Appendix A

Cross Sections Established in the Upper Spawning Reach and Gravel Mining Reach for Monitoring Channel Bed Topography.

(see figure 11, page 26 for planform location of cross sections)

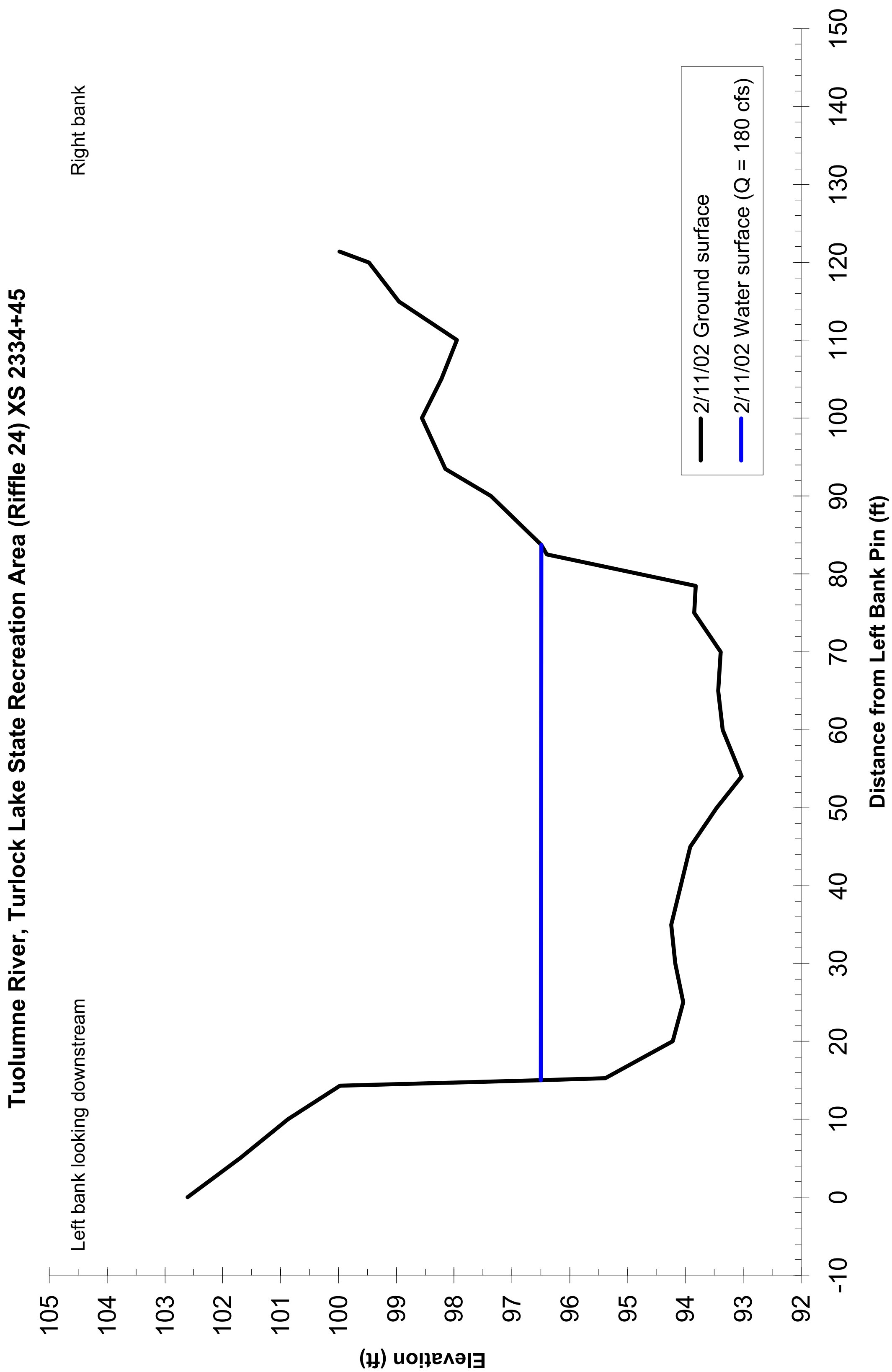
Tuolumne River Cross Section Pin Elevation Summary Sheet

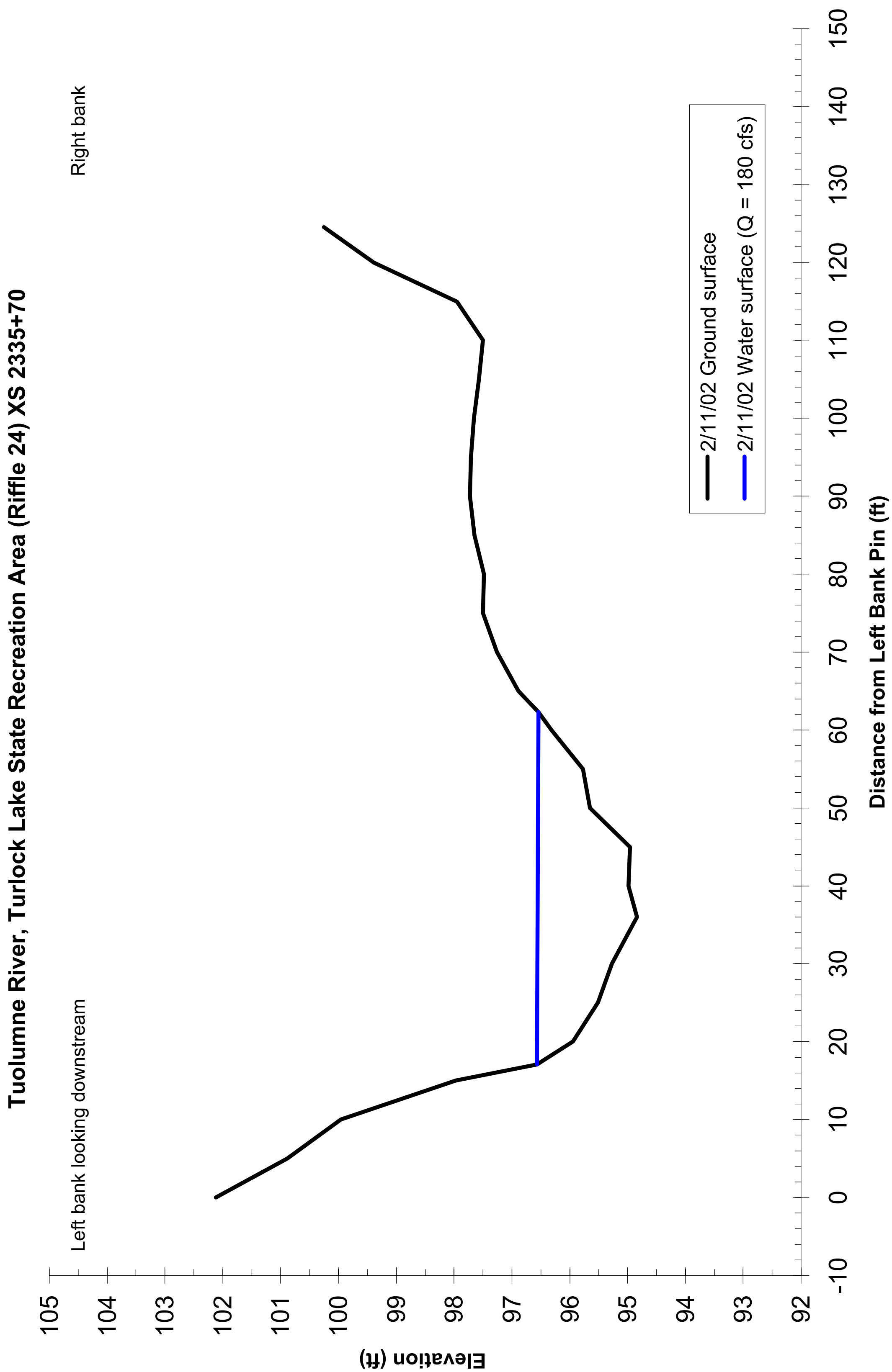
Site Name	Current Cross Section Label	Old Cross Section Label	BM Elevation (ft)	Top Upper Left Bank Pin Elev. (ft)	Top Left Bank Pin Elev. (ft)	Top Right Bank Pin Elev. (ft)	Total cross section length (ft)	Fieldbook # and Page #'s	Notes
TLRSA	2334+45				102.97	100.0		Fieldbook 9, page 104	
	2335+70				102.54	100.25		Fieldbook 9, page 104	
	2336+35				101.73	100.78		Fieldbook 9, page 104	
	2337+10				105.18	99.42		Fieldbook 9, page 104	
			175.61						Old basso bridge brass benchmark
Riffle 4B			165.81						5/8 inch rebar pin at Riffle 4B next to concrete block
	2670+00	A			158.64	161.16	654.70	Fieldbook #10, page #46-57	
	2672+00	B			159.08	158.35	218.20	Fieldbook #10, page #38-41	
Riffle 5A	2674+00	C			160.52	163.32	255.30	Fieldbook #10, page #38-41	
	2685+00	D		169.15	159.38	158.86	700.10	Fieldbook #10, page #58-63	
	2690+00	E		163.96	160.15	160.20	288.30	Fieldbook #10, page #64-67	
Riffle 4A	2699+00	F			164.19	161.91	255.40	Fieldbook 10, page 88-91	
	2702+00	G		166.09	164.39	165.07	762.00	Fieldbook 10, page 80-87	
	2705+00	H			164.59	165.77	191.10	Fieldbook 10, page 92-95	
	2722+00	J			176.02	165.33	328.10	Fieldbook 10, page 96-99	
Riffle 3B	2728+00	K			172.50	166.22	193.60	Fieldbook 10, page 108-111	
	2731+00	L		174.87	166.71	167.76	664.60	Fieldbook 10, page 112-115	
	2735+00	M			173.08	174.70	308.50	Fieldbook 10, page 112-115	
	2799+00	R			181.59	180.32	369.70	Fieldbook # 9, page 54-56	Elevation based on back calculation from XS 2802+00
	2802+00	S			182.57	182.32	361.50	Fieldbook 9, page 42-51	
	2804+00	T			178.35	182.70	357.10	Fieldbook 9, page 42-51	
	2842+00	W			183.89	187.90	260.90	Fieldbook 10, page 146-149	
	2844+00	X			182.51	177.09	259.60	Fieldbook 10, page 140-143	
	2846+00	Y			182.49	184.61	272.30	Fieldbook 10, page 134-139	
	2847+00	Z			184.71	184.33	260.20	Fieldbook 10, page 130-133	

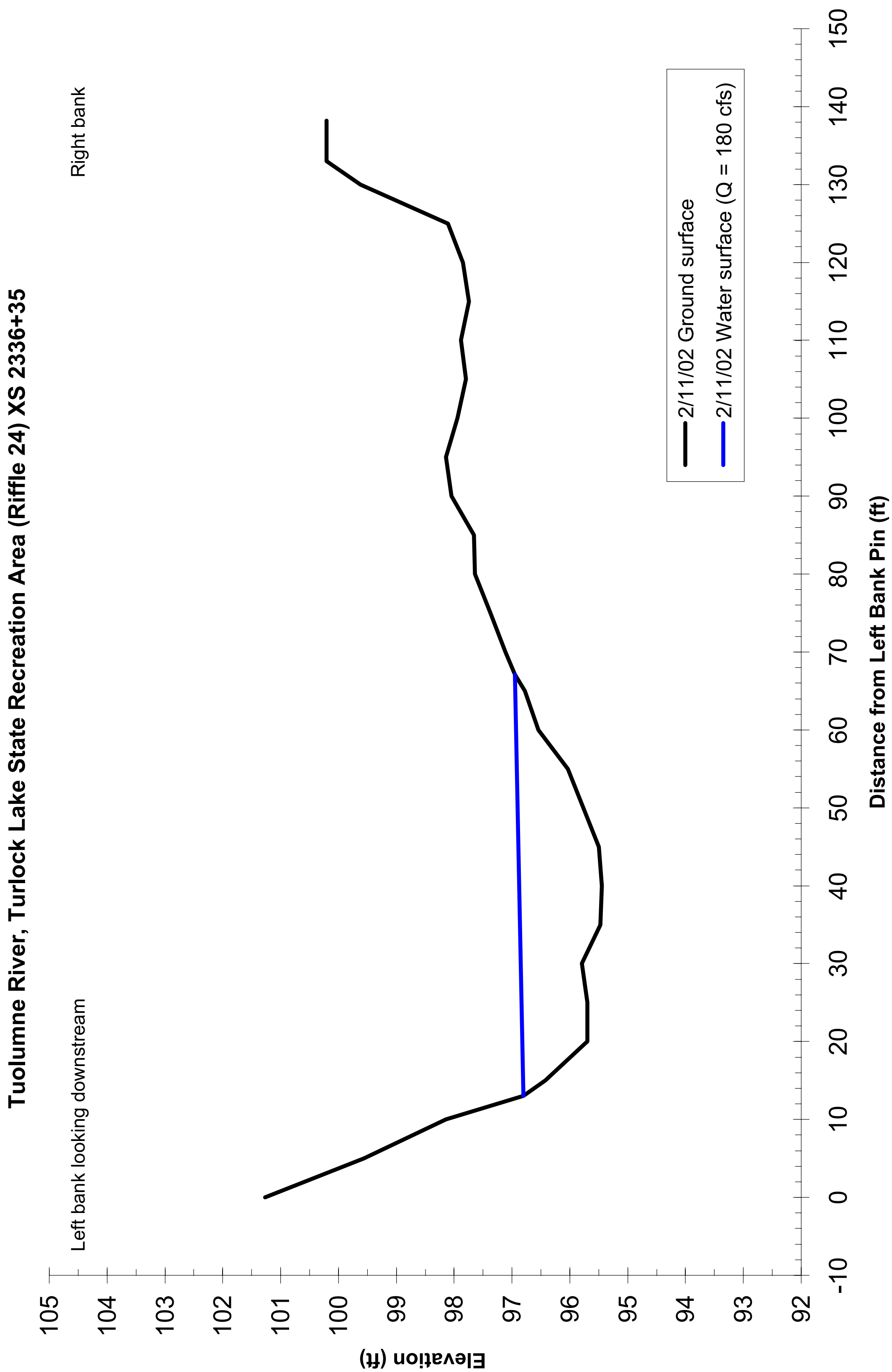
Tuolumne River Sediment Management Reach, Turlock Lake State Recreation Area to La Grange Dam. Benchmark and Cross Section Pin Elevation Summary Sheet.

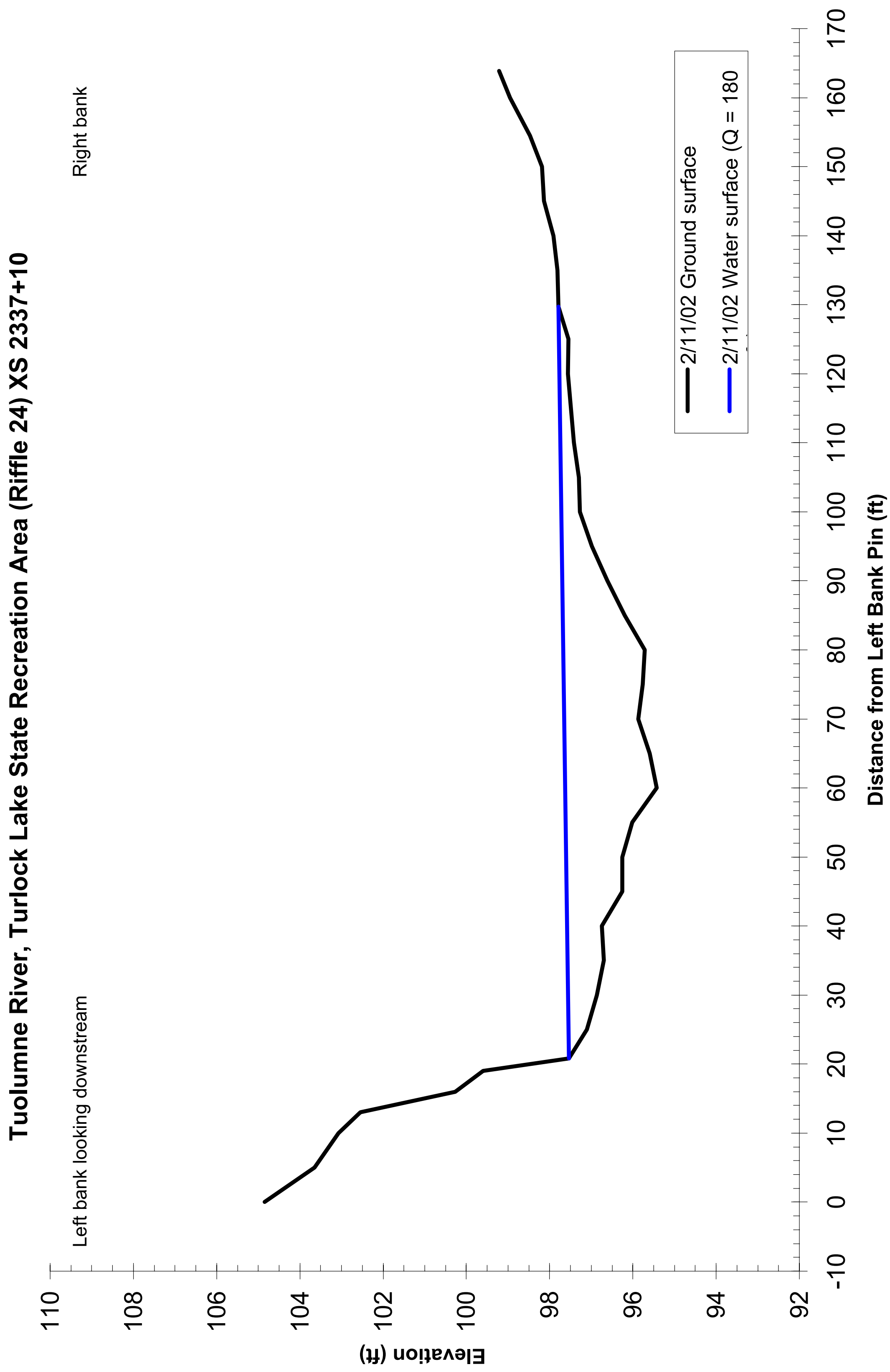
Name	Northing	Easting	XS Letter Code	XS Feature Code
1	2066126.84	6572356.54		REBAR10
2	2064452.41	6577609.73		SPIKE
3	2064946.56	6573796.43	R	RB2799+00
4	2064835.40	6574053.97	S	RB2802+00
5	2064767.23	6574251.11	T	RB2804+00
6	2064433.91	6574122.76	T	LB2804+00
7	2064601.42	6573662.97	R	LB2799+00
8	2064599.16	6573732.97		ORANGEREBAR
9	2061435.30	6565513.33	E	ULB2690+00
10	2061510.23	6565247.11	E	RB2690+00
12	2063092.28	6565850.96		STILLWATERORANGEREBAR
13	2062924.83	6565700.29	H	LB2705+00
14	2063052.09	6565557.98	H	RB2705+00
15	2062687.39	6565473.73	G	LB2702+00
16	2062774.89	6565254.53	G	RB2702+00
18	2062433.18	6565237.48	F	RB2699+00
19	2062488.92	6565486.21	F	LB2699+00
20	2062447.21	6565937.91	G	ULB2702+00
21	2063617.52	6566946.22	J	LB2722+00
23	2063838.84	6566705.08	J	RB2722+00
25	2064420.56	6566982.76	K	RB2728+00
26	2064754.79	6567157.36	L	RB2731+00
27	2065125.05	6567570.06	M	RB2735+00
28	2064860.98	6567728.54	M	LB2735+00
29	2064618.68	6567306.96	L	LB273100
30	2064362.45	6567165.79	K	LB2728+00
32	2064296.87	6567636.64	L	ULB2731+00
33	2063783.06	6566765.96	J	REBAR
34	2063849.22	6566827.57		REBAR
35	2061016.29	6565240.30	D	LLB2685+00
36	2060959.78	6565345.45	D	ULB2685+00
37	2061137.44	6565054.18	D	RB2685+00
38	2060308.29	6564483.53	C	LB2674+00
39	2060208.19	6564346.28	B	LB2672+00
41	2060084.85	6564086.51	A	LLB2670+00
42	2060317.26	6564015.22	A	RB2670+00
43	2060448.81	6563896.52	A	RBFPON2670+00
44	2060398.19	6564239.12	B	RB2672+00
45	2060540.06	6564376.93	C	RB2674+00
50	2065196.59	6570447.11		REBAR
52	2065240.42	6569987.82		REBAR
53	2065129.03	6569604.70		REBAR
54	2065049.18	6568354.81		REBAR
55	2065052.77	6567883.21		REBAR
56	2064932.21	6577839.71	Y	RB2846+00
57	2064840.94	6577916.70		REBAR
58	2064679.66	6577443.19	W	RB2842+00
59	2064460.15	6577581.68	W	LB2842+00
60	2064730.72	6578064.10	Z	LB2847+00
61	2064696.60	6577975.54	Y	LB2846+00
62	2064981.44	6577997.19	Z	RB2847+00
63	2064823.87	6577703.67	X	RB2844+00
64	2064576.83	6577782.41	X	LB2844+00
65	2057433.40	6563006.83		USGSLBOLDBASSO

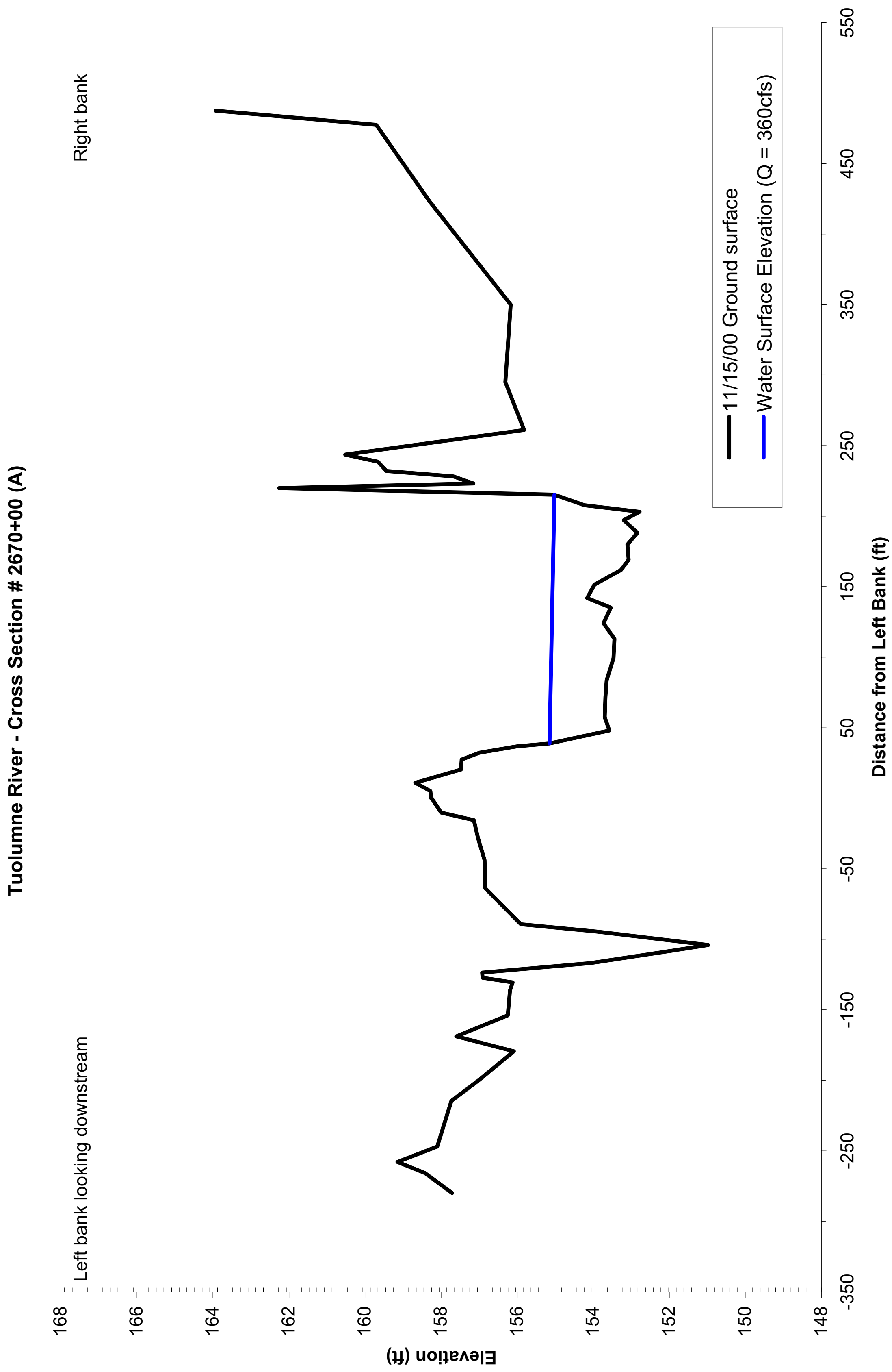
Tuolumne River Sediment Management Reach, Turlock Lake State Recreation Area to La Grange Dam. Benchmark and cross section pin coordinate summary (northing and easting). Note: Use pin elevations from 'pin elevation summary sheet' in conjunction with coordinates (northing and easting).

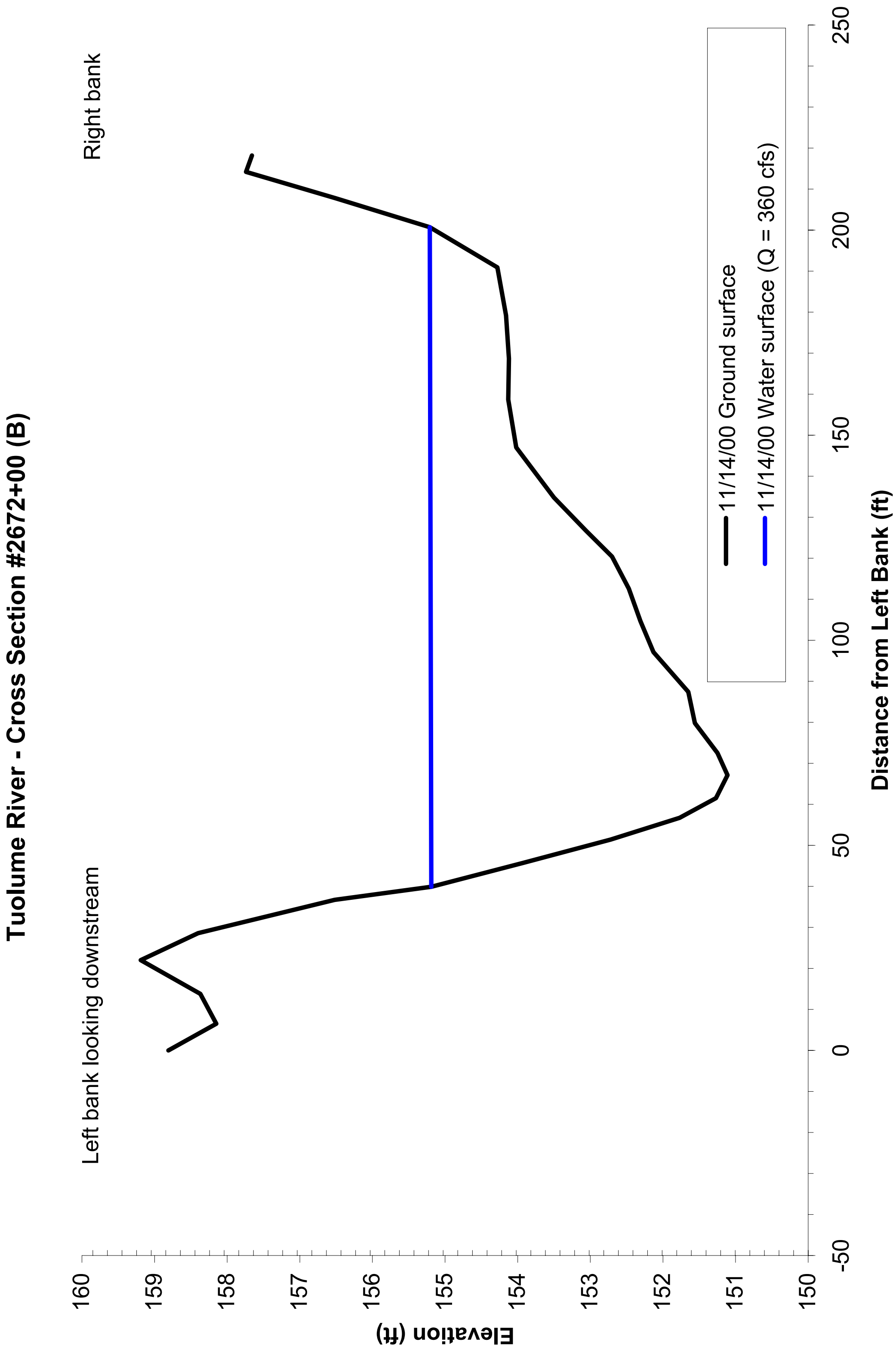

Tuolumne River, Turlock Lake State Recreation Area (Riffle 24) XS 2334+45
Left bank looking downstream
Right bank
2/11/02 Ground surface
2/11/02 Water surface (Q = 180 cfs)
Elevation (ft)
Distance from Left Bank Pin (ft)
105
104
103
102
101
100
99
98
97
96
95
94
93
92
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

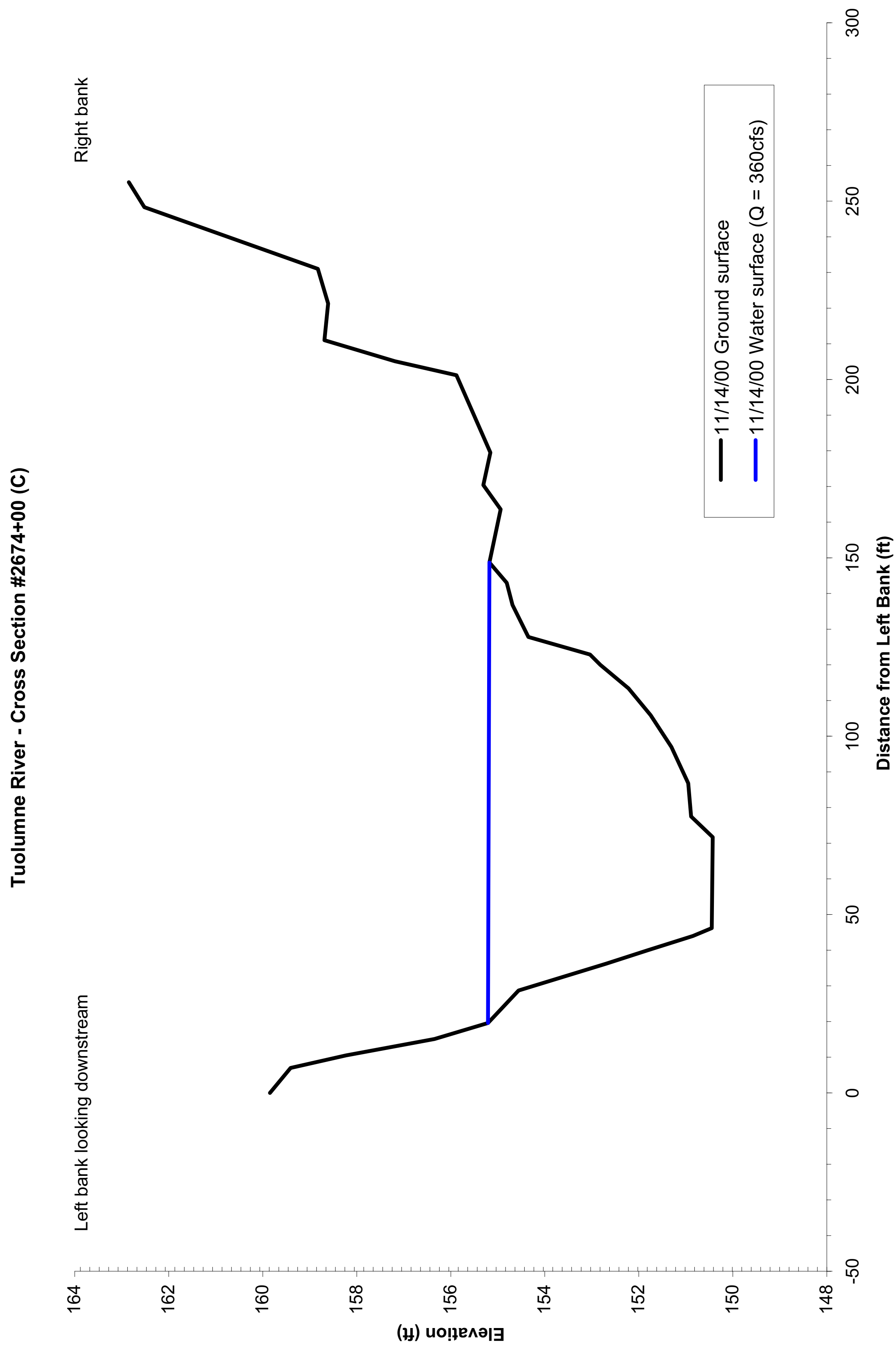

Tuolumne River, Turlock Lake State Recreation Area (Riffle 24) XS 2335+70
Left bank looking downstream
Right bank
2/11/02 Ground surface
2/11/02 Water surface (Q = 180 cfs)
Elevation (ft)
Distance from Left Bank Pin (ft)
105
104
103
102
101
100
99
98
97
96
95
94
93
92
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

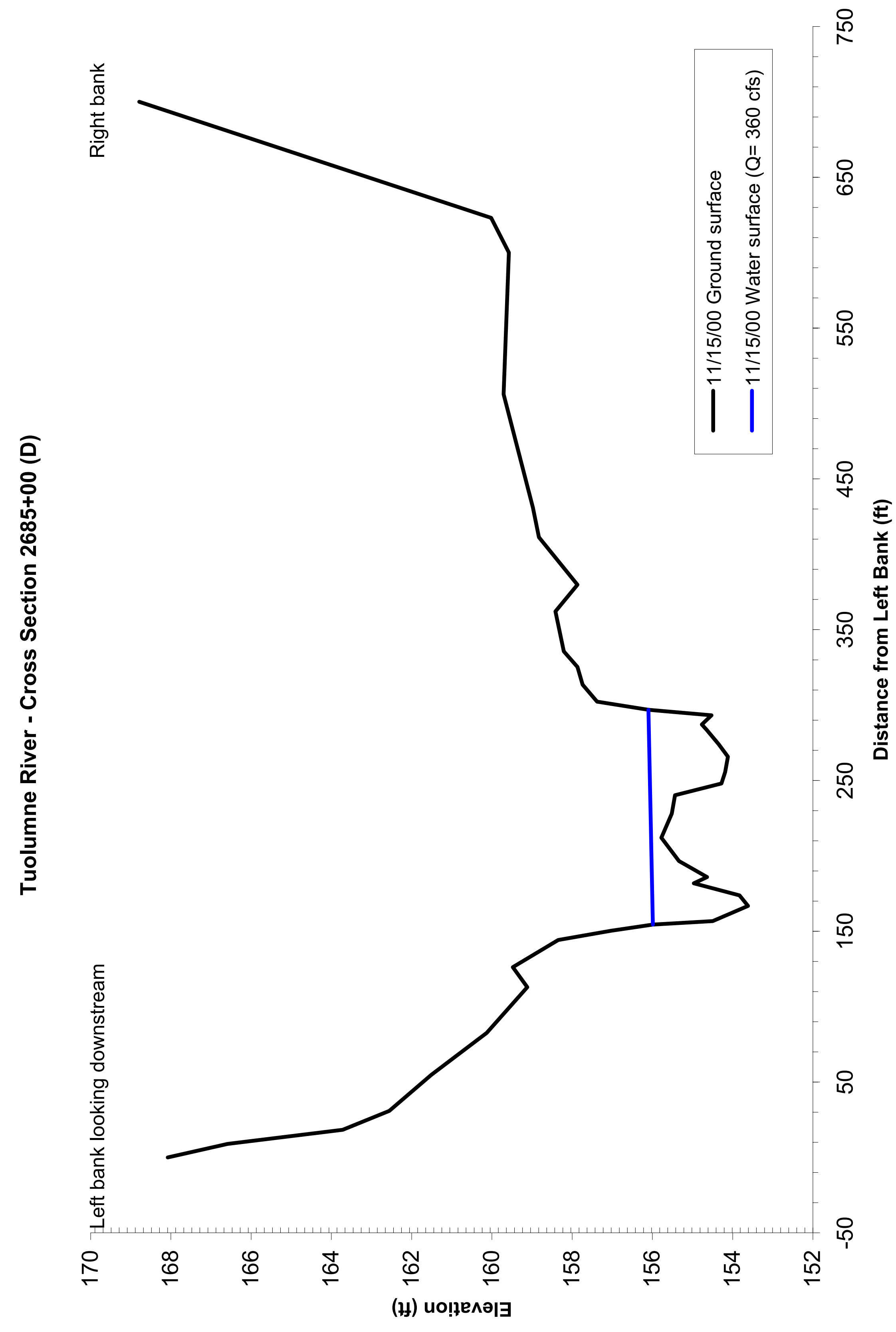

Tuolumne River, Turlock Lake State Recreation Area (Riffle 24) XS 2336+35
Left bank looking downstream
Right bank
2/11/02 Ground surface
2/11/02 Water surface (Q = 180 cfs)
Elevation (ft)
Distance from Left Bank Pin (ft)
105
104
103
102
101
100
99
98
97
96
95
94
93
92
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


Tuolumne River, Turlock Lake State Recreation Area (Riffle 24) XS 2337+10
Left bank looking downstream
Right bank
2/11/02 Ground surface
2/11/02 Water surface (Q = 180
Elevation (ft)
Distance from Left Bank Pin (ft)
110
108
106
104
102
100
98
96
94
92
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170

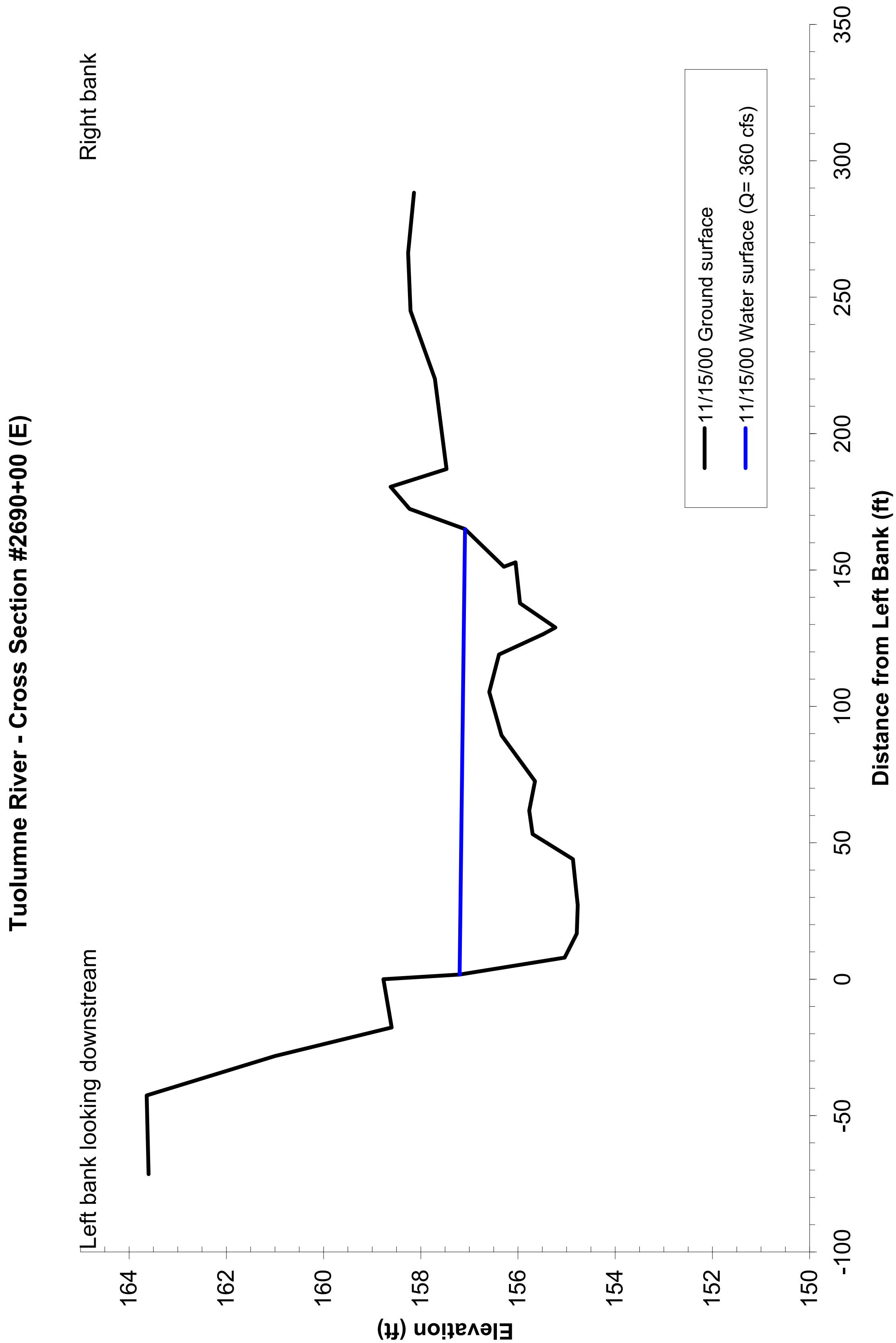

Tuolumne River - Cross Section # 2670+00 (A)
Left bank looking downstream
Right bank
11/15/00 Ground surface
Water Surface Elevation (Q = 360cfs)
Elevation (ft)
168
166
164
162
160
158
156
154
152
150
148
Distance from Left Bank (ft)
-350
-250
-150
-50
50
150
250
350
450
550

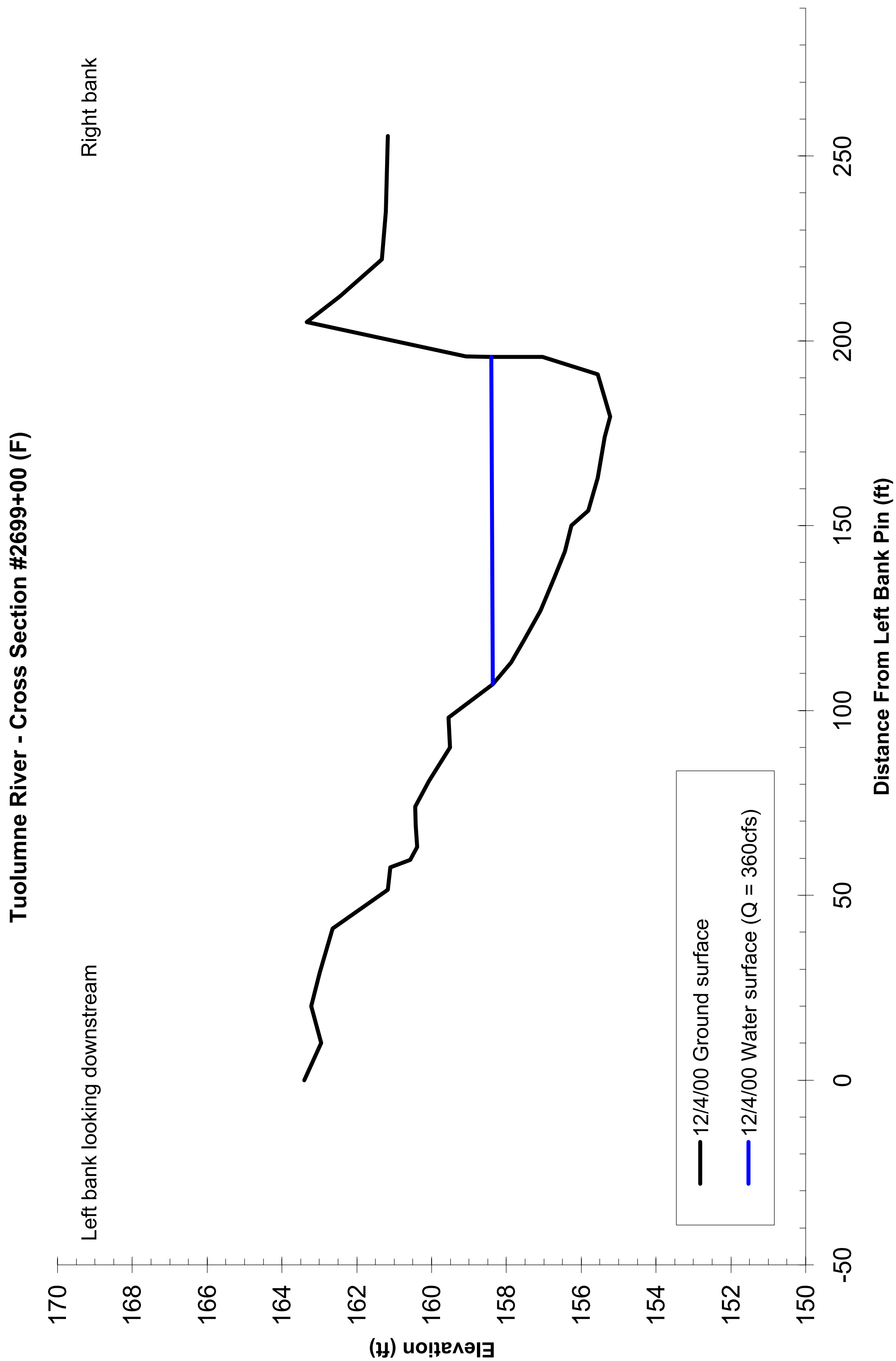

Tuolume River - Cross Section #2672+00 (B)
Left bank looking downstream
Right bank
11/14/00 Ground surface
11/14/00 Water surface (Q = 360 cfs)
Elevation (ft)
160
159
158
157
156
155
154
153
152
151
150
Distance from Left Bank (ft)
-50
0
50
100
150
200
250

