0	0	0
235.96	29,461	5,361	10,288	44,453	214.81	0	0	0	0

Table A-1 (cont). 2 of 6
Average Vegetation Width (ft) ***Sacramento River Alternatives Analysis***

River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest	River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest
214.8	0	0	0	0	205.25	89,048	36,698	67,875	100,437
214.75	0	0	0	0	205	176,726	21,875	100,602	153,242
214.5	0	0	0	0	204.75	136,676	43,990	52,648	64,295
214.25	0	0	0	0	204.5	93,292	13,032	20,607	98,645
214	0	0	2,284	0	204.25	40,269	0	16,413	233,821
213.75	0	0	0	0	204	10,850	0	12,855	42,856
213.5	2,128	0	0	15,809	203.75	2,541	2,626	8,509	48,736
213.25	0	0	0	7,219	203.5	0	0	7,873	108,991
213	494	1,009	185	26,329	203.25	218,450	839	23,023	423,210
212.75	369	2,337	3,385	21,566	203	37,054	33,451	39,667	157,601
212.5	11,267	800	14,754	20,798	202.5	1,587	2,748	6,307	17,770
212.25	202,241	6,707	12,647	69,841	202.25	6,137	7,121	16,443	49,585
212	53,911	13,949	23,849	174,185	202	5,770	9,323	10,549	31,435
211.75	153,855	23,625	36,979	227,369	201.75	0	0	11,452	64,802
211.46	44,546	6,932	734	14,286	201.5	7,870	0	14,843	27,595
210.52	71,436	3,403	3,944	3,006	201.25	0	0	20,559	47,780
210	41,990	17,862	20,573	20,573	201	31,232	23,614	24,734	13,514
209.75	17,954	825	927	5,295	200.75	15,893	0	1,117	20,530
209.5	127,361	0	5,811	71,954	200.5	15,188	2,268	7,431	29,783
209.25	41,577	21	42,741	139,135	200.25	353	360	9,103	22,837
209	78,545	487	3,740	66,043	200	0	0	3,376	22,925
208.75	59,080	416	25,269	57,927	199.75	0	0	11,858	19,278
208.5	4,532	7,963	10,513	146,233	199.5	29,872	6,727	18,210	66,982
208.25	1,419	0	8,198	28,556	199.25	0	0	0	42,589
207.75	21,042	3,572	19,427	63,906	199	0	184	5,651	27,260
207.38	75,502	6,213	28,883	105,784	198.75	12,255	17,744	12,247	26,678
207.25	15,693	0	28,318	256,631	198.67	21,180	32,071	44,329	28,856
207	29,766	285	59,769	158,673	198.63	0	0	18,967	0
206.75	18,683	4,953	32,499	60,790	198.61	0	0	6,258	0
206.5	64,372	4,843	26,010	29,560	198.5	20,524	16,770	14,429	48,354
206.25	13,639	0	6,826	37,087	198.25	7,700	18,357	27,316	14,550
206	8,936	1,877	3,549	10,818	198	23,090	18,087	24,841	8,968
205.75	38,157	12,462	28,693	41,253	197.75	21,374	0	13,609	51,831
205.5	32,218	2,298	6,550	51,993	197.5	49,545	0	70,209	67,819

Table A-1 (cont). 3 of 6
Average Vegetation Width (ft) ***Sacramento River Alternatives Analysis***