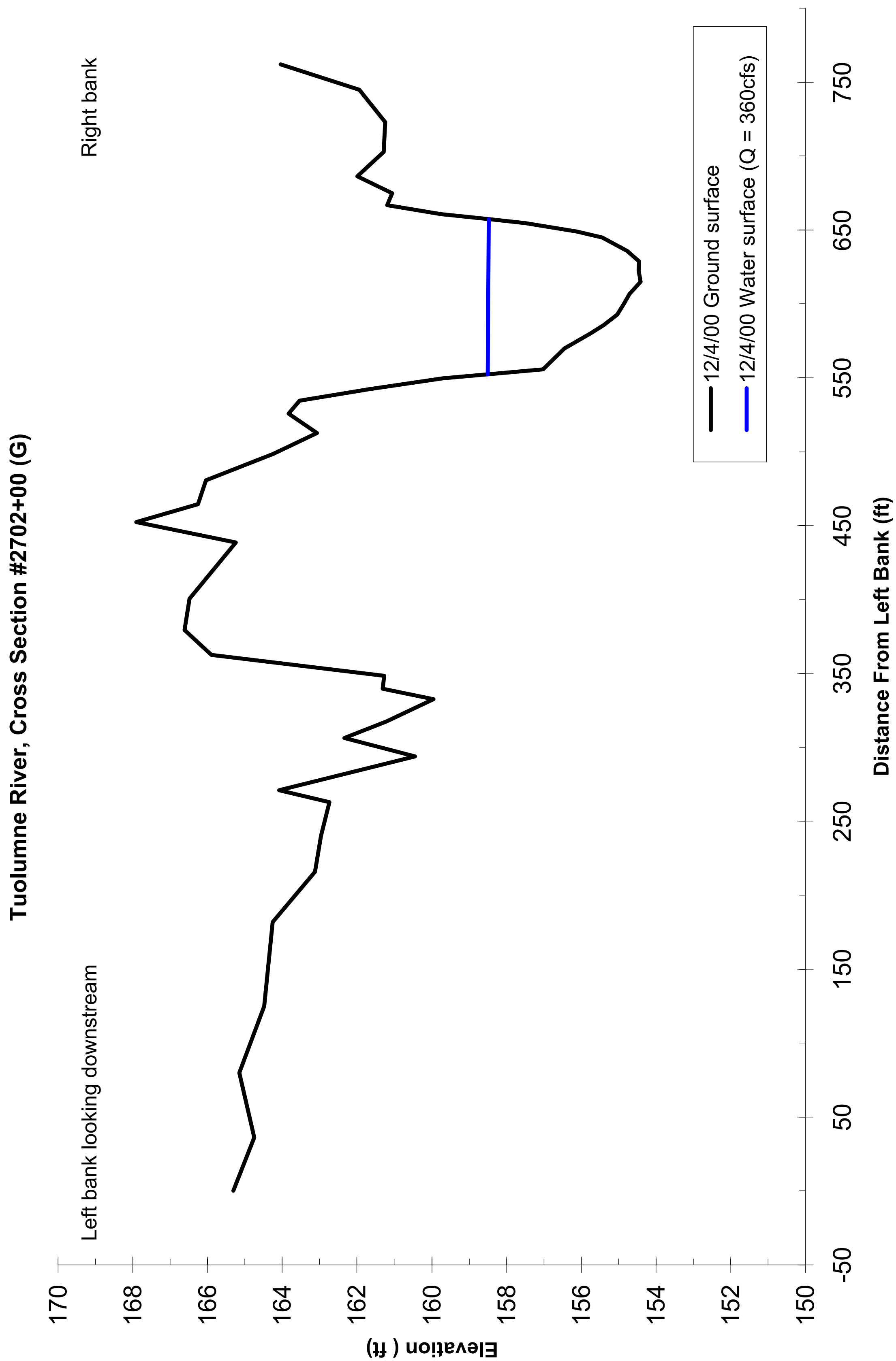

Tuolumne River - Cross Section #2674+00 (C)
Left bank looking downstream
Right bank
11/14/00 Ground surface
11/14/00 Water surface (Q = 360cfs)
Elevation (ft)
164
162
160
158
156
154
152
150
148
Distance from Left Bank (ft)
-50
0
50
100
150
200
250
300

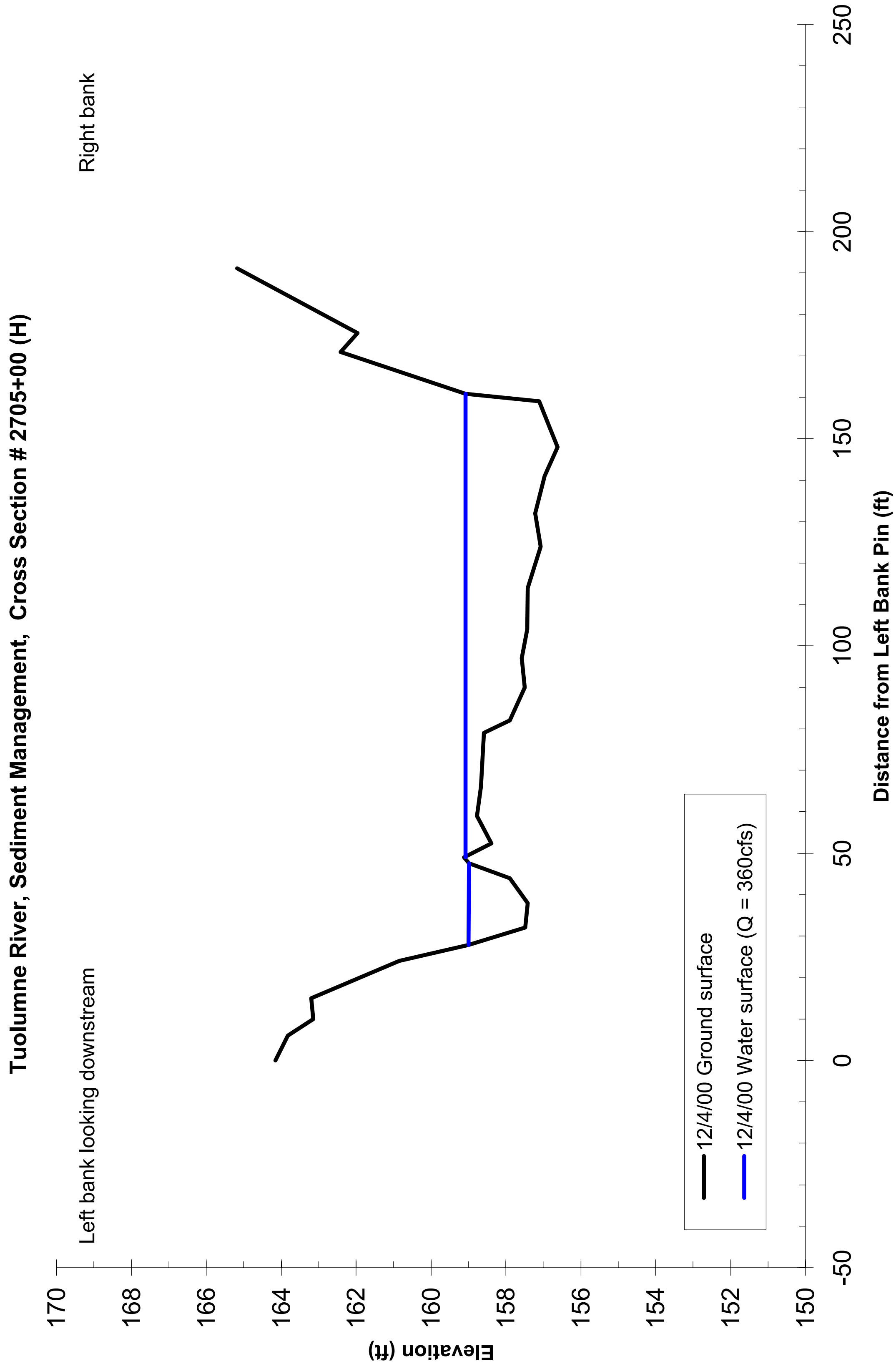


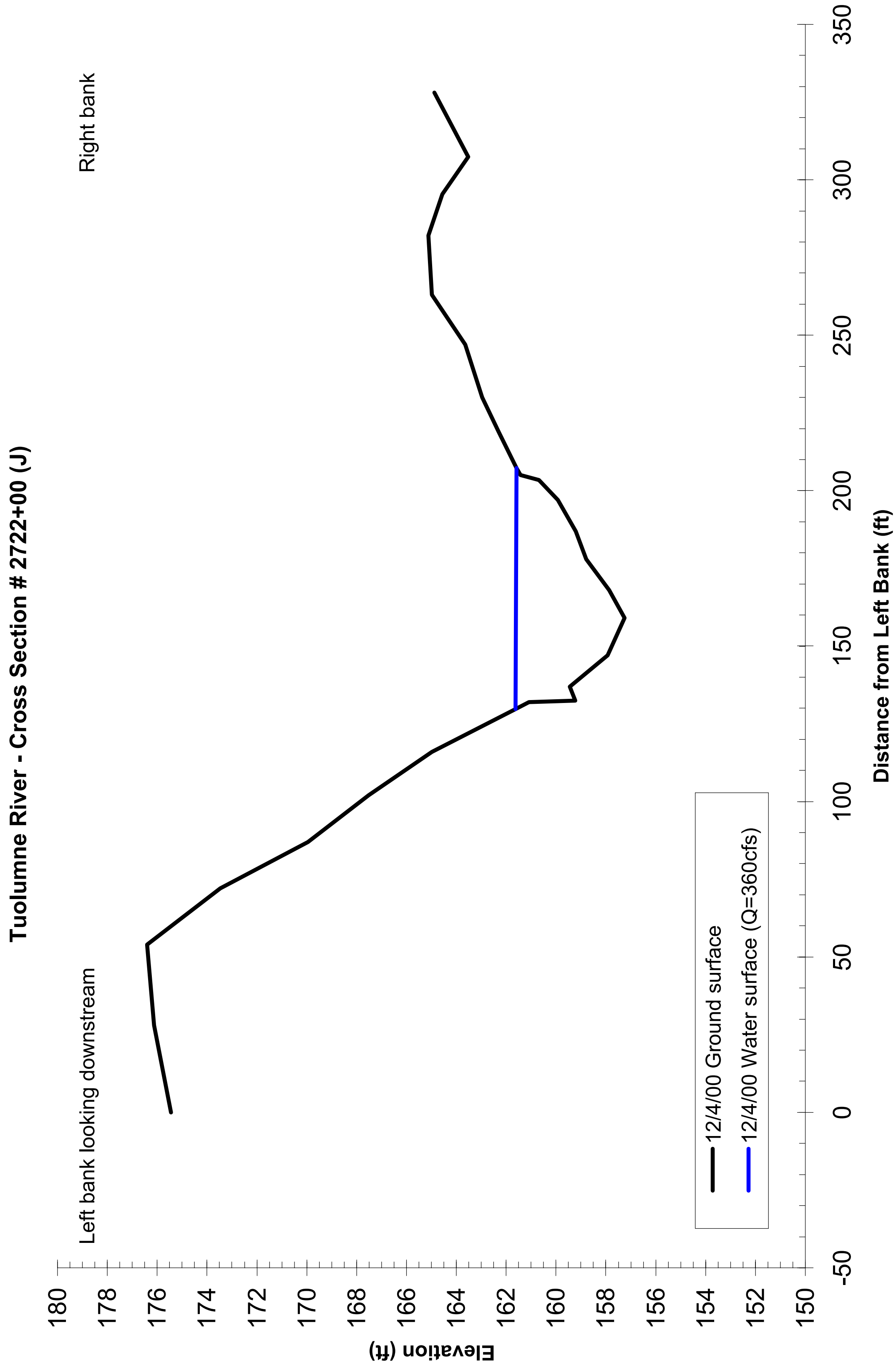
Tuolumne River - Cross Section 2685+00 (D)
Left bank looking downstream
Right bank
11/15/00 Ground surface
11/15/00 Water surface (Q= 360 cfs)
Elevation (ft)
170
168
166
164
162
160
158
156
154
152
Distance from Left Bank (ft)
-50
50
150
250
350
450
550
650
750

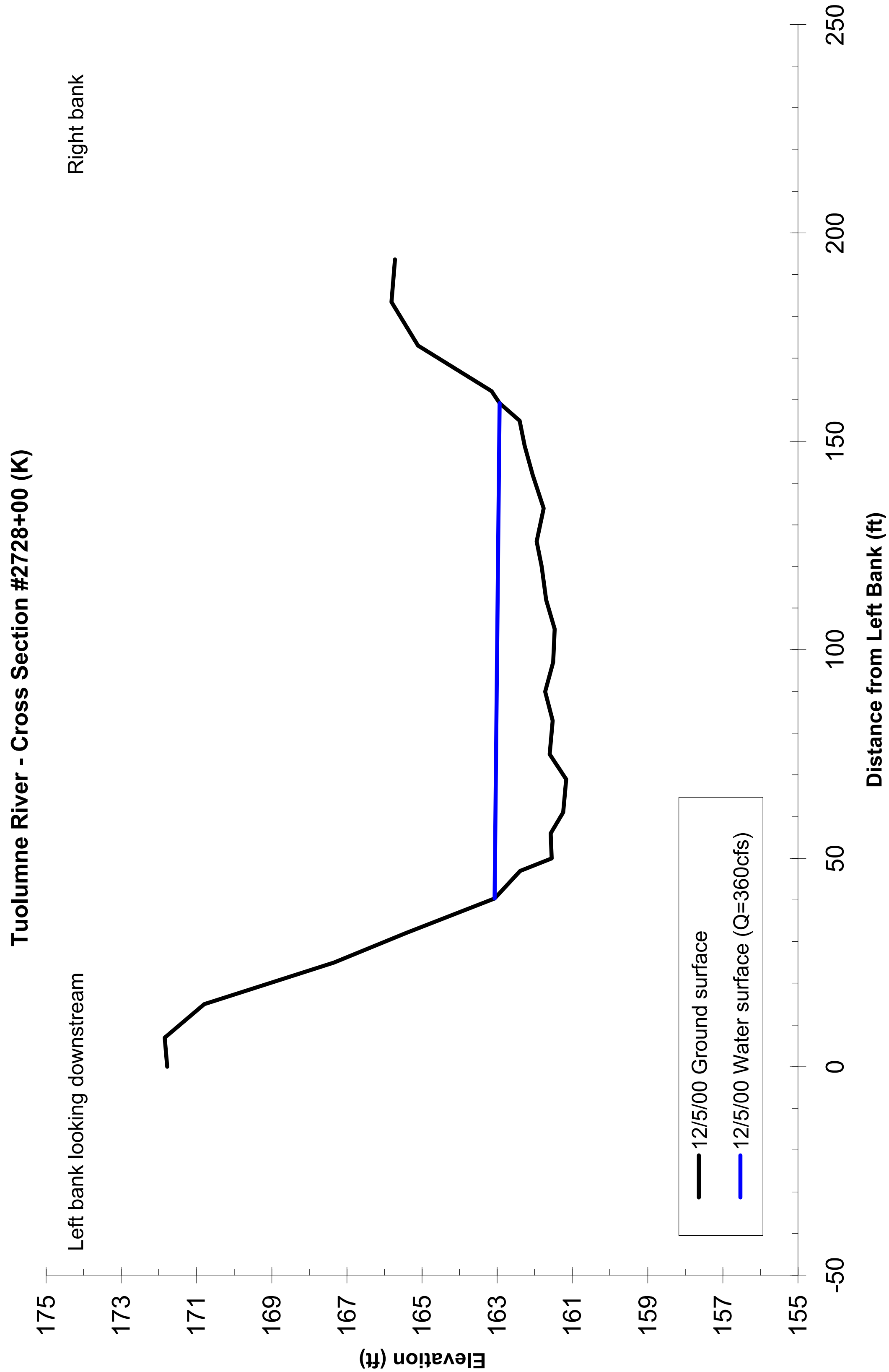

Tuolumne River - Cross Section #2690+00 (E)
Left bank looking downstream
Right bank
11/15/00 Ground surface
11/15/00 Water surface (Q= 360 cfs)
Elevation (ft)
164
162
160
158
156
154
152
150
Distance from Left Bank (ft)
-100
-50
0
50
100
150
200
250
300
350

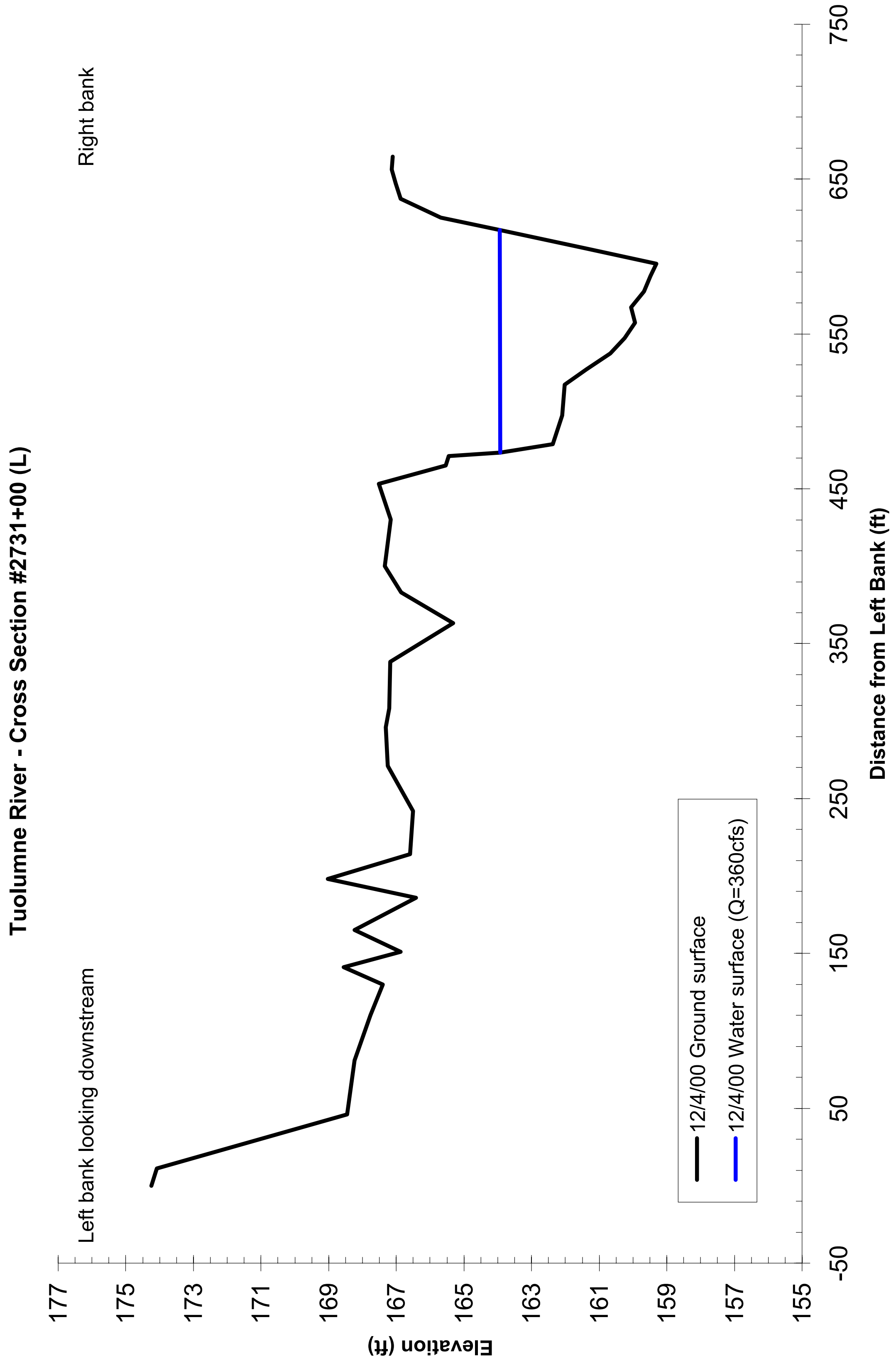

Tuolumne River - Cross Section #2699+00 (F)
Left bank looking downstream
Right bank
12/4/00 Ground surface
12/4/00 Water surface (Q = 360cfs)
Elevation (ft)
170
168
166
164
162
160
158
156
154
152
150
Distance From Left Bank Pin (ft)
-50
0
50
100
150
200
250

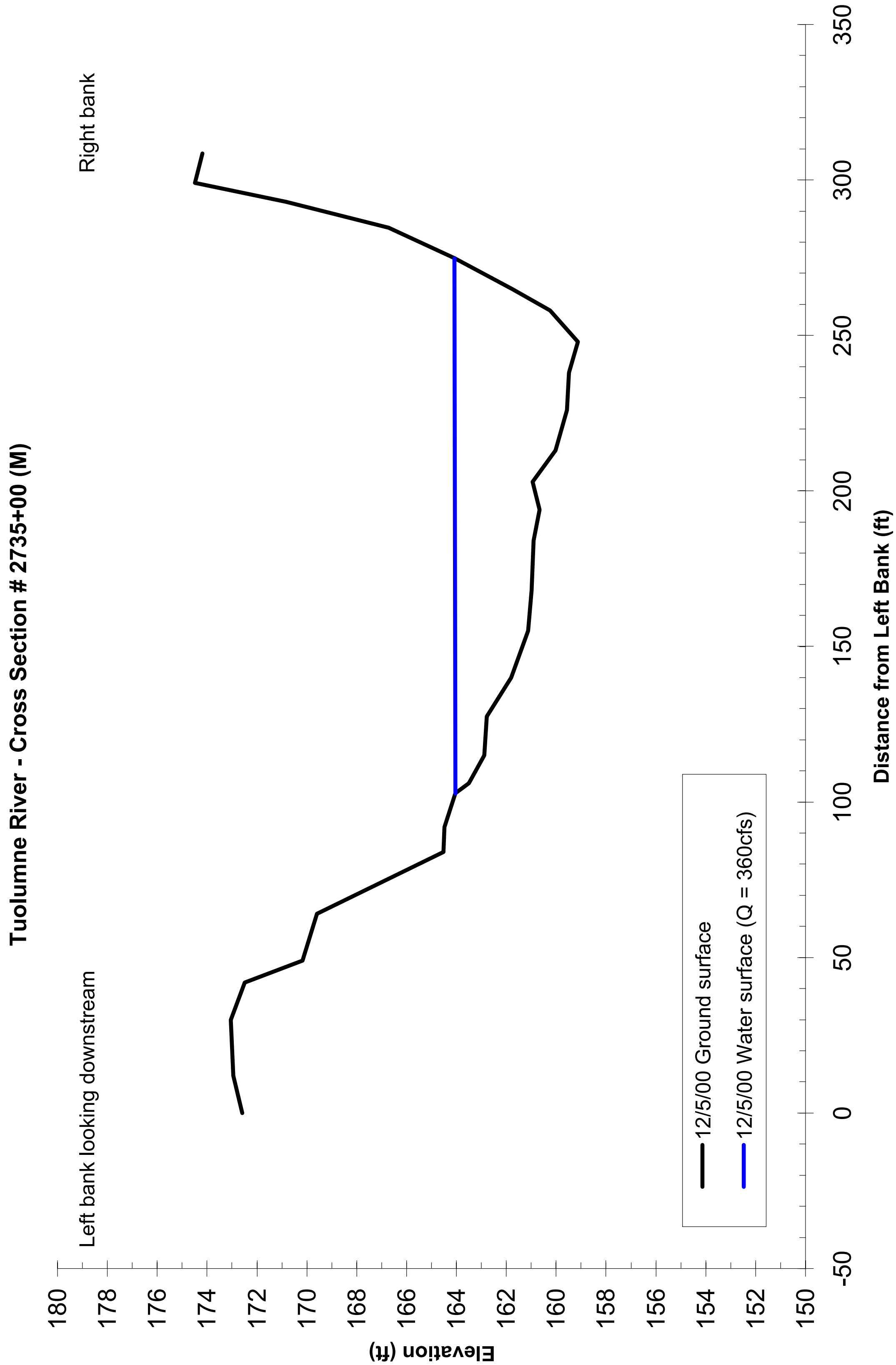

Tuolumne River, Cross Section #2702+00 (G)
Left bank looking downstream
Right bank
12/4/00 Ground surface
12/4/00 Water surface (Q = 360cfs)
Elevation (ft)
Distance From Left Bank (ft)
170
168
166
164
162
160
158
156
154
152
150
-50
50
150
250
350
450
550
650
750

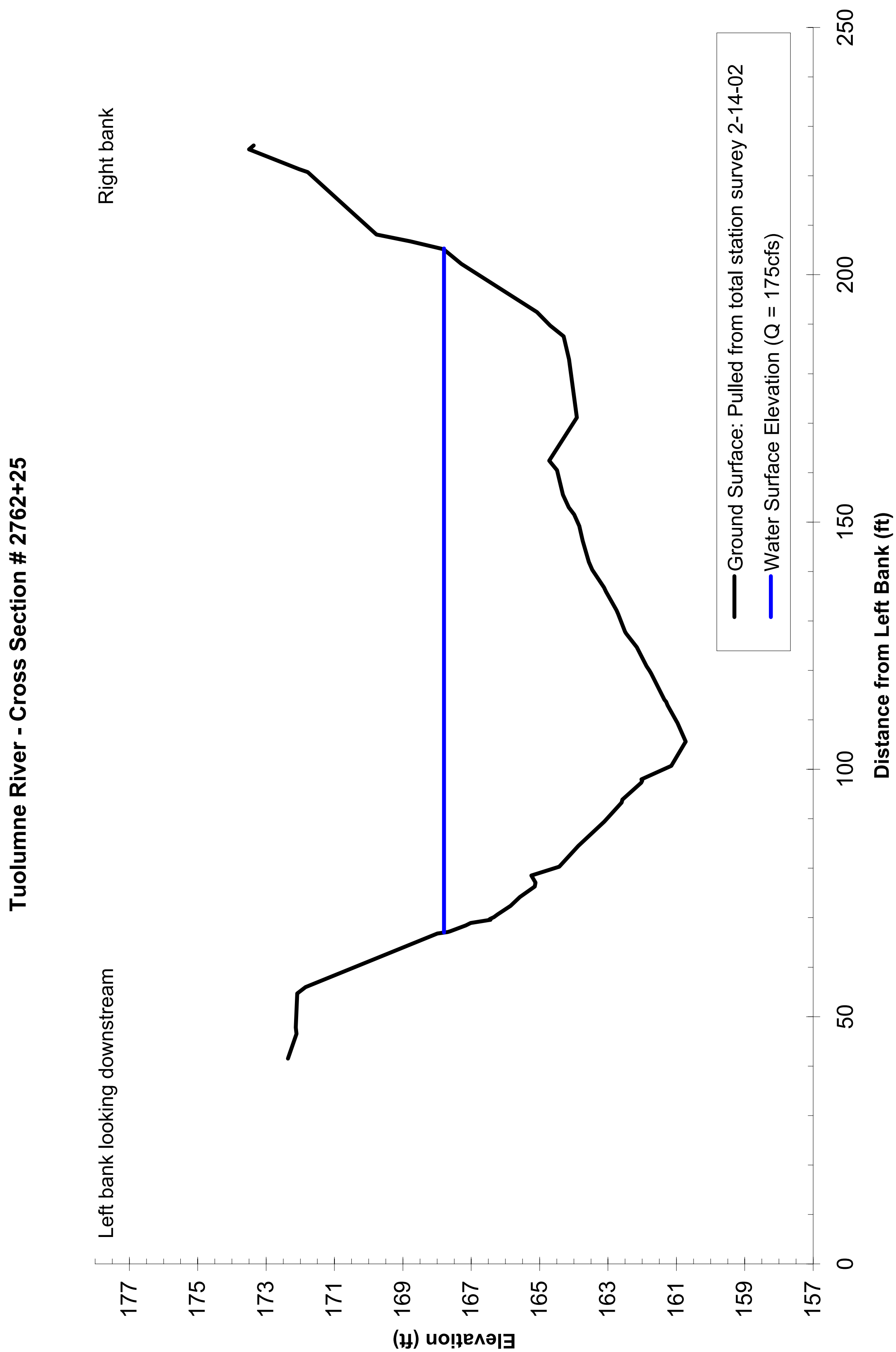

Tuolumne River, Sediment Management, Cross Section # 2705+00 (H)
Left bank looking downstream
Right bank
12/4/00 Ground surface
12/4/00 Water surface (Q = 360cfs)
Elevation (ft)
Distance from Left Bank Pin (ft)
170
168
166
164
162
160
158
156
154
152
150
-50
0
50
100
150
200
250

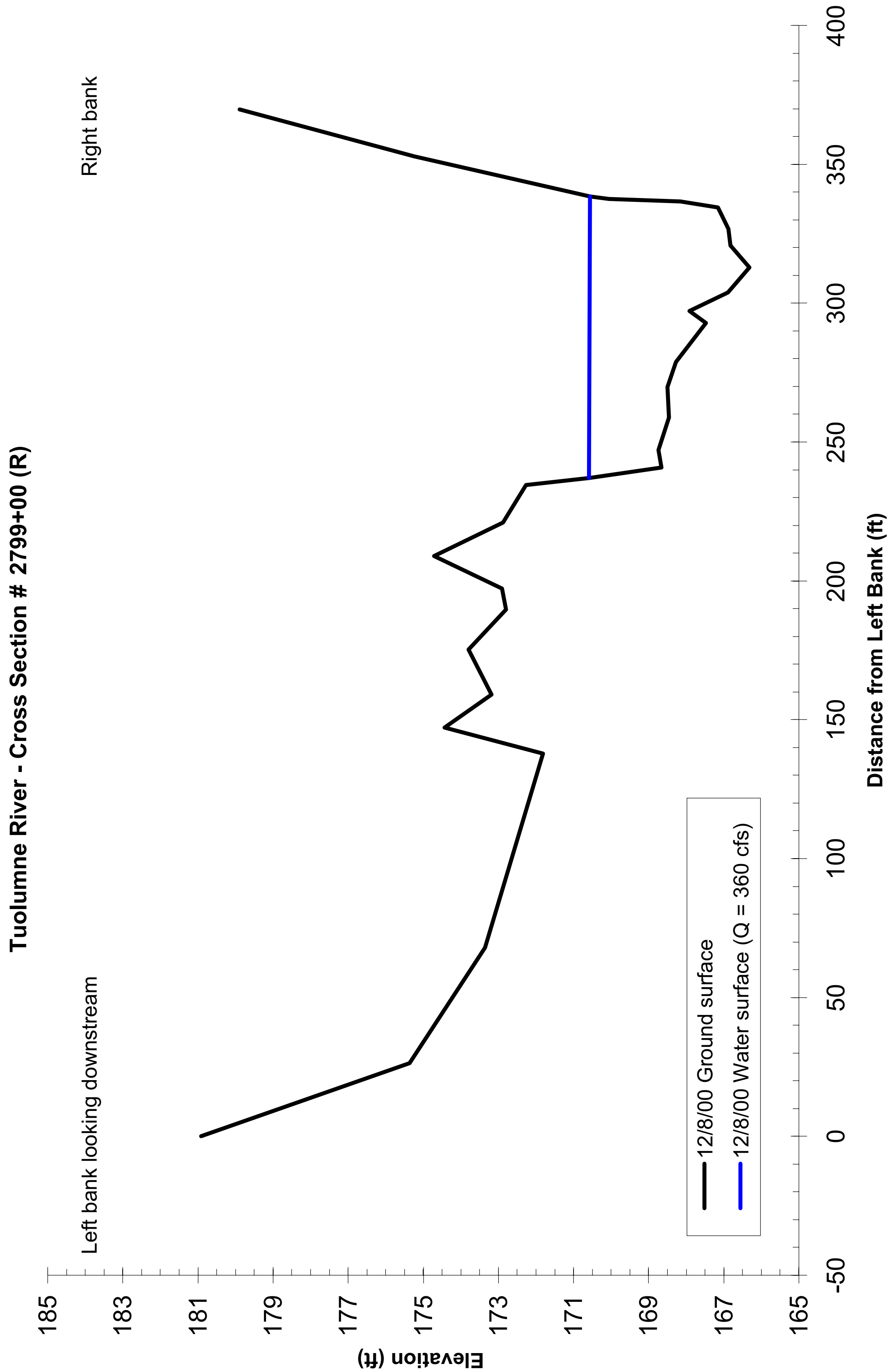

Tuolumne River - Cross Section # 2722+00 (J)
Left bank looking downstream
Right bank
12/4/00 Ground surface
12/4/00 Water surface (Q=360cfs)
Elevation (ft)
180
178
176
174
172
170
168
166
164
162
160
158
156
154
152
150
Distance from Left Bank (ft)
-50
0
50
100
150
200
250
300
350


Tuolumne River - Cross Section #2728+00 (K)
Left bank looking downstream
Right bank
12/5/00 Ground surface
12/5/00 Water surface (Q=360cfs)
Elevation (ft)
Distance from Left Bank (ft)
175
173
171
169
167
165
163
161
159
157
155
-50
0
50
100
150
200
250

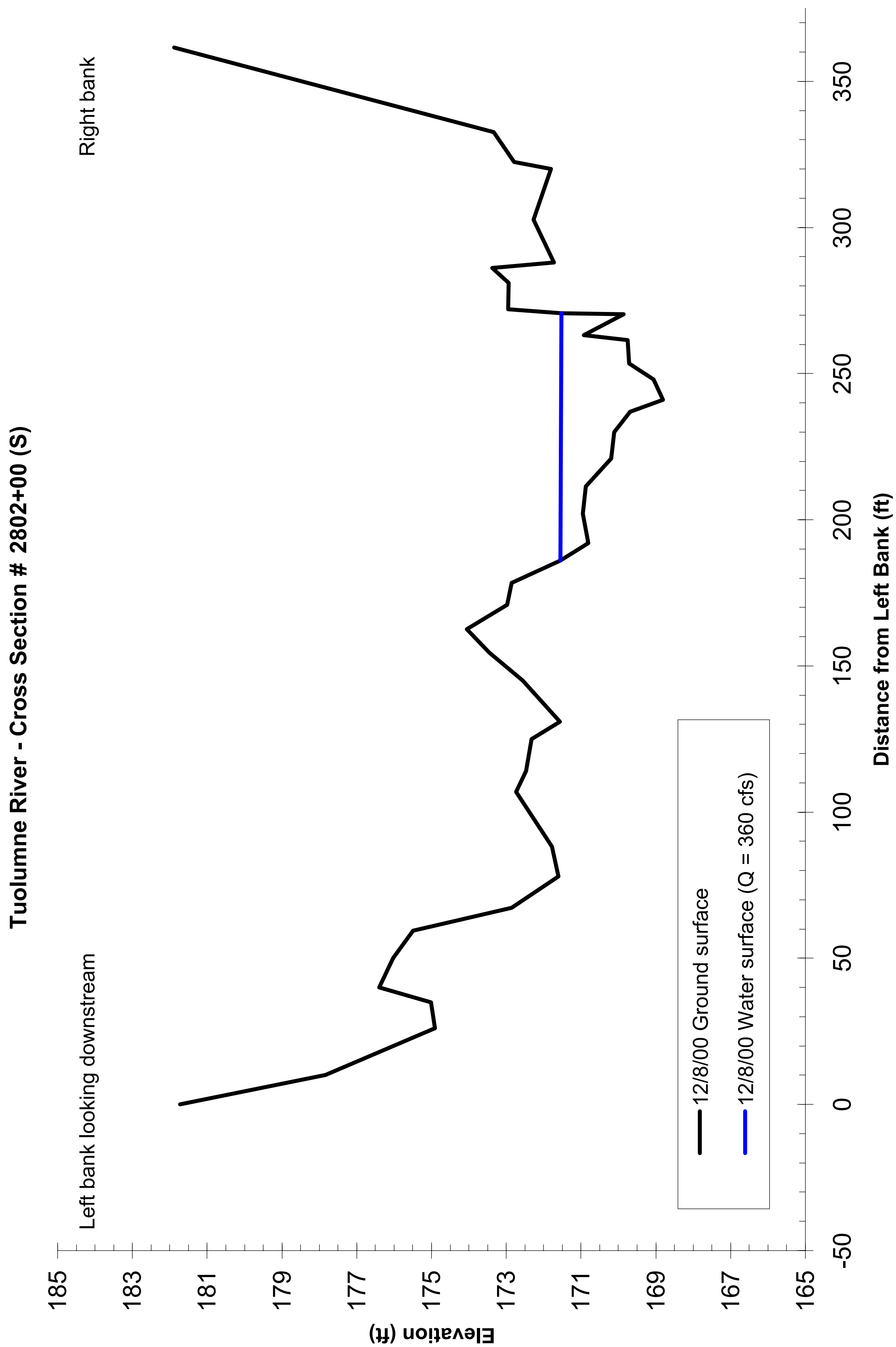

Tuolumne River - Cross Section #2731+00 (L)
Left bank looking downstream
Right bank
Elevation (ft)
177
175
173
171
169
167
165
163
161
159
157
155
Distance from Left Bank (ft)
-50
50
150
250
350
450
550
650
750
12/4/00 Ground surface
12/4/00 Water surface (Q=360cfs)

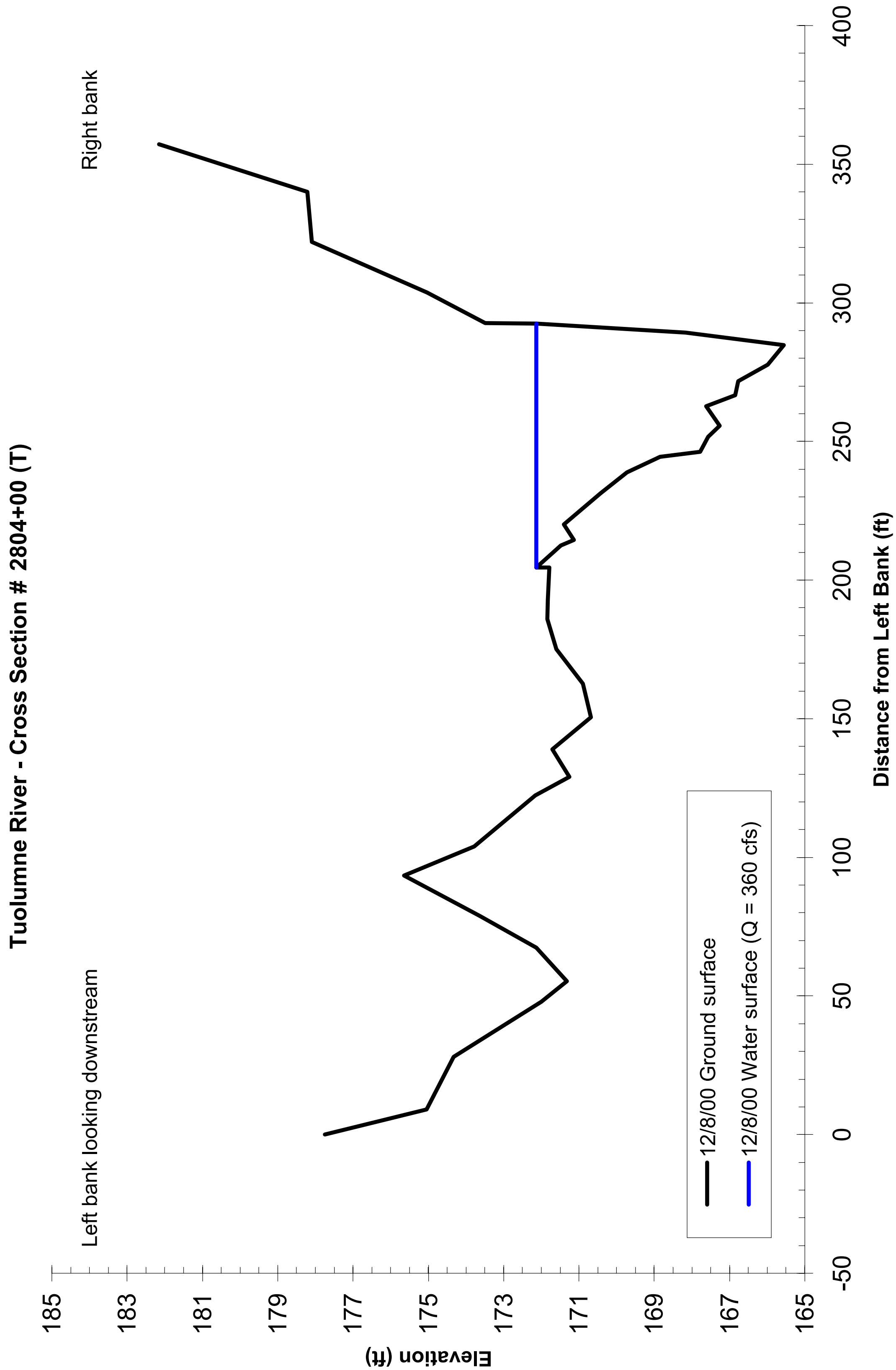

Tuolumne River - Cross Section # 2735+00 (M)
Left bank looking downstream
Right bank
12/5/00 Ground surface
12/5/00 Water surface (Q = 360cfs)
Elevation (ft)
180
178
176
174
172
170
168
166
164
162
160
158
156
154
152
150
Distance from Left Bank (ft)
-50
0
50
100
150
200
250
300
350

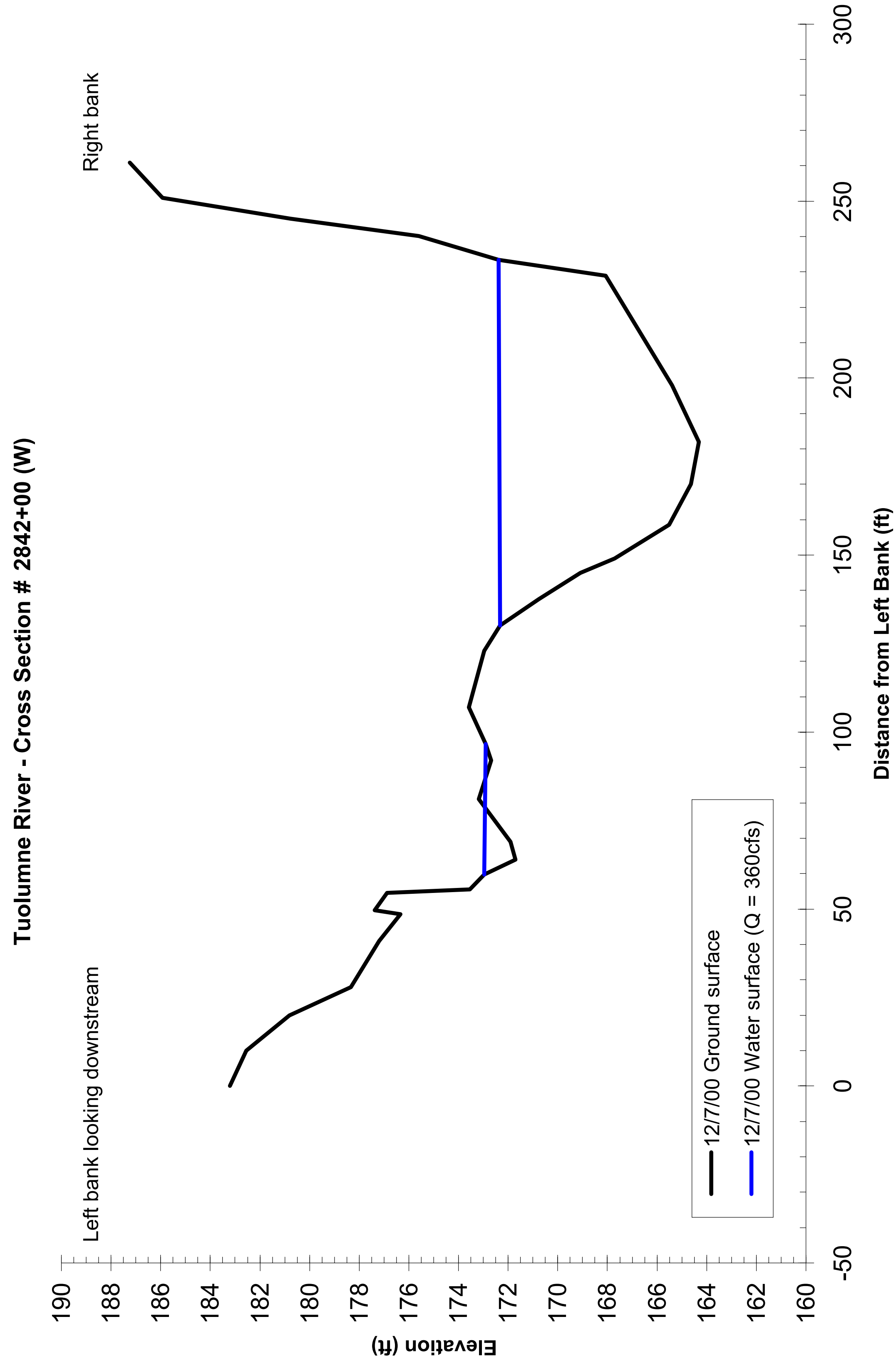

Tuolumne River - Cross Section # 2762+25
Left bank looking downstream
Right bank
Ground Surface: Pulled from total station survey 2-14-02
Water Surface Elevation (Q = 175cfs)
Elevation (ft)
177
175
173
171
169
167
165
163
161
159
157
0
50
100
150
200
250
Distance from Left Bank (ft)

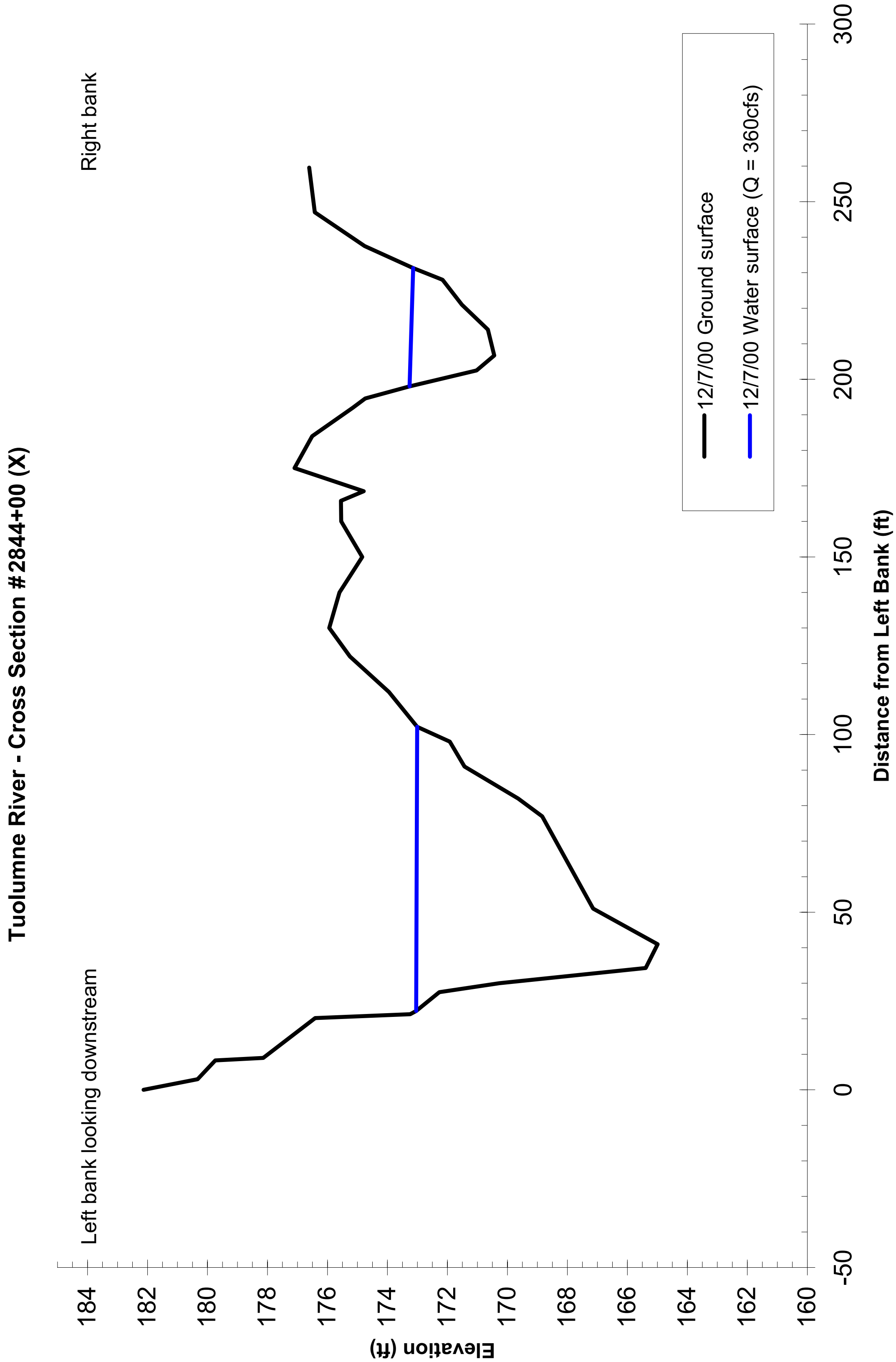


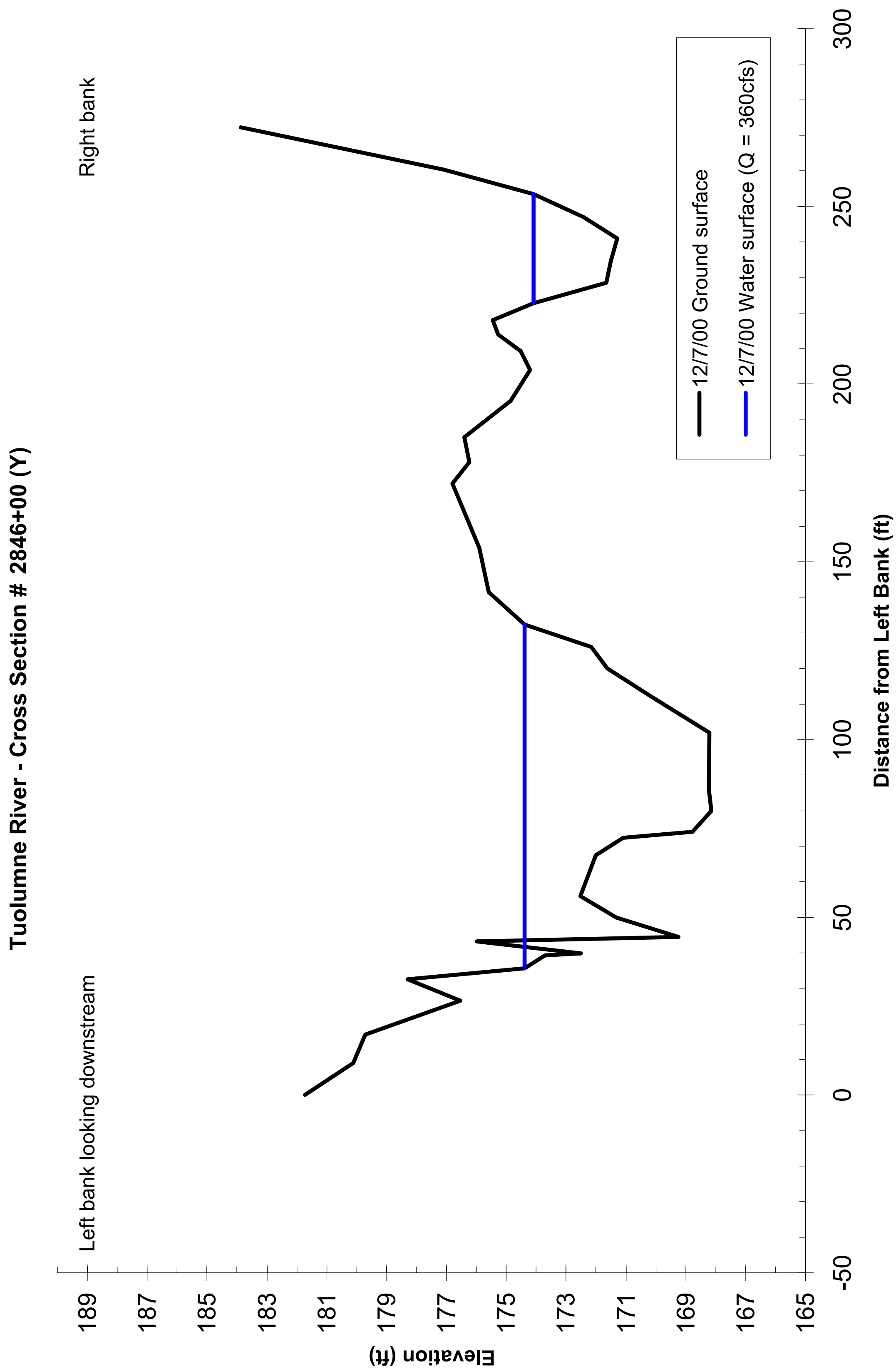
Tuolumne River - Cross Section # 2799+00 (R)
Left bank looking downstream
Right bank
12/8/00 Ground surface
12/8/00 Water surface (Q = 360 cfs)
Elevation (ft)
185
183
181
179
177
175
173
171
169
167
165
Distance from Left Bank (ft)
-50
0
50
100
150
200
250
300
350
400

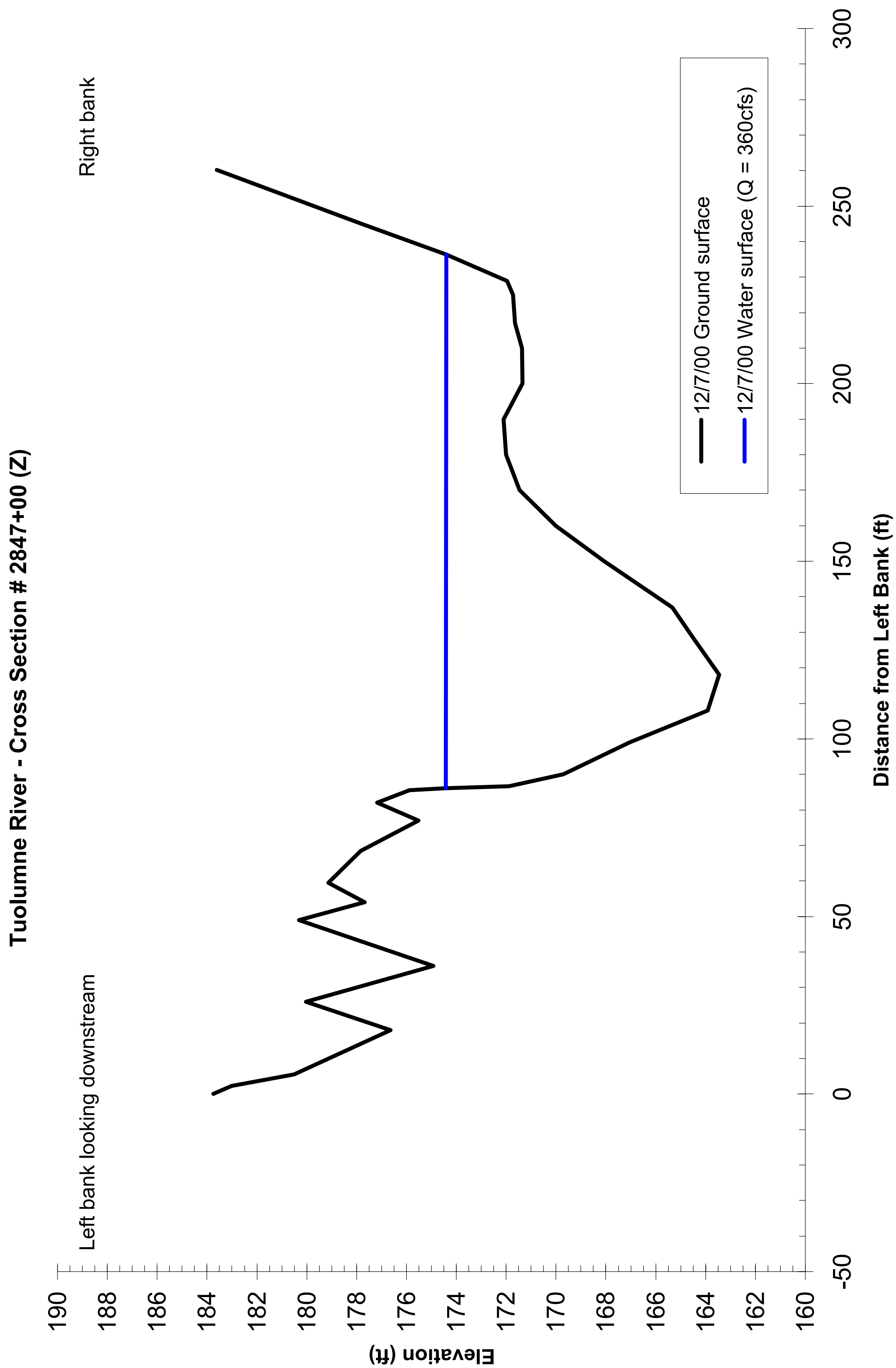

Tuolumne River - Cross Section # 2802+00 (S)
Left bank looking downstream
Right bank
12/8/00 Ground surface
12/8/00 Water surface (Q = 360 cfs)
Elevation (ft)
Distance from Left Bank (ft)
185
183
181
179
177
175
173
171
169
167
165
-50
0
50
100
150
200
250
300
350


Tuolumne River - Cross Section # 2804+00 (T)
Left bank looking downstream
Right bank
12/8/00 Ground surface
12/8/00 Water surface (Q = 360 cfs)
Elevation (ft)
Distance from Left Bank (ft)
185
183
181
179
177
175
173
171
169
167
165
-50
0
50
100
150
200
250
300
350
400

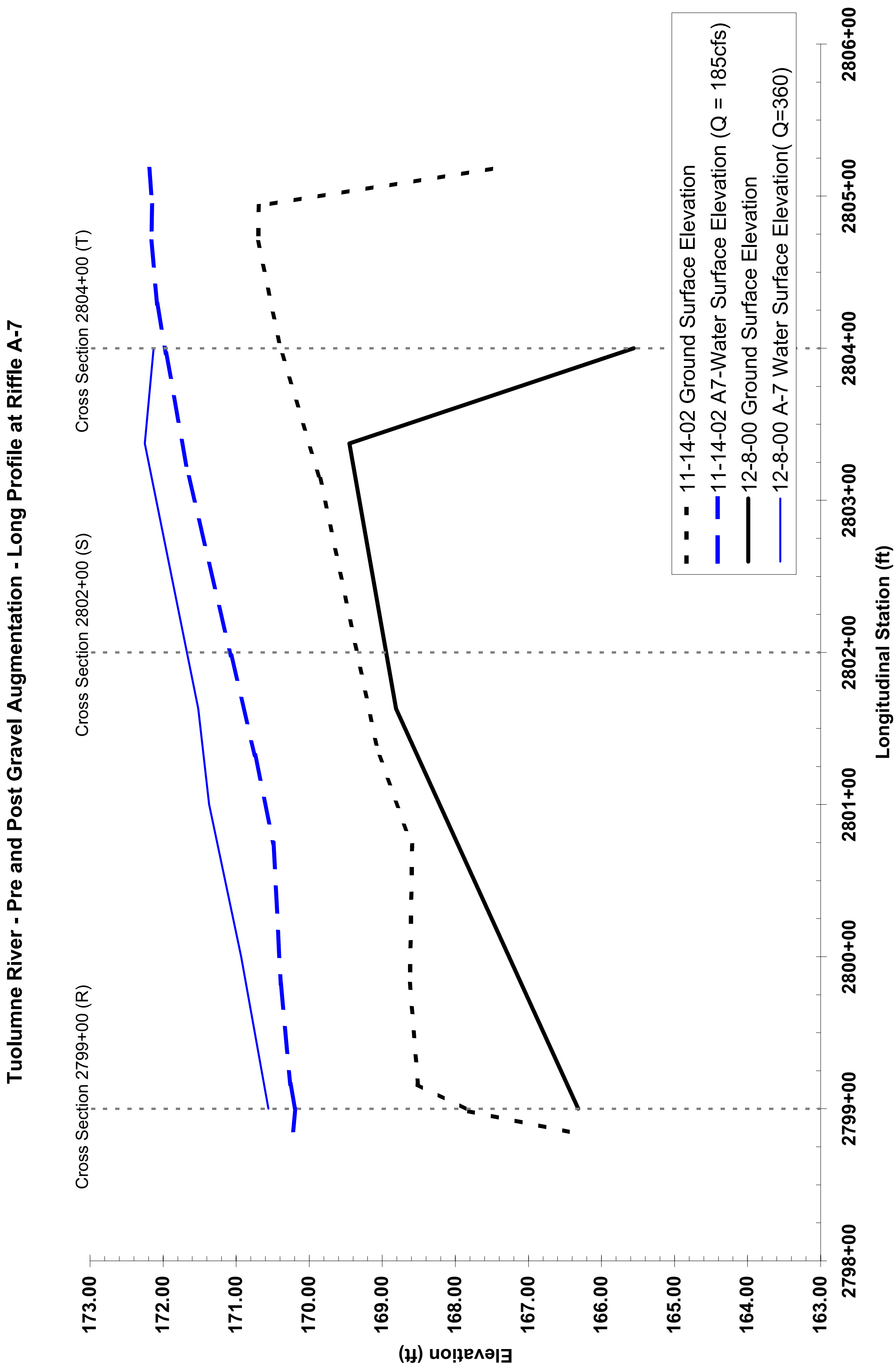

Tuolumne River - Cross Section # 2842+00 (W)
Left bank looking downstream
Right bank
12/7/00 Ground surface
12/7/00 Water surface (Q = 360cfs)
Elevation (ft)
Distance from Left Bank (ft)
190
188
186
184
182
180
178
176
174
172
170
168
166
164
162
160
-50
0
50
100
150
200
250
300

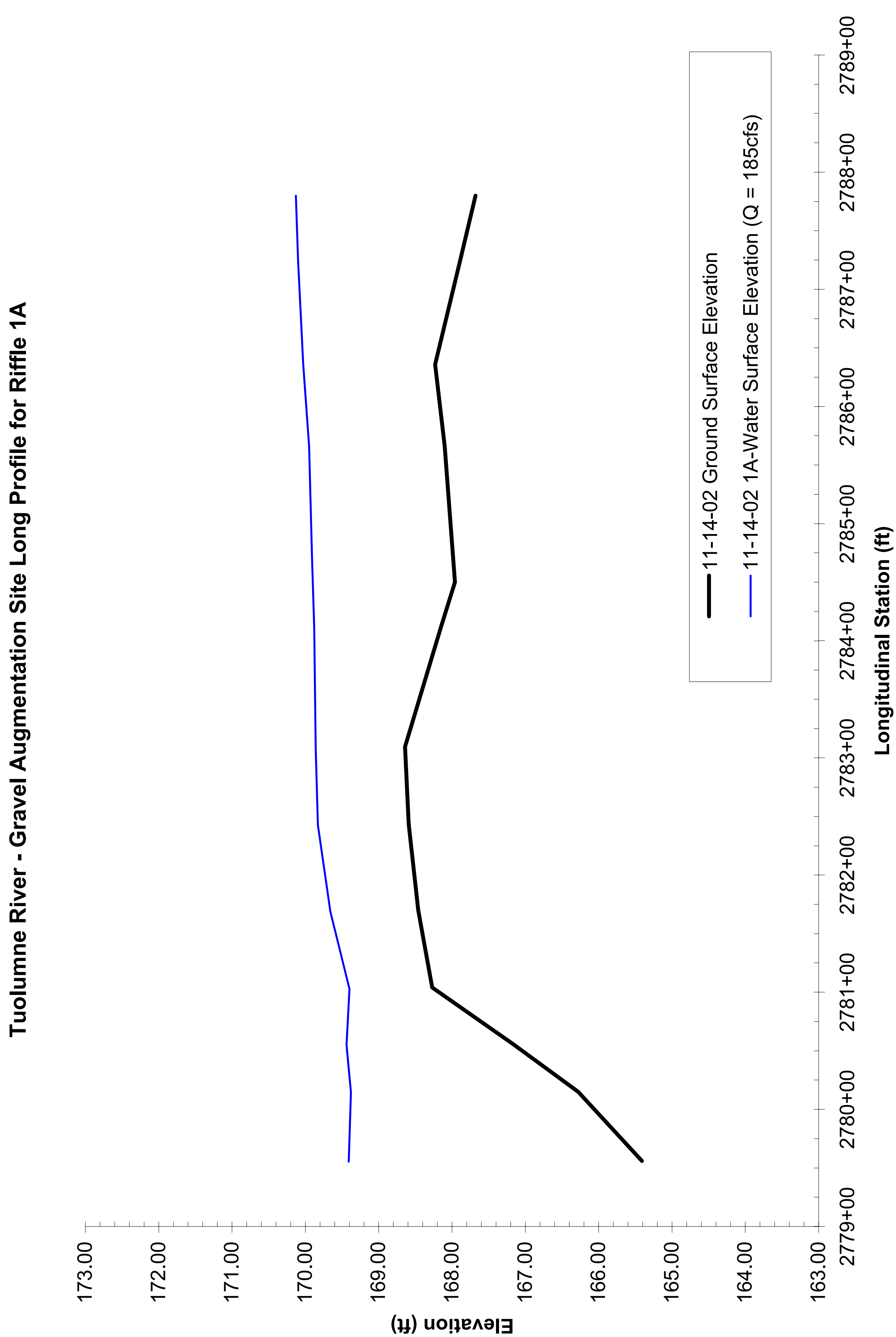

Tuolumne River - Cross Section #2844+00 (X)
Left bank looking downstream
Right bank
12/7/00 Ground surface
12/7/00 Water surface (Q = 360cfs)
Elevation (ft)
184
182
180
178
176
174
172
170
168
166
164
162
160
Distance from Left Bank (ft)
-50
0
50
100
150
200
250
300

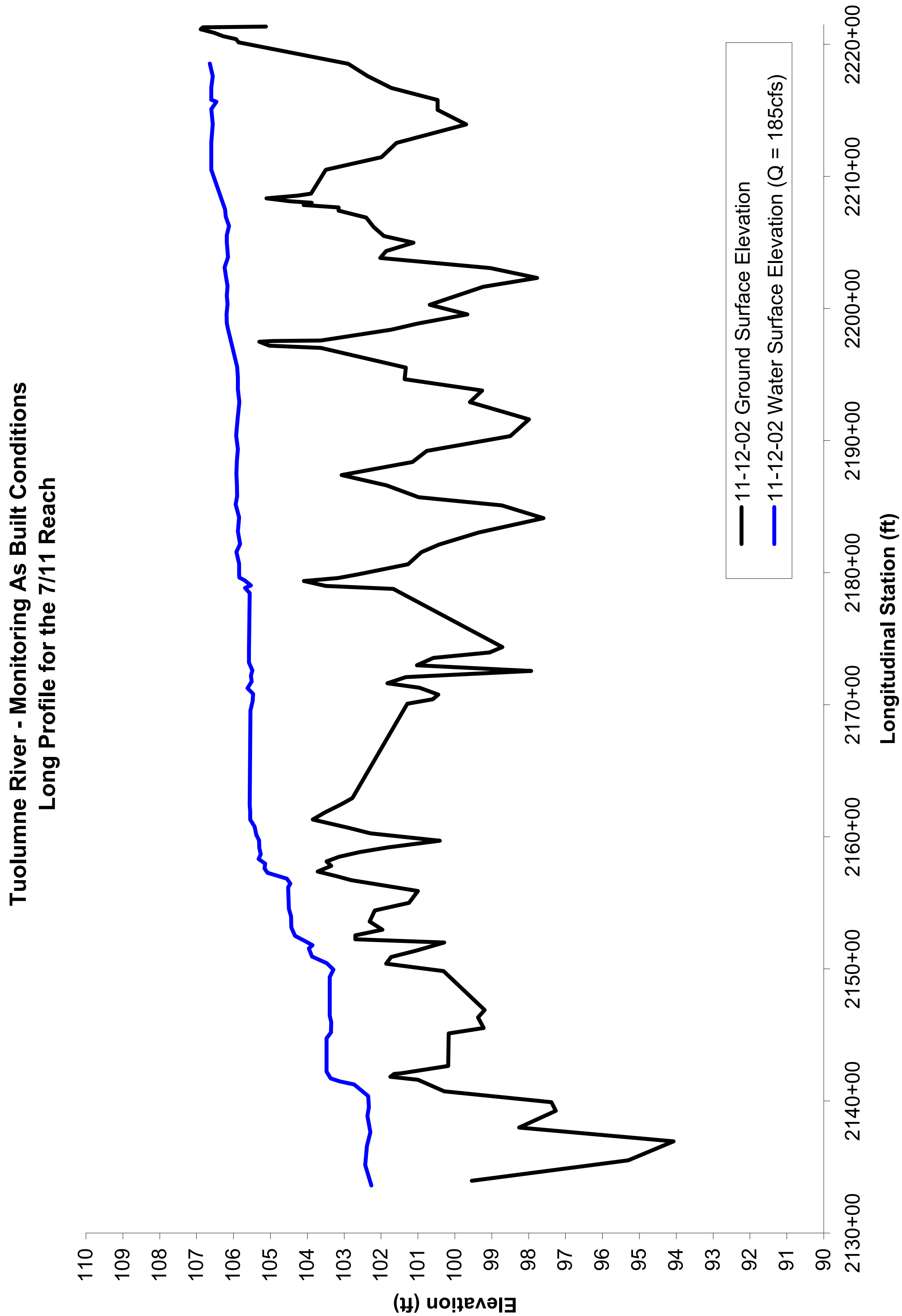

Tuolumne River - Cross Section # 2846+00 (Y)
Left bank looking downstream
Right bank
12/7/00 Ground surface
12/7/00 Water surface (Q = 360cfs)
Distance from Left Bank (ft)
Elevation (ft)
-50
0
50
100
150
200
250
300
165
167
169
171
173
175
177
179
181
183
185
187
189



Tuolumne River - Cross Section # 2847+00 (Z)
Left bank looking downstream
Right bank
12/7/00 Ground surface
12/7/00 Water surface (Q = 360cfs)
Distance from Left Bank (ft)
Elevation (ft)
-50
0
50
100
150
200
250
300
160
162
164
166
168
170
172
174
176
178
180
182
184
186
188
190


Tuolumne River - Pre and Post Gravel Augmentation - Long Profile at Riffle A-7
Cross Section 2799+00 (R)
Cross Section 2802+00 (S)
Cross Section 2804+00 (T)
11-14-02 Ground Surface Elevation
11-14-02 A7-Water Surface Elevation (Q = 185cfs)
12-8-00 Ground Surface Elevation
12-8-00 A-7 Water Surface Elevation(Q=360)
Elevation (ft)
173.00
172.00
171.00
170.00
169.00
168.00
167.00
166.00
165.00
164.00
163.00
Longitudinal Station (ft)
2798+00
2799+00
2800+00
2801+00
2802+00
2803+00
2804+00
2805+00
2806+00

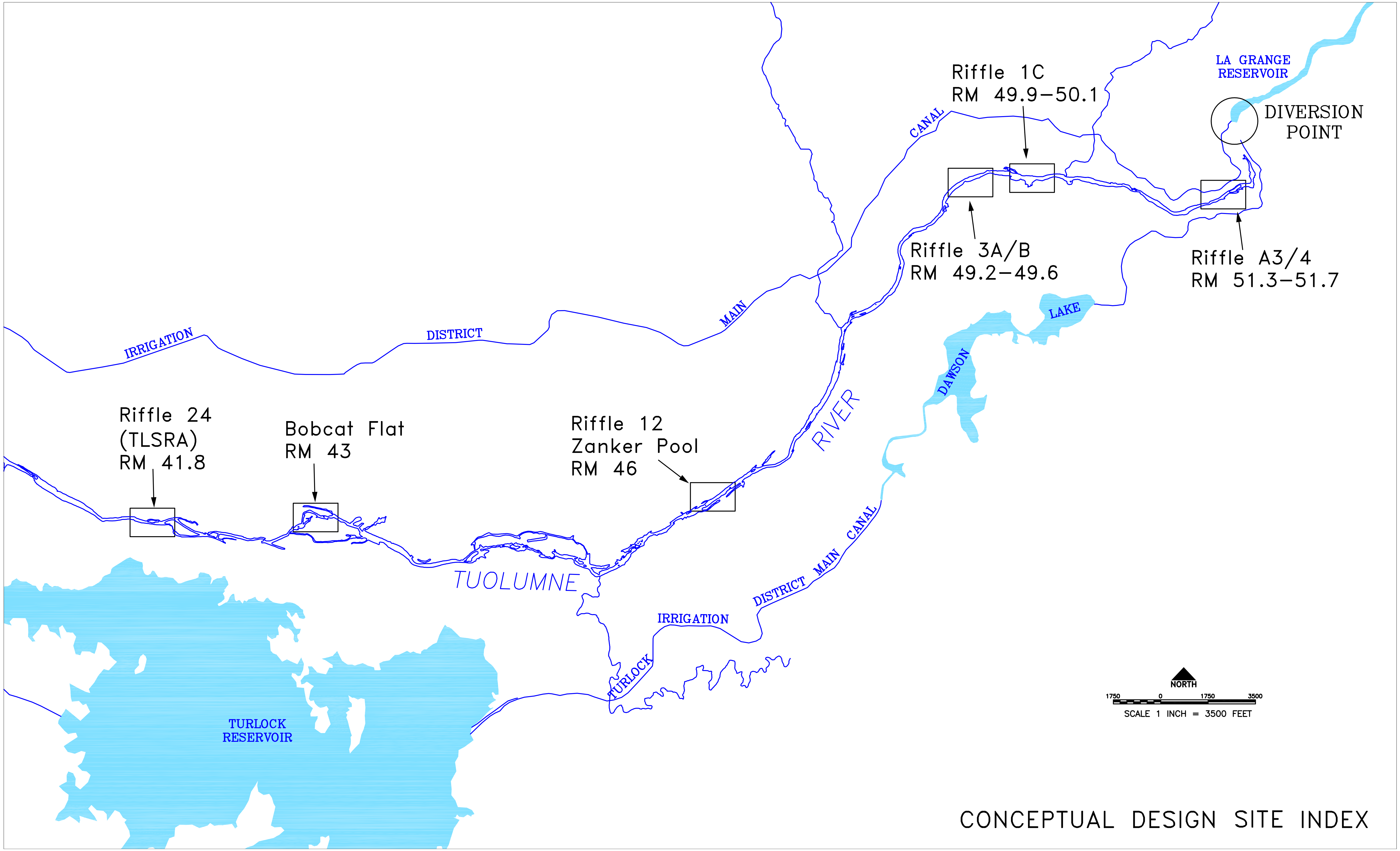

Tuolumne River - Gravel Augmentation Site Long Profile for Riffle 1A
Elevation (ft)
173.00
172.00
171.00
170.00
169.00
168.00
167.00
166.00
165.00
164.00
163.00
2779+00
2780+00
2781+00
2782+00
2783+00
2784+00
2785+00
2786+00
2787+00
2788+00
2789+00
Longitudinal Station (ft)
11-14-02 Ground Surface Elevation
11-14-02 1A-Water Surface Elevation (Q = 185cfs)


Tuolumne River - Monitoring As Built Conditions
Long Profile for the 7/11 Reach
Elevation (ft)
Longitudinal Station (ft)
11-12-02 Ground Surface Elevation
11-12-02 Water Surface Elevation (Q = 185cfs)
110
109
108
107
106
105
104
103
102
101
100
99
98
97
96
95
94
93
92
91
90
2130+00
2140+00
2150+00
2160+00
2170+00
2180+00
2190+00
2200+00
2210+00
2220+00

Appendix B

Conceptual Designs Developed for High Priority Sediment Augmentation Sites.

Riffle A 3/4
Riffle 1C
Riffle 3 A/B
Zanker Site
Bobcat Flat
Turlock Lake State Recreation Area


Riffle 1C
RM 49.9–50.1
LA GRANGE RESERVOIR
DIVERSION POINT
CANAL
Riffle 3A/B
RM 49.2–49.6
Riffle A3/4
RM 51.3–51.7
IRRIGATION
DISTRICT
MAIN
LAKE
DAWSON
Riffle 24
(TLSRA)
RM 41.8
Bobcat Flat
RM 43
Riffle 12
Zanker Pool
RM 46
RIVER
TUOLUMNE
CANAL
MAIN
DISTRICT
IRRIGATION
TURLOCK
TURLOCK RESERVOIR
NORTH
1750 0 1750 3500
SCALE 1 INCH = 3500 FEET
CONCEPTUAL DESIGN SITE INDEX

Coarse Sediment Augmentation Volume Estimates

1) Extend pool tail and riffle between stations 2847+75 and 2846+75.
   Approximate Coarse Sediment 1,600 cu. yds.

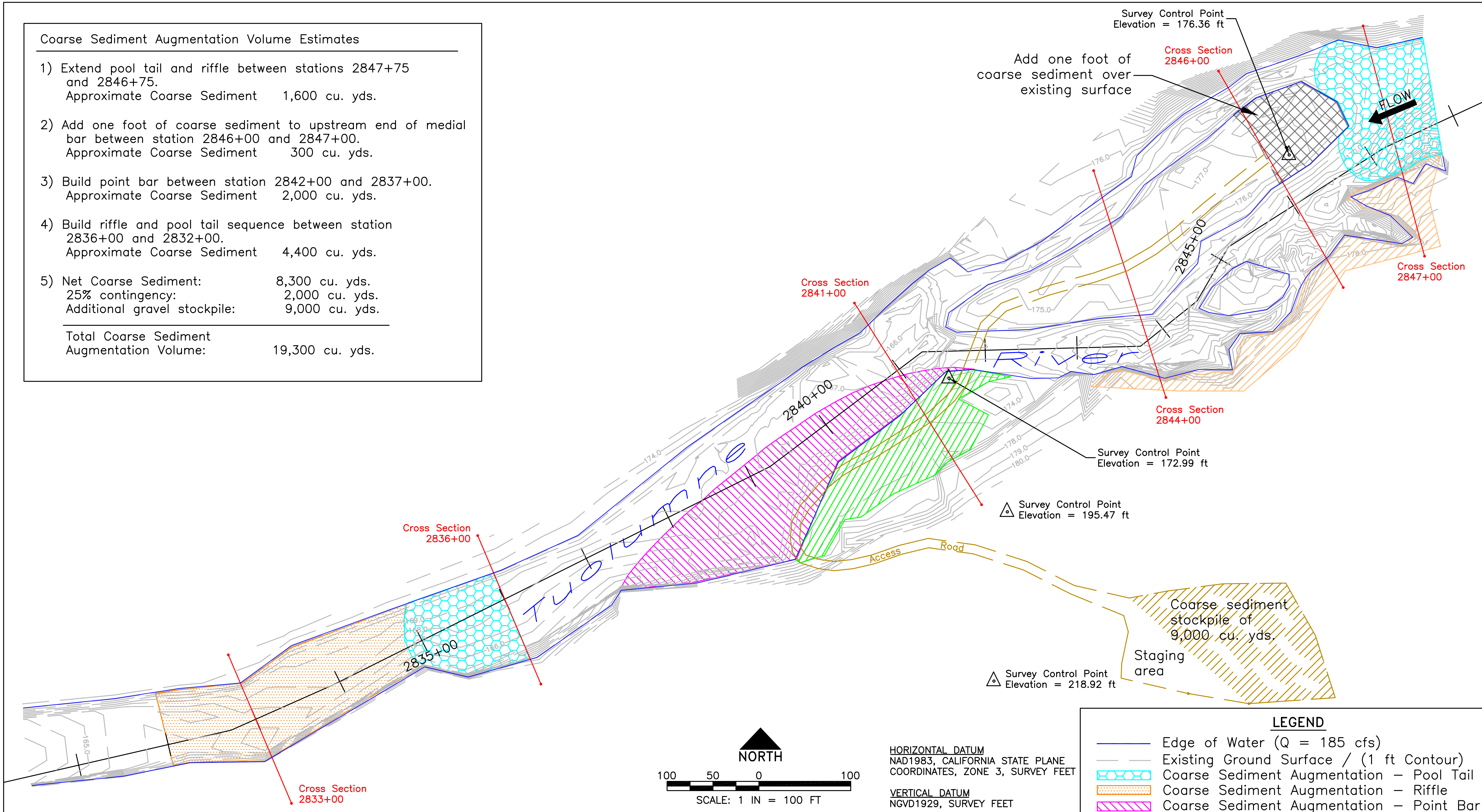
2) Add one foot of coarse sediment to upstream end of medial bar between station 2846+00 and 2847+00.
   Approximate Coarse Sediment 300 cu. yds.

3) Build point bar between station 2842+00 and 2837+00.
   Approximate Coarse Sediment 2,000 cu. yds.

4) Build riffle and pool tail sequence between station 2836+00 and 2832+00.
   Approximate Coarse Sediment 4,400 cu. yds.

5) Net Coarse Sediment: 8,300 cu. yds.
   25% contingency: 2,000 cu. yds.
   Additional gravel stockpile: 9,000 cu. yds.

Total Coarse Sediment Augmentation Volume: 19,300 cu. yds.



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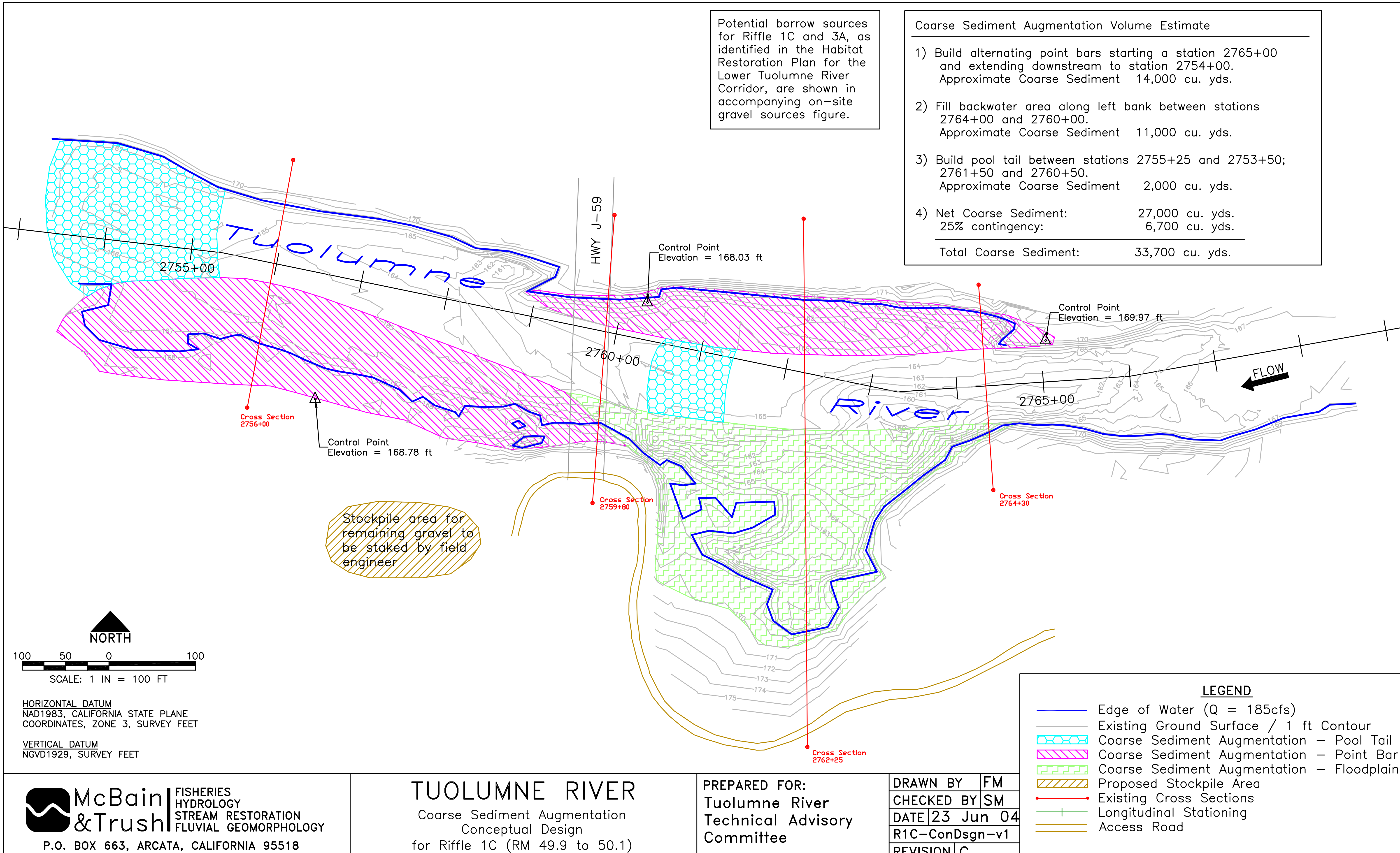
TUOLUMNE RIVER

Coarse Sediment Augmentation
Conceptual Design
for Riffle A 3/4 (RM 51.3 to 51.7)

PREPARED FOR:
Tuolumne River Technical Advisory Committee

DRAWN BY	FM
CHECKED BY	SM
DATE	23 Jun 04
RA3–4ConDsgn–v1	
REVISION	C


Potential borrow sources for Riffle 1C and 3A, as identified in the Habitat Restoration Plan for the Lower Tuolumne River Corridor, are shown in accompanying on-site gravel sources figure.
Coarse Sediment Augmentation Volume Estimate
1) Build alternating point bars starting a station 2765+00 and extending downstream to station 2754+00.
Approximate Coarse Sediment 14,000 cu. yds.
2) Fill backwater area along left bank between stations 2764+00 and 2760+00.
Approximate Coarse Sediment 11,000 cu. yds.
3) Build pool tail between stations 2755+25 and 2753+50; 2761+50 and 2760+50.
Approximate Coarse Sediment 2,000 cu. yds.
4) Net Coarse Sediment: 27,000 cu. yds.
25% contingency: 6,700 cu. yds.
Total Coarse Sediment: 33,700 cu. yds.
Tuolumne River
HWY J-59
2755+00
2760+00
2765+00
Control Point Elevation = 168.03 ft
Control Point Elevation = 169.97 ft
Control Point Elevation = 168.78 ft
FLOW
Cross Section 2756+00
Cross Section 2759+80
Cross Section 2764+30
Cross Section 2762+25
Stockpile area for remaining gravel to be staked by field engineer
NORTH
100 50 0 100
SCALE: 1 IN = 100 FT
HORIZONTAL DATUM
NAD1983, CALIFORNIA STATE PLANE COORDINATES, ZONE 3, SURVEY FEET
VERTICAL DATUM
NGVD1929, SURVEY FEET
LEGEND
Edge of Water (Q = 185cfs)
Existing Ground Surface / 1 ft Contour
Coarse Sediment Augmentation – Pool Tail
Coarse Sediment Augmentation – Point Bar
Coarse Sediment Augmentation – Floodplain
Proposed Stockpile Area
Existing Cross Sections
Longitudinal Stationing
Access Road
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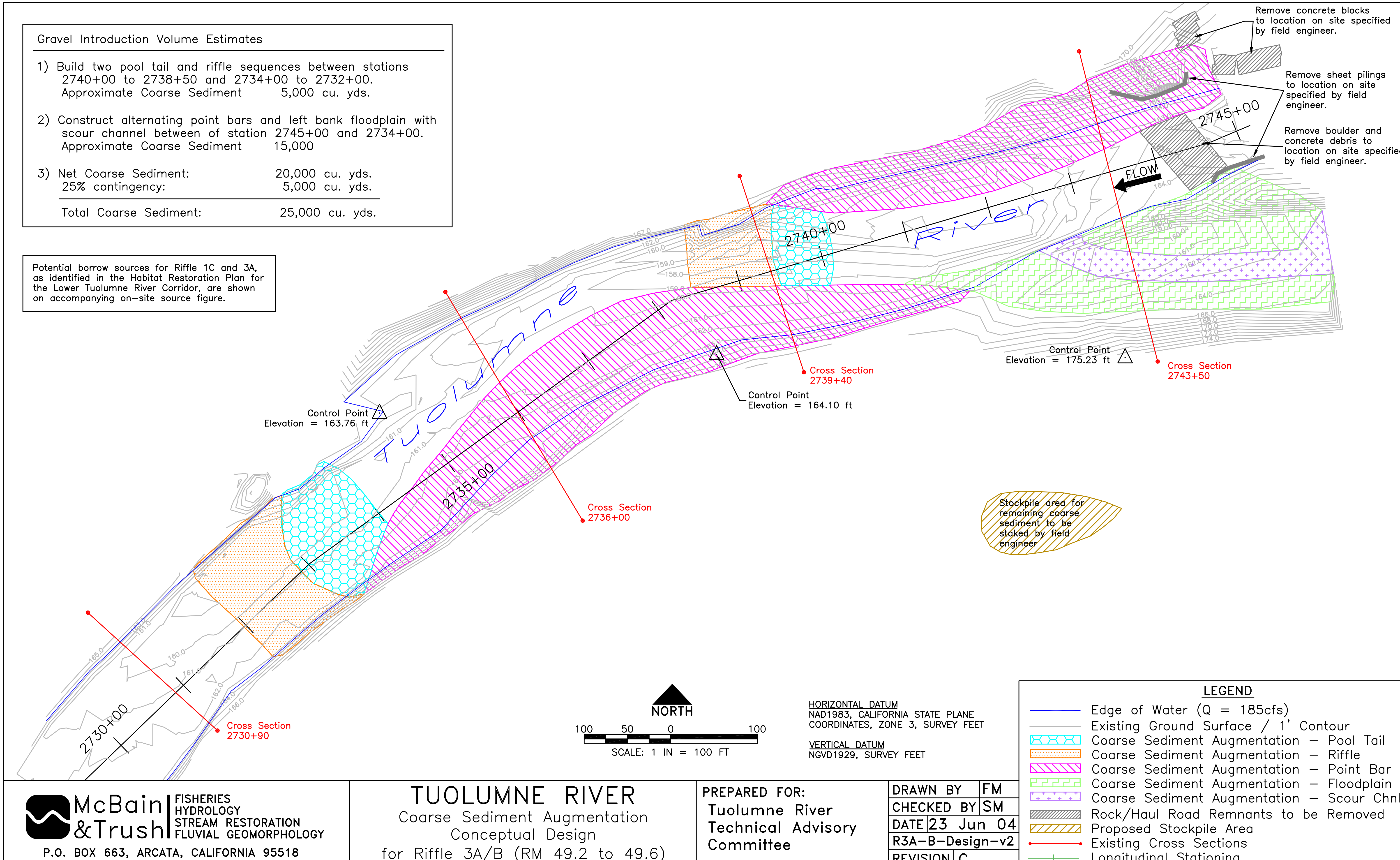
TUOLUMNE RIVER
Coarse Sediment Augmentation Conceptual Design for Riffle 1C (RM 49.9 to 50.1)
PREPARED FOR:
Tuolumne River Technical Advisory Committee
DRAWN BY FM
CHECKED BY SM
DATE 23 Jun 04
R1C-ConDsgn-v1
REVISION C


Gravel Introduction Volume Estimates
1) Build two pool tail and riffle sequences between stations 2740+00 to 2738+50 and 2734+00 to 2732+00. Approximate Coarse Sediment 5,000 cu. yds.
2) Construct alternating point bars and left bank floodplain with scour channel between of station 2745+00 and 2734+00. Approximate Coarse Sediment 15,000
3) Net Coarse Sediment: 20,000 cu. yds.
25% contingency: 5,000 cu. yds.
Total Coarse Sediment: 25,000 cu. yds.
Potential borrow sources for Riffle 1C and 3A, as identified in the Habitat Restoration Plan for the Lower Tuolumne River Corridor, are shown on accompanying on-site source figure.
Remove concrete blocks to location on site specified by field engineer.
Remove sheet pilings to location on site specified by field engineer.
Remove boulder and concrete debris to location on site specified by field engineer.
FLOW
Tuolumne River
2730+00
2735+00
2740+00
2745+00
Control Point Elevation = 163.76 ft
Control Point Elevation = 164.10 ft
Control Point Elevation = 175.23 ft
Cross Section 2730+90
Cross Section 2736+00
Cross Section 2739+40
Cross Section 2743+50
Stockpile area for remaining coarse sediment to be staked by field engineer
NORTH
100 50 0 100
SCALE: 1 IN = 100 FT
HORIZONTAL DATUM
NAD1983, CALIFORNIA STATE PLANE COORDINATES, ZONE 3, SURVEY FEET
VERTICAL DATUM
NGVD1929, SURVEY FEET
LEGEND
Edge of Water (Q = 185cfs)
Existing Ground Surface / 1' Contour
Coarse Sediment Augmentation – Pool Tail
Coarse Sediment Augmentation – Riffle
Coarse Sediment Augmentation – Point Bar
Coarse Sediment Augmentation – Floodplain
Coarse Sediment Augmentation – Scour Chnl.
Rock/Haul Road Remnants to be Removed
Proposed Stockpile Area
Existing Cross Sections
Longitudinal Stationing
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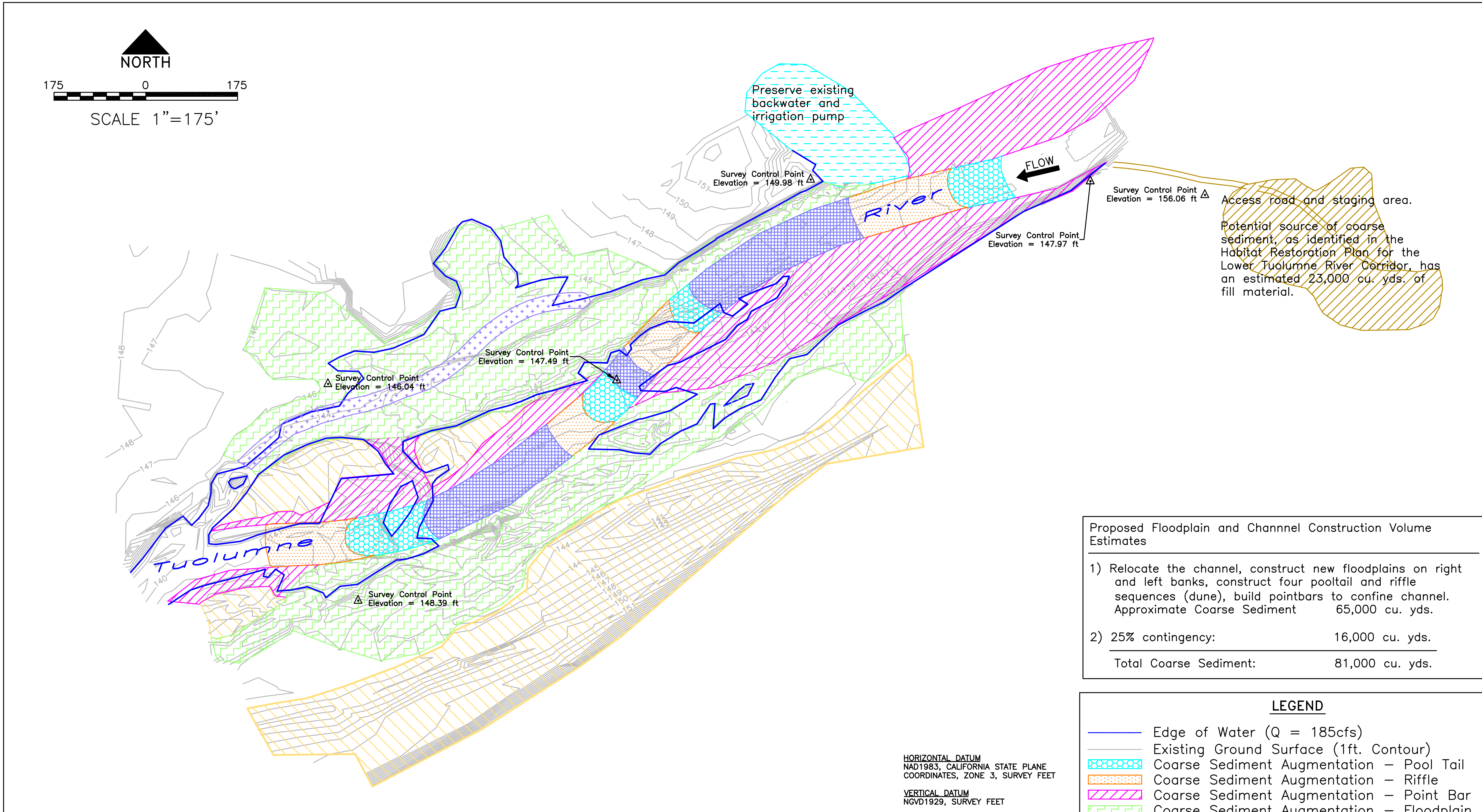
P.O. BOX 663, ARCATA, CALIFORNIA 95518
TUOLUMNE RIVER
Coarse Sediment Augmentation Conceptual Design for Riffle 3A/B (RM 49.2 to 49.6)
PREPARED FOR:
Tuolumne River Technical Advisory Committee
DRAWN BY FM
CHECKED BY SM
DATE 23 Jun 04
R3A-B-Design-v2
REVISION C



Proposed Floodplain and Channel Construction Volume Estimates

1) Relocate the channel, construct new floodplains on right and left banks, construct four pooltail and riffle sequences (dune), build pointbars to confine channel.