River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest	River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest
197.25	70,753	41,014	33,545	66,056	188.5	7,995	11,773	2,658	10,175
197	102,611	16,271	18,800	63,418	188.25	11,550	3,769	1,404	3,077
196.75	80,092	16,195	14,294	59,114	188	35,109	6,118	3,112	3,098
196.5	101,003	40,685	27,483	94,291	187.75	60,963	7,810	6,675	3,023
195.75	1,478	0	0	5,622	187.5	61,702	10,507	6,923	498
195.5	12,662	0	1,463	15,286	187.25	67,353	2,879	3,627	61
195.25	29,705	899	6,183	29,808	187	45,984	15,098	14,343	31,491
195	35,296	38,025	33,008	77,710	186.75	47,232	20,750	9,941	81,449
194.75	126,091	119,052	84,314	142,005	186.5	45,160	15,717	10,610	293
194.5	37,915	2,463	17,667	55,063	186.25	13,973	6,860	1,666	15,666
194.25	178,142	7,663	34,790	86,750	186	32,330	1,216	3,757	49
194	48,047	617	16,223	47,905	185.75	39,949	7,837	5,574	10
193.75	129,087	41,637	70,855	143,050	185.5	37,843	4,250	4,497	33,225
193.5	128,853	13,917	59,356	172,896	185.25	83,167	33,187	14,548	9,200
193.25	149,089	69,715	107,507	169,808	185	104,795	15,208	11,434	393
193	101,844	68,582	76,482	103,028	184.75	14,987	11,539	4,996	17,351
192.75	55,583	34,234	63,936	180,496	184.5	11,222	2,606	6,633	15
192.5	0	0	0	0	184.25	24,340	1,420	9,339	21,949
192.25	7,631	16,359	16,283	43,433	184	49,270	66,078	37,845	23,761
192	30,124	8,262	7,587	14,390	183.75	12,707	12,946	12,423	469
191.75	50,794	35,509	13,544	322	183.5	13,291	3,667	1,261	15
191.5	77,888	39,058	51,610	280	183.25	29,727	31,372	20,993	12,534
191.25	22,822	14,616	12,730	523	183	22,882	5,397	1,478	32,038
191	30,181	10,849	11,888	279	182.85	7,398	30,243	13,515	533
190.75	23,838	52,559	1,041	2	182.84	2,505	9,917	3,984	261
190.5	63,881	6,062	6,987	181	182.83	3,234	2,868	399	363
190.4	4,233	31,394	14,285	270	182.82	13,813	9,218	1,163	778
190.25	40,107	10,566	5,083	12,313	182.75	2,498	10,161	21,712	4,243
190	80,943	66,403	26,887	36,883	182.5	24,453	6,314	2,413	55,928
189.75	39,853	30,229	13,662	26,158	182.25	26,728	24,953	12,546	26,004
189.5	21,658	19,118	12,466	41,345	182	34,811	20,652	18,785	1,307
189.25	9,145	15,465	12,392	66,038	181.75	14,565	20,852	17,737	14,535
189	19,713	3,402	509	79,262	181.5	43,962	15,165	10,585	18,152
188.75	38,250	52,000	24,609	78,547	181.25	60,728	15,293	12,520	128

Table A-1 (cont). 4 of 6
Average Vegetation Width (ft) ***Sacramento River Alternatives Analysis***

River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest	River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest
181	28,242	17,438	9,642	345	172.5	46,263	10,108	32,251	18,806
180.75	104,819	4,290	2,333	31,080	172	51,456	6,448	23,453	18,900
180.5	22,590	12,554	10,774	25,815	171.75	57,953	28,251	32,260	35,014
180.25	15,816	954	683	29,677	171.5	33,608	30,640	50,299	91,974
180	358	1,294	8,168	51,986	171.25	69,970	6,279	3,941	19,398
179.75	26,316	12,993	5,137	26,545	171	102,703	15,615	10,135	50,579
179.5	59,493	20,520	12,326	31,725	170.75	113,181	13,320	10,520	57,159
179.25	971	9,781	25,772	19,170	170.5	95,656	26,222	32,567	32,337
179	652	1,300	33,691	89,747	170.25	57,376	17,964	12,927	61,779
178.75	48,136	25,642	19,931	121,165	170	49,035	27,405	8,942	83,498
178.5	59,115	56,742	28,917	114,697	169.75	555	3,663	1,299	139,761
178.25	108,298	17,965	25,707	47,304	169.5	14,241	9,712	23,292	191,105
178	260,968	109,349	54,119	59,611	169.25	53,044	15,184	9,193	124,138
177.75	113,319	33,709	24,284	67,495	169	93,361	7,002	20,917	150,749
177.5	138,907	58,480	37,735	34,446	168.75	68,316	37,195	29,222	140,652
177.25	149,493	45,740	49,347	114,344	168.5	57,471	51,992	45,465	191,937
177	130,118	24,709	13,728	72,898	168.25	116,135	80,365	87,732	124,504
176.75	120,746	67,889	32,505	34,688	168	65,348	17,487	74,830	40,733
176.5	101,947	81,828	24,471	33,043	167.75	106,761	29,837	69,586	136,192
176.25	119,021	106,968	18,584	45,822	167.5	129,312	12,212	27,661	140,677
176	120,353	75,873	14,523	12,593	167.25	135,040	47,596	26,415	48,465
175.75	25,584	86,163	7,960	423	167	42,260	28,000	31,866	25,617
175.5	244	3,198	2,028	39	166.79	0	0	0	0
175.25	95	1,841	16,947	34,975	166.78	0	0	0	0
175	156	489	7,660	6,620	166.77	0	0	0	0
174.75	2,825	5,739	7,605	18,609	166.76	0	0	0	0
174.5	0	0	9,254	0	166.75	28,642	2,868	17,287	33,685
174.25	29,000	481	21,512	39,770	166.5	152,911	83,319	127,075	188,169
174	20,910	3,681	20,398	93,877	166.25	59,206	53,913	60,342	107,863
173.75	82,813	22,048	33,579	74,871	166	71,926	48,675	41,891	93,869
173.5	56,894	26,636	31,062	78,822	165.75	37,487	5,502	7,750	38,612
173.25	102,998	19,949	31,337	48,273	165.5	80,353	23,912	36,622	49,659
173	55,715	61,306	78,082	175,391	165.25	14,351	36,412	28,623	100,094
172.75	129,227	3,516	51,195	37,734	165	58,161	24,614	19,274	62,884