Approximate Coarse Sediment	65,000 cu. yds.
2) 25% contingency:	16,000 cu. yds.
Total Coarse Sediment:	81,000 cu. yds.

LEGEND

- Edge of Water (Q = 185cfs)
- Existing Ground Surface (1ft. Contour)
- Coarse Sediment Augmentation – Pool Tail
- Coarse Sediment Augmentation – Riffle
- Coarse Sediment Augmentation – Point Bar
- Coarse Sediment Augmentation – Floodplain
- Coarse Sediment Augmentation – Pool/Run
- Coarse Sediment Augmentation – Scour Chnl.
- No Construction – Saved Vegetation
- Backwater and Irrigation Pump
- Access Road

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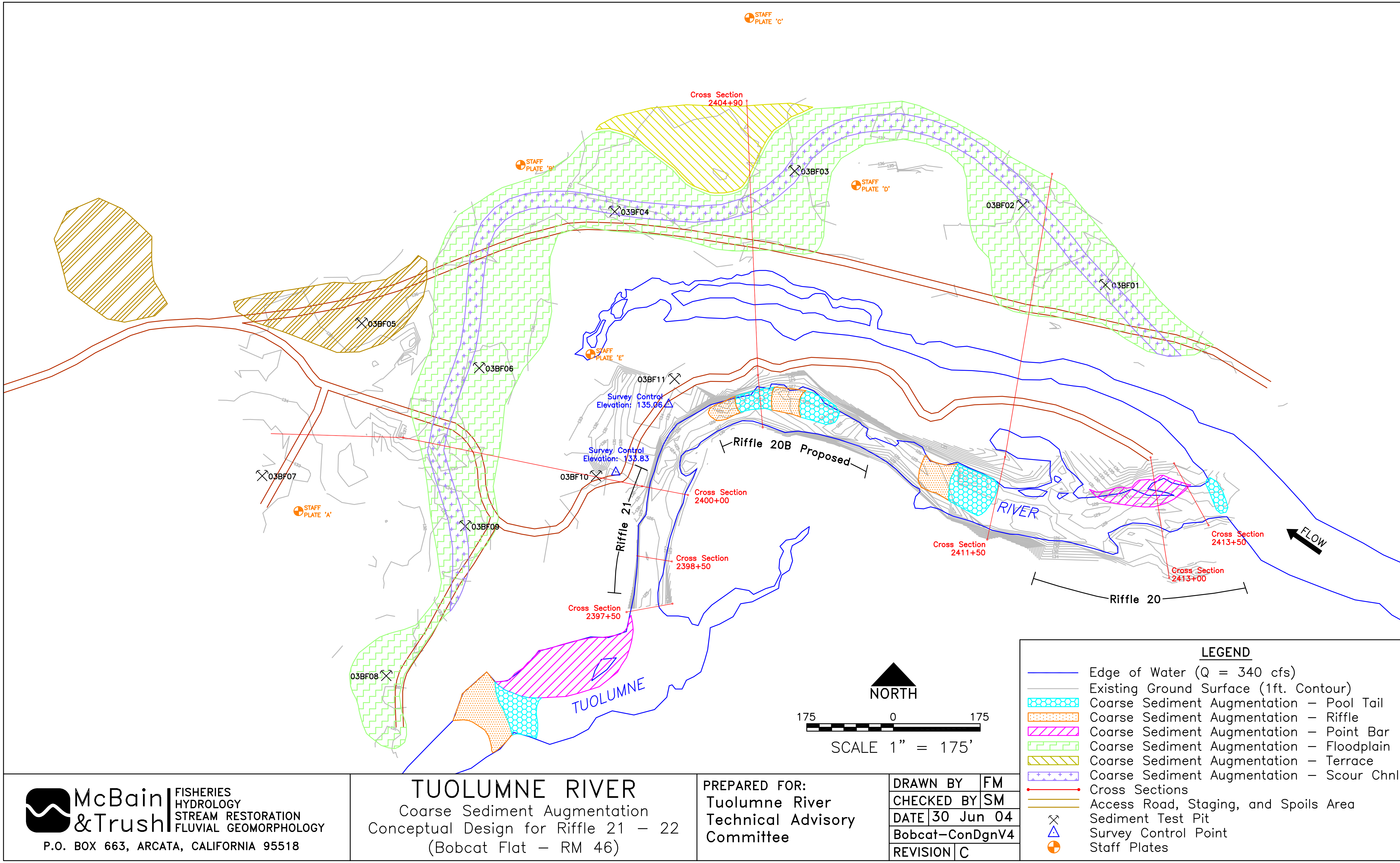
TUOLUMNE RIVER

Coarse Sediment Augmentation Conceptual Design for Riffle 12 (Zanker Site – RM 46)

PREPARED FOR: Tuolumne River Technical Advisory Committee

DRAWN BY	FM
CHECKED BY	SM
DATE	21 Jun 04
Zanker–ConDgnV1	
REVISION	B


STAFF PLATE 'C'
Cross Section 2404+90
STAFF PLATE 'B'
03BF03
STAFF PLATE 'D'
03BF04
03BF02
03BF01
03BF05
STAFF PLATE 'E'
03BF06
03BF11
Survey Control Elevation: 135.06
Riffle 20B Proposed
Survey Control Elevation: 133.83
03BF10
03BF07
Cross Section 2400+00
STAFF PLATE 'A'
03BF09
Riffle 21
RIVER
Cross Section 2411+50
Cross Section 2413+50
FLOW
Cross Section 2413+00
Cross Section 2398+50
Riffle 20
Cross Section 2397+50
03BF08
TUOLUMNE
NORTH
175 0 175
SCALE 1" = 175'
LEGEND
Edge of Water (Q = 340 cfs)
Existing Ground Surface (1ft. Contour)
Coarse Sediment Augmentation – Pool Tail
Coarse Sediment Augmentation – Riffle
Coarse Sediment Augmentation – Point Bar
Coarse Sediment Augmentation – Floodplain
Coarse Sediment Augmentation – Terrace
Coarse Sediment Augmentation – Scour Chnl.
Cross Sections
Access Road, Staging, and Spoils Area
Sediment Test Pit
Survey Control Point
Staff Plates
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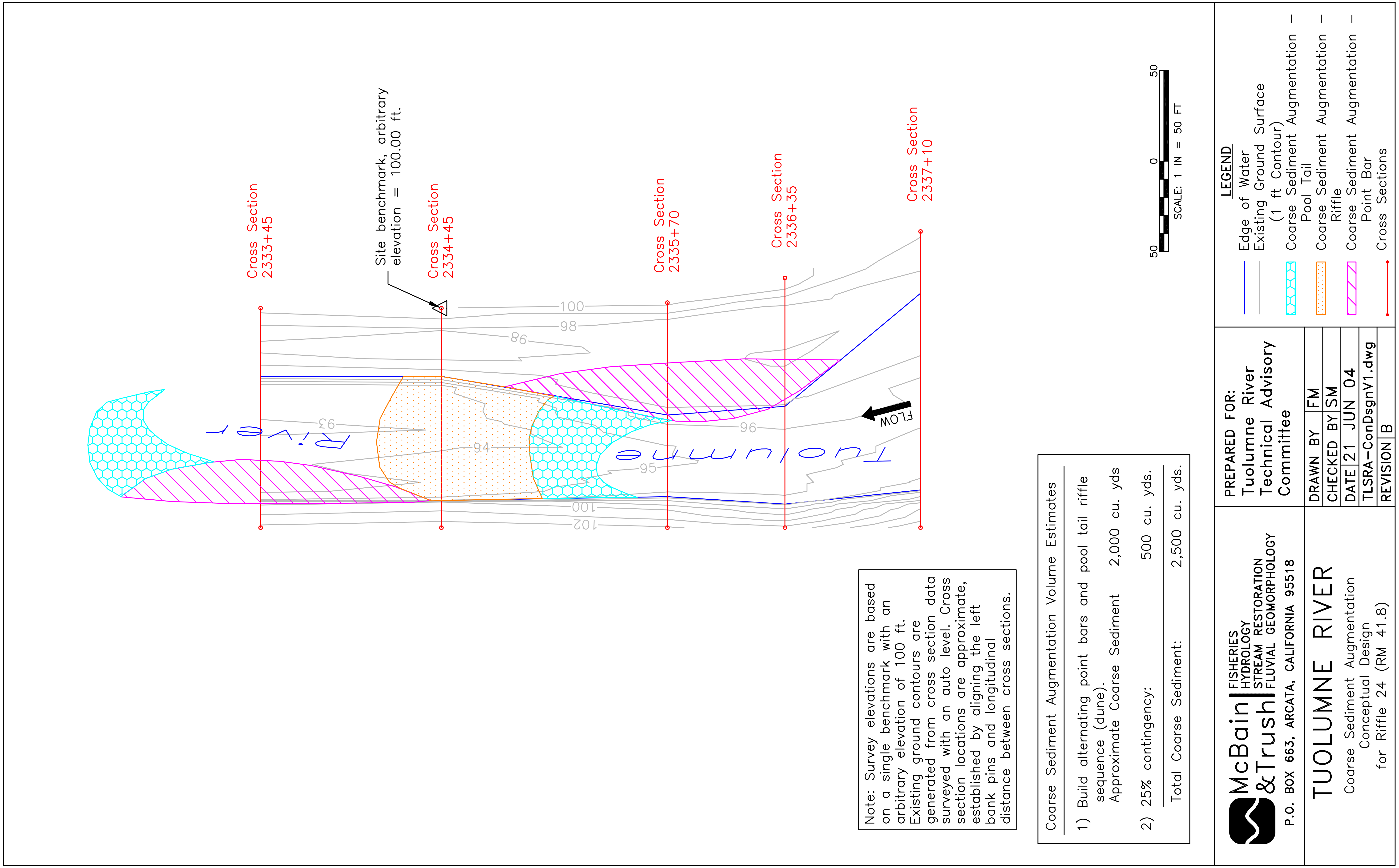
TUOLUMNE RIVER
Coarse Sediment Augmentation
Conceptual Design for Riffle 21 – 22
(Bobcat Flat – RM 46)
PREPARED FOR:
Tuolumne River
Technical Advisory
Committee
DRAWN BY FM
CHECKED BY SM
DATE 30 Jun 04
Bobcat–ConDgnV4
REVISION C


Cross Section 2333+45
Site benchmark, arbitrary elevation = 100.00 ft.
Cross Section 2334+45
Cross Section 2335+70
Cross Section 2336+35
Cross Section 2337+10
100
98
96
95
94
93
102
FLOW
Tuolumne River
SCALE: 1 IN = 50 FT
50 0 50
LEGEND
Edge of Water
Existing Ground Surface (1 ft Contour)
Coarse Sediment Augmentation – Pool Tail
Coarse Sediment Augmentation – Riffle
Coarse Sediment Augmentation – Point Bar
Cross Sections
Note: Survey elevations are based on a single benchmark with an arbitrary elevation of 100 ft. Existing ground contours are generated from cross section data surveyed with an auto level. Cross section locations are approximate, established by aligning the left bank pins and longitudinal distance between cross sections.
Coarse Sediment Augmentation Volume Estimates
1) Build alternating point bars and pool tail riffle sequence (dune).
Approximate Coarse Sediment 2,000 cu. yds
2) 25% contingency: 500 cu. yds.
Total Coarse Sediment: 2,500 cu. yds.
PREPARED FOR:
Tuolumne River Technical Advisory Committee
DRAWN BY FM
CHECKED BY SM
DATE 21 JUN 04
TLSRA-ConDsgnV1.dwg
REVISION B
McBain & Trush
FISHERIES
HYDROLOGY
STREAM RESTORATION
FLUVIAL GEOMORPHOLOGY
P.O. BOX 663, ARCATA, CALIFORNIA 95518
TUOLUMNE RIVER
Coarse Sediment Augmentation Conceptual Design for Riffle 24 (RM 41.8)

Appendix C

Reach-Scale Bedload Transport Model Results on the Tuolumne River Downstream Riffle 4B - Stillwater Sciences Technical Memorandum

Stillwater Sciences

2532 Durant Avenue, Suite 201 Berkeley, CA 94704 Phone (510) 848-8098 Fax (510) 848-8398

TECHNICAL MEMORANDUM

DATE: July 10, 2001

TO: McBain & Trush

FROM: Yantao Cui and Noah Hume

SUBJECT: Reach-Scale Bedload Transport Model Results on the Tuolumne River Downstream Riffle 4B

INTRODUCTION

As a component of McBain & Trush's coarse sediment management plan being developed for the Tuolumne River Technical Advisory Committee (TRTAC), Stillwater Sciences integrated recent survey and bedload transport data into the *EASI* (Enhanced Acronym Series 1 & 2 with Interface) sediment transport model to assess gravel transport at the Tuolumne River downstream of Riffle 4B. The objective of this task is to understand the gravel transport rate through the system and to guide the ongoing and future gravel introduction projects in the reach. This report summarizes the results of modeling and sensitivity tests performed to provide information on planned gravel augmentation projects in the Tuolumne River.

The *EASI* sediment transport model is the implementation of the surface-based bedload transport equation of Parker (1990a, b) modified to apply to natural gravel-bedded rivers. The model calculates gravel transport capacity for a given cross section, friction slope, water discharge, and surface or bedload grain size distribution. The model also calculates normalized Shields stress, which provides an estimate of bed mobility threshold. The gravel transport capacity is the maximum possible gravel transport rate in a reach in the case of unlimited gravel supply. In a supply-limited case, the actual gravel transport rate in the river reach is smaller than the model-calculated gravel transport capacity. If the channel is not supply-limited, the sediment transport rate in the reach is equal to transport capacity. Whether the channel is supply-limited is best assessed by field observations.

METHODS

Prior to the current modeling effort, the most recent version of *EASI* model (Version 4.2) allowed for the delineation of the cross section into a main channel and a floodplain. Gravel transport was assumed to occur only in the main channel and the floodplain was assumed to function only as flood passage during high flow events. During the current modeling exercise, it became necessary to update the model so that it could accommodate both left and right bank floodplains in addition to the main channel. The current model is Version 4.3.

The relevant data provided by McBain & Trush are as follows:

- Eight cross sections given in river-feet upstream of the confluence with the San Joaquin River: XS-2670+00, XS-2672+00, XS 2674+00, XS-2685+00, XS-2690+00, XS-2699+00, XS-2702+00 and XS-2705+00.
- Thalweg profile in a 5,500-ft reach downstream of the Old Basso Bridge between 2585+00 and 2640+00; water surface profile at various discharges in the same reach; and water surface profile between 2647+40 and 2760+00 at 5,400 cfs discharge.
- Pebble counts at cross sections XS-2670+00, XS-2690+00, XS-2699+00 and a cross section further upstream.
- Bedload measurement at Riffle 4B (XS 2690+00) on March 19 and March 20, 2000 with estimated discharges of 4,020 cfs, 4,960 cfs, 5,980 cfs and 6,700 cfs.

One of the necessary parameters of the model is the friction slope of the modeled reach, which was approximated by the water surface slope calculated from the 1996 water surface survey data supplied. Other necessary information for running the model includes the discharge record from water year (WY) 1971 to WY 1999 from the USGS gauge Tuolumne River below La Grange Dam near La Grange (11289650).

During the modeling exercises, the Stillwater Sciences performed a reconnaissance field trip to the model reach. Field observations indicated that the reach is typical pool-riffle morphology void of bedrock outcrops and large boulder pavements. It was judged that sediment transport in this reach is at capacity. The floodplain was characterized with a Manning's n value of 0.07 based on the observation that the edge of the main channel is lined with medium-sized trees.

RESULTS

EASI Model Results: Results of the model runs are presented in the attached MS-Excel files. Because the *EASI* model is a reach-scale gravel transport model, its application requires the selection of a typical cross section to represent the reach. In order to test the sensitivity of the model results to selection of a representative cross section, all the cross sections provided by McBain & Trush except those at the upstream end (XS-2705+00) and downstream end (XS-2670+00) of the reach were used in the simulation. The main channel portion of each cross section is shown in Figure 1.

The water surface survey data between 2761+75 and 2872+60 at 5,400 cfs discharge (Figure 2) provided by McBain & Trush were used to estimate water surface slope and a value of 0.0014 was obtained for input in the calculation.

The surface grain size distributions from the four pebble-counts were all within a relatively narrow band as shown in Figure 3. The representative of the four sets of data used for model input was the average of the maximum and minimum cumulative percent finer values of the given grain sizes. This representative grain size distribution is also shown in Figure 3.

Daily average discharge from USGS gauge Tuolumne River below La Grange Dam near La Grange (11289650) from WY 1971 to WY 1999 (post-New Don Pedro Reservoir period) were used to calculate the long-term flow duration curve. The duration curve, shown in Figure 4, was used in the model to calculate long-term average annual gravel transport rate.

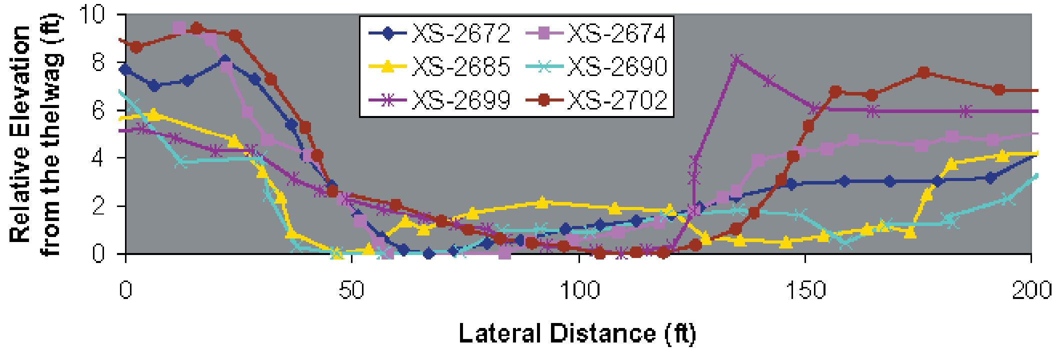


Figure 1. Cross sections in the modeling reach

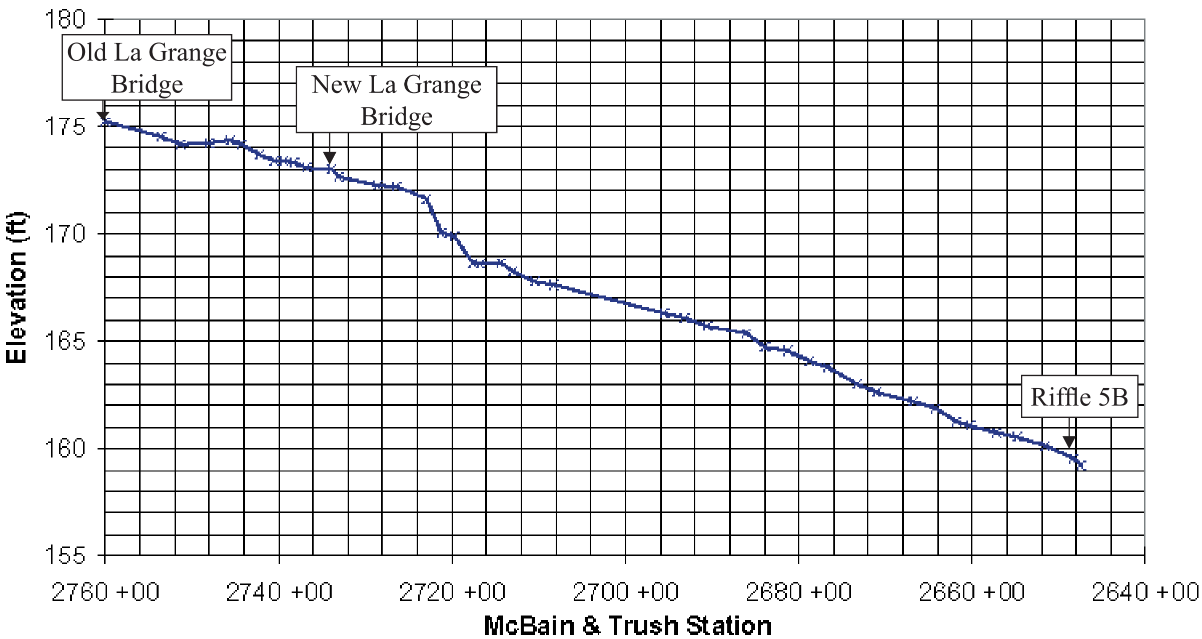


Figure 2. Tuolumne River water surface profile surveyed at a discharge of 5,400 cfs on March 26, 1996 by McBain & Trush

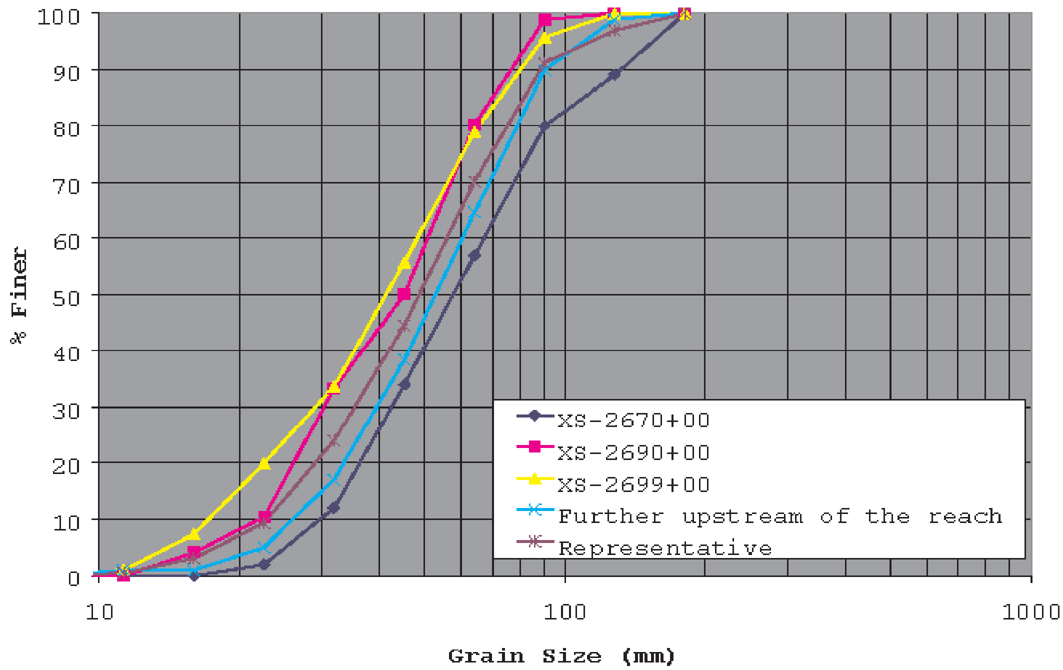


Figure 3. Grain size distributions on channel surface from McBain & Trush pebble counts. A representative grain size distribution was constructed for model input.

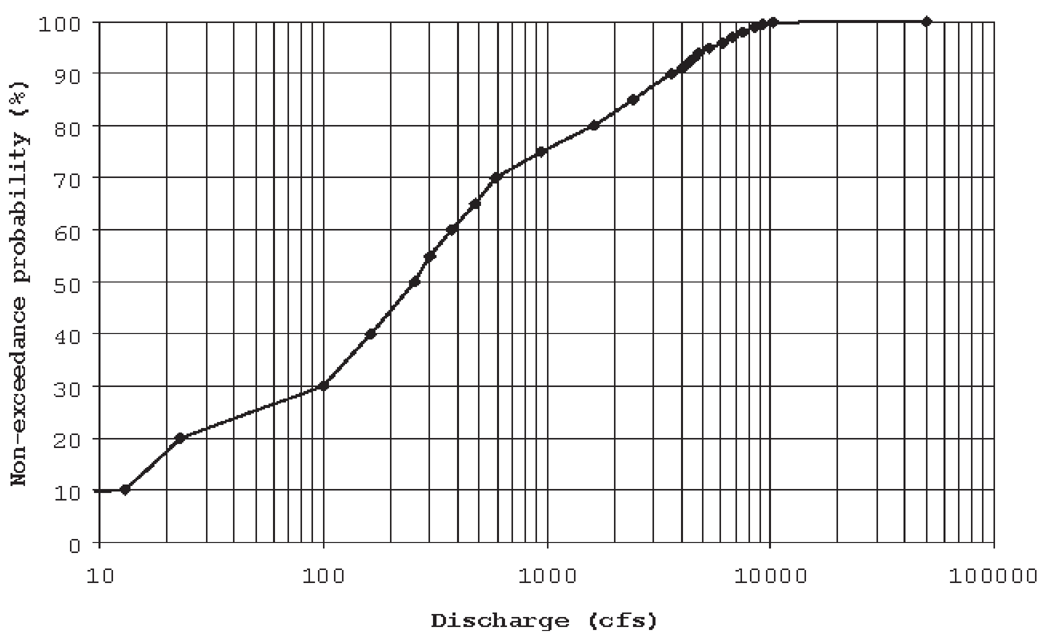


Figure 4. Flow duration curve based on post-New Don Pedro Reservoir (WY 1971 – WY 1999) daily discharge records at USGS gauge Tuolumne River below La Grange Dam near La Grange (station no. 11289650)

The calculated transport rates of gravel (> 8 mm) are shown in Figure 5 along with the field data provided by McBain & Trush. The calculated normalized Shields stresses, which are the ratio between surface-geometric-mean-based Shields stresses and a reference Shield stress, are shown in Figure 6. Note that the reference Shield stress can be viewed as a surrogate for the critical Shields stress, and thus a normalized Shields stress of unity is equivalent to thresholds for bed mobility. The long-term average annual gravel transport rates and the discharges corresponding to normalized Shields stress of unity for the simulated cross sections are shown in Table 1.

Table 1. Predicted long-term average gravel transport rate and discharge for bed mobility threshold with different cross sections as model input

Cross section used for simulation	Long-term average gravel transport rate (kt/a)	Discharge for bed mobility threshold (cfs)
XS 2702+00	1.69	6,950
XS 2699+00	2.11	6,510
XS 2690+00	0.94	10,670
XS 2685+00	0.82	9,520
XS 2674+00	2.43	8,770
XS 2672+00	1.76	9,620
Average	1.67	8,670

The calculated gravel transport rates range between 1–10 kt/a and are systematically lower than the measured bedload transport data by more than an order of magnitude (Figure 5). The calculated normalized Shields stresses shown in Figure 6 and Table 1 suggest that the threshold for gravel transport is between 6,510 cfs and 10,670 cfs. This result only partially confirms the McBain & Trush observations at Riffle 4B that flows of 6,880 cfs are capable of mobilizing cobbles and gravels. It, however, does support McBain & Trush conclusion that the bed will not be mobilized by flows less than 7,000 to 8,000 cfs in most reaches (McBain & Trush 2000, p.79-84).

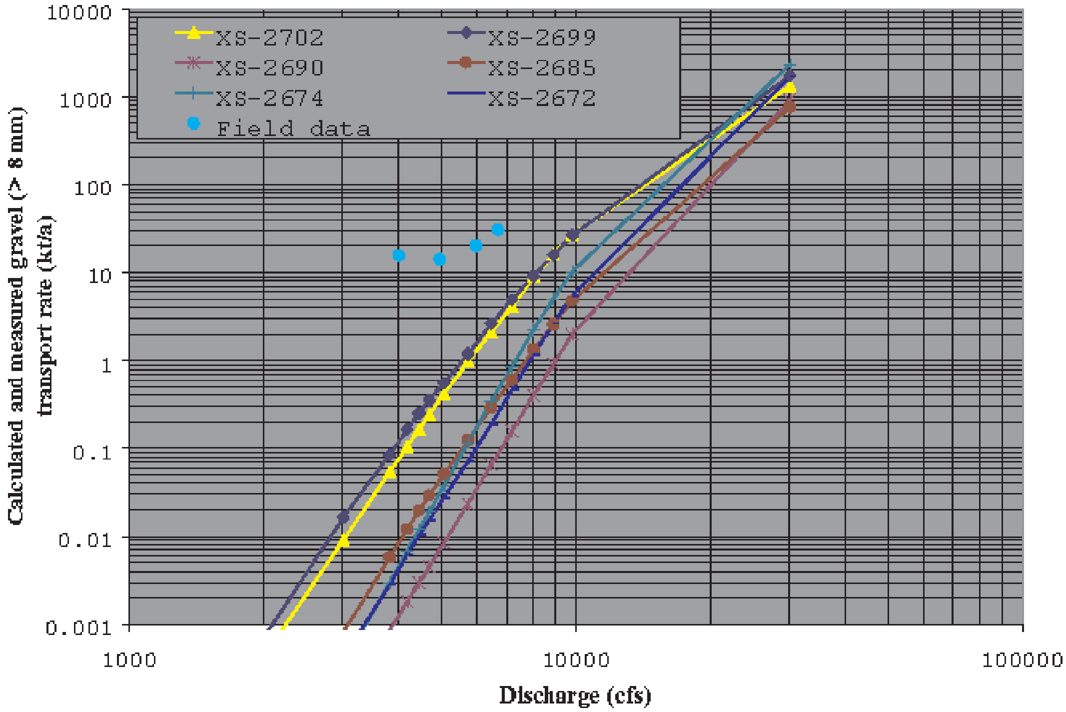


Figure 5. Calculated and measured gravel transport rates

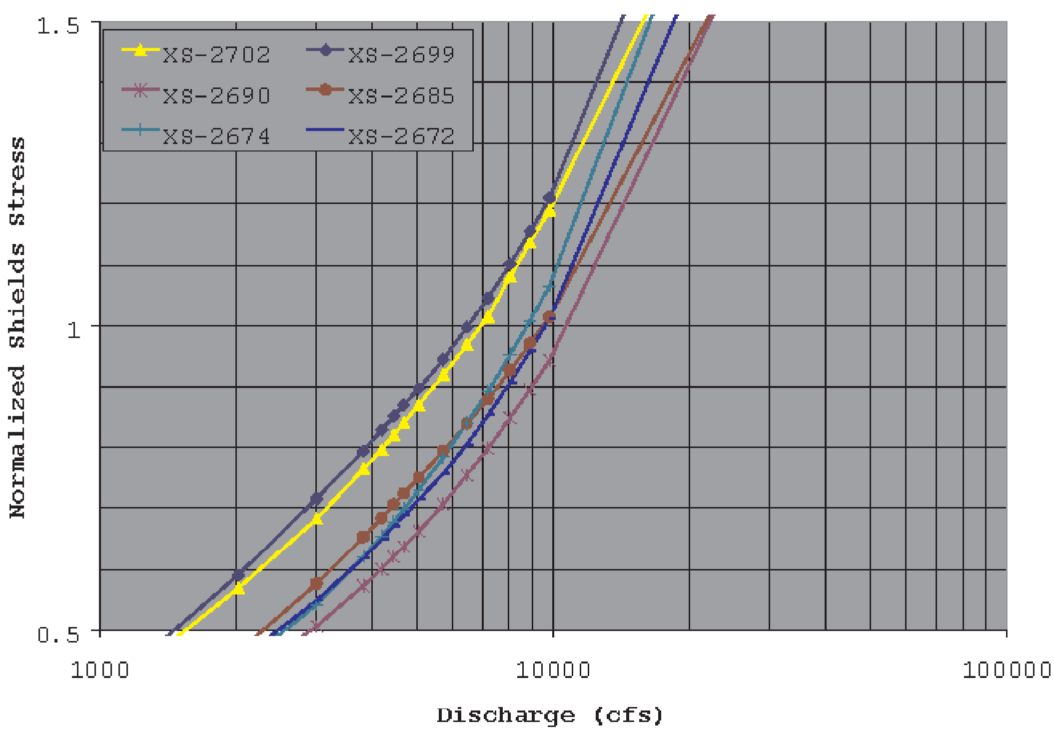


Figure 6. Calculated normalized Shields stress

Sensitivity test of floodplain assumptions: The bedload transport model results (Figure 5) indicate that the difference between the highest and lowest gravel transport rate predictions calculated with different cross sections as input data varied over an order of magnitude for low flow conditions and by a factor of two for high flow conditions. The difference between the highest and lowest long-term average gravel transport rate predictions is within a factor of three, which falls within the estimated general range of accuracy of the model. Arbitrarily selecting XS-2702+00 as the representative cross section, an additional run was performed by assuming that flow is confined in the main channel. The complete cross section XS 2702+00 and the delineation of the main channel and floodplains are given in Figure 7.

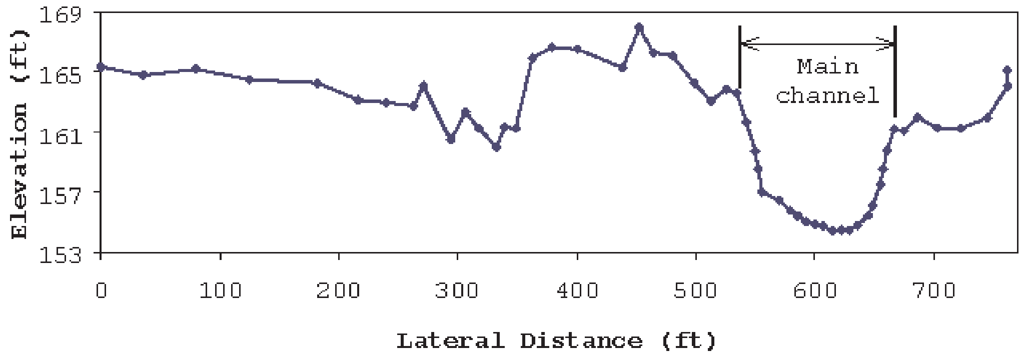


Figure 7. Cross section XS-2702+00, showing floodplains and the main channel

The predicted long-term average gravel transport rate increased from 1,690 ton/year to 5,340 ton/year, a change of a factor of about 3. Comparison of gravel transport rating curve and normalized Shields stresses is shown in Figures 8 and 9, respectively. Note that there is no difference between the two runs for low flow conditions. The differences in predicted gravel transport rates and normalized Shields stresses begin to appear at bankfull flow and increase as discharge increases.

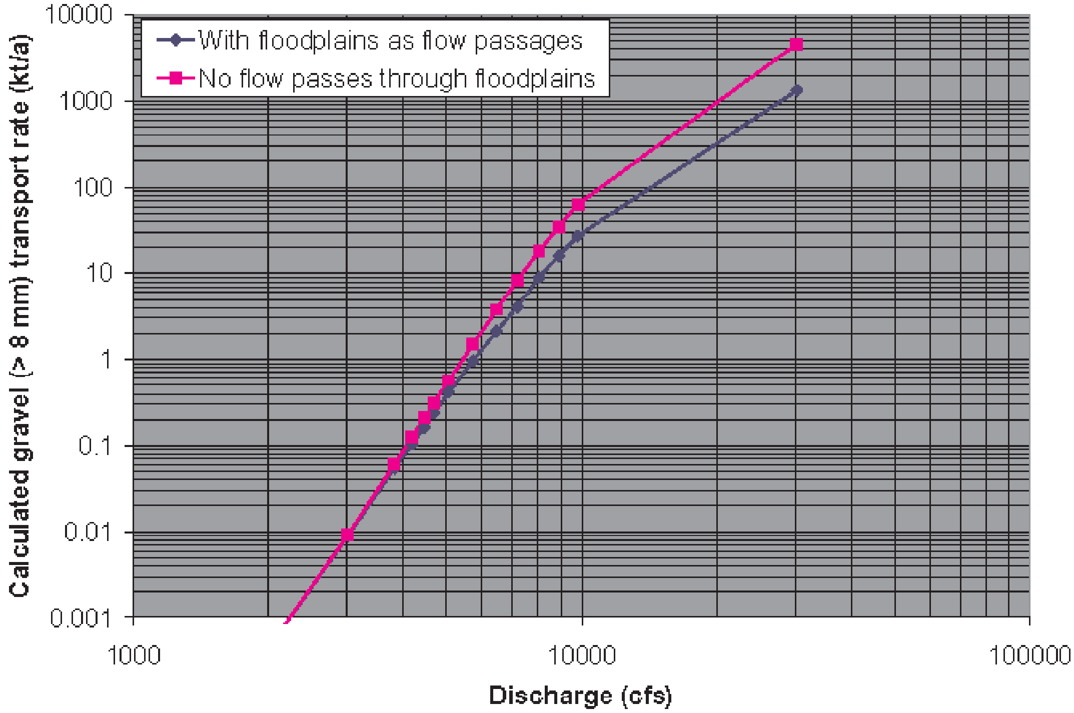


Figure 8. Calculated gravel transport rate with XS-2702+00 as representative cross section and different assumptions on flow passages

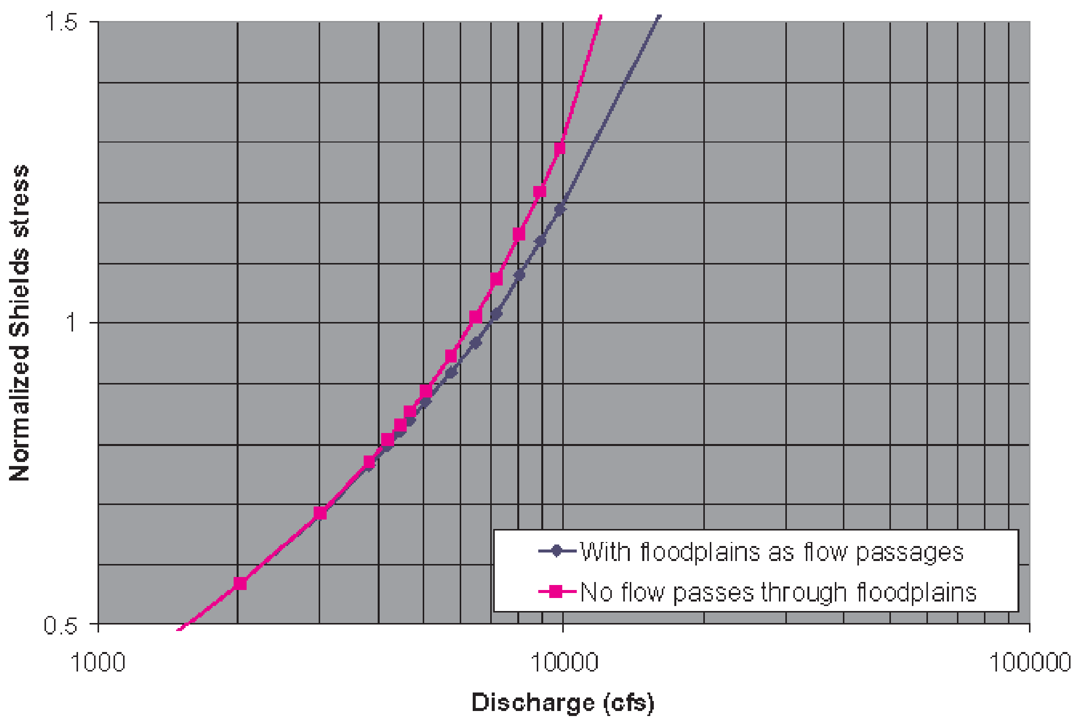


Figure 9. Calculated normalized Shields stress with XS-2702+00 as representative cross section and different assumptions on flow passages

Sensitivity test of water surface slope: Cross section XS-2702+00 was selected arbitrarily as a representative cross section for the sensitivity test on water surface slope. In addition to the calculation reported in earlier, two additional runs were performed using water surface slopes changed by ±20%. The predicted gravel transport rating curves and normalized Shields stresses are shown in Figures 10 and 11. Varying water surface slope by ±20% resulted in a change in gravel transport rate by a factor of 9 for low flow conditions and by a factor of less than 3 for high flow conditions. Decreasing water surface slope by 20% resulted in a decrease in long-term gravel transport rate from 1,690 ton/year to 480 ton/year. Increasing water surface slope by 20% resulted in an increase in long-term gravel transport rate from 1,690 ton/year to 4,360 ton/year.

Sensitivity test of surface grain size distribution: Two runs were performed by varying surface grain size distribution. These two runs used pebble counts at XS-2699+00 and XS-2670+00, the finest and coaresest of all pebble counts available, respectively, as model input. Using pebble count at XS-2699+00 and XS-2670+00 as surface grain size input changed the long-term gravel transport rate prediction to 4,010 ton/year and 490 ton/year, respectively, from the original 1,690 ton/year, or factors of 2.4 and 3.4, respectively. The predicted gravel transport rating curves and normalized Shields stresses are shown in Figures 12 and 13.

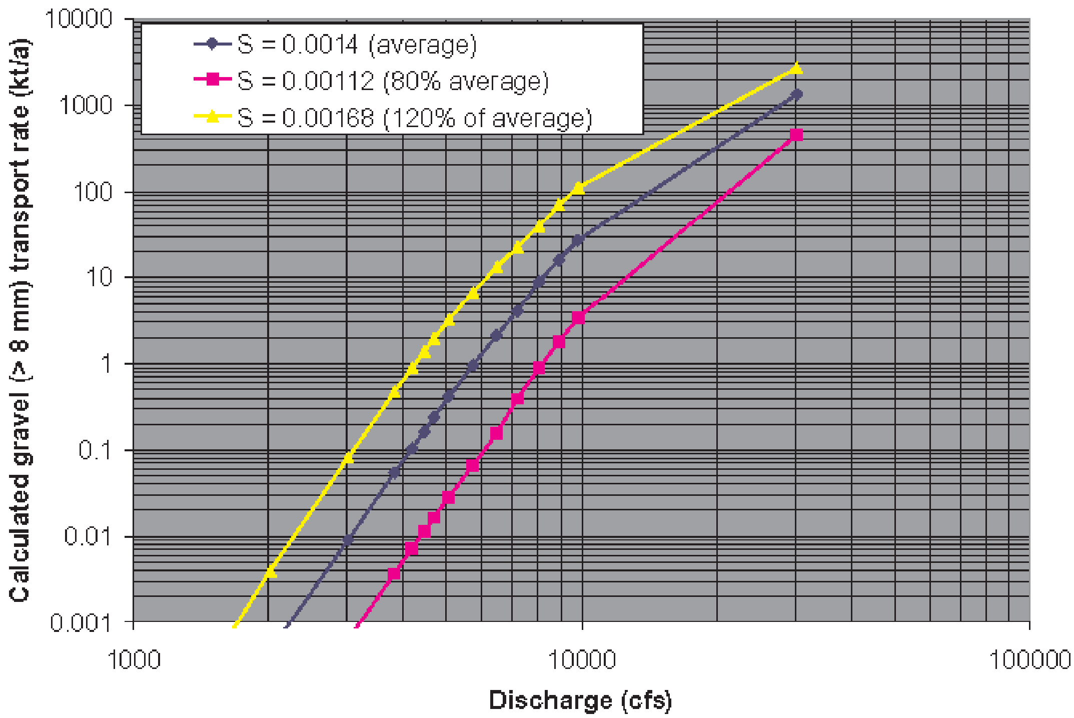


Figure 10. Predicted gravel transport rating curve with XS-2702+00 and different water surface slope as input

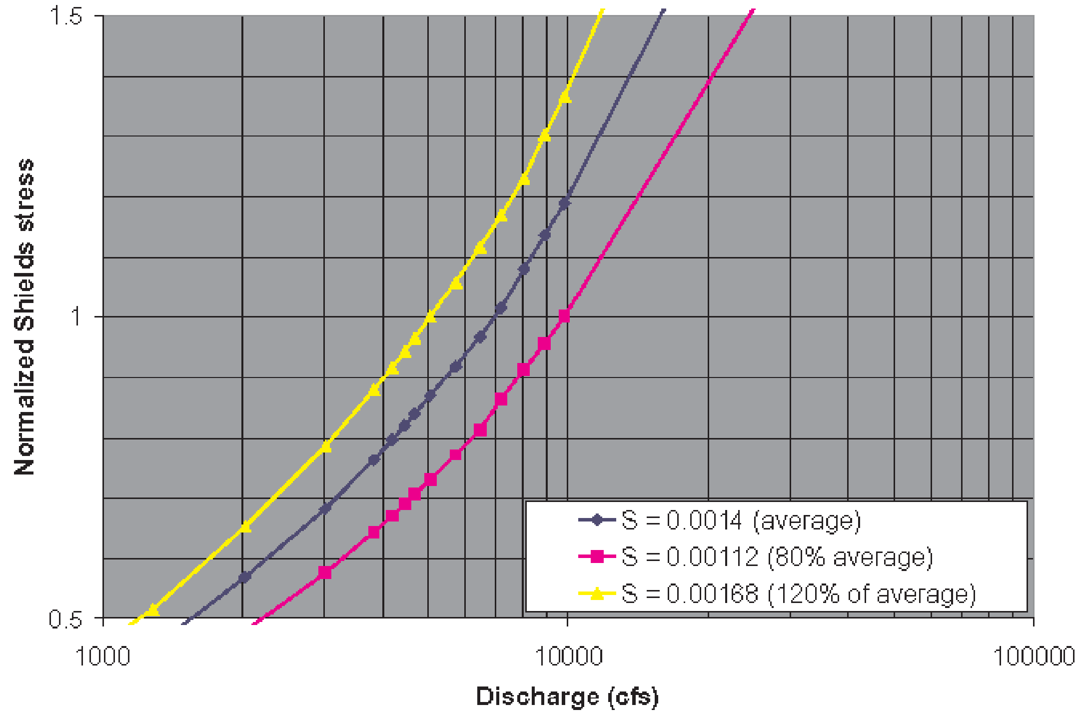


Figure 11. Predicted normalized Shields stress with XS-2702+00 and different water surface slope as input

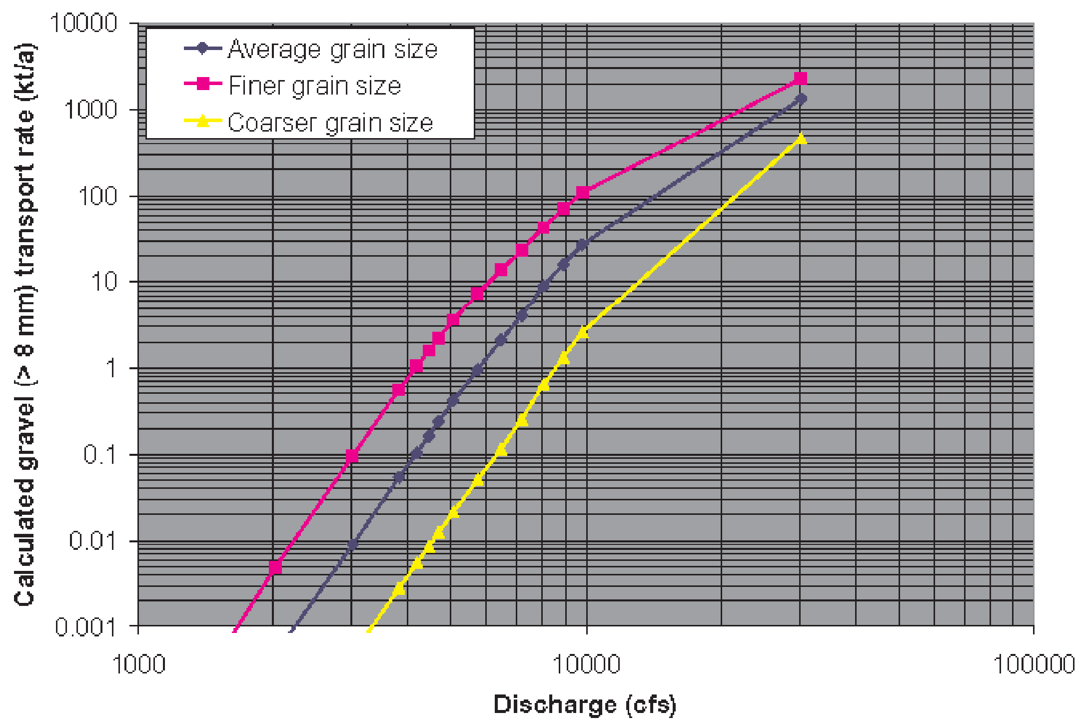


Figure 12. Predicted gravel transport rating curve with XS-2702+00 and different surface grain size distributions as input

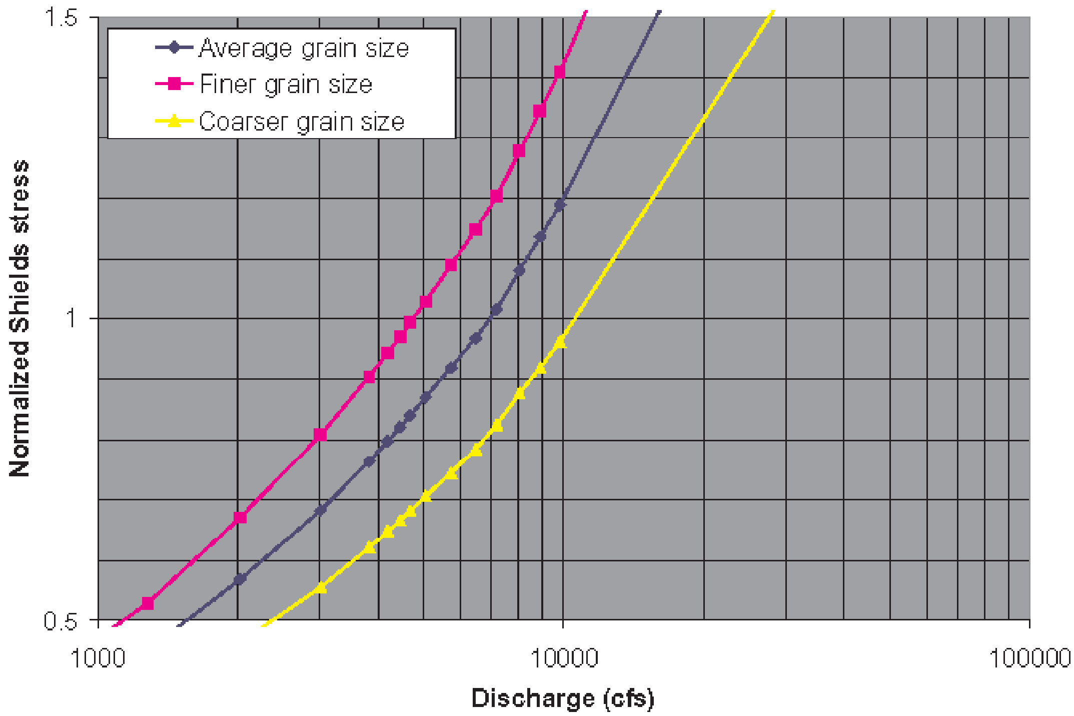


Figure 13. Predicted normalized Shields stress with XS-2702+00 and different surface grain size distributions as input

DISCUSSION

The sensitivity tests illustrated that the model results are sensitive to many input parameters. Among them, reasonable variations in cross section, surface grain size distribution, or water surface slope can result in a change in predicted gravel transport rate by a factor of 2 to 3 (Table 2). The predicted gravel transport rates are significantly lower than rates measured with a cable-held Helley-Smith bedload sampler as shown in Figure 5. Adjusting the input parameters within the ranges tested did not appreciably reduce the discrepancy. We believe that the discrepancy between the model results and field measurements could be a result of the following factors:

- The model could under-predict the gravel transport rate by a factor of 2 to 3. Field observation indicates that the reach has relatively simple morphology and channel geometry, reducing the probability of less accurate predictions.
- The measurement of water surface slope was performed in March 1996, and other input data were collected in March 2000. The channel may have experienced significant change in bed slope during that period of time considering that there was a flow event of more than 60,000 cfs on January 3, 1997.
- The model predicts reach-average sediment transport rate for a quasi-equilibrium state. The introduction of gravel upstream of the modeling reach may have resulted in non-equilibrium conditions, which is supported by McBain & Trush (2000) observation that the bed mobility is discontinuous with the neighboring reaches. This non-equilibrium state downstream of the gravel introduction site might have resulted in significant increase in sediment transport

rates in the modeling reach. Cui et al. (2001) demonstrated that sediment transport rate could increase from the equilibrium value by 2 orders of magnitude downstream of an introduced sediment pulse for certain period of time.

- Sampling error in the field measurement of bedload transport rate could occur due to the short duration of the sampling and small number of samples. Ryan (1998) reported that annual sediment accumulation predicted using historical gauge records are often within a factor of 2 compare with measurement in a weir pond. Sampling accuracy at an individual cross section for a single event, however, is not known.

Table 2. Predicted minimum and maximum annual gravel transport rate (ton/year) by varying input within a reasonable range

	Variation in Cross Section	**Floodplain Assumption[c]**	**Varying water surface slope by ±20%**	**Varying surface grain size distribution**
Minimum Prediction	820	1,690	480	490
Maximum Prediction	2,430	5,430	4,360	4,010
Average[a]	1,412	3,029	1,447	1,447
Deviation Factor[b]	1.72	1.79	3.01	3.01

a. Geometric average of the minimum and maximum predictions;

b. Ratio of maximum prediction to geometric average, which equals to the ratio of geometric average to minimum prediction.

c. Assumes that flow is confined to the active channel (maximum prediction) or the available flood (minimum prediction).

CONCLUSIONS AND RECOMMENDATIONS

We believe that the predicted gravel transport rating curve should be used as the long-term restoration guidance for future gravel introduction projects. The bedload measurements at Riffle 4B should not be used as the basis for estimates of long-term gravel transport rate because of the high possibility of non-equilibrium sediment transport at the reach during the measurement. Based on model predictions, long-term gravel transport rate in the modeling reach is about 820 to 2,430 ton/yr, which can be used as an estimate of future gravel augmentation rate. New model runs should be performed to improve the predictions if additional data are collected in the future.

REFERENCES

Cui, Y., Parker, G., Lisle, T.E., Gott, J., Hansler, M.E., Pizzuto, J.E., Allmendinger, N.E., and Reed, J.M. (2001) Sediment pulses in mountain rivers. Part 1. Experiments. *Water Resources Research*, in press.

McBain & Trush (2000) Habitat restoration plan for the lower Tuolumne River corridor. March.

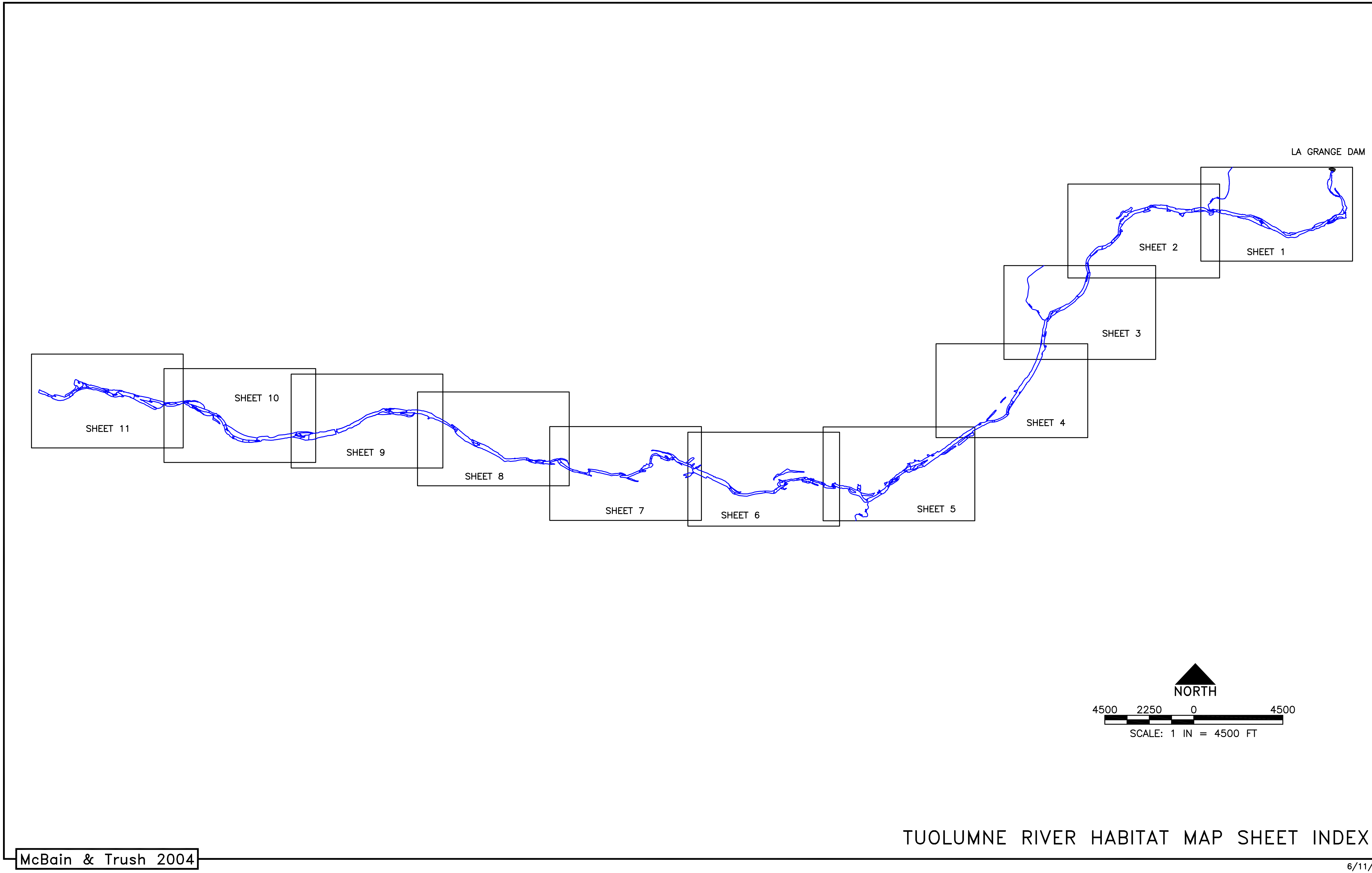
Parker, G. (1990a) Surface-based bedload transport relation for gravel rivers. *Journal of Hydraulic Research*, 28(4), 417-436.

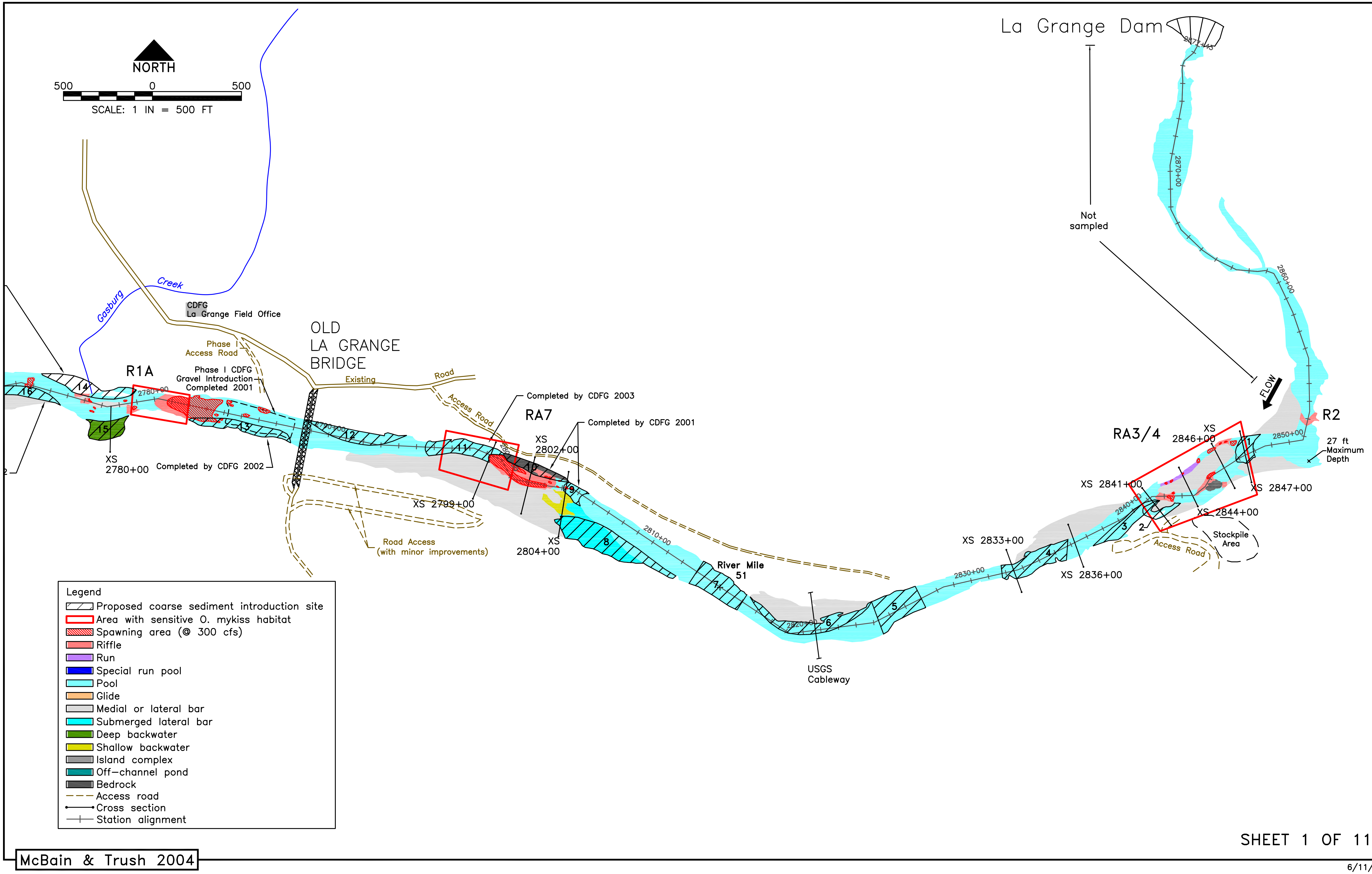
Parker, G. (1990b) The "ACRONYM" series of PASCAL programs for computing bedload transport in gravel rivers. External Memorandum No. M-220, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis. February. 124p.

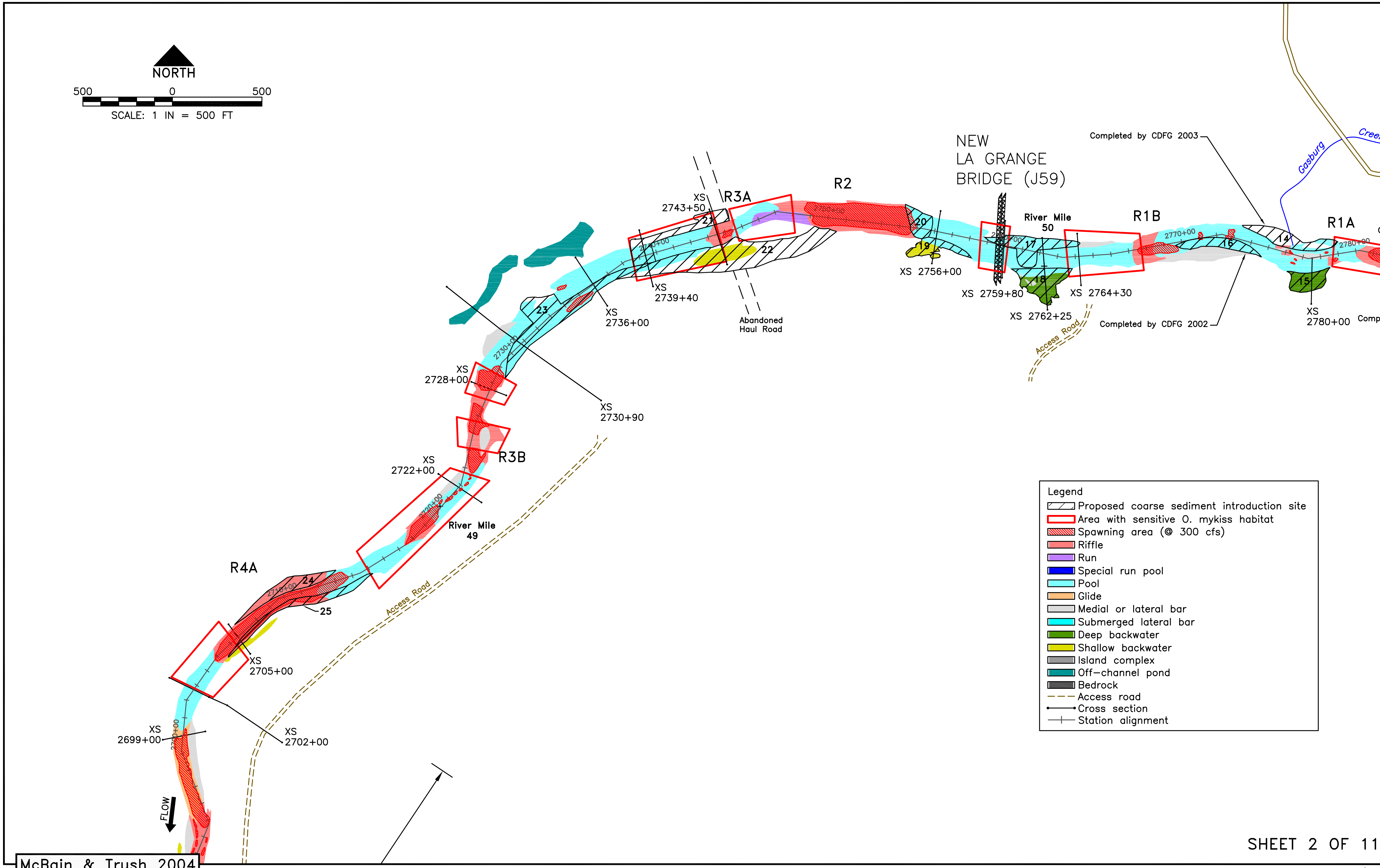
Ryan, S.E. (1998) Sampling bedload transport in coarse-grained mountain channels using portable samplers. *Proceedings of the Federal Interagency Workshop: Sediment Technology for the 21'st Century*. St. Petersberg, FL, February 17-19. (http://water.usgs.gov/osw/techniques/sedtech21/ryan.html)

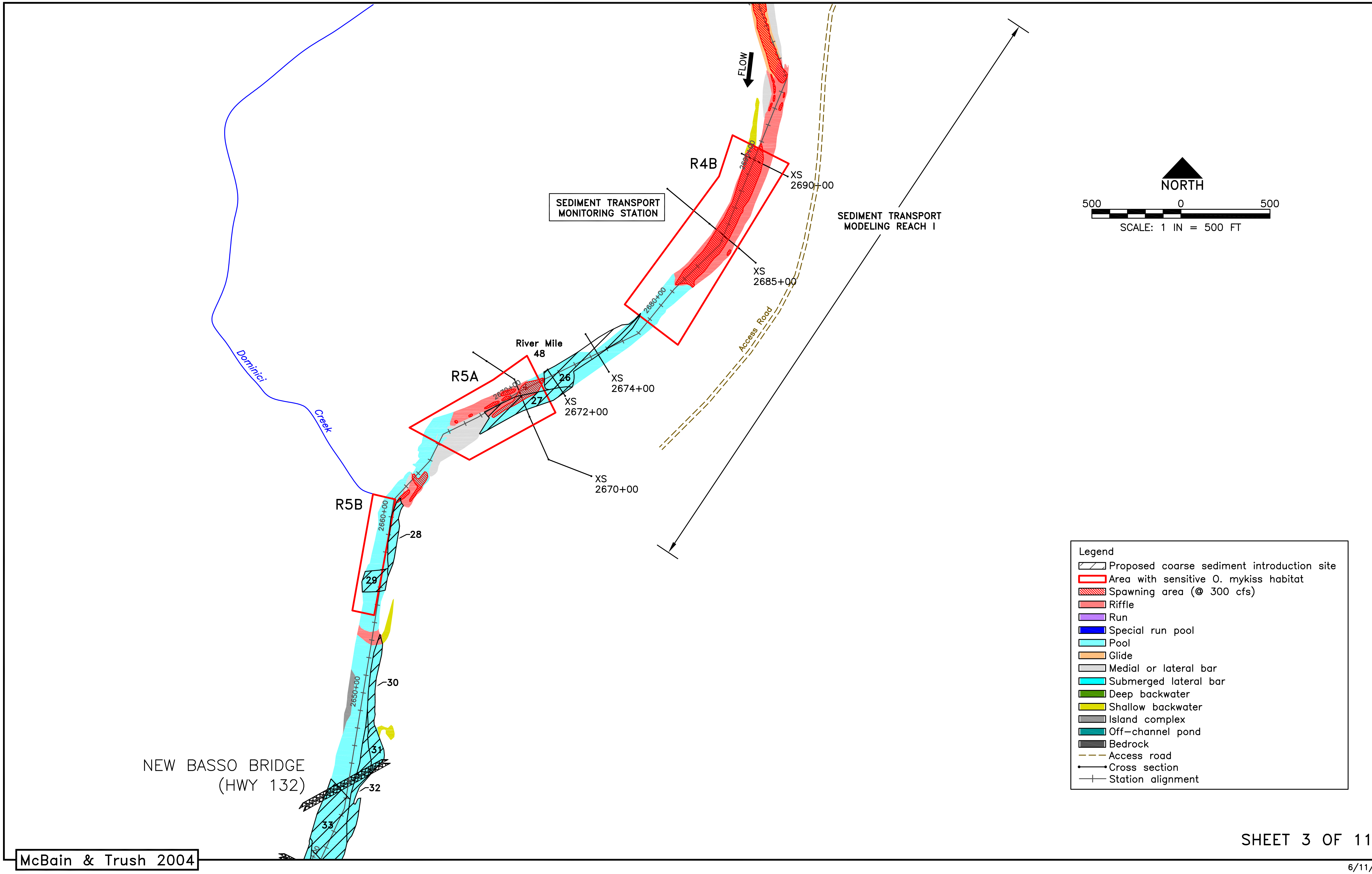
Appendix D

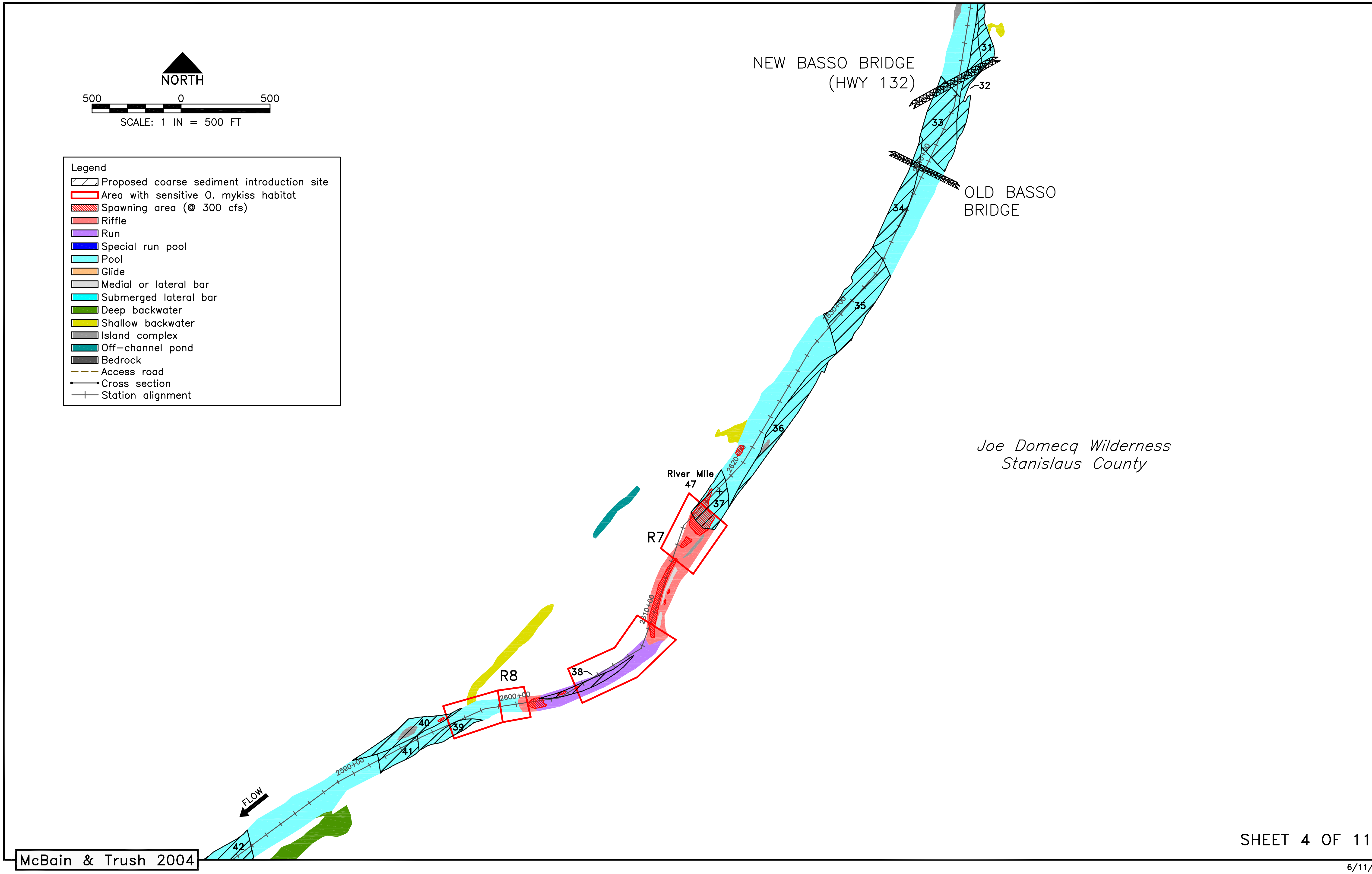
Habitat Maps and Coarse Sediment Augmentation Sites Developed for the Upper 15.8 Miles of Gravel-Bedded Reach.

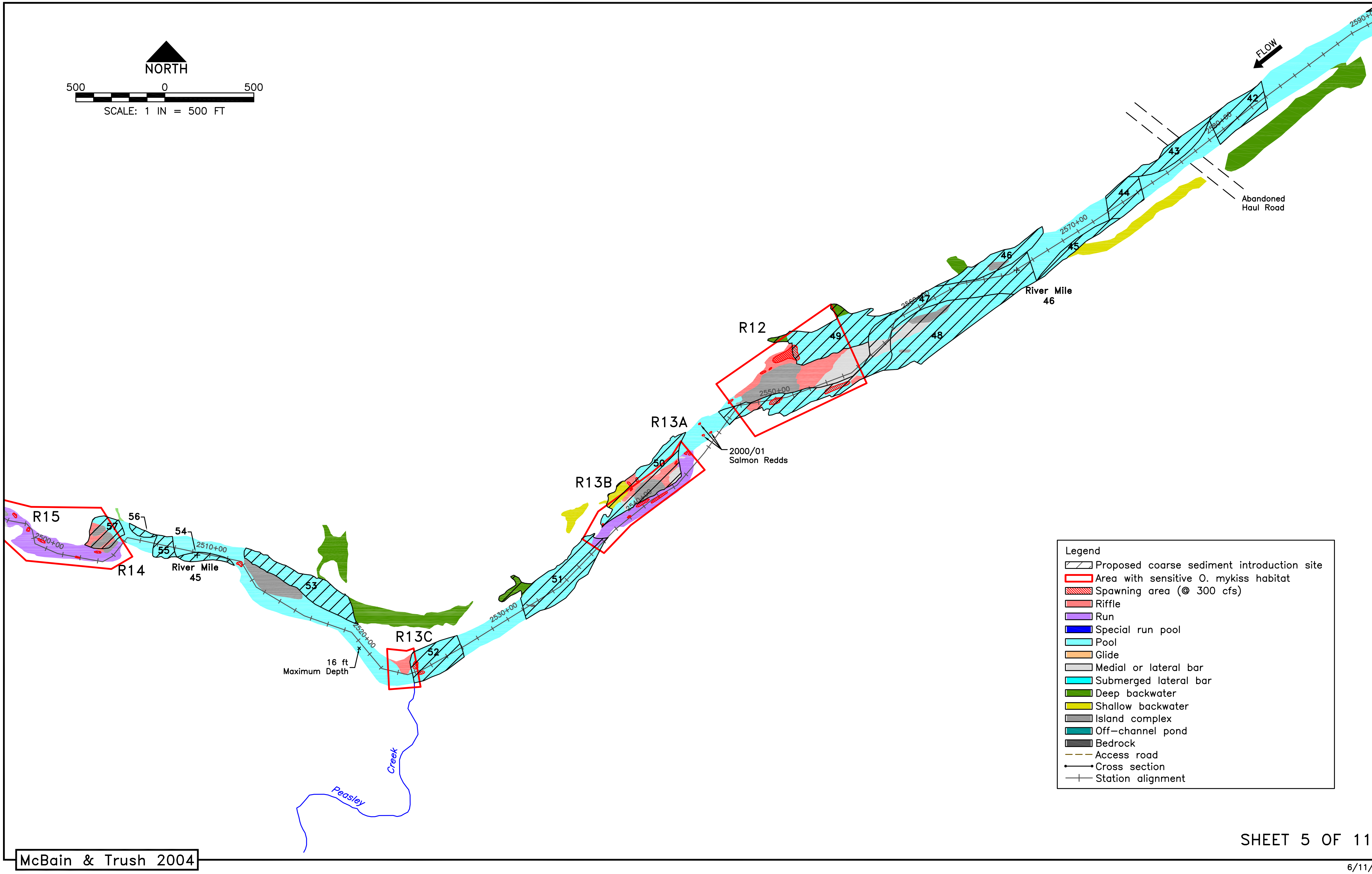

LA GRANGE DAM
SHEET 1
SHEET 2
SHEET 3
SHEET 4
SHEET 5
SHEET 6
SHEET 7
SHEET 8
SHEET 9
SHEET 10
SHEET 11
NORTH
4500 2250 0 4500
SCALE: 1 IN = 4500 FT
TUOLUMNE RIVER HABITAT MAP SHEET INDEX
McBain & Trush 2004
6/11/04

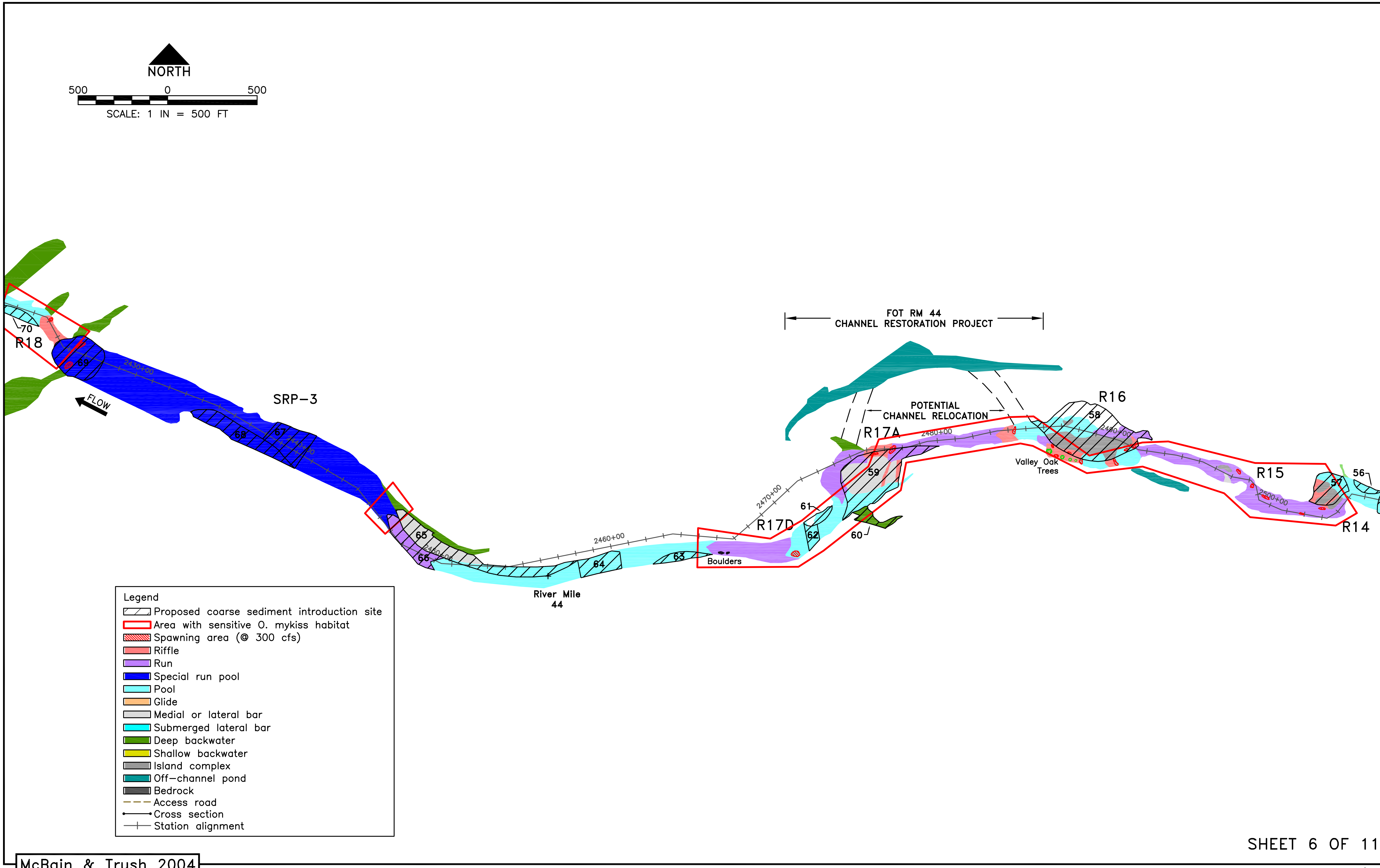

NORTH
500 0 500
SCALE: 1 IN = 500 FT
La Grange Dam
Not sampled
Gasburg Creek
CDFG La Grange Field Office
OLD LA GRANGE BRIDGE
Existing Road
Phase I Access Road
Phase I CDFG Gravel Introduction Completed 2001
R1A
XS 2780+00
Completed by CDFG 2002
Access Road
Completed by CDFG 2003
RA7
XS 2802+00
Completed by CDFG 2001
XS 2799+00
XS 2804+00
Road Access (with minor improvements)
River Mile 51
USGS Cableway
XS 2833+00
XS 2836+00
RA3/4
XS 2846+00
XS 2841+00
XS 2847+00
XS 2844+00
Stockpile Area
Access Road
FLOW
R2
27 ft Maximum Depth
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 1 OF 11
McBain & Trush 2004
6/11/04

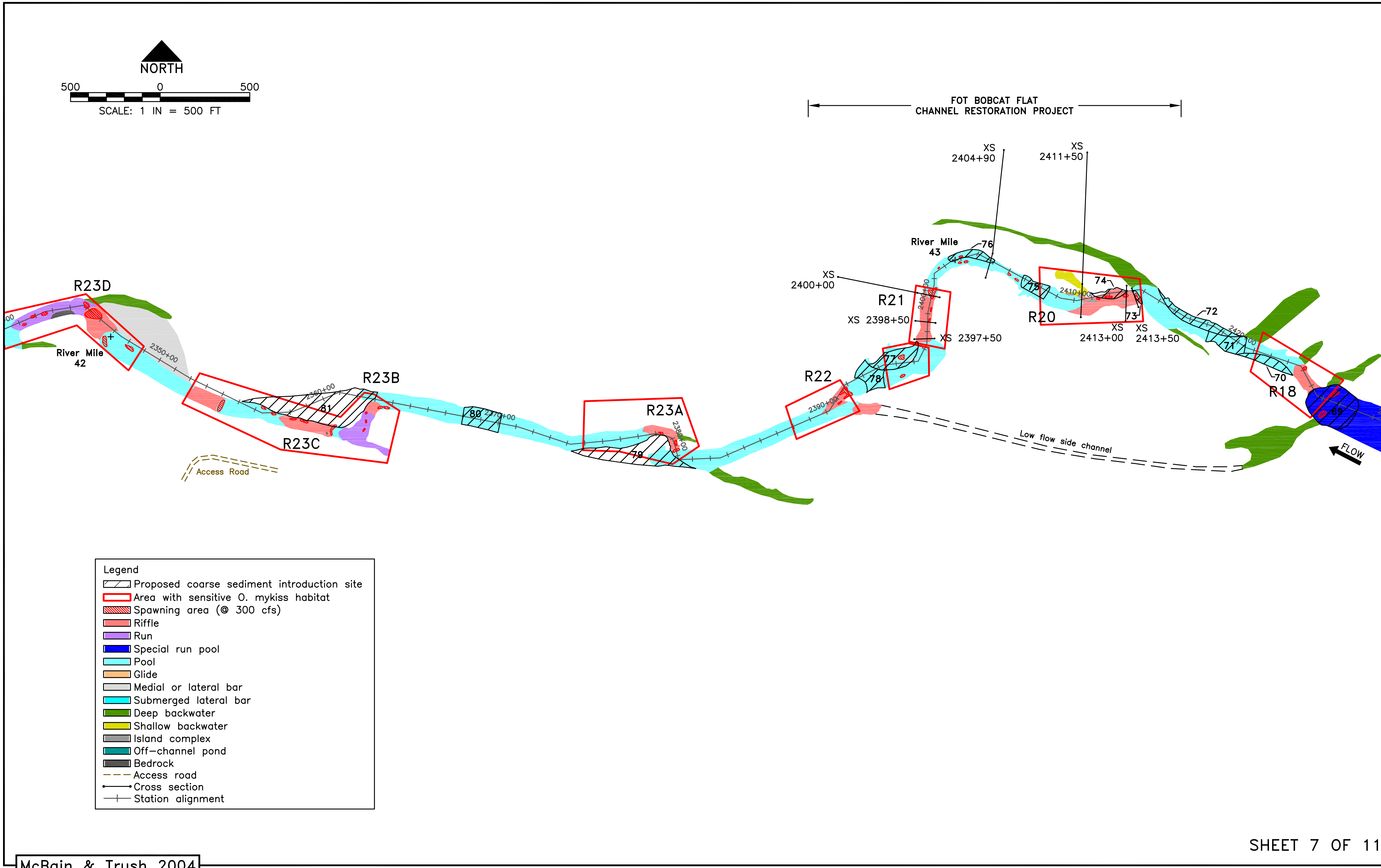

NORTH
500 0 500
SCALE: 1 IN = 500 FT
NEW LA GRANGE BRIDGE (J59)
R1A
R1B
R2
R3A
R3B
R4A
River Mile 50
River Mile 49
Completed by CDFG 2003
Completed by CDFG 2002
Gasburg Creek
Abandoned Haul Road
Access Road
XS 2743+50
XS 2739+40
XS 2736+00
XS 2730+90
XS 2728+00
XS 2722+00
XS 2705+00
XS 2702+00
XS 2699+00
XS 2756+00
XS 2759+80
XS 2762+25
XS 2764+30
XS 2780+00
FLOW
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off–channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 2 OF 11
McBain & Trush 2004
6/11/04


FLOW
R4B
XS 2690+00
XS 2685+00
SEDIMENT TRANSPORT MONITORING STATION
SEDIMENT TRANSPORT MODELING REACH I
Access Road
River Mile 48
R5A
26
27
XS 2674+00
XS 2672+00
XS 2670+00
2680+00
2660+00
2650+00
Dominici Creek
R5B
28
29
30
31
32
33
NEW BASSO BRIDGE (HWY 132)
NORTH
500 0 500
SCALE: 1 IN = 500 FT
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off−channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 3 OF 11
McBain & Trush 2004
6/11/04