Table A-1 (cont). 5 of 6
Average Vegetation Width (ft) ***Sacramento River Alternatives Analysis***

River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest	River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest
164.75	52,939	33,279	69,385	223,484	156.5	3,079	19,873	3,375	3,076
164.5	105,104	61,382	30,475	216,725	156.25	9,079	9,695	4,900	29,491
164.25	100,267	28,952	16,865	161,067	156	31,884	7,426	1,489	55,806
164	156,231	39,582	24,232	67,170	155.75	80,149	14,943	6,848	54,019
163.75	68,937	56,852	28,323	52,043	155.5	102,666	10,827	9,455	101,641
163.5	52,489	27,496	39,104	14,681	155.25	94,102	37,289	37,982	47,850
163.25	9,481	3,128	3,597	10	155	49,748	29,339	27,227	54,892
163	17,913	1,538	6,122	90,216	154.5	25,448	12,583	5,180	21,864
162.75	38,987	6,082	121,468	341,310	154.25	45,100	5,347	4,389	30,116
162.5	41,566	3,338	33,895	39,794	154	5,775	4,029	3,637	88,032
162.25	2,879	15,204	5,116	31,727	153.75	163,465	27,464	19,602	44,891
162	1,936	11,523	1,299	39,160	153.5	29,780	359	8,054	12,837
161.75	35,213	9,050	7,530	37,296	153.25	9,682	867	6,062	2,660
161.5	29,559	12,634	8,317	75,100	153	6,207	430	3,743	3,399
161.25	2,070	23,081	31,914	16,152	152.75	142	1,351	9,510	8
161	88,113	235	8,034	37,059	152.5	1,680	281	4,860	4,003
160.75	69,259	9,789	27,756	17,654	152.25	11,011	4,271	4,203	5
160.5	96,153	18,596	7,718	94,649	152	12,907	10,306	1,186	42
160.25	86,738	30,833	19,212	144,350	151.75	309	1,585	281	2,651
160	30,232	1,347	3,127	26,571	151.5	308	2,539	7,849	25,765
159.75	0	0	9,158	67,926	151.25	0	0	15,322	8,754
159.5	19,639	120	7,948	24,166	151	591	1,867	3,157	21,169
159.25	45,972	17,571	48,791	15,844	150.75	140	1,317	91	20,072
159	0	0	18,477	23,789	150.5	11	174	14,016	97,512
158.75	1,653	2,943	5,060	108,865	150.25	861	1,449	10,918	17,673
158.5	28,458	6,073	10,341	26,137	150	14,799	3,264	12,001	12,806
158.25	8,588	7,007	9,276	12,579	149.75	22,565	8,465	19,800	33,452
158	16,198	5,277	7,755	17,361	149.5	12,747	2,958	6,848	21,835
157.75	41,885	19,595	5,978	67,739	149.25	33,452	30,356	26,885	31,421
157.5	13,120	659	8,477	12,610	149	17,118	27,207	12,638	44,845
157.25	19,265	0	8,628	0	148.75	18,507	13,884	6,822	216
157.03	0	0	0	0	148.5	8,181	3,413	629	6,459
156.94	0	0	0	0	148.25	0	0	0	4,779
156.75	6,456	6,611	4,544	59	148	11,651	0	5,382	0

Table A-1 (cont). 6 of 6
Average Vegetation Width (ft)

River Mile	cotton-wood	narrow leaf willow	Gooding' black willow	mixed forest
147.75	50,757	200	17,772	17,967
147.5	87,643	46,843	29,404	68,241
147.25	0	0	5,441	75,032
147	67,057	46,653	43,122	41,569
146.75	49,959	18,705	7,009	17,800
146.5	73,644	15,841	16,622	43,906
146.25	115,883	19,050	31,983	23,368
145.94	210,593	16,067	16,237	5,677
145.75	49,890	2,058	13,090	25,168
145.5	142,518	6,204	107,975	50,291
145.25	31,479	39,735	123,915	72,054
145	22,930	54	40,199	0
144.75	46,853	3,297	11,615	16
144.5	55,303	9,061	6,013	65,339
144.25	66,910	2,654	8,556	21,499
144	15,177	13,499	16,454	52
143.75	0	0	5,878	5,878
143.5	250	1,571	5,149	3,928
143.27	0	0	5,893	67
143.26	7	160	1,862	1,019
143.25	5	24	158	110
143	2	20	59	0