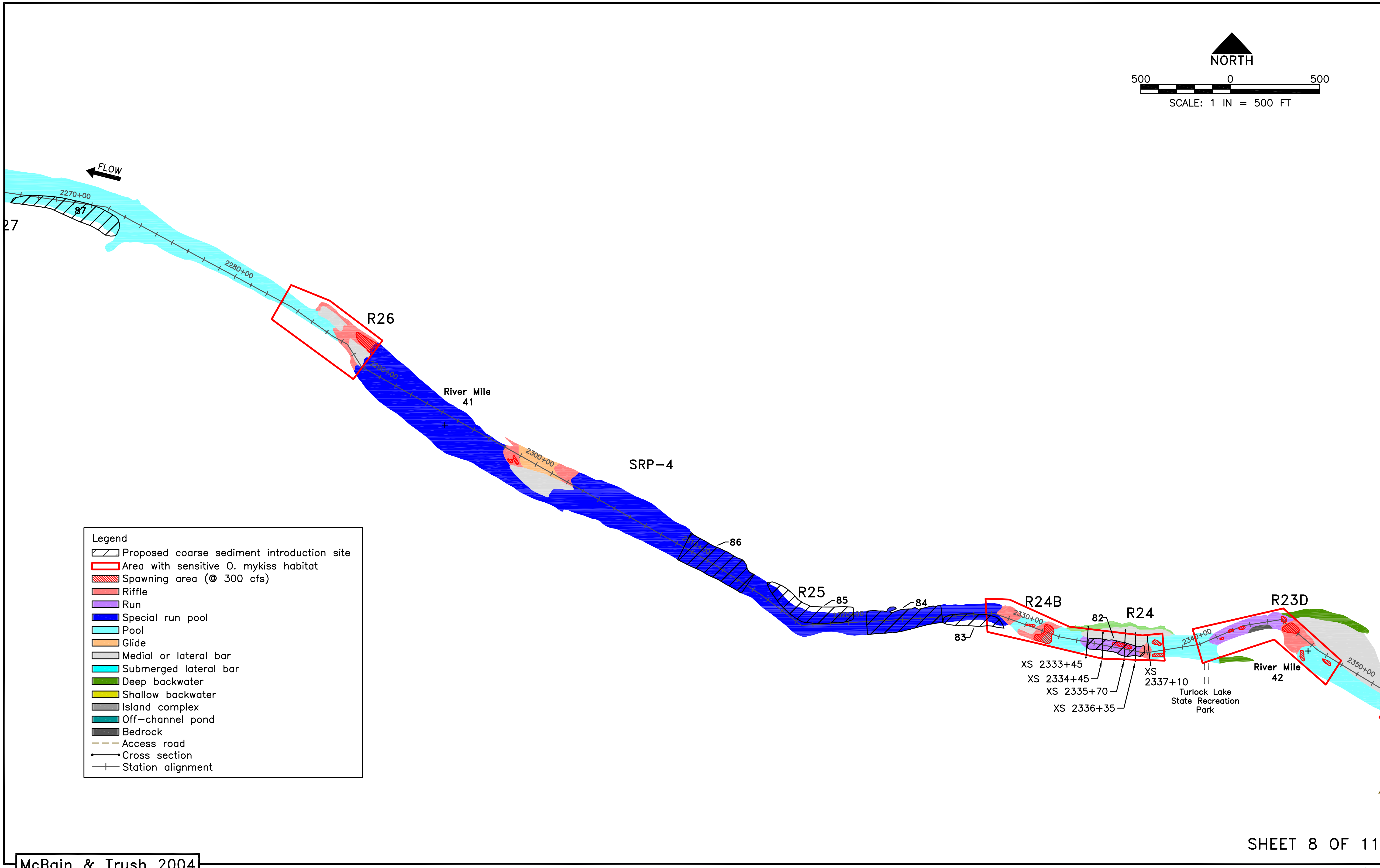

NORTH
500 0 500
SCALE: 1 IN = 500 FT
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off–channel pond
Bedrock
Access road
Cross section
Station alignment
NEW BASSO BRIDGE
(HWY 132)
OLD BASSO
BRIDGE
Joe Domecq Wilderness
Stanislaus County
River Mile
47
R7
R8
FLOW
31
32
33
34
35
36
37
38
39
40
41
42
2620+00
2610+00
2600+00
2590+00
SHEET 4 OF 11
McBain & Trush 2004
6/11/04

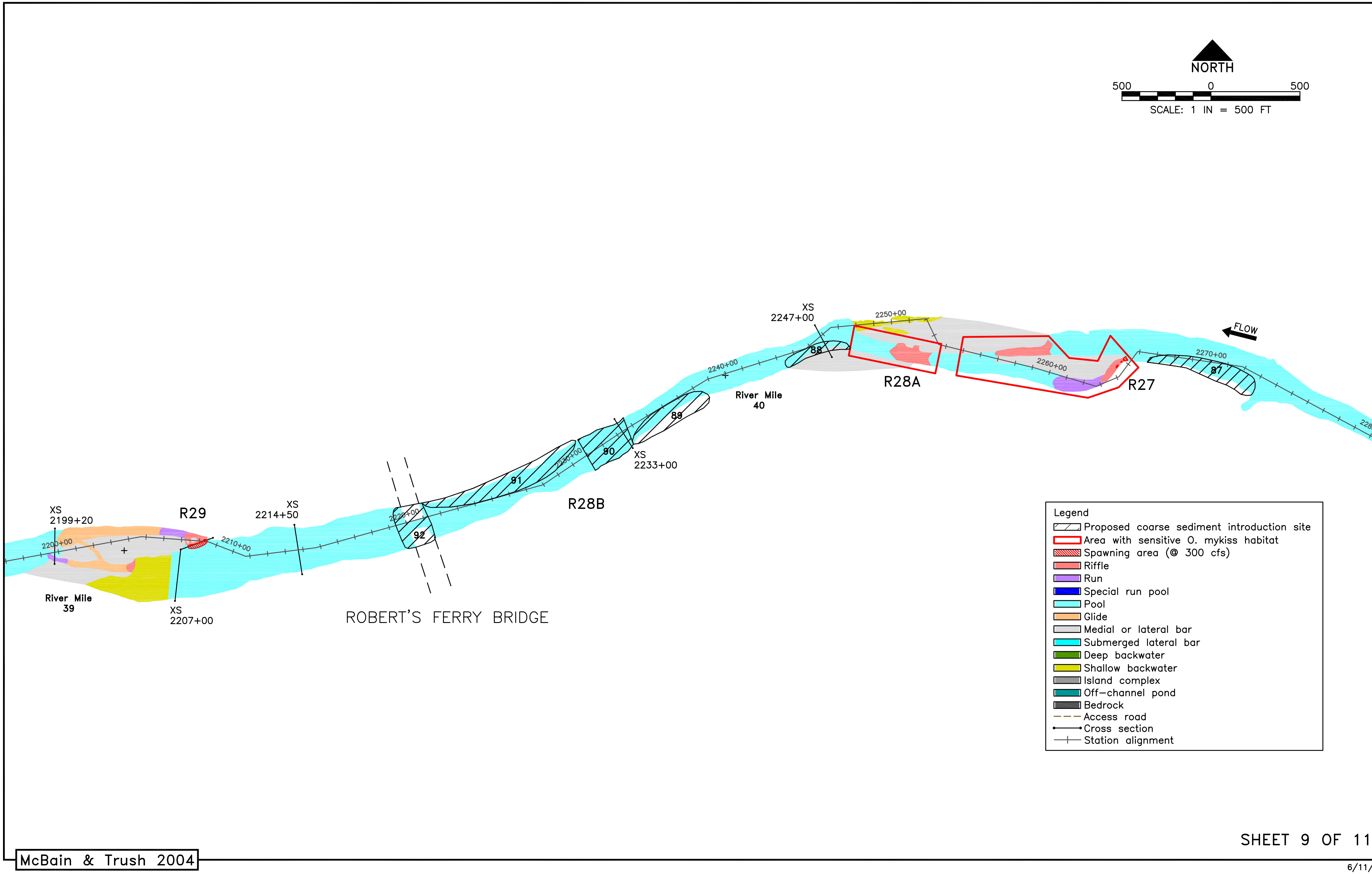

NORTH
500 0 500
SCALE: 1 IN = 500 FT
FLOW
Abandoned Haul Road
River Mile 46
River Mile 45
R12
R13A
R13B
R13C
R14
R15
2000/01 Salmon Redds
16 ft Maximum Depth
Peasley Creek
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
2590+00
2570+00
2550+00
2530+00
2520+00
2510+00
2500+00
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 5 OF 11
McBain & Trush 2004
6/11/04

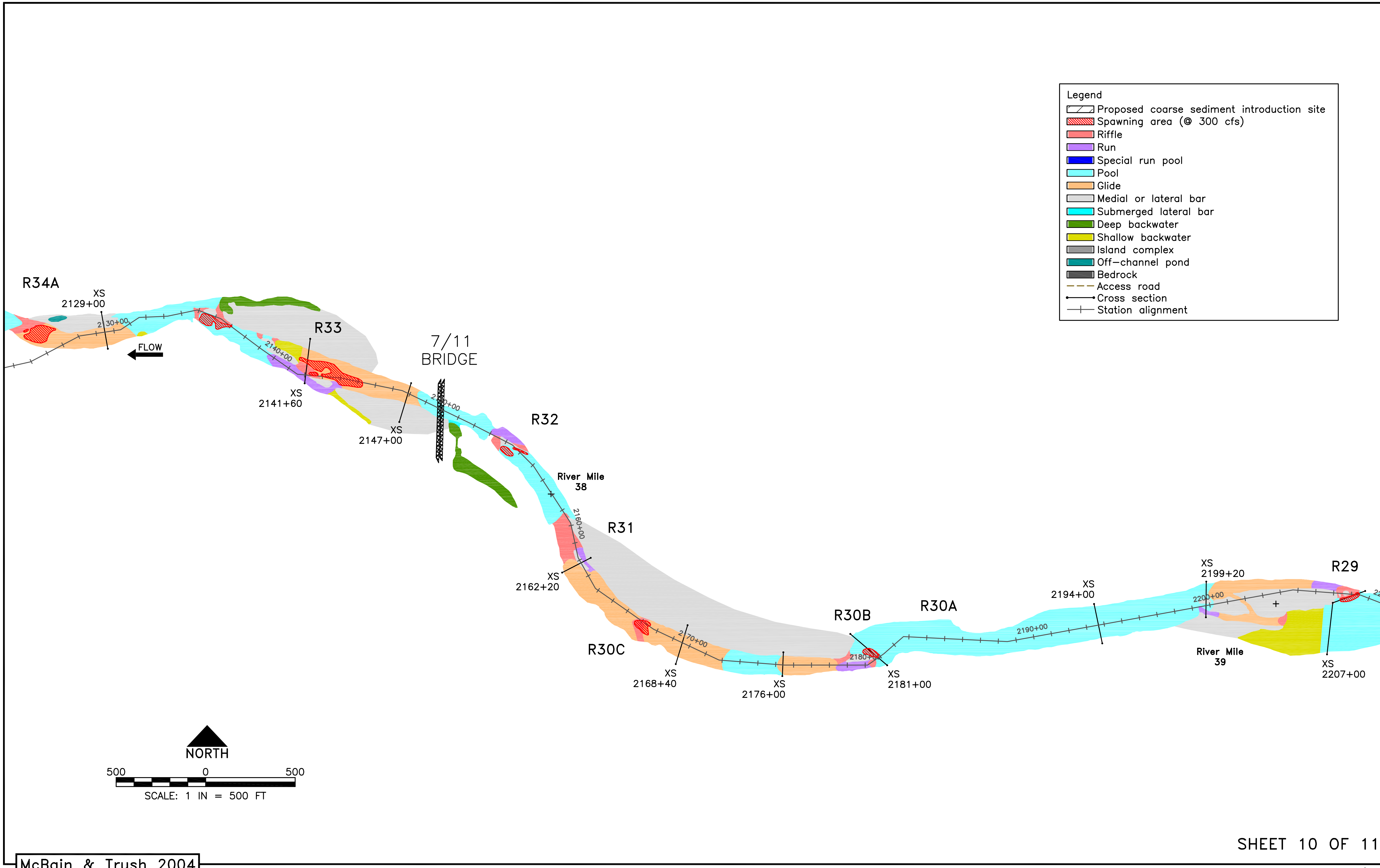

NORTH
500 0 500
SCALE: 1 IN = 500 FT
FOT RM 44
CHANNEL RESTORATION PROJECT
POTENTIAL
CHANNEL RELOCATION
SRP-3
FLOW
R18
R17A
R17D
R16
R15
R14
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
Boulders
Valley Oak
Trees
River Mile
44
2430+00
2450+00
2460+00
2470+00
2480+00
2490+00
2500+00
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 6 OF 11
McBain & Trush 2004
6/11/04

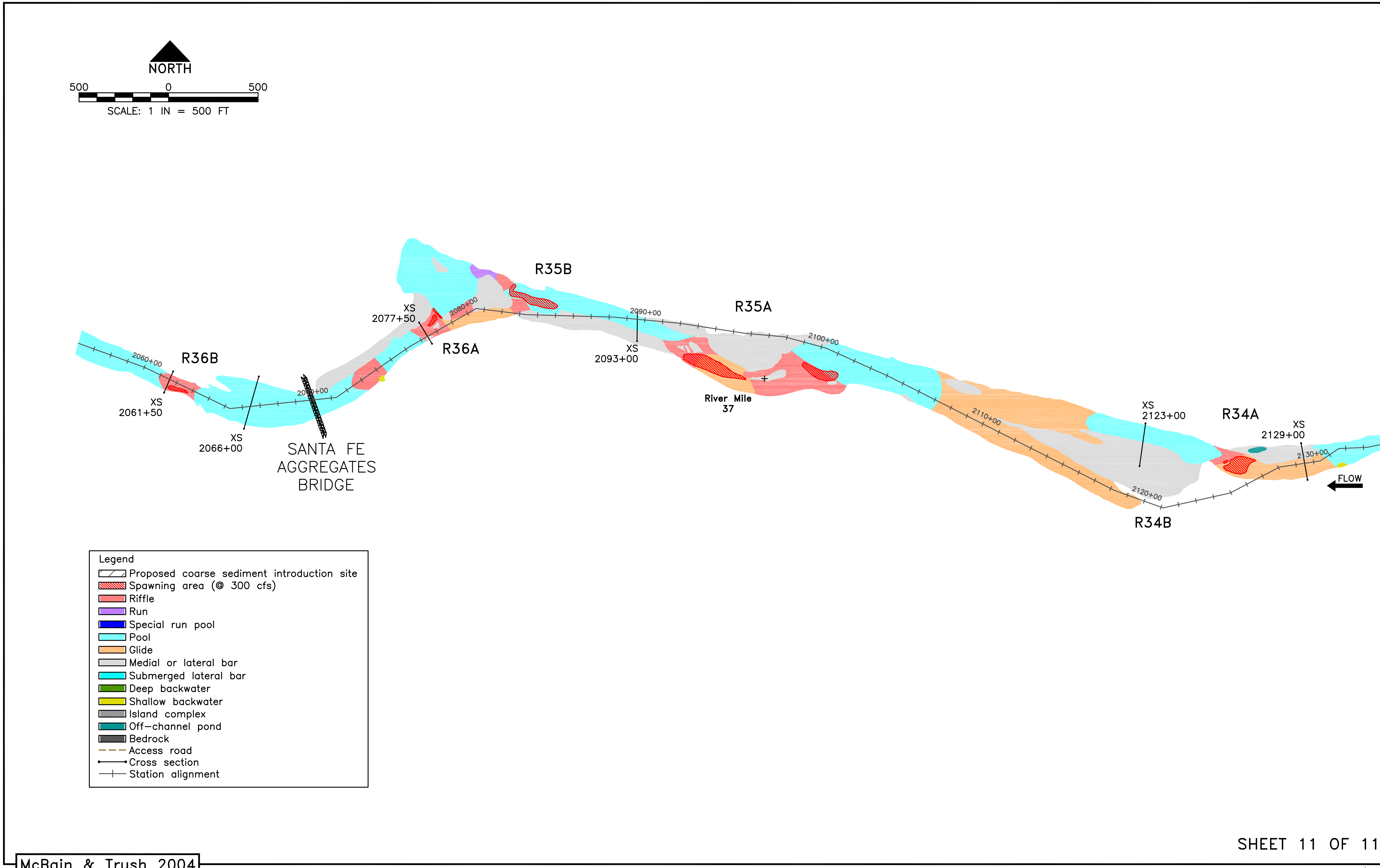

NORTH
500 0 500
SCALE: 1 IN = 500 FT
FOT BOBCAT FLAT
CHANNEL RESTORATION PROJECT
XS 2404+90
XS 2411+50
River Mile 43
XS 2400+00
XS 2398+50
XS 2397+50
XS 2413+00
XS 2413+50
R23D
River Mile 42
2350+00
R23B
R23C
R23A
R22
R21
R20
R18
81
80
79
78
77
76
75
74
73
72
71
70
69
2360+00
2370+00
2380+00
2390+00
2400+00
2410+00
2420+00
Access Road
Low flow side channel
FLOW
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 7 OF 11
McBain & Trush 2004

6/11/04


NORTH
500 0 500
SCALE: 1 IN = 500 FT
FLOW
27
87
R26
River Mile 41
SRP-4
86
R25
85
84
83
R24B
82
R24
R23D
XS 2333+45
XS 2334+45
XS 2335+70
XS 2336+35
XS 2337+10
Turlock Lake State Recreation Park
River Mile 42
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 8 OF 11
McBain & Trush 2004
6/11/04


NORTH
500 0 500
SCALE: 1 IN = 500 FT
FLOW
XS 2199+20
R29
XS 2214+50
River Mile 39
XS 2207+00
ROBERT'S FERRY BRIDGE
92
91
R28B
90
89
XS 2233+00
River Mile 40
XS 2247+00
88
R28A
R27
87
2200+00
2210+00
2220+00
2230+00
2240+00
2250+00
2260+00
2270+00
Legend
Proposed coarse sediment introduction site
Area with sensitive O. mykiss habitat
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 9 OF 11
McBain & Trush 2004
6/11/04


Legend
Proposed coarse sediment introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
R34A
XS 2129+00
FLOW
R33
XS 2141+60
7/11 BRIDGE
XS 2147+00
R32
River Mile 38
R31
XS 2162+20
R30C
XS 2168+40
XS 2176+00
R30B
XS 2181+00
R30A
XS 2194+00
XS 2199+20
R29
River Mile 39
XS 2207+00
NORTH
500 0 500
SCALE: 1 IN = 500 FT
SHEET 10 OF 11
McBain & Trush 2004
6/11/04


NORTH
500
0
500
SCALE: 1 IN = 500 FT
R35B
R35A
R36B
R36A
R34A
R34B
XS 2077+50
XS 2093+00
XS 2061+50
XS 2066+00
XS 2123+00
XS 2129+00
2060+00
2070+00
2080+00
2090+00
2100+00
2110+00
2120+00
2130+00
River Mile 37
SANTA FE AGGREGATES BRIDGE
FLOW
Legend
Proposed coarse sediment introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off–channel pond
Bedrock
Access road
Cross section
Station alignment
SHEET 11 OF 11
McBain & Trush 2004
6/11/04

Appendix E

Results of Summer 2001 Snorkel Surveys of Fine Sediment Deposits in the Lower Tuolumne River - Stillwater Sciences Technical Memorandum

Stillwater Sciences

2532 Durant Avenue, Suite 201 Berkeley, CA 94704 Phone (510) 848-8098 Fax (510) 848-8398

TECHNICAL MEMORANDUM

DATE: July 10, 2001

TO: McBain & Trush

FROM: Martin Trso and Noah Hume

SUBJECT: Results of Summer 2001 Snorkel Surveys of Fine Sediment Deposits in the Lower Tuolumne River

INTRODUCTION

As a component of McBain & Trush's coarse sediment management plan being developed for the Tuolumne River Technical Advisory Committee (TRTAC), Stillwater Sciences conducted a three-day reconnaissance-level snorkel survey of fine sediment deposits of the lower Tuolumne River from the USGS gaging station below La Grange Dam (RM 52) to Roberts Ferry Bridge (RM 39.6). The purpose of this investigation was to provide estimates of fine sediment accumulation in pools and to assess the relative contribution of in-channel sand and finer grain sources relative to tributary creeks (*i.e.*, Gasburg, Dominici and Peasley creeks). This interim memorandum will be integrated with prior spawning gravel quality reports in conjunction with a literature review on gravel cleaning methods to provide an assessment of the effectiveness of various gravel cleaning methods in improving spawning gravels within the lower Tuolumne River.

METHODS

On June 19–21, 2001, Stillwater Sciences surveyed the entire river reach from above the Old La Grange Bridge (RM 51.7) to Roberts Ferry Bridge (RM 39.6). River flows were approximately 90 cfs. The surveys were conducted by canoe and on foot using snorkel and Silvey rod to assess all fine sediment deposits for boundaries, type, average depth, textures, and geomorphic association in pools delineated in 1997 by EA (the pool habitat units comprised runs, side channels, bedrock chutes and backwater areas under flow conditions of 620 cfs) and adjacent areas within the bankfull-flow channel. Additionally, substrate characteristics and maximum depth in all pools were investigated. Locations of current riffles were checked against the 1997 locations. The confluences of Gasburg, Dominici, and Peasley creeks were briefly investigated for signs of sediment loading relative to transport capacity.

To help guide the field reconnaissance, all 1999 1:1,200 scale aerial photos (stored on a CD ROM) were examined in the office for preliminary identification of fine sediment deposits. In the field, all fine sediment deposits located within river's active channel were identified and sketched on the maps. The active channel was defined as a "bankfull" channel under the current post-dam hydraulic regime (approx. 3,000 cfs). Due to the nearly rectangular low-flow channel bank sections, the location of the 90-cfs low-flow channel boundaries approximated the 620-cfs wetted perimeter on the 1997 inundation maps for the purpose of mapping in the field during the surveys. The areas that lay between the 1,000-cfs to 3,000-cfs wetted perimeters adjacent to the low-flow channel were investigated to a limited extent and no further than 150 meters (500 feet) away from the low-flow channel boundary.

Maps: Two sets of maps were used for the field surveys. From the USGS gauge station (RM 52) downstream to New Basso Bridge, fine sediment deposit boundaries were mapped onto recent (1997) 1:6,000-scale aerial photos (Aerial Photgraphs 1–4) and their attributes recorded on Tables 1 and 2. The 1:6,000-scale photos were generated from the original 1:24,000-scale aerial photos (TID 1997 [KAV]?). From the New Basso Bridge to Roberts Ferry Bridge, fine sediment deposits were mapped onto laminated maps featuring channel habitat type and various inundation surfaces made prior to the 1997 floods (Aerial Photgraphs 5-9, TID 1997; Tables 1 and 2).

Pool Habitat Units: All pools were numbered consecutively (Aerial Photgraphs 1-9; Tables 1 and 2) and located by the upstream and downstream riffle or pool designations on the 1997 inundation maps (except for the relict Special Run Pools of mining origin). Data collected in each pool included: maximum depth (using depth sounder); visual estimate of percent area alluvium/bedrock (100% alluvium assumed, unless noted otherwise); visual assessment of substrate characteristics (by texture and presence of sand in the substrate matrix and on the surface of the bed substrate in the form of veneer); a photograph of the streambed substrate, and assessment of discreet fine sediment deposits. Due to summer low flow conditions during the June 19-21, 2001 surveys, the measured maximum pools depths reasonably approximated the maximum residual pool depths. The substrate texture was classified by a visually estimated areal coverage of each size fraction (*e.g.*, gravel and cobble (or cobble and gravel)=50/50; gravel (cobble) with cobble (gravel) =70/30; gravel and/with cobble and some boulder = 40/40/20; mossy substrate). The substrate sand veneer was characterized as follows: no or thin veneer; 0.5–1 inch thick veneer, and 1–2 inch thick veneer. Sometimes embeddedness estimates were made to give a sense of degree of mantling of gravel substrate with sand or silt (generally embededdness did not exceed 50% for 0.5–1 inch thick veneer). Assessment of discreet fine sediment deposits is described further below.

Discreet Fine Sediment Deposits: All discreet fine sediment deposits were noted and sketched on the field maps (Aerial Photgraphs 1-9). The discreet fine sediment deposits surveyed included those located within the low-flow channel (in the form of mainstem or side channel pool bottom sand/silt deposit, or mainstem or side channel in-stream wetland deposit), on top of gravel bars (vegetated or unvegetated), in sand bars (vegetated or unvegetated), and overbank sand deposits (unvegetated deposits on 1,000–3,000-cfs surfaces adjacent to the mainstem river channel). Extensive side channels or pits were not thoroughly investigated due to time constraints; extent of fine sediment deposits in these areas was roughly estimated, as indicated by question marks on the photos and maps (Aerial Photgraphs 1–9).

All fine sediment deposits were associated with a habitat type (*e.g.,* riffle, pool, bar) and categorized by the percentage of their areal extent within and outside the low-flow channel (Tables 1 and 2). Deposit textures (Table 1) were classified as follows: SA=sand, SI=silt, MUD=mud. The first component implies dominance (*e.g.,* SISA implies dominant silt mixed with sand). Deposit depths were measured with a Silvey rod. Fine sediment depth was determined by probing with the rod through sand or silt until the rod stroke coarser streambed material. When deposits appeared variably thick or irregular in shape, several depth measurements were taken for averaging. Otherwise only a few measurements of depth were taken. Degree of consolidation was not systematically assessed due to time constraints, but the conditions for unvegetated deposits ranged from loose to compacted. On that basis, a range of dry bulk densities from 1.14 to 1.86 t/m^3 reported for reservoir sediment in northern California (Anderson 1975) were used to convert from bulk volume to mass.

Tributaries: All three confluences (*i.e.*, Gasburg, Peasley, and Dominici creeks) were inspected from the river and by walking a short reach upstream of their confluence with the mainstem Tuolumne River. At each tributary, channel dimensions and geomorphic association were noted to assess relative contributions of fine sediment to the mainstem river.

RESULTS

General Observations: To help guide the field reconnaissance, all 1999 1:1,200 scale aerial photos (stored on a CD ROM) were examined in the office for preliminary identification of fine sediment deposits. Only a few deposits identified from these turned out to be substantial discreet fine sediment deposits. The majority was found to be approximately 1-inch thick veneer of sand on the pool streambed substrate. Interestingly, comparison between the pre-1997 inundation and habitat maps and the most recent (McBain & Trush) habitat maps suggests only minor changes in riffle areas and locations only, and the changes were generally limited to changes in shape of the riffles. The greatest changes have occurred between Old La Grange Bridge and Basso Bridge, where some riffles have been substantially re-formed in this reach. In the lower reach from New Basso Bridge to Roberts Ferry Bridge, most of the riffle locations and sizes have remained unchanged since 1997, except for a few which either have been broken down to a series of pool-riffle short segments or have actually increased in length (noted on maps). A number of submerged riffles, generally less than one channel width long but at least 1-meter below the water surface, were identified in the middle of long and deep pool runs.

Pool Substrates: Most of the mainstem pools have surface substrates of sand-rich (even sand matrix-supported) mixed gravel and cobble. Most of the pools have a sand veneer (veneer thickness varied from 0.5 to 2 inches, thicker veneers were sketched on the habitat maps as dashed blue polygons). Upon visual inspection of the surface bed (involving partial removal of the pavement layer in several pools), the sand content in the surface substrate appeared high in all pools. In several cases the gravel interstitial space was fully infilled with sand, implying a sand content of at least 40% of the gravel if a typical porosity is assumed.

No spatial distribution or pattern in the degree of mantling was apparent in the field. Often, 'dirty' substrate pools were abruptly followed by 'clean' substrate pools, and vice versa, etc. Further inspection of the field maps may reveal associations between potential sediment source areas (*e.g.,* pits, side channels) and observed sand conditions in the mainstem channel. Observations in the sub-reach below SRP 4 and above Roberts Ferry Bridge showed the pool substrates that were generally mossy.

Discreet Fine Sediment Deposits: Discreet fine sediment deposits identified in the field are summarized in Tables 1 and 2. These deposits were mapped as blue infill polygons on Aerial Photgraphs 1–9 of the survey maps for GIS entry. Information regarding the pool substrate fine sediment veneer has not been mapped on the survey maps except for veneers thicker than 2 inches (such appear as dashed blue polygons). In general, all alluvial stream banks outside the bankfull-flow channel appeared relatively stable, and no substantial streamside cliff sources of sediment were observed. As noted above, all streambed surface and subsurface substrates investigated appeared rich in sand, implying a large storage of sand in the subsurface.

Overall, only limited fine sediment deposits were identified in pools in the reach above Dominici Creek. Moderate storage was identified between Dominici and Peasley creeks, with the first substantial deposit located downstream of Basso Bridge below Peasley Creek. There was higher sediment storage between Peasley Creek and Roberts Ferry Bridge (one of the largest deposits was located immediately downstream of Peasley Creek) with other substantial deposits located in abandoned pits and side channels.

Table 1 shows that about 78,000 m^3 of fine sediment deposits was identified within the active channel in the study reach from the USGS gauge station to the Roberts Ferry Bridge. Assuming dry bulk density ranging from 1.14 to 1.86 t/m^3 (Anderson 1975), this volume amounts to an estimated total mass ranging from 89,000 to 145,000 tons. About 60,000 m^3 of fine sediment (77% of the total), ranging from 68,300 to 111,000 tons, is deposited in pools within the low-flow mainstem and side channels. Approximately 3,200 m^3 of sediment is stored in pools outside the low flow channel with the remaining fine deposits (15,079 m^3, or 17,000-28,000 tons) stored on top of gravel bars and in overbank sand deposits outside of the low-flow channel.

Side channel pools and wetlands store about 32,000 m^3, or 36,000-59,000 tons, approximately 40% of the total surveyed. The largest of these deposits is a wetland area just downstream of Peasley Creek with over 14,000 m^3 located at SRP 2 (Table 1). Several side channels were infilled with wetland-type fine sediment to capacity, likely concealing pool topography.

Tributaries: For the three tributaries surveyed, Peasley Creek appeared to be the largest contributor of fine sediment downstream of Basso Bridge. The first deposit downstream of Gasburg Creek Deposit 4 on Table 1) was estimated at 4,050 m^3 of fine sediment, with approximately 1,200 m^3 deposited in Pool 16 below Dominici Creek (Table 2). However, the largest single deposit associated with tributary input lies within a wetland area just downstream of Peasley Creek with over 14,000 m^3 located at SRP 2 (Table 1). The three tributaries are summarized below:

> Gasburg Creek: The 5-meter (16 feet) wide creek gently cuts across the mainstem's gravel pre-dam 10-yr (estimate) floodplain for about 200 meters before it exits into pool No.7, located between riffles R1A and R1B (Aerial Photgraphs 1 and 2). A brief inspection of the upland reach of the creek did not reveal evidence of recent downcutting (the creek banks are composed of alluvium and appear stable). The streambed was comprised of sand-matrix-supported gravel with no evidence of sand loading beyond river's transport capacity (no recent sand bars or overbank sand deposits). Most overbank sand deposits located on the mainstem's pre-dam 10-yr floodplain appear to be of 1997 origin based on vegetation. A three-meter-high (10 feet) gravel delta/bar located at the confluence between low-flow channels of the Tuolumne River and Gasburg Creek appears to be of 1997 origin based on vegetation.

> Dominici Creek: The 5-meter (16 feet) wide creek exits in pool No. 16 located between riffles R5B and R6 (Aerial Photgraph 3). Comparison of aerial photos and maps shows that the generalized floodplain delineation in the 1997 inundation maps in this area needs field verification. No delta deposit was associated with the confluence was observed, suggesting only moderate sediment supply. The creek channel appeared historically entrenched.; The streamside banks exhibited moderate erosion. The streambed characteristics were not investigated due to access constraints, but signs of high sediment supply (gravel bars, thick streambed) were observed.

> Peasley Creek: The 3-5 meter (10-16 feet) wide creek exits in pool No. 28, located between the riffle R13B and pool SRP2 (Aerial Photgraph 5). Comparison of aerial photos and maps

shows that the generalized floodplain delineation in the 1997 inundation maps in this area needs field verification. A 20 m^2 (200 ft^2) sand delta was observed at the confluence with the mainstem Tuolumne River. A two-meter (6-feet) high bedrock knickpoint in the streambed is located at 70 meters (230 feet) upstream of the confluence. Upstream of the knickpoint the channel appeared historically entrenched by 1–1.5 meters (3–5 feet) and the streambed was sand-matrix-supported medium gravel. Downstream of the knickpoint, the streambed consisted of 0.3–1-meter (1- to 3-feet) thick sand. Although the streamside banks appeared relatively stable (showing only ravel and minor slumps), this creek appeared to be the highest contributor of fine sediment of all three tributaries. At least two irrigation canal crossings on this creek possibly contribute to local erosion and sediment supply downstream.

DISCUSSION

Removal of Existing Fine Sediment Storage: Assessing the feasibility of mechanical or suction dredging removal of pool deposits of fine sediment in terms of the existing sediment inventory suggest that dredging of pools above Basso Bridge (where most useable spawning area occurs) is probably not warranted. The majority of pools in the upper river reaches above Basso Bridge were “clean”, exhibiting only a veneer of sand over sand-rich mixed gravel and cobble. However, fine sediment deposition increases markedly in pools below Basso Bridge (Table 2) and attaining improved in spawning gravels in riffles in the lower reaches may require some removal of these deposits.

Quantifying Rates of Fine Sediment Supply: Both the effectiveness of any proposal for dredging pool deposits or riffle cleaning requires an assessment of re-supply from upstream sources. Based on inspection of tributary junctions none of the three tributaries appeared to be delivering large amounts of sediment to the mainstem river at present, suggesting that the current sand-rich conditions on the mainstem Tuolumne River may either be a legacy of the 1997 flood event, which transported approximately 200,000 yd^3 of sand to the lower Tuolumne River (McBain & Trush 2000), and/or are related to other sources of sediment (bleeding pits or side channels). The observed sand-rich conditions may also be related to long-term immobility of the channel bed as a result of decreased peak flows. However, all three tributaries exhibited evidence of historic entrenchment and sediment-rich conditions in the streambed substrate, implying a need for sediment source analysis to quantify sediment delivery to the mainstem river.

Although fine sediment transport generally exceeds coarse sediment transport rates by an order of magnitude, fine sediment transport is limited by the rate of upstream supply. Without further knowledge of characteristics of the alluvial river mantle (average total depth to bedrock or inactive valley fill, and overall sand content; active sand deposits on the floodplains, etc.) and sediment supply from upstream of the La Grange Dam and main tributaries, we cannot adequately answer whether dredging the fine sediment deposits located within the low-flow channel pools will lead to reduction of in-channel fine sediment transport and thus sand re-infiltration in downstream riffles that may be cleaned.

CONCLUSIONS

Estimated total mass of fine sediment deposits within the active channel in the study reach from RM 51.7 (d/s USGS gauge station) to RM 39.6 (Roberts Ferry Bridge) ranges from 89,000 to 146,000 tons. Approximately 66% (or 59,000–97,000 tons) of the total fine sediment storage inventoried was associated with low-flow channel pools, with an additional 4% (or 3,700-6,000 tons) in side channel pools and wetland habitats. Although the majority of pools in the upper reaches above Basso Bridge had little or no discreet fine sediment deposits, nearly all pool substrates were filled with sand in the interstitial spaces. Sand deposition in pools increased markedly below Basso Bridge.

Although none of the three main tributaries (*i.e.,* Gasburg, Dominici, and Peasley Creeks) appeared to be delivering large amounts of sediment to the mainstem river at present, we cannot make confident conclusions without a more thorough sediment source analysis. The 20 m^2 sand delta and 14,400 m^3 deposit below Peasley Creek suggests that this is the largest tributary source of fine sediment to the lower Tuolumne River. Other sources, such as bars, riffles and overbank sand deposits within the low flow channel (10% of the inventoried total or 9,000–15,000 tons) and in the 1,000-3,100 cfs floodplain (19% of the total or 17,000–28,000 tons) could be transported downstream under high flow conditions and deposit in the tributary confluences or other areas. These latter sources and fine sediment deposits located between the low-flow and bankfull-flow channel boundaries should be considered carefully because they may exceed fine sediment delivery from all three tributaries below La Grange Dam.

Although removal of stored sediment in pools above Basso Bridge may not be warranted at this time, the feasibility of gravel cleaning methods has not yet been evaluated. Because fine sediment transport rates directly determine the rates of re-deposition in pools and riffle interstices, a separate sediment source analysis may be required to adequately quantify the rates of re-supply of fine sediment in the lower Tuolumne River.

REFERENCES

Anderson, H.W. (1975). Report of the Committee on Quantification of Erosion and Sedimentation, Watershed Management Workshop for Earth Science Specialists, Region V, U.S. Forest Service, Fresno, CA, February 25-27, 1975.

McBain & Trush (2000). Habitat restoration plan for the lower Tuolumne River corridor. March.

Table 1 - Fine Sediment Deposits Surveyed in the lower Tuolumne River, June 19-21, 2000.

Discreet Fine Sediment Deposit No.	1997 location (up/ downstream)	Habitat unit	Pool No.	Ave. Deposit depth, m	% above low-flow LF channel	% in low-flow LF channel	Texture	Est. area, m2	Est. volume, m3	Est. volume within LC, m3	GIS area, m2	GIS-based volume, m3	Comment
1	RA3B-RA5A	LF mainstem pool	1	0.13	0	100	SA	80	10.4	10.4			
2	RA5A-RA5B	LF mainstem pool	2	0.15	0	100	SA	15	2.25	2.3			
	RA5B-RA6	LF mainstem pool	3										
	SRP1	LF mainstem pool	4										
	SRP1-RA7B	LF mainstem pool	5										
3	RA7B-R1A	LF mainstem pool	6	0.14	0	100	SA	60	8.4	8.4			
	R1A-R1B	LF mainstem pool	7										
4	R1B-R1C	LF mainstem pool	8	0.75	0	100	SA	5400	4050	4050			
	R1C-R2	LF mainstem pool	9										
	R2-R3A	LF mainstem pool	10										
	R3A-R3B	LF mainstem pool	11										
5	R3B-R4A	LF mainstem pool	12	0.4	20	80	SA	2700	1080	864			
	R4A-R4B	LF mainstem pool	13										
	R4B-R5A	LF mainstem pool	14										
6	R5A	OLF sand bar	n/a	0.6	100	0	SA	3300	1980	0			overbank sand deposit (OSD), sand bar
	R5A-R5B	LF mainstem pool	15										
7	R5B	OLF sand bar	n/a	0.75	100	0	SA	1800	1350	0			OSD, sand bar
8	R5B-R6	LF mainstem pool	16	0.15	0	100	SASI	240	36	36			
9	R5B-R6	LF mainstem pool	16	0.3	0	100	SASIMUD	1300	390	390			
10	R5B-R6	OLF sand bar	n/a	0.3	100	0	SA	300	90	0			OSD, sand bar
11	R5B-R6	LF mainstem pool	16	0.11	0	100	SASIMUD	5400	594	594			could be Dominici Cr related
12	R5B-R6	OLF lateral bar	n/a	0.5	100	0	SA	3000	1500	0			vegetated OSD, sand bar
13	R5B-R6	LF mainstem pool	16	0.5	0	100	SA	450	225	225			deep riffle, part of pool
	R6-R7	LF mainstem pool	17										
	R7-R8	LF mainstem pool	18										
14	R8-R9A	OLF sand bar	n/a	0.6	100	0	SASI	6000	3600	0			vegetated sand bar
15	R9A-R9B	LF riffle	n/a	0.6	0	100	SA	2400	1440	1440			in-stream side channel (SC) wetland; deep riffle
16	R9A-R9B	LF side channel pool	19	0.6	0	100	SASI	130	78	78			sand deposit at the mouth of the side channel
17	R9A-R9B	LF side channel pool	19	0.15	0	100	SASIMUD	6400	960	960			SC wetland/pond
18	R9A-R9B	LF sand bar	n/a	0.6	100	0	SA	200	120	0			vegetated sand bar
19	R9B-R11	LF mainstem pool	20	0.6	0	100	SISA	200	120	120			
20	R11-R12A	LF mainstem pool	21	0.9	0	100	SA	140	126	126			
21	R11-R12A	LF side channel pool	21	0.15	0	100	SA	1000	150	150			SC pool deposit, as long as SC
22	R11-R12A	LF SC and mainstem pool	21	0.75	0	100	SISA	4800	3600	3600			wetland located in both main and side channel (50%)
23	R12A-R12B	LF mainstem pool	22	0.75	0	100	SASI	1200	900	900			
24	R12A-R12B	LF mainstem pool	22	0.9	50	50	SA	1500	1350	675			
25	R12A-R12B	LF mainstem pool	22	0.11	0	100	SASI	1000	110	110			
26	R12B-R13A	LF sand bar	n/a	0.9	50	50	SA	300	270	135			unvegetated sand bar
27	R12B-R13A	LF sand bar	n/a	0.9	50	50	SA	300	270	135			unvegetated sand bar
28	R13A-R13B	LF riffle	n/a	0.15	0	100	SA	300	45	45			former pool
29	R13B	LF riffle	n/a	0.6	50	50	SA	130	78	39			vegetated sand bar
30	R13B	LF riffle	n/a	0.6	50	50	SA	100	60	30			unvegetated sand deposit
31	R13B	OLF mid-channel gr. bar	n/a	1.5	100	0	SA	150	225	0			vegetated sand mantle on top of GR bar
32	R13B-SRP2	LF mainstem pool	23	0.6	20	80	SASI	3600	2160	1728			
33	R13B-SRP2	LF mainstem pool	23	0.9	0	100	SA	1800	1620	1620			
34	SRP2	LF mainstem pool	24	0.6	0	100	SA	150	90	90			
35	SRP2	OLF gravel bar	n/a	1.7	100	0	SA	150	255	0			gravel bar with sand deposit
36	SRP2	LF mainstem pool	24	0.9	0	100	SASI	16000	14400	14400			in-stream mainstem wetland, major deposit
	R14-R15	LF mainstem pool	25										

Table 1 - Fine Sediment Deposits Surveyed in the lower Tuolumne River, June 19-21, 2000.

Discreet Fine Sediment Deposit No.	1997 location (up/ downstream)	Habitat unit	Pool No.	Ave. Deposit depth, m	% above low-flow LF channel	% in low-flow LF channel	Texture	Est. area, m2	Est. volume, m3	Est. volume within LC, m3	GIS area, m2	GIS-based volume, m3	Comment
	R15-R16A	LF mainstem pool	26										
37	R16A-R16B	LF mainstem pool	27	1.2	0	100	SASI	800	960	960			
38	R16B-R16C	LF mainstem pool	28	0.6	0	100	SASI	200	120	120			
39	R16B-R16C	OLF mid-channel gravel bar	n/a	1.1	100	0	SASI	200	220	0			vegetated gravel bar with sand deposit
40	R16C-R17A1	LF mainstem pool	29	0.75	0	100	SA	100	75	75			
41	R17A1-R17A2	LF riffle	n/a	1.2	0	100	SASI	600	720	720			former pool
42	R17A1-R17A2	LF riffle area & OLFsand bars	n/a	1.5	50	50	SASI	7000	10500	5250			OSD, sand bars (50% area)
43	R17A2-R17B	LF pool & OLF sand bar	n/a	0.75	50	50	SA	400	300	150			OSD, sand bars (50% area)
44	R17A2-R17B	LF mainstem pool	30	1.2	50	50	SA	400	480	240			wetland
45	SRP3	LF mainstem pool	31	0.9	0	100	SIMUD	5300	4770	4770			
46	SRP3	OLF?/LF? side channel pool	31	0.9	0	100	SIMUD	5000	4500	4500			wetland is formerly LF pool infilled to capacity now
47A	SRP3	LF mainstem pool	31	0.3	50	50	SA	700	210	105			
47B	R18-R19	LF mainstem pool	32	0.9	50	50	SASI	2400	2160	1080			
48	R18-R19	LF mainstem pool	32	0.3	0	100	SISA	120	36	36			
49	R19-R20	LF side channel pool	33	1.2	0	100	SASI	5800	6960	6960			wetland; need to investigate the extent of deposit
50	R20-R21	LF mainstem pool	34	0.15	50	50	SA	600	90	45			
51	R21-R22S	LF mainstem pool	35	0.75	50	50	SASI	1000	750	375			
	R22S-R23A1	LF mainstem pool	36										
52	R23A1-R23A2	LF mainstem pool	37	0.45	50	50	SIMUD	250	112.5	56			
	R23A2-R23C1S	LF mainstem pool	38										
	R23C1S-R23C2	LF mainstem pool	39										
53	R23D	LF side channel pool	40	0.6	0	100	SASIMUD	1000	600	600			in-stream SC wetland
	R23D-R24S	LF mainstem pool	41										
	R24S--R25	LF mainstem pool	42										
54	R25	LF riffle	n/a	0.15	0	100	SIMUD	250	37.5	38			vegetated sand deposit
	R25-SRP4	LF mainstem pool	43										
55	SRP4	LF mainstem pool	44	0.3	0	100	SA	4000	1200	1200			
56	SRP4	LF mainstem pool	45	0.11	0	100	SIMUD	900	99	99			
	R26-R27A	LF mainstem pool	45										
	R27A-R27B	LF mainstem pool	46										
	R27B-R28A	LF mainstem pool	47										
	R28A-R28B	LF mainstem pool	48										
					23%	77%			**78243**	59940			Total within Low flow
									31728	31488			
									55183	51958			Total Mass in Low Flow Pools
										3224			Pool Deposits between 1,000-3,000 cfs wetted Perimeter
									20680	5670			Bars within Low Flow
										15010			Overbank Sand Deposits and Bars between 1000-3100 cfs wetted Perimeter
									2381	2312			Riffles within Low Flow
										69			Riffles Between 1,000-3100 cfs Wetted PerimeterOutside Low Flow

	1.14 to 1.86 t/m3 (Anderson 1975)	
Est. total within the bankfull-flow channel surveyed: 78,243 m^3, or	**89,197**	**145,532 tons**
Est. total within the low-flow channel: 59,940 m^3, or	**68,331**	**111,488 tons**
Est. total in Pools outside Low Flow Channel: 3,224 m^3 , or	**3,676**	**5,997 tons**
Est. total in Bars, Riffles and Overbank Dep. Within Low Flow: 7,982 m^3, or	**9,099**	**14,846**
Est. total in Bars, Riffles and Overbank Dep. Outside Low Flow: 15,079 m^3, or	**17,190**	**28,047 tons**

Table 2 - Fine Sediment Deposits in Pools Surveyed in the Lower Tuolumne River, June 19-21, 2001

1997 pool No.	1997 location (up/ downstream)	Habitat unit	Max Water Depth, m	Pool Substrate	Predominant Sand Cover	Discreet Fine Sediment Deposit No.	Deposit Texture	Avg depth of deposit, m	est. area, m^2	Tot est. volume, m^3	GIS area, m^2	Tot Volume, m^3	% outside low-flow channel	% in low-flow channel	Total Mass, t	Mass in LF pools, ton
1	RA3B-RA5A	LF mainstem pool	3	GR-CO	0.5-1" veneer	1	SA	0.13	80	10.4			0	100	10.4	10
2	RA5A-RA5B	LF mainstem pool	3	GR	0.5-1" veneer	2	SA	0.15	15	2.25			0	100	2.25	2
3	RA5B-RA6	LF mainstem pool	3	CO	clean											
4	SRP1	LF mainstem pool	5	BO-GR-CO	0.5-1" veneer											
5	SRP1-RA7B	LF mainstem pool	n/a	GR-CO	clean											
6	RA7B-R1A	LF mainstem pool	3	GR-CO	clean	3	SA	0.14	60	8.4			0	100	8.4	8
7	R1A-R1B	LF mainstem pool	4	GR	0.5-1" veneer											
8	R1B-R1C	LF mainstem pool	3	GR	n/a	4	SA	0.75	5400	4050			0	100	4050	4050
9	R1C-R2	LF mainstem pool	2	GR-CO	clean											
10	R2-R3A	LF mainstem pool	4	GR-BDR (20%)	clean											
11	R3A-R3B	LF mainstem pool	3	GR	0.5-1" veneer											
12	R3B-R4A	LF mainstem pool	2	GR-CO	clean	5	SA	0.40	2700	1080			20	80	1080	864
13	R4A-R4B	LF mainstem pool	1.3	CO-GR	clean											
14	R4B-R5A	LF mainstem pool	1.2	CO-GR, wBO	clean											
15	R5A-R5B	LF mainstem pool	1.6	GR wBDR (10%), CO	clean											
16	R5B-R6	LF mainstem pool	2.3	CO wGR	0.5-1" veneer	8-9,11,13	SASIMUD	0.17	7390	1245			0	100	1245	1245
17	R6-R7	LF mainstem pool	n/a	CO-GR	0.5-1" veneer											
18	R7-R8	LF mainstem pool	1.8	GR wCO	clean											
19	R9A-R9B	LF mainstem&side channel pool	2.3	GR wCO	0.5-1" veneer	16-18	SASIMUD	0.17	6730	1158			0	100	1038	1038
20	R9B-R11	LF mainstem pool	2.3	GR-CO	0.5-1" veneer	19	SISA	0.60	200	120			0	100	120	120
21	R11-R12A	LF mainstem&side channel pool	2.5	FiGR	clean	20-22	SASI	0.65	5940	3876			0	100	3876	3876
22	R12A-R12B	LF mainstem pool	1.5	GR	1-2" veneer	23-25	SASI	0.64	3700	2360			29	71	2360	1685
23	R13B-SRP2	LF mainstem pool	1.3	GR wCO	1-2" veneer	32-33	SASI	0.70	5400	3780			11	89	3780	3348
24	SRP2	LF mainstem pool	3.4	GR wCO	0.5-1" veneer	34, 36	SASI	0.90	16150	14490.02			0	100	14490.02	14490.02
25	R14-R15	LF mainstem pool	1.2	GR	clean											
26	R15-R16A	LF mainstem pool	2	GR	clean											
27	R16A-R16B	LF mainstem pool	0.5	GR	clean	37	SASI	1.20	800	960			0	100	960	960
28	R16B-R16C	LF mainstem pool	1.5	GR	0.5-1" veneer	38	SASI	0.60	200	120			0	100	120	120
29	R16C-R17A1	LF mainstem pool	1	CO wGR	clean	40	SA	0.75	100	75			0	100	75	75
30	R17A2-R17B	LF mainstem pool&bar	1.3	GR	1-2" veneer	44	SA	1.20	400	480			50	50	480	240
31	SRP3	LF mainstem&SC pool	2.3	CO wGR, BDR (30%)	1-2" veneer	45,46,47A	SIMUD	0.86	11000	9480			1	99	9480	9375
32	R18-R19	LF mainstem pool	2.5	CO wGR	1-2" veneer	47B-48	SASI	0.87	2520	2196			49	51	2196	1116
33	R19-R20	LF side channel pool	1.5	CO-GR	0.5-1" veneer	49	SASI	1.20	5800	6960			0	100	6960	6960
34	R20-R21	LF mainstem pool	2	GR wCO	clean	50	SA	0.15	600	90			50	50	90	45
35	R21-R22S	LF mainstem pool	2.1	CO wGR	0.5-1" veneer	51	SASI	0.75	1000	750			50	50	750	375
36	R22S-R23A1	LF mainstem pool	2.1	CO wGR	0.5-1" veneer											
37	R23A1-R23A2	LF mainstem pool	n/a	n/a	n/a	52	SIMUD	0.45	250	112.5			50	50	112.5	56.25
38	R23A2-R23C1S	LF mainstem pool	1	CO-GR	clean											
39	R23C1S-R23C2	LF mainstem pool	0.9	GR wCO	clean											
40	R23C2-R23D	LF side channel pool	0.6	CO wGR	clean	53	SASIMUD	0.60	1000	600			0	100	600	600
41	R23D-R24S	LF mainstem pool	1	CO wGR	0.5-1" veneer											
42	R24S-R25	LF mainstem pool	2.3	CO wGR	0.5-1" veneer											
43	R25-SRP4	LF mainstem pool	1	GR, BDR (50%)	clean											
44	SRP4	LF mainstem pool	4.3	CO wGR	0.5-1" veneer	55-56	SASIMUD	0.27	4900	1299			0	100	1299	1299
45	R26-R27A	LF mainstem pool	2.1	GR	algae											
46	R27A-R27B	LF mainstem pool	n/a	n/a	n/a											
47	R27B-R28A	LF mainstem pool	0.5	GR wCO	algae											
48	R28A-R28B	LF mainstem pool	2	GR wCO, BDR (20-30%)	some algae											
													6%	94%	55183	51959
																3224

Est. total within the Low Flow Channel Pools: 51,959 m^3, or 59,000 to 97,000 tons

Est. total in Pools outside Low Flow Channel: 3,224 m^3 , or 3,700 to 6,000 tons

Aerial Photographs 1 - 4: Fine sediment deposit boundaries were mapped onto recent (1997) 1:6,000-scale aerial photos from the USGS gauge station (RM 52) downstream to New Basso Bridge. The 1:6,000-scale photos were generated from the original 1:24,000-scale aerial photos (TID 1997).

Aerial Photographs 5 - 9: Fine sediment deposits from the New Basso Bridge to Roberts Ferry Bridge, were mapped onto laminated maps featuring channel habitat type and various inundation surfaces made prior to the 1997 floods.

Aerial photograph sets are available upon request.

Appendix F

Evaluation of Fine Sediment Removal Methods for use in the Tuolumne River - Stillwater Sciences Technical Memorandum

Stillwater Sciences

2532 Durant Avenue, Suite 201 Berkeley, CA 94704 Phone (510) 848-8098 Fax (510) 848-8398

TECHNICAL MEMORANDUM

DATE: November 18, 2002

TO: McBain & Trush

FROM: Noah Hume, Peter Baker and Jay Stallman

SUBJECT: Evaluation of Fine Sediment Removal Methods for use in the Tuolumne River

INTRODUCTION

Previous studies of the quality of spawning gravels in the lower Tuolumne River in 1988 and 1989 attributed low salmonid survival-to-emergence rates to poor riffle quality, which has resulted from the deposition of fine sediment in the gravel substrate (TID/MID 1992a). Recent gravel permeability studies have reinforced this supposition (Stillwater Sciences 2001). Gravel quality is a key factor influencing the success of incubation and emergence of salmonid eggs and alevins. Accumulation of fine sediment in spawning gravel reduces salmonid survival-to-emergence through two mechanisms: (1) reduction of intragravel flow, and (2) entombment of emerging fry. The intrusion of fine sediment into gravel interstices reduces intragravel flow by reducing gravel permeability (Cooper 1965, Lotspeich and Everest 1981, McNeil 1960, Platts et al. 1979) and results in reduced rates of oxygen delivery to and removal of metabolic wastes (carbon dioxide and ammonia) from the eggs and alevins (Coble 1961, Silver et al. 1963, McNeil 1960, Wickett 1958). Fine sediments in the gravel interstices can also physically impair the ability of alevins to emerge through the gravel layer, trapping (or entombing) them within the gravel (Philips et al. 1975, Hausle and Coble 1976).

The Habitat Restoration Plan for the Lower Tuolumne River Corridor (McBain and Trush 2000) recommended that coarse sediment supply be increased and fine sediment supply be reduced, with the overall goal of improving spawning habitat conditions for salmon. The Tuolumne River Technical Advisory Committee (TRTAC) is preparing overall sediment management and implementation plans to address these issues. The Turlock and Modesto Irrigation Districts (the Districts) contracted McBain and Trush to develop a Coarse Sediment Management Plan for the lower Tuolumne River (funded by the implement an Anadromous Fisheries Restoration Program (AFRP) funded Coarse Sediment Management Plan for the lower Tuolumne River. The Districts have also received funding to develop a Fine Sediment Management Plan for the lower Tuolumne River, and have retained Stillwater Sciences to complete this work. As a component of the Coarse Sediment project, Stillwater Sciences recently completed two tasks to summarize existing information regarding potential fine sediment removal:

1) A literature review and evaluation of fine sediment removal methods from similar alluvial rivers used by salmonids in California (Feather and Trinity Rivers), Idaho (Palouse River) and Washington (Cedar, Nadina, and Horsefly Rivers), among others.
2) An evaluation of the cost and effectiveness of mechanical gravel cleaning methods used by the Turlock and Modesto (TID/MID) Irrigation Districts in the early 1990s.

REVIEW OF FINE SEDIMENT SOURCE CONTROL METHODS

Several non-flow source control measures may reduce the rate of introduction of fine sediments in the primary spawning reach of the lower Tuolumne River, including changes in upstream land use and a number of-instream control measures. Although the LaGrange and Don Pedro dams act as highly efficient sediment traps, they are located above several sediment sources (*e.g.*, Gasburg Creek, Dominici Creek, etc.) to the Tuolumne River. For dams located above major fine sediment sources, substantial deposition of sediments is likely to occur (Reider et. al. 1989), particularly given the generally lowered hydrograph peaks and flushing capacities under natural flow conditions. Einstein (1968) found that the rate of accumulation of fine sediment in spawning gravels is dependent of the concentration of suspended sediment, but is independent of either the flow velocity or the amount of material already present in interstices. This reinforces the need for a fine sediment source control program prior to the implementation of a gravel cleaning program. Below we describe several methods for reducing fine sediment inputs into the Tuolumne River.

Land Use Changes. Although the sediment contribution to streams from roads is often much greater than that of other land management use activities (Gibbons and Salo, 1973, Reid 1981) a number of historical land uses (e.g., sand mining, road and canal cuts, etc.) have resulted in soil instability with the potential for landslides and erosion (Stillwater Sciences 2002a). With the exception of large flood events such as the 1997 floods, recent field surveys have identified Gasburg and Dominici Creeks as chronic sources of fine sediment to the lower Tuolumne River. The most effective means for controlling fine sediment inputs is to eliminate the sediment sources by stabilizing disturbed lands. In the absence of soil stabilization techniques for past construction activities or long term changes in land use, perhaps the most effective means of fine sediment source control from the tributary watersheds in the near term is the use of sedimentation basins.

Sedimentation Basins. The current Fine Sediment Management Project Plan includes the design and construction of a sedimentation basin on Gasburg Creek, which is the furthest upstream tributary in the spawning reach of the Tuolumne River. Sedimentation basins provide a passive means of reducing or eliminating input of the coarser sand component of fine sediment from flowing water. Although gravity settling of solids that have a specific gravity greater than water is well understood, sedimentation basins are ineffective in the removal of silts and clays with low settling velocities. In general, sedimentation basin effectiveness will depend upon the size of the basin, the upstream sediment load, and the frequency of cleaning.

Suction Dredge Removal of Pool Deposits. As part of the overall Coarse Sediment Management Plan, in June 2001 Stillwater Sciences conducted a three day snorkel survey of fine sediment deposits of the lower Tuolumne River from the USGS gauging station below La Grange Dam (RM 52.0) to Robert's Ferry Bridge (RM 39.6). Approximately 65,000 m^3 (104,000 tons, assuming a bulk density of 1.6 tons/m^3) were mapped, and about 70 % of the total volume was deposited in low-flow pools, with about 5 % in pools outside the low-flow channel, and the remainder deposited on top of gravel bars and as overbank deposits. One question arises is whether removal of these deposits using suction dredges will reduce the rate of downstream transport and affect re-infiltration of fine sediments into recently cleaned gravels. Although suction dredging in spawning gravels for gold mining has a number of short-term impacts on invertebrate communities and spawning use (Harvey and Lisle 1999), dredging in pools is not considered to represent a major impact provided the materials are not discharged onto downstream gravels. Suction dredging methods for removal of sand from pools will be evaluated under the Tuolumne River Fine Sediment Project.

Mechanical Removal from Riparian Berms and Floodplain. The primary spawning reach of the Tuolumne River below La Grange and Don Pedro dams is characterized as a low gradient, meandering alluvial river by relatively low gradients than those historically used by the anadromous fishes of the Tuolumne River. Because the upstream dams interrupt the sediment supply from the watershed, the resupply of spawning gravels is largely limited to bank erosion of the relict floodplain deposits. The current regulated flow regime mobilizes these materials much less frequently than the natural flow regime and consequently, there has been a significant accumulation of fine sediments both within the bankfull channel, and on floodplain surfaces. These floodplain deposits are prone to remobilization during infrequent overbank flows. One solution to reducing the rates of fine sediment re-introduction into the spawning reach into the channel is mechanical excavation, sorting, and removal of fines and replacement. Although the costs of this strategy are high due to the vast magnitude of floodplain deposits (on the order of hundreds of thousands of cubic yards), these should be addressed in comparison to the costs of coarse sediment importation from long distances. There is potential for cost reduction by prioritizing for excavation large deposits closer to the channel. The primary question that we sought to address in our literature review is how the fine sediment currently stored in the spawning gravels of the lower Tuolumne River can be removed most economically, either by mechanical or hydraulic means.

REVIEW OF FINE SEDIMENT REMOVAL METHODS

In addition to the source control measures discussed above, other approaches (i.e., engineered, mechanical) have been proposed to reduce the impact of fine sediments on spawning and incubation conditions in the lower Tuolumne River. The primary question that we sought to address in our literature review is how the fine sediment currently stored in the spawning gravels of the lower Tuolumne River can be removed most economically, either by mechanical or hydraulic means. We evaluated several mechanical and hydraulic methods for fine sediment removal from the spawning reach, including suction dredging from pools, disruption of the coarse armor layer by gravel ripping, gravel excavation and replacement, hydraulic disturbance, and other gravel cleaning methods. This review supplements and extensive review of existing gravel cleaning methodologies completed for the District's in 1991 (TID/MID 1992b) and is separated into mechanical and hydraulic methodologies, summarized in Tables 1 and 2.

Suction Dredge Removal of Pool Deposits. As part of the Coarse Sediment Management Plan, in June 2001 Stillwater Sciences conducted a three day snorkel survey to identify fine sediment deposits in the lower Tuolumne River from the USGS gauging station below La Grange Dam (RM 52.0) to Robert's Ferry Bridge (RM 39.6). Approximately 65,000 m^3 (104,000 tons, assuming a bulk density of 1.6 tons/m^3) were mapped. About 70 % of the total volume was deposited in low-flow pools, with about 5 % in pools outside the low-flow channel. The remainder was deposited on top of gravel bars and as overbank deposits. We have formulated two hypotheses regarding fine sediment reduction from pool sources. First, removal of these deposits using a suction dredge may reduce the rate of downstream transport and therefore reduce re-infiltration of fine sediments into recently cleaned gravels. Second, the annual rate of fine sediment transport may be much larger than the accumulated pool deposits and dredging effects may only last a season or more. The Tuolumne River Fine Sediment Project includes a pilot investigation of suction dredging from pools to answer these questions. Although suction dredging in spawning gravels for gold mining has a number of short-term impacts on invertebrate communities and spawning use (Harvey and Lisle 1999), dredging in pools is not considered to represent a major impact provided the materials are not discharged onto downstream gravels.

Hydraulic Gravel Cleaning Methods. In order to operate within the constraints of the current (*i.e.*, post New Don Pedro Project) flow and sediment transport regime of the lower Tuolumne River, the hydraulic methods evaluated involved inducing localized disturbance of the channel bed to mobilize fines, which allows for either suction removal or allows river flows below the bed mobilization threshold to wash them further downstream. Table 1 provides a summary of our review of available studies on hydraulic gravel cleaning methods. The simplest hydraulic methods involves baffles or gates (Einstein 1965, Mih, 1978) to use the river flows create high local velocities and shear stresses sufficient to mobilize fine sediments. A second set of techniques uses water jets from pumped water (Mundie and Mounce 1978; Mih 1979; Mih and Bailey 1981; Allen et al. 1981; Andrew 1981; Shackle et al. 1999; Shields 1968) to disrupt the armor layer of the bed and mobilize fines. However, in addition to difficulties in achieving adequate penetration of the bed, all of these methods rely on river flow to carry the fines downstream. Since, redeposition of fines in downstream spawning areas is generally considered a serious drawback, higher effectiveness rankings were assigned to these methods when used in conjunction with sedimentation ponds or other means to prevent the re-introduction of fines into the channel bed (Shields 1968, Meehan 1971, Mih 1979).

Mechanical Methods. The most common mechanical method used in removing fines from spawning gravels is a using a bulldozer to disturb the sediment and release the fines (Hall and Baker 1982). Table 2 summarizes other mechanical methods, including raking and ripping (EA 1989; Gerke 1990; Hampton 1990; Painter 1990; Shackle et al. 1999; Stemple 1990; West 1984), and gravel removal and replacement with cleaned or newly supplied gravels (Andrew 1981; Heiser 1971; Mih 1978; Wilson 1976). In cleaned areas that had an armored surface substrate, incomplete removal of the underlying sand was identified as a potential source of fine sediment load to downstream spawning areas (Mih 1978). With the exception of complete excavation and replacement with clean gravels, all of these methods, especially raking and ripping, release turbidity and suspended sediments to the water column that may deposit further downstream. In armored stream beds, disruption of the armor layer may increase bed erosion rates following cleaning and this bed instability may be have been associated with observations of spawner avoidance of gravels on the Trinity River (Hampton 1990).

High Flow Releases. The simple recreation of natural hydraulic conditions capable of mobilizing fine sediments offers promise in removal of fine sediments from the mainstem Tuolumne River. Natural flushing flows in headwater streams are the primary means of gravel sorting and maintaining spawning gravel quality for stream fishes (Kondolf et. al. 1987; Kondolf and Wilcock 1996). In laboratory studies, Einstein (1968) found that once fines are deposited in the gravel bed there is minimal upward or horizontal movement of the particles within the interstices until shear stresses are large enough to mobilize the majority of the larger particles that make up the bed. Under unimpaired conditions, high river flows mobilize coarse sediments, liberating fine sediments stored in the channel bed for downstream transport.

In contrast to headwater streams, because dams act as nearly perfect sediment traps, high flow releases should maintain lower deposition of fines in downstream spawning gravels. As a management tool, because the Tuolumne River dams are located above major several sediment sources (*e.g.*, Gasburg Creek, Dominici Creek, etc.), substantial deposition of sediments is likely to occur (Reiser et. al. 1989), particularly given the generally lowered hydrograph peaks and flushing capacities under natural flow conditions. The absence of a natural upstream coarse sediment supply means that flushing flows of sufficient magnitude to mobilize the channel bed may also deplete available spawning habitat unless the gravels are replaced by a long-term coarse sediment augmentation program.

Results. We attempted to evaluate the relative costs vs. benefits of these gravel cleaning methods by comparing the costs per unit area of coarse gravel cleaned, and the effectiveness of each technique in removing fines. Only limited cost data was available from published reports (Tables 1 and 2). In general, costs ranges very broadly, from less than $1.00 per square meter cleaned, to more than $47/m^2 cleaned. The level of effectiveness of different techniques also ranged quite broadly, from complete removal of all fine sediments (e.g., excavation-sieving-replacement techniques) to only surficial removal of fines in one location and relocation of those fines to downstream riffles (gravel ripping and bulldozing techniques). Table 3 ranks the available data as a qualitative rank from 0–1. These rankings were developed by multiplication of individual scores assessed for each of the following factors: Cost (1 = High Cost, 3 = Low Cost), Effectiveness (1 = Low, 3 = High) and Ecological impact (1 = High, 3 = Low). When all data was available, rankings were expressed as the quotient of the three score product (*i.e.,* from 1 to 9 divided by 9), using a maximum score of six when cost data was unavailable. The biggest differences in methodologies related to secondary ecological impacts.

EFFECTIVENESS OF PRIOR GRAVEL CLEANING STUDIES ON THE LOWER TUOLUMNE RIVER, 1991-1993

Between 1988 and 1993, the Districts experimented with several gravel cleaning methodologies to improve gravel quality (TID/MID 1992b), including: (1) a bulldozer with its blade angled to plow furrows through the riffle bed; (2) an excavator that lifted up buckets full of gravel and sifted them back into place allowing fines to be winnowed out and transported away as the gravels fell through the water column; (3) hydraulic back flushing using a small pump and single nozzle; and (4) a small suction pump and nozzle tested in conjunction with the back-flushing.

Gravel samples taken before and after the 1991 tests indicated that the back-flushing method offered the most uniform cleaning of fines from the gravels (EA 1991). The gravel cleaning machine developed for the Tuolumne River included ripper bars to break up the armor layer at the gravel surface, nozzles to inject high velocity streams of water into the gravels and suction nozzles to remove fine particles flushed from the gravels. In order to test the concepts of the design, a prototype was built. The prototype consisted of one of the five cells intended for inclusion in the final cleaning machine shown in Figure 1. Each cell included ripper bars, two ¾ inch jets, and 3-inch suction nozzles (these were later modified during the 1993 tests) (Figure 2a).

In May 1992 the gravel cleaning machine was tested, but the flows (550 cfs at La Grange) were too high to permit a quantitative assessment of the cleaner’s effectiveness. The high velocity jets did appear to backflush fines from the gravels, but the suction configuration was inadequately designed to remove the amount of fines flushed into the water column. Based on these observations, several modifications were implemented for the 1993 Tuolumne River Gravel Cleaning Experiments.

1993 Equipment Modifications. The primary modification made to the prototype gravel-cleaning machine was the suction nozzle configuration. The previous configuration included splitting the suction line into two between the pump and the cleaner. Two lines went into the cleaner and were adjustable from side to side and front to back in the cleaner’s central box (Figure 2a). The lines were open-ended pipes with no nozzle to facilitate flow of water into them. This configuration was determined to be a significant source of head loss in the suction system. No advantage was seen in having two suction lines, and there appeared to be a disadvantage to having no nozzles to direct flow into the suction hose.

In the new configuration, the alignment of the single vertical four-inch suction pipe was swept forward and flared to a rectangular opening which covered the entire cross-section of the downstream end of the cleaner box (Figure 2). The heavy mesh screens of the cleaner box were replaced by a single flat bar screen (3/8 inch). The front part of the screen sloped back at approximately 45 degrees from the top to the bottom of the box. At the bottom it ran parallel to the bottom edge of the box. This screen design was used to alleviate the problem of organic material building up on the mesh screens (particularly the front screen) and impeding the flow of water and fine particles into the box for removal. The angled flat bar design screened heavy materials as well as the mesh screens did, but also allowed lighter materials such as plant material that easily became impinged on mesh screens, to be washed away by the flow across it.

The 1992 tests showed that a cloud of fine particles often escaped from the front of the cleaner (rebounding forward from the jets), and flowed out around the side of the machine. In 1993, a hood was designed to funnel water and entrained fine particles from in front of the machine back into the suction nozzle for removal (Figure 2). It would also serve to create a venturi effect in low velocity water to accelerate the flow of water into the machine. The hood was 48 inches wide and 24 inches high at the front end and narrowed back to the same outer dimensions of the front of the cleaner box (approximately 26 x 10 inches). The sides of the hood had doors that were hinged at the front and could be opened toward the rear so that excess flow could be spilled along the side of the machine in situations when the flow entering the hood overwhelmed the capacity of the machine to remove or pass water, and a “bow wave” effect was created at the front of the machine. The doors could also be removed completely if necessary. At the bottom of the sides of the hood were permanent deflector wings that directed flow inward and toward the front of the cleaner box even when the doors were opened or removed.

Site Location. The study area was established in Riffle 5A, approximately 3/4 mile upstream of Basso Bridge on the Tuolumne River. The general location is the same site used in 1992, but the actual treatment and control areas were different from the area cleaned in 1992. The treatment area was established in the thalweg of the riffle. It was 30 feet wide by 100 feet long. A rebar benchmark was established on the river-left side of the treatment site. A control area was established upstream of the treatment area, to avoid disturbance from the tractor or incidental disturbance during the cleaning tests.

Visual Assessment of Cleaning Effectiveness. After the gravel cleaning tests were completed, ten sites in the treatment area were selected at random to determine the effective depth of cleaning. At each site the initial depth of water was measured. The site was then excavated by hand until interstitial deposits were encountered. When plumes of fine sediment could be seen washing out of the substrate a depth measurement was taken and subtracted from the initial depth to calculate the depth of effective cleaning. In addition to the estimates of cleaning depth, photographs and video tapes were also taken of all aspects of the gravel cleaning and data collection processes for general documentation. Although the major substrate facies were traced onto clear acetates for future digitization, gravel composition was estimated by the gravel sampling methods below.

Gravel Sampling Methods. Four sets of gravel-composition samples were taken in Riffle 5A during July 1993 prior to gravel cleaning. Two sets of fifty randomly selected samples each were collected before and after the cleaning experiment using a modified McNeil sampler (EA 1991, McNeil and Ahnell 1960). Two additional sets of five samples each were taken from the upstream control area before and after the cleaning experiment.

Each bulk sample that was collected before the cleaning was divided into top and bottom sub-samples. The top portion was the armor layer at the surface: the coarse and discolored substrate overlaying the generally finer material below. The separation of the portions was done to allow separate, as well as combined, analyses of the samples. Separate analyses are done because the purpose of the study was to look at the effects of gravel cleaning on the particle sizes of the gravel where salmon eggs would be deposited. This egg deposition zone is between six and 18 inches below the surface. Because the surface layer of gravel tends to become coarse and armored over time, the inclusion of this layer in the analysis can skew the particle size estimates upward, reducing estimates of the effects of the fine particle sizes in the subsurface gravels.

Following the gravel cleaning, another 50 McNeil samples were taken from the pre-test locations within the treatment area. This was permissible because the cleaning process is so disruptive to the substrate that there was no possibility of biasing the results by sampling at the pre-test sampling activity locations. For the same reasons, the post-cleaning McNeil samples did not include an armor layer since the particles were completely redistributed from the surface down to the depth of effective cleaning.

Control Sampling. Five McNeil samples were taken in the control area before sampling, using the same methods described above for pre-test sampling. McNeill samples were also collected in the control area after cleaning was completed to document the depths at which fines sediments appeared in uncleaned gravels and compare these to the effective cleaning depths in the treatment area. The samples were collected from undisturbed locations immediately adjacent to the original control samples to minimize the effect of spatial variability of the particle size distributions of the spawning gravels, and attempted to reduce the need to collect large numbers of control samples.

Sample Processing and Analysis. Processing and analysis of both the McNeil samples was done in a step-wise fashion by analyzing the least number of samples that are expected to show a discernable difference in gravel composition, if one exists. Pre-treatment and control samples were separated into surface and sub-surface samples as they were collected. In all, only 64 of the 100 samples from the cleaning test area were dried and sieved (32 randomly selected from each set). The remaining 36 samples were dried but not sieved.

All samples from the control area were dried and sieved. Processing the McNeil samples involved separating the sample material into different size categories and determining the weight of material in each. After drying (80 ^{o}C) the samples were transferred to a set of sieves of geometrically decreasing size from 128 mm down to 0.0625 mm. The weight of the material retained by each sieve was recorded.

Gravel Sample Analysis. To assess the quality of the gravel samples the particle size distribution of the entire sample should be characterized, rather than just the percentage of a sample that falls below an arbitrarily defined limit of “fine” particles. Research on the effect of gravel quality on survival to emergence (Chapman 1988, Tappel and Bjornn 1983, Milhous 1982) has indicated that the effect of fine sediments on intergravel flow depends in part on the size distribution of the coarser particles. A heterogeneous mixture of coarse gravels would likely have better intergravel flow and provide better quality spawning habitat than a homogeneous mixture of smaller gravels that contained the same percentage of fine sediments.

Tappel and Bjornn (1983) suggested that ideal quality spawning gravel size composition for chinook salmon (*Onchorhyncus tshawytscha*) and steelhead trout (*O. mykiss*) is adequately characterized by the cumulative percentage by weight of gravel finer than 0.85 mm diameter, in combination with the percentage by weight of gravel finer than 9.5 mm diameter. Tappel and Bjornn related those percentages to survival of chinook salmon eggs with the following equation:

$$\text{Survival} = 0.934 - 17.1 q_{9.5} q_{0.85} + 3.87 q_{0.85}$$

where q_d is the fraction by weight of the sample less than d mm in diameter. To characterize the quality of the gravel samples, the weights of the material retained in each of the standard sieves are recorded. The entire sample was used for these calculations (that is, the data were not “truncated” at 25.4mm, as in other analyses). The sieve set used did not include sieves of 0.85 and 9.5mm; the values used to compute the index were found by interpolation from the particle size distribution.

In addition to the Tappel and Bjornn index, we also calculated several other gravel quality indices:

- *Fraction Fines*. This was simply defined as $q_{2.0}$, the fraction by weight of the sample less than 2mm in diameter.
- *Geometric Mean Diameter*. This was calculated as $(d_{0.84}d_{0.16})^{1/2}$, where d_q is such that q % of the sample by weight is less than d_q in diameter (Shirazi and Siem 1981). The values of $d_{0.16}$, $d_{0.84}$ were estimated by interpolation from a log-probit linearization of the particle size distribution.
- *Fredle Index*. This was calculated as $(d_{0.84}d_{0.16})^{1/2} / (d_{0.75} / d_{0.25})^{1/2}$ (Lotspeich and Everest 1981). the values of $d_{0.16}$, $d_{0.25}$, $d_{0.75}$, $d_{0.84}$ were estimated by interpolation from a log-probit linearization of the particle size distribution.

Cleaning Test Results. The values of the gravel quality indices were calculated using the combined (surface and sub-surface) samples to account for mixing of the surface and subsurface layer during cleaning. Table 4 shows the Tappel-Bjornn Index, Fraction of Fines, Geometric Mean Diameter and Fredle Indices and Figure 3 summarizes these in box-plot form. For the cleaning test samples, with the exception of the Tappel-Bjornn Index, all gravel quality indices improved as a result of cleaning (Table 5). Using two-sided two-sample heteroscedastic t-tests, the first set of results reported (all samples combined) show the fraction of fines and Fredle index decreased and differed very significantly ($p < 10^{-3}$, $p = 0.03$) from the pre-test samples. However, the increase in geometric mean diameter was not found to be significant ($p = 0.06$) by this test.

To improve the lower power of parametric tests (i.e., t-test) to demonstrate statistical differences between the treatment and control samples, Figure 4 shows a graphical representation of non-parametric analyses of the gravel cleaning results. Figure 2 shows that non-parametric estimates for the distribution of index values among samples in the treatment area were generally non-normal, especially the distributions of the Tappel-Bjornn index and geometric mean diameter.

This explains the disagreement between the different forms of the t-test shown in Figure 1 and Table 5. Figure 4 shows that for all samples combined, bootstrap tests for equality of the before- and after-cleaning index distributions shown in Figure 3 are significantly different ($p < 0.01$).

Because of reported problems with the gravel cleaner operation, a number of downstream cleaning locations were apparently contaminated by a front of fines swept ahead of the gravel cleaner by the high-pressure jets. Figure 5 shows that somewhere near 50 feet from the upstream end of test area, the cleaner began to lose effectiveness and in some cases more fine sediments were found in the post cleaning samples. In an attempt to improve the pre- and post-test comparisons, Table 5 separates the pooled results into upstream and downstream portions of the test area, showing some improvements in the prior indices, but no significant increase in the Tappel-Bjornn index.

Control Site Results. Interestingly, significant changes were detected in the four gravel quality indices for samples from the control area (Table 5). The 95% confidence interval for the changes control area gravel quality indices included those observed in the treatment area, so that the t-tests do not rule out the possibility that the increases seen in the treatment area did not result from some systematic changes over time unrelated to the cleaning. However, because the number of control samples was small, the power of the test to rule out this possibility was very poor. The changes in the control area gravel quality were in all cases much smaller than those of the treatment area.

DISCUSSION

Review of Gravel Cleaning Methodologies. All of the gravel cleaning methods evaluated in this memorandum depended upon the separation of sediment fines by some mechanical disturbance, followed by a variety of sediment removal methods (*e.g.,* hydraulic flushing, mechanical sorting, etc.). Hydraulic cleaning methods generally ranked highest in terms of cleaning effectiveness. Although improvement in survival to emergence has been demonstrated in several gravel cleaning studies, subsequent use by spawners was often delayed (Wilson 1976), suggesting that some disturbance of the invertebrate community or other factors may be responsible for an initial decline in spawning use. For this reason, our analysis tended to favor hydraulic methodologies that showed lower impacts on the re-establishment of invertebrate populations (Allen et al. 1981; Meehan 1971; Mih 1979; Mih and Bailey 1981; Shields 1968; Shields 1999; TID/MID 1992). In-situ mechanical methods (*i.e.,* bulldozing and tilling) generally ranked slightly below hydraulic methods in effectiveness and disturbance (Hall and Baker 1982, Gerke 1990; Mih 1979; Shackle et al. 1999). Although intuitively simple, excavation, cleaning, and replacement of spawning gravels (Andrew 1981; Mih 1978; Wilson 1976) ranked among the lowest of the methods evaluated due to high energy costs, moderate effectiveness and high ecological impact (Table 3).

Implementation of the 1993 Gravel Cleaning Experiments. The prototype gravel cleaning machine developed by the Districts was designed to break up the armor layer by mechanically ripping the gravel, break up interstitial deposits using high pressure jets, and then vacuum the fine sediments for their removal (TID/MID 1992b). Although the initial conceptual design of the cleaner was intended to take advantage of differential settling velocities of fine and coarse sediment, a number of field modification were made to accommodate low suction velocities. Implementation of the single-cell prototype tests were most affected by use of a back-hoe, which affected the use of the ripper bars and also required separating the pumping assembly from the cleaner shown in Figure 1.

Mounting the cleaner to the backhoe appeared logical: the backhoe could imitate the linear motions of the bulldozer through the water and would permit closer and safer examination of the machine and its operation in the stream than would a bulldozer. However, the prototype gravel cleaner was designed for use on a bulldozer that would drag it in one direction and orientation in the river. Placement of the ripper teeth and the jetting and suction nozzles was designed to use the unidirectional flow to backflush, suspend, and direct the fine sediments back into the suction nozzle for removal. Use of the cleaner in a radial pattern changed the orientation of the cleaner relative to the river flow, causing the back-flushed sediment to be washed past the mouth of the machine instead of being swept back into the suction nozzle. Lastly, the separation of the suction pump from the cleaner during the 1993 prototype tests created large suction losses that prevented the cleaner from developing its design hydraulic capacity and large amounts of fine sediments escaped the cleaner hood. Interestingly, removal of the narrow-bore jet nozzles increase jetting effectiveness noticeably and the final tests were conducted without the ripper bars.

Results of the 1993 Gravel Cleaning Experiments. Past estimates of probability of survival of salmonid eggs in uncleaned gravels, based on particle size distributions of the gravels (Tappel and Bjornn 1983) have ranged from 0 to less than 30 percent in the Tuolumne (TID/MID 1992a). Although the prior Tuolumne River studies indicated that survival-to-emergence was low, the 1993 gravel-cleaning results showed much higher Tappel & Bjornn indices in both treatment and control gravels. Some of the results were low, but the mean survival-to-emergence for treatment and controls was near 90% (Table 4). Recent permeability studies in the spawning reach predicted survival-to-emergence ranged from 34 percent (95% Confidence Interval (CI): 31–37 percent) at Riffle 7 to 51 percent (95% CI: 35–67 percent) at Riffle 2 (TID/MID 2000). This discrepancy may either be due differing methodologies in that the recent studies developed Tappel Bjornn indices from permeability measurements. These differences may also be due to the 1993 test within riffles area with particularly clean substrate, followed by large volumes of fine sediment deposited in from the 1997 flood, and possibly some sampling artifact that under-represented the fines present in the bulk samples. In any case, the analysis of the 1993 gravel cleaning data do show a significant difference between pre- and post-cleaning and controls.

CONCLUSIONS AND RECOMMENDATIONS

Source Control Measures. A coarse sediment augmentation program in conjunction with managed high flow releases was suggested as an important component of the overall restoration of the lower Tuolumne River (McBain &Trush 2000). Limitations on long-term coarse sediment supplies and available water may also natural sorting processes to re-establish high quality spawning gravels. In the near term, fine sediment source control (*e.g.*, Gasburg Creek sedimentation basin, changes in land uses) and cleaning of the existing interstitial deposits may be the most effective means of improving productivity of the available spawning habitat in the lower Tuolumne River.

Relative Costs of Gravel Cleaning Methods. The costs and effectiveness of gravel cleaning methodologies reviewed appear to depend on the size of the area to be cleaned. However, the available cost data was variable and this could not be explained by economies of scale. For example, of the six mechanical cleaning citations reviewed that provided cost data, the highest inflation-adjusted cost was over \$47/m^2 for a large excavation and gravel replacement projects, whereas another large scale excavation and replacement project was among the lowest in cost (\$0.72/m^2). Of the in-situ methods, ripping and tilling were among the least expensive (0.3/m^2 and \$0.42/m^2), but were largely ineffective at low river flows. For the hydraulic methods reviewed, only two studies provided cost data (\$0.6/m^2 and \$3.2/m^2).

Recommended Cleaning Methodologies. The methods reviewed for this evaluation were largely demonstration studies not yet developed as long-term sediment management tools. All methods were effective to some degree, with varying ecological impacts due to the disruption of the spawning gravels (*i.e.*, impacts to the invertebrate community). Impacts increased due to turbidity or disruption of the ecological community as the hydraulic methods increased in energy intensity from vacuum methods, to hydraulic jets to mechanical removal and cleaning. Based on our review of gravel cleaning methods, we recommend the following fine sediment removal methods be considered for additional experimentation and implementation:

1. *High Flow Releases.* A combination of upstream gravel augmentation and high flow releases in excess of the bed-mobilizing thresholds offers the simplest approach to creating and maintaining large areas of high quality spawning habitat. This strategy requires implementation of a gravel augmentation program in combination with fine sediment reduction program to eliminate inputs from tributary watersheds (Gasburg Creek, Dominici Creek) and floodplain deposits.

2. *Hydraulic Methods.* Although the top five methods reviewed were hydraulic, none of these studies provided cost data. A modified form of the gravel cleaning machine offers a viable means for removing fine sediment from spawning gravels. Creation of localized shear stresses by use of weirs or baffles was one of the simplest methods reviewed and may be also an effective strategy of fine sediment removal in the relatively uniform spawning riffles of the lower Tuolumne River.

3. *Mechanical Methods.* Mechanical methods ranked below hydraulic methods, but they may be suitable to the large pools of the spawning reaches in the lower Tuolumne River that tend to trap and store large volumes of sand. A program combining mechanical displacement of fines by high flow releases followed by suction dredging of sand accumulated in pools may offer a relatively effective, low-cost approach.

The prototype gravel-cleaning machine developed by the Districts appeared to improve all gravel quality indices, with an expected improvement in survival to emergence of cleaned areas. We recommend the 2003 pilot scale gravel cleaning tests be conducted using the same approach as the prior experiments. This will employ either ripper bars and/or hydraulic jets to disrupt the armor layer and mobilize fines followed by vacuum removal of suspended sediments.

1. Given the corrosion damage to the Districts gravel cleaning machine since its last use in May 1993 and its relatively small size, it may be unsuitable for large scale gravel cleaning in its present condition. We recommend the rehabilitation of the existing unit or the fabrication of a new cleaner with a careful re-examination of pump selections, jet and suction velocities.

2. Each suction nozzle should be supplied with an independent venturi-type (*e.g.*, wye-inlet) suction nozzle. This design would allow remote pumping and also remote location of sand separators, while reducing nozzle suction losses to a minimum.

3. Separation of the suspended sediments can be accomplished by settling ponds constructed on the floodplains or by cyclone separator with recycling of the supernatant water back to the river. Stockpiled sands should be removed or deposited on the back of floodplains to reduce the risks of future re-infiltration into the spawning gravels.

In summary, the feasibility of gravel cleaning as a long-term management tool for enhanced salmonid production relates to the sensitivity of the streambed to disturbance (*i.e.*, ESA limitation on in-stream activities at certain times of the year) and the rate of re-introduction of new fines from upstream and the mobilization of relict floodplain deposits. Two questions remain as to whether a gravel-cleaning machine can be employed as an effective tool to manage fine sediment accumulation in the Tuolumne River. First is the costs and feasibility of employing such a device on a large scale in the spawning reach. The second question is how long the benefits of cleaned gravel will last. The Fine Sediment Management Plan will address both these questions, and includes implementation and monitoring of gravel cleaning experiments in 2003. Following an initial gravel cleaning program, a fine sediment source control program coupled with coarse sediment augmentation may be the most cost effective sediment management tool for maintenance of high spawning gravel quality in the Tuolumne River.

REFERENCES

Allen, R. L., J. E. Seeb, and D. D. King. 1981. A preliminary assessment of field operations with a salmon-spawning gravel cleaning machine. Pages 1-14 in Salmon-spawning gravel: a renewable resource in the Pacific Northwest? State of Washington Water Research Center, Washington State University, Pullman, and the University of Washington, Seattle.

Andrew, F. J. 1981. Gravel cleaning to increase salmonid production in rivers and spawning channels. Pages 15-31 in Salmon-spawning gravel: a renewable resource in the Pacific Northwest? State of Washington Water Research Center, Washington State University, Pullman, and the University of Washington, Seattle.

Bowman, A.W. and A. Azzalini. 1997. Applied Smoothing Techniques for Data Analysis. Oxford Statistical Science Series 18. Oxford University Press Inc., New York. 193 pages.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117: 1-21.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Transactions of the American Fisheries Society 90: 469-474.

EA (Engineering, Science, and Technology). 1991. Salmonid spawning gravel cleaning machine: conceptual design. Prepared for Turlock Irrigation District and Modesto Irrigation District, California by EA, Lafayette, California.

Einstein, H. A. 1965. Spawning grounds. Final Report 14-06-200-436-A. University of California Berkeley.

Einstein, H. A. 1968. Deposition of suspended particles in a gravel bed. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, 94: 1197-1205.

Gerke, R. 1990. Washington Department of Fisheries, Olympia. Personal communication with J. P. Clancy, EA Engineering, Science, and Technology, Lafayette, California. January.

Gibbons, D. R. and E. O. Salo 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada, U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station.

Hall, J. D., and C. O. Baker. 1982. Rehabilitating and enhancing stream habitat: 1. Review and evaluation. General Technical Report PNW-138. U.S. Forest Service.

Hampton, M. 1990. U. S. Fish and Wildlife Service, Lewiston, California. Personal communication with J. P. Clancy, EA Engineering, Science, and Technology, Lafayette, California. 9 February.

Harvey, B. C. and T. E. Lisle 1999. Scour of chinook salmon redds on suction dredge tailings.North American Journal of Fisheries Management 19(2): 613-617.

Hausle, D. A., D. W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout (*Salvelinus fontinalis*). Transactions of the American Fisheries Society, 105:1 57–63.

Heiser, D. W. 1971. Spawning gravel improvement techniques tested on Western Washington streams, 1969-1970. Supplemental Progress Report, Pugent Sound Stream Studies. Pages 62-76 in Johnson, R. C., R. J. Gerke, D. W. Heiser, and R. F. Orrell. Pink and chum salmon investigations, 1969. Washington State Department of Fisheries, Olympia.

Kondolf, G.M., G.F. Cada and M.J. Sale. 1987. Assessment of flushing flow requirements for brown trout spawning gravels in steep streams. Water Resources Bulletin, 23:927-935.

Kondolf, G.M., and P.R. Wilcock. 1996. The flushing flow problem: defining and evaluating objectives. Water Resources Research. 32(8):2589-2599.

Lotspeich, F.B., and F.H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. Research Note PNW-369. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

McBain & Trush. 2000. Habitat restoration plan for the lower Tuolumne River corridor. March.

McNeil, W. J., and W. H. Ahnell. 1960. Measurement of gravel composition of salmon stream beds. Circular 120. Fisheries Research Institute.

Meehan, W. R. 1971. Effects of gravel cleaning on bottom organisms in three southeast Alaska streams. The Progressive Fish-Culturalist 33: 107-111.

Mih, W. C. 1978. A review of restoration of stream gravel for spawning and rearing of salmon species. Fisheries 3: 16-18.

Mih, W. C. 1979. Hydraulic restoration of stream gravel for spawning and rearing of salmon species. Report No. 33. State of Washington Water Research Center, Washington State University, Pullman.

Mih, W. C., and G. C. Bailey. 1981. The development of a machine for the restoration of stream gravel for spawning and rearing of salmon. Fisheries 6: 16-20.

Milhous, R. T. 1982. Effect of sediment transport and flow regulation on the ecology of gravel-bed rivers. Pages 819-841 *in* R. D. Hey, J. C. Bathurst and C. R. Thorne, editors. Gravel bed rivers. John Wiley and Sons, New York.

Mundie, J. H., and D. E. Mounce. 1978. Application of stream ecology to raising salmon smolts in high density. Internationale Vereinigung fuer Theoretische und Angewandte Limnologie Verhandlungen 20: 2013-2018.

Painter, R. 1990. California Department of Fish and Game, Red Bluff. Personal communication with J. P. Clancy, EA Engineering, Science, and Technology, Lafayette, California. 16 September.

Platts, W. S., M. A. Shirazi, and D. H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. Ecological Research Series EPA-600/3-79-043. U. S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis, Oregon.

Reid, L. 1981. Sediment production from gravel-surfaced forest roads, Clearwater basin, Washington. Report FRI-UW-8108. University of Washington, College of Fisheries, Fisheries Research Institute, Seattle.

Reiser, D.W., M.P. Ramey, and T.A. Wesche. 1989. Flushing flows. Pages 91-135 in J. Gore and G Petts, editors. Alternatives in regulated river management. CRC Press, Florida.

Shackle, V. J., S. Hughes & V. T. Lewis. 1999. The influence of three methods of gravel cleaning on brown trout, *Salmo trutta*, egg survival. Hydrological Processes 3: 477-486.

Shields, H. J. 1968. Riffle Sifter for Alaska salmon gold. Separate 3586. 1968 Yearbook of Agriculture.

Shirazi, M. A., and W. K. Seim. 1981. Stream system evaluation with emphasis on spawning habitat for salmonids. Water Resources Research 17: 592-594.

Silver, S. J., C. E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different velocities. Transactions of the American Fisheries Society 92: 327-343.

Stemple, M. 1990. U. S. Fish and Wildlife Service. Personal communication with J. P. Clancy, EA

Engineering, Science, and Technology, Lafayette, California. 16 September.

Stillwater Sciences. 2002a. Draft Gasburg Creek Sediment Source Analysis. Technical memorandum from Martin Trso, Christian Brauderick and Anthony Falzone, Stillwater Sciences, Berkeley, California to McBain & Trush, Arcata, California.

Stillwater Sciences. 2002b. Results of Summer 2001 Snorkel Surveys of Fine Sediment Deposits in the Lower Tuolumne River. Technical memorandum from Martin Trso and Noah Hume, Stillwater Sciences, Berkeley, California to McBain & Trush, Arcata, California.

TID/MID (Turlock and Modesto Irrigation Districts). 1992a. Lower Tuolumne River spawning gravel studies report. Appendix 8 to Don Pedro Project Fisheries Studies Report (FERC Article 39, Project No. 2299). *In* Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Vol. IV. Prepared by Ecological Associates, Lafayette, California.

TID/MID. 1992b. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Vol. II. Prepared by Ecological Associates, Lafayette, California.

TID/MID. 2000. Tuolumne River Substrate Permeability Assessment and Monitoring Program, Report 2000-7. *In* Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Vol. II. Prepared by Stillwater Sciences, Berkeley, California.

West, J. P. 1984. Enhancement of salmon and steelhead spawning and rearing conditions in the Scott and Salmon rivers, California. Proceedings of the Pacific Northwest Stream Habitat

Management Workshop.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada 11: 933-953.

Wilson, D. A. 1976. Salmonid spawning habitat improvement study. Project Completion Report 1-93-D. Washington State Department of Fisheries and the National Marine Fisheries Service.

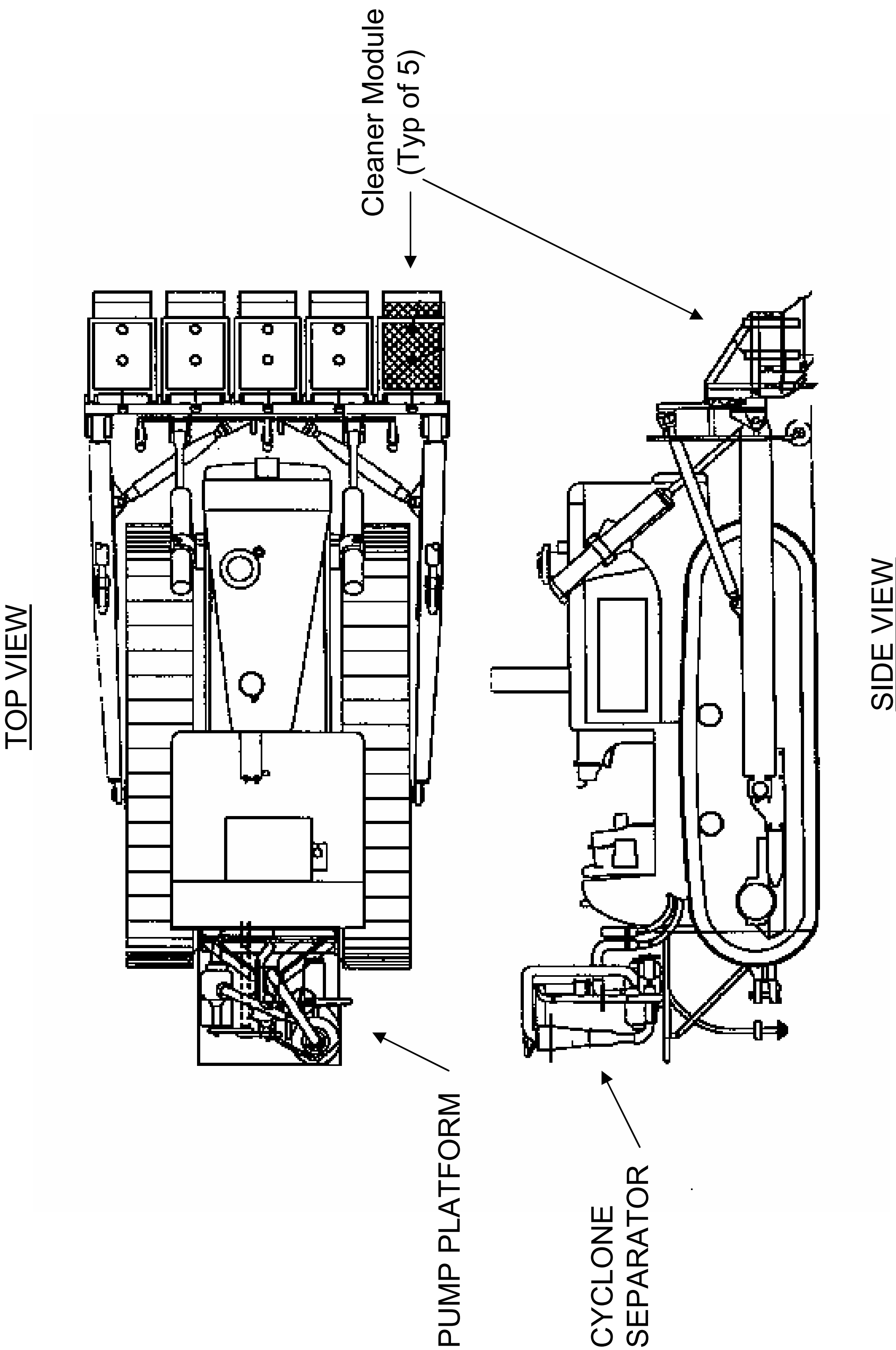
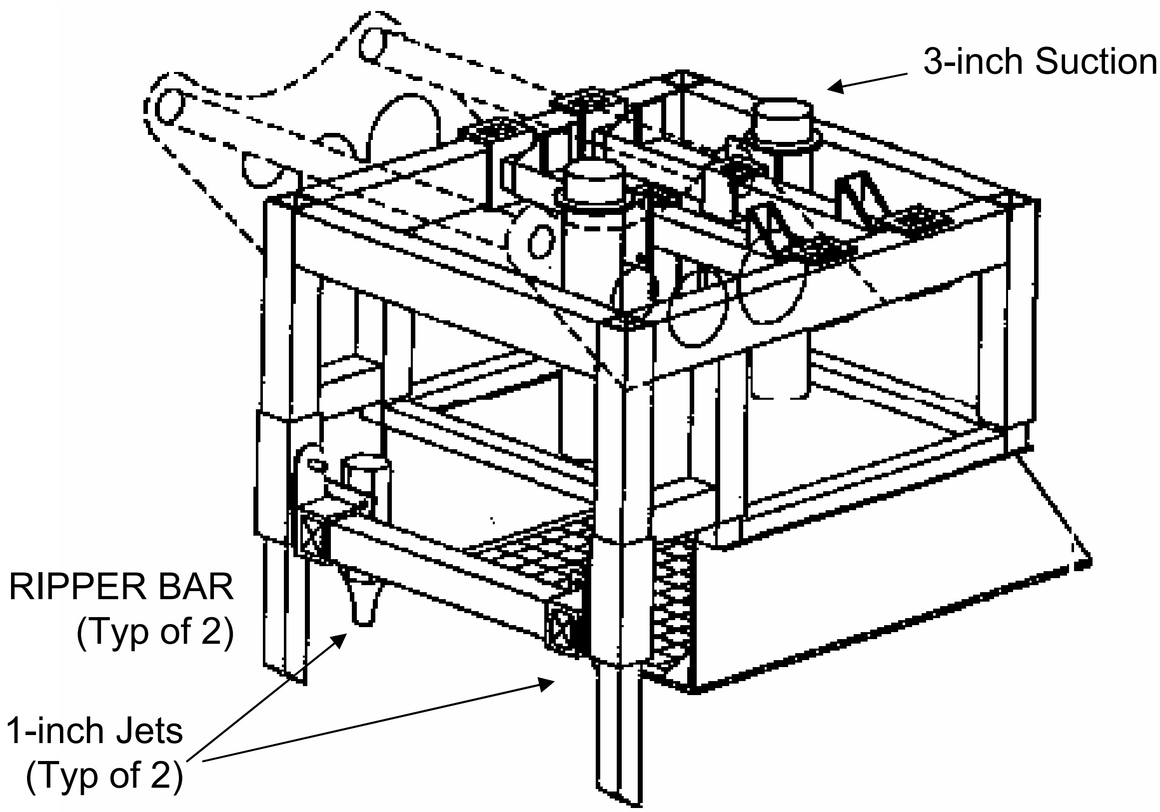


Figure 1. Conceptual Design for self-contained spawning gravel cleaner (EA 1991)



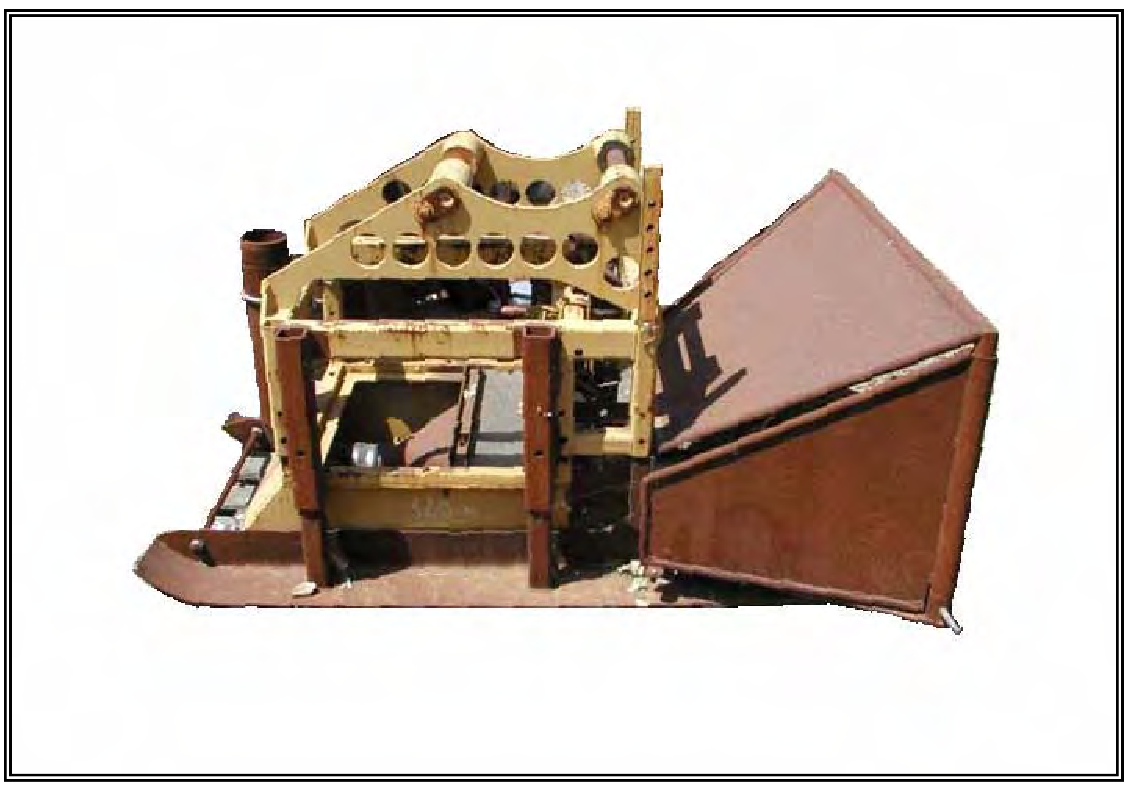


Figure 2. 1991 Cleaner Module Design (Top) and 1993 Inlet Baffle Modifications (Bottom)

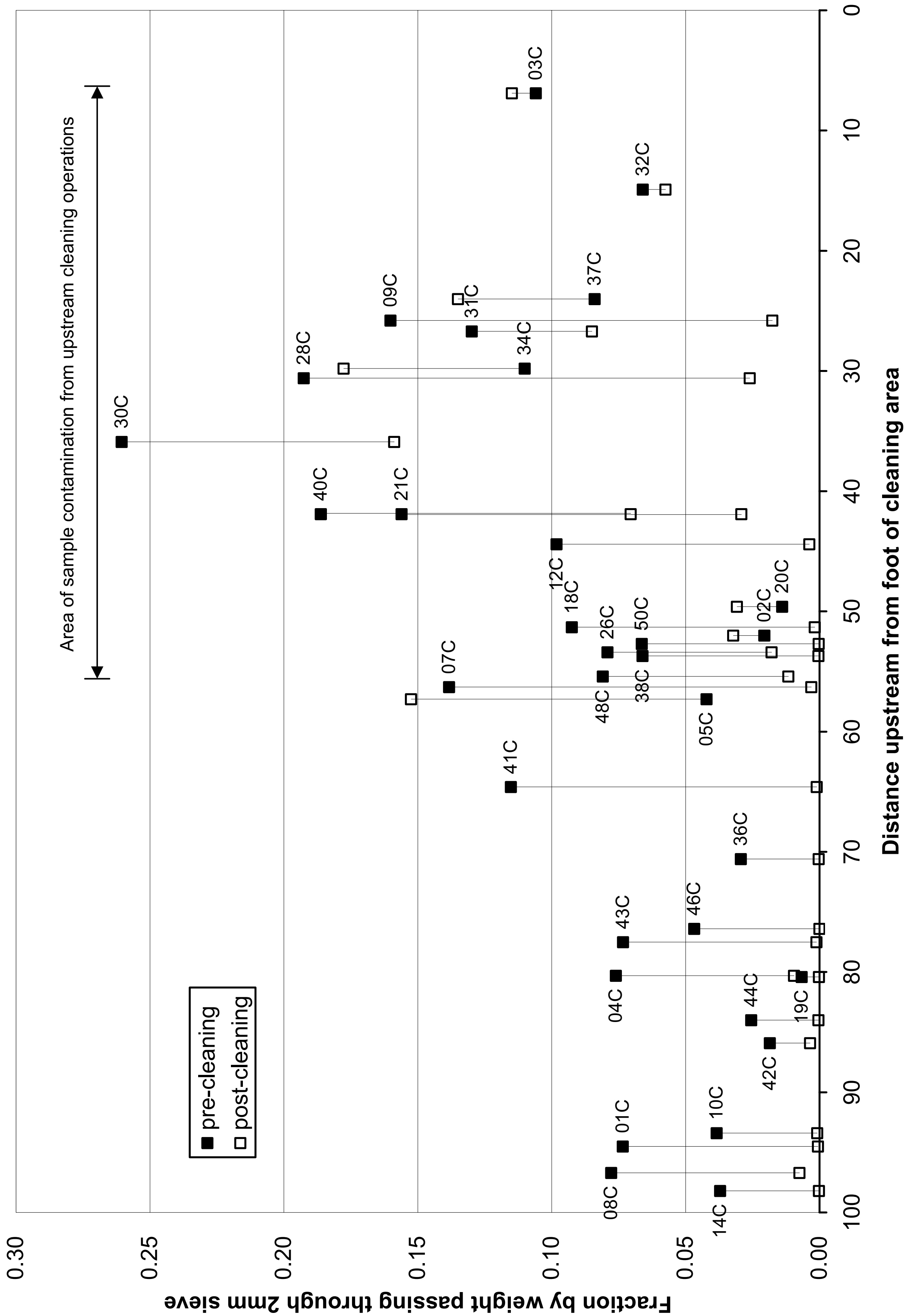
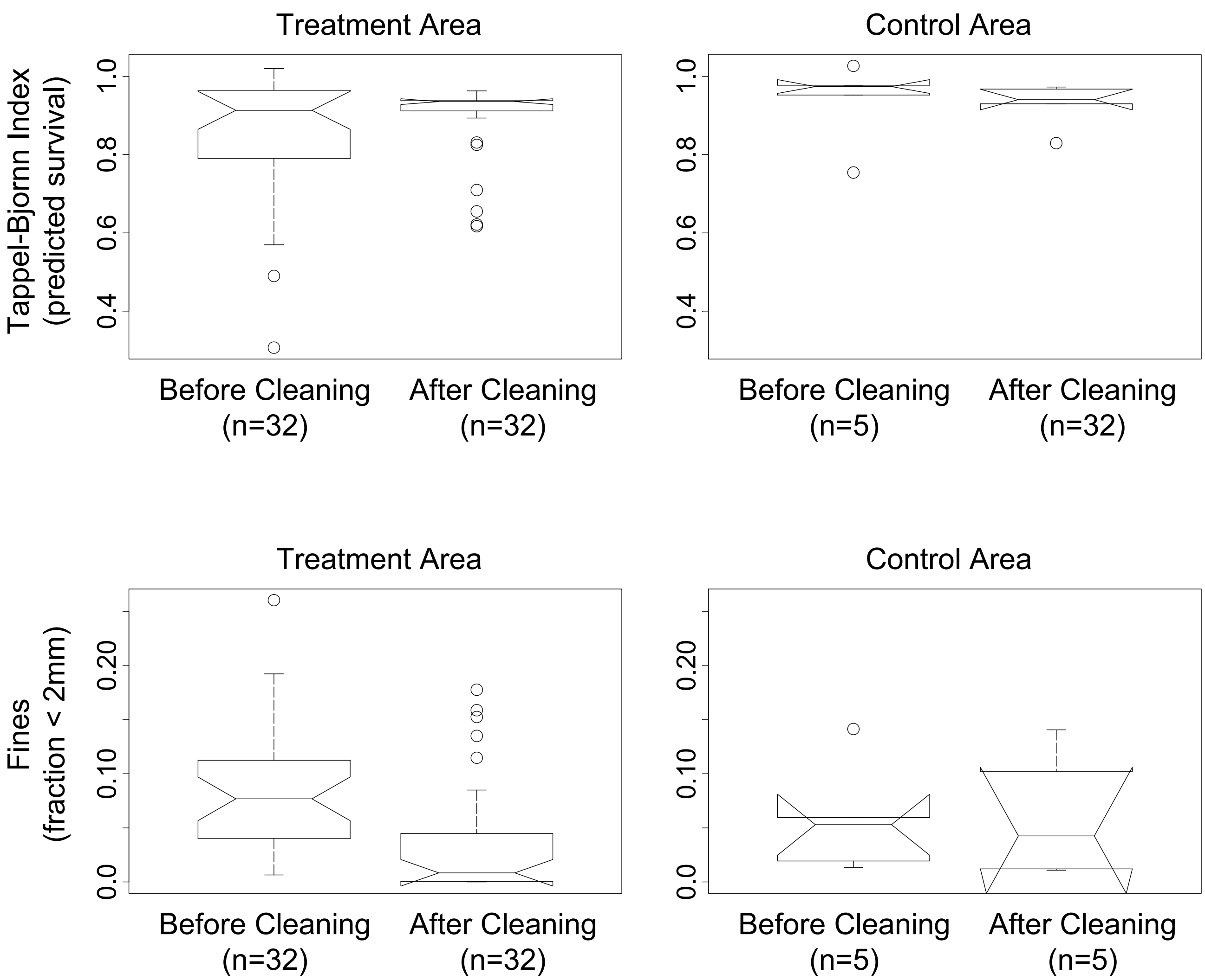


Figure 3. Pre- and Post-Cleaning Comparisons of Fraction Fines in 1993 Treatment Areas.



Notes on Box and Whisker Plots:

1. The basic box extends from the first to the third quartile of the data values, the horizontal central line in each box marks the median.
2. Vertical central lines extend from the median by 1.5 times the inter-quartile range towards the minimum to maximum, with values in excess of this range shown individually.
3. V-“notches” in the boxes show the approximate 95% tests for equality of medians, using an order-statistic-based version of the standard two-sample t-test (note that notches may extend above or below the boxes).

Figure 4. Summary of gravel quality index values for gravel samples collected as part of 1993 gravel cleaning experiments.

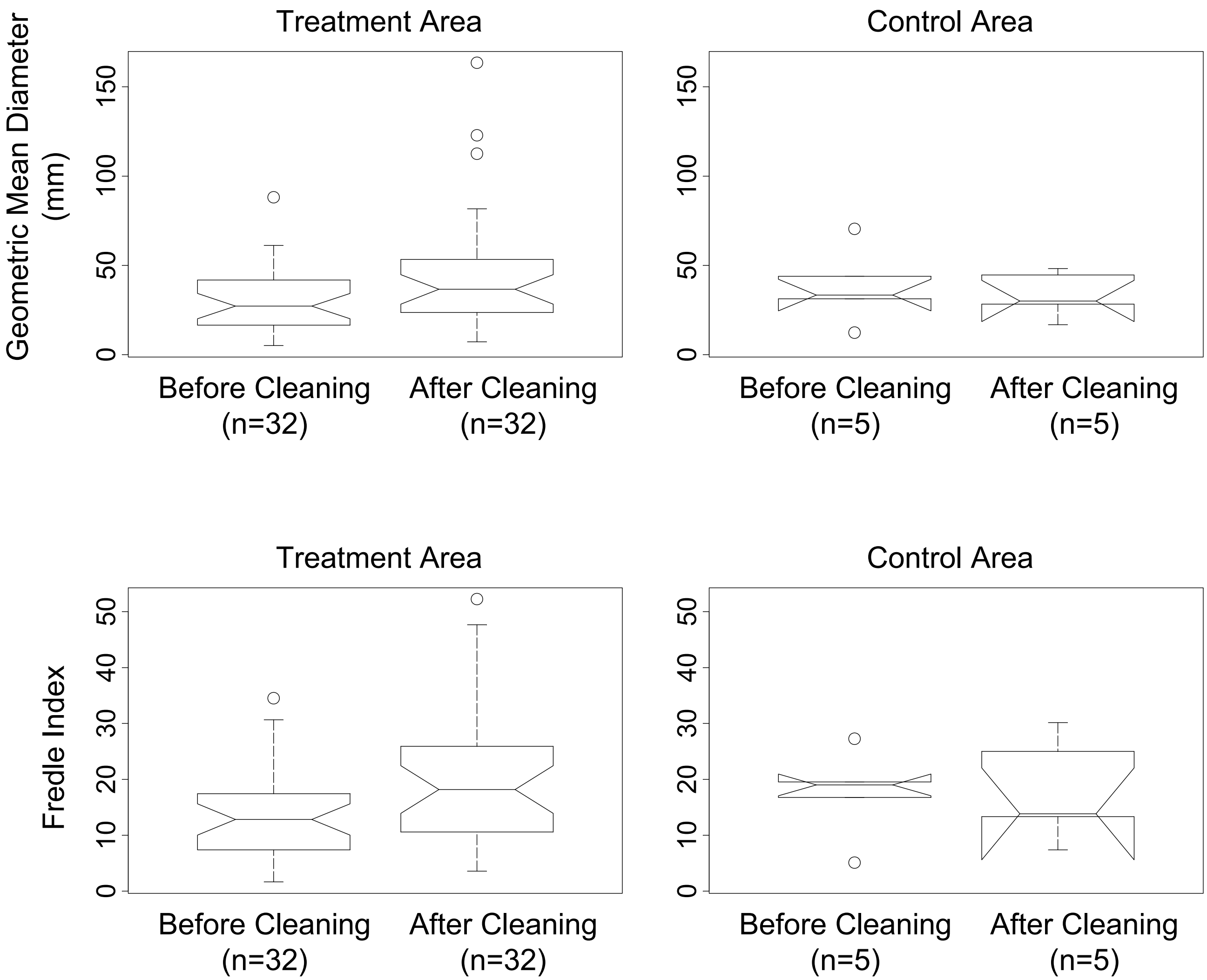
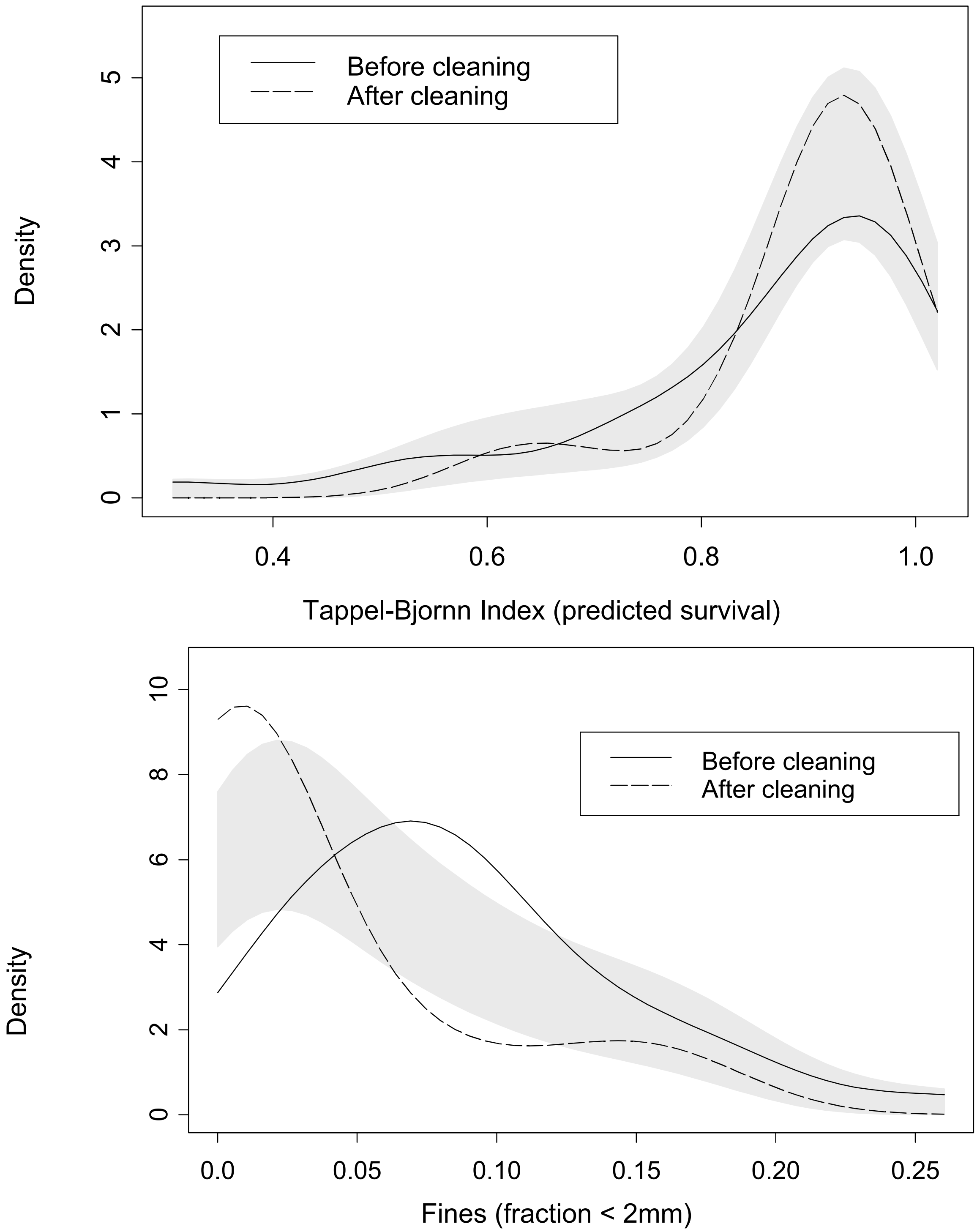
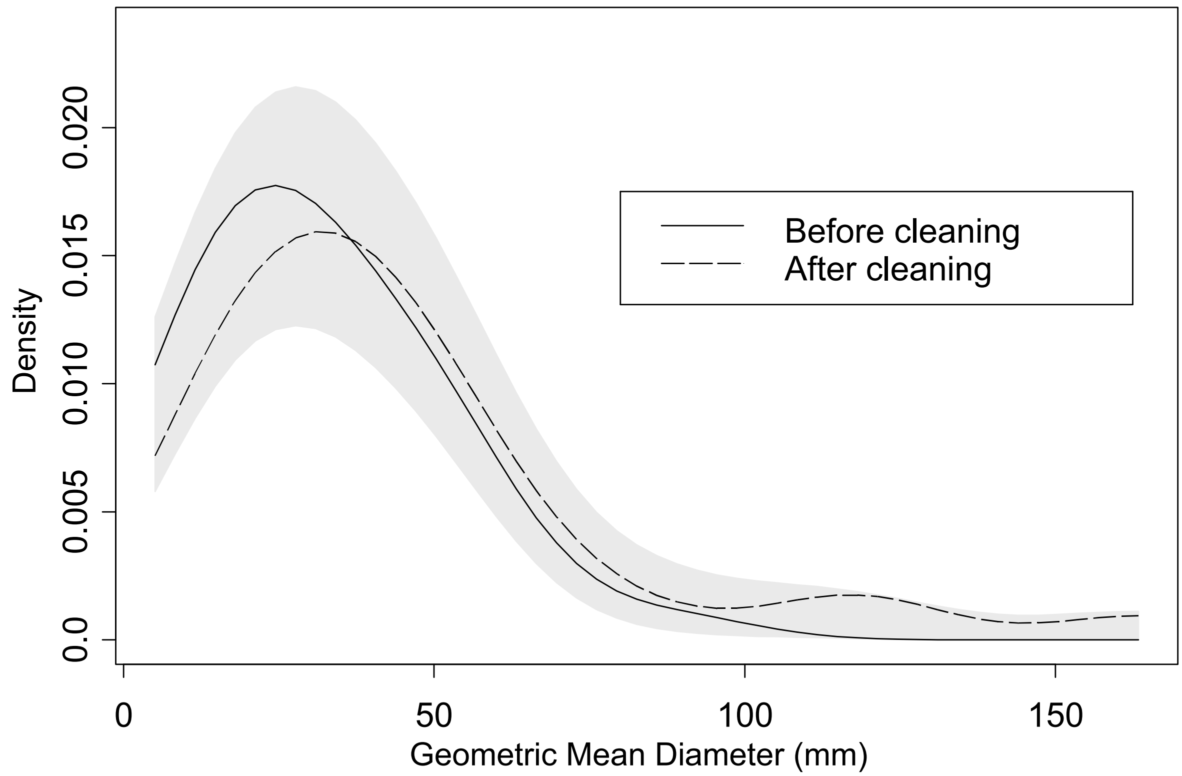


Figure 4 (continued). Summary of gravel quality index values for gravel samples collected as part of 1993 gravel cleaning experiments.



Notes: Assuming the before- and after-cleaning samples are from the same underlying distribution (null hypothesis), both curves should lie within the 95% confidence band (shaded). Places at which the curves approach or cross the boundaries of the reference band are therefore places at which the before- and after-cleaning distributions are most different.

Figure 5. Non-parametric gravel quality index distributions, determined after Bownan and Azzalani (1997).



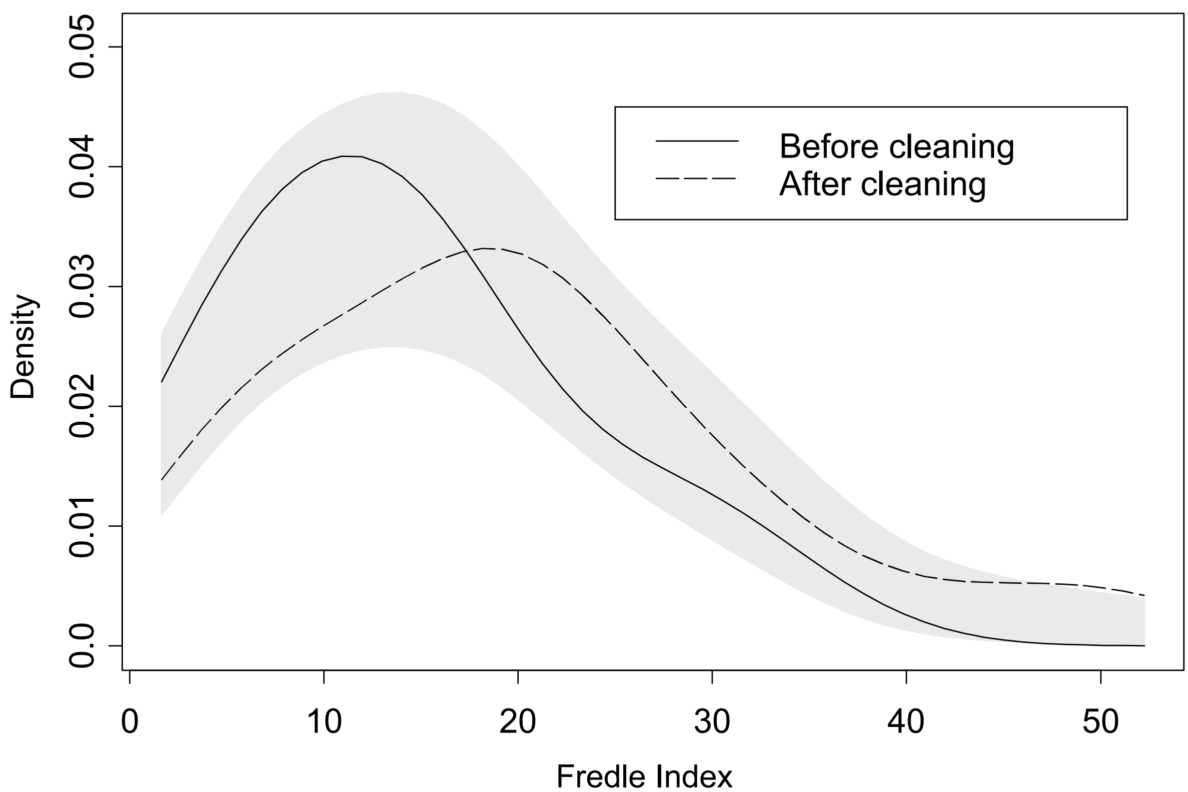


Figure 5 (continued). Non-parametric gravel quality index distributions, determined after Bownan and Azzalani (1997).

Table 1 - A Literature Review Summary of Hydraulic Gravel Cleaning Methods and Applications

reference	location	method	corrected cost $/m^2$	effectiveness	secondary effects/impacts	ranking
Andrew 1981	Gates Creek spawning channel, Horsefly River, McKinley River	Two rows of 5.1 cm (2 in) diameter pipes, mounted 31-46 cm (12-18 in) on center, extended 23 cm (9 in) into the gravel bed. Water was pumped at 20 psi through each of the 21 pipes to wash the gravel. Suspended fine sediments were pumped to the surface and allowed to flush downstream. The machine was towed downstream by a track-mounted G-600 Warner-Swasey Gradall at about 1.5 cm/s.	0.61	Cleaning on Gates Creek removed all material finer than approximately 1.3 cm (0.5 inches) to a depth of 40.6 cm (16 in). Cleaning on the Horsefly and McKinley Rivers removed all material less than 2 mm and some of the material up to 10 mm. However, much of the material coarser than 1mm accumulated on the gravel surface to a depth of 2.5-15 cm (1-6 in). Large in-stream boulders interferred with passage of the cleaner and prohibited adequate penetration. Gravel sampling of cleaned sites 2 months after spawning indicated a significant reduction in survival to emergence survival rates, while sampling 8.5 months after cleaning indicated survival was substantially increased by cleaning.	Coarser bed material that accumulated in front of the cleaner had to be periodically removed. Reduced survival may have resulted from the deposition of coarse material on the gravel surface during cleaning followed by redistribution of this material to redd sites during spawning. Short-term increases in turbidity and suspended sediment occurred downstream of cleaning operations.	0.50
TID/MID 1992	Riffle 5A -- Tuolumne River, CA	The design included a mechanism to break up the armor layer at the gravel surface, jetting nozzles to inject high velocity streams of water into the gravels, and suction nozzles to remove fine particles suspended in the water column. The machine was mounted on the articulating arm of a backhoe that worked in the downstream direction. After testing in 1992, modifications were made to the suction line and the cleaner box, a hood was added to funnel water and entrained sediments into the suction nozzle for removal, and skids were added to better control the position of the cleaner above the stream bottom.	3.26	Effective cleaning depth was18-inches. Mean egg survival rates, calculated from particle size distributions of bulk gravel samples before and after treatment (Tappel and Bjornn 1983), increased from 29.4 % (pre-treatment) to 63.7 % (post-tretament). Photographs and videotape indicat that some of the sand flushed from the substrate was mobilized downstream by the river instead of being picked up by the suction nozzle.		0.33
Einstein 1965	flume experiments	A movable gate was placed above the streambed perpendicular to flow, causing increased hydraulic pressure to be exerted on the silted gravels.	N/A	The cleaning process was slow and created a force sufficient to remove only superficial fines.		0.67
Mih 1978	Tehama-Colusa Canal (artificial spawning channel)	A carriage-mounted baffle gate was lowered into the flow to create a hydraulic force sufficient to scour spawning gravels.	N/A	Gravels were scoured to a depth of 0.76 m (2.5 feet). The technique is limited to highly regulated, trapezoidal channels.		0.67
Mundie and Mounce 1978	small unknown channel	A small pump and firehose was used to direct a jet of water into spawning gravels.	N/A	The small size of the machine resulted in uneven cleaning.	Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.67
Mih 1979	flume experiments	Jet nozzles positioned above the streambed were directed into a gravel bed to flush fines. Jet diameters, angles, elevations, and water velocities were varied to derermine the optimum cleaning effect.	N/A	Cleaning depth increased as jet velocity and jet diameter increased, jet angles of 60 and 90 degrees resulted in deeper cleaning than those at 45-degree angles, and cleaning depth increased with increased jet elevation up to approximately 40.6 cm for a 2.5 cm jet diameter. All particles smaller than 3 mm were removed from the cleaned layer.		0.56
Mih and Bailey 1981, Allen et al. 1981	Palouse River, Idaho; Kennedy Creek and Cedar River, Washington	A hydraulic gravel cleaner, referred to as the "Gravel Gertie," was mounted on a trailer and towed through the riffle. Design specification included a 19 mm (3/4 in) jet diameter, a jet velocity of 24.4 m/s, a jet elevation of 30.5 cm (12 in) above the bed, a 90 degree angle of impingement, and a machine speed of 1.83 cm/s. A rectangular collection hood and suction system removed fines from the streamflow.	N/A	Average cleaning depths were 15-30 cm.	Samples taken downstream before and after cleaning showed an increase in total suspended solids from 5 to 140 ppm and an increase in turbidity from 2 to 60 NTU after 30 minutes of operation. Reduced downstream transport rates of spawning gravels was observed in the years folowing cleaning operations.	0.56

reference	location	method	corrected cost $/m^2	effectiveness	secondary effects/impacts	ranking
Shackle et al. 1990	Kennet River, Coln River, Windrush River, and Leach River in southern England	The first method involved high-pressure jet washing using a KEW 5203 KD pressure washer. River water was pumped at 150 bar through a hand-held lance with jets of 5 mm and 1 mm in diameter. A second method involved pump washing, using a Pacer pump with a 3 Hp Briggs and Stratton engine. River water was pumped through a lance formed from 1 m of 22 mm copper tubing.	N/A	Gravel treated by both methods was noticeably looser than adjacent uncleaned gravels. The pump washer disturbed a shallower, wider area of gravel (2 to 3 cm depth, 10 to 15 cn diameter), forcing a greater volume of water horizontally through the bed. Freeze core samples taken before and after treatment indicated a 1.5% to 3.5% reduction (by weight) in silt content. Significant increases in the number of living eggs recovered from egg boxes in control and treated reache were found in 3 of 5 pump-washed reaches and 1 of 5 pressure-washed reaches.	Fine sediments released during cleaning were carried downstream to other potential spawning sites.	0.50
Shields 1968, Meehan 1971, Mih 1979	Several Alaskan streams including Fish Creek, Slocum Creek, and an artificial spawning channel at Lover's Cove Creek; Trinitiy River, CA	The design included pipes inserted 30.5 cm into the bed to hydraulically flush fines from the gravel. Suspended fines wer directed back toward the surface where they were suctioned from the water column and jetted onto the streambank. An amphibious vehicle carrying the machine was drawn downstream at a rate of 3 cm/s by a cable attached to a winch anchored downstream.	N/A	The method removed up to 65 % of particles less than 0.4 mm. Mechanical problems occurred that were related to the inability of the flushing pipes to adequately penetrate the gravels, and detachment of the anchor due to a large drag force on the machine.	Unquantified decreases in aquatic invertebrates occurred following cleaning. Aquatic invertebrate populations returned to pretreatment levels after 1 year.	0.50

Notes:
N/A = not applicable or not available

Table 2 - A Literature Review Summary of Mechanical Gravel Cleaning Methods and Applications

reference	location	method	corrected cost $/m^2	effectiveness	secondary effects/impacts	ranking
Heiser 1971	Lower Dungeness River, WA	A D-5 Caterpiller tractor pushing a blade angled at 45 degrees upstream to expose and clean spawning gravels to a depth of 0.25-0.36 m.	0.72	Sediment sampling before and after treatment indicated a 2% to 8% reduction in fine sediments less than 0.8 mm. One-fourth of all spawning Pink salmon in the lower Dungeness River were attracted to the cleaned areas. Pink salmon fry survival was 90% in treated areas and 47.5% in adjacent untreated areas. Fry survival increased by 89% in treated areas.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are placed in locations out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.8
Wilson 1976	Cleaning occurred on the Entiat River, WA; replacement occurred on the Nisqually River, Tarboo Creek, Dogfish Creek, East Fork Satsop River, McLane Creek, and Swift Creek in Washington	A bulldozer with a tilt-and-angle blade worked across the stream at about a 15 degree angle into the current. Passes were made 1.5 - 2.5 m apart progressing downstream. At gravel replacement sites, existing gravels were removed to a depth of 0.3 m by a bulldozer and replaced with clean gravels. Gabion weirs were constructed to contain the new gravels, and riprap was placed to protect banks from erosion	47.57	Spawner utilization was generally low in gravel replacement sites. Some of these sites experienced a significant loss of the new gravel.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.8
Mih 1978	Palouse River, ID; Kennedy Creek and Cedar River, WA	A Gradall, carrying a modified 2.1 m digging bucket with a screened bottom constructed of 3.2 mm (1/8-inch) wire mesh, scooped gravel to a depth of approximately 0.61 m and vibrated the bucket in the water to remove fines through the screened bottom. The cleaned gravel in the bucket was then returned to the hole.	4.10	Fines were removed from the upper 30.5 cm of the bed, under which a layer of concentrated fines was left.	Cleaned areas experienced twice the erosion rate of uncleaned areas. Subsurface fines created a potential source of fine sediment when the surface gravels are mobilized.	0.8
Andrew 1981	Nadina and Horsefly rivers, WA	A 1.5 m-wide digging bucket was mounted on a G-600 Gradall. Moving downstream, the Gradall excavated to a depth of 30-60 cm. Excavated gravel was then poured back onto the stream bed, allowing flow to entrain the suspended fines.	1.44	Cleaning resulted in a 12 % reduction in material less than 0.5 mm and complete removal of fines less than 0.3 mm. Areas cleaned on the Nadina River showed significant increases in permeability but were not used by subsequent spawners. Areas cleaned on the Horsefly River were heavily used by subsequent spawners but showed no improvement in gravel permeability or egg survival to emergence.	Fines removed during cleaning were swept downstream and deposited in pools. Erosion in cleaned areas was double that in uncleaned areas.	0.8
Hall and Baker 1982, Gerke 1990	Entail River, WA	A bulldozer moved up and across the stream at a 45-degree angle to flow with its blade angled upstream. Gravels were turned to a depth of 25-36 cm and pushed up into the flow. After each pass the bulldozer crossed the river and began another pass 1.5 -2.5 m downstream of the last pass.	N/A	Gravel sampling indicated decreased fines and increased spawning in treated areas compared to untreated areas. The method was most effective when executed during high flows to allow maximum flushing of gravels.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.8
West 1984	Scott River, CA	A Caterpillar D-6 tractor equiped with tilt-and-angle blade was used to rip spawning gravels. Gravels were repeatedly ripped until it became visually evident that further treatment would not reduce fines.	0.30	Gravel manipulation successfully loosened embedded gravels. McNeil samples taken before and after treatment indicated a reduction in the concentration of sand from 16.9% to 12.0% and the concentration of fines (<3.3 mm) from 24.3% to 6.1%. Treatment was followed by moderate to heavy spawner use.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.8
EA 1989	Tuolumne River, CA	Steel tongs mounted on a bulldozer were raked through gravels during low flow. Gravels were raked perpendicular to flow, parallel to flow, and in a combination of directions.	N/A	Ripping appeared to remove clay and silt from the subsurface but not sand. There was no significant change in the ammount or distribution of fine sediments on the bed surface. No significant change in subsequent spawning was observed.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.8

reference	location	method	corrected cost $/m^2	effectiveness	secondary effects/impacts	ranking
Hampton 1990	Trinity River, CA	Gravels were ripped to a depth of approximately 0.6 m during low flow (1/3 bankfull discharge, average point velocities were 0.46-0.61 m/s) using a rip bar mounted on a crawl tractor.	N/A	Surface embeddedness decreased by approximately 20 percent, but fines likely settled during ripping rather than being removed.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.8
Stemple 1990	Trinity River, CA	A ripping bar mounted to a bulldozer was drawn through the gravel.	N/A	McNeil samples before and after ripping showed no significant decrease in fines. A slight increase in spawning was observed in ripped areas.	Deep ripping brought large material to the surface that was not conducive to spawning. Reducing the ripping depth from 24 to 18 inches decreased the number of large cobbles and boulders brought to the surface.	0.8
Painter 1990	Feather River, CA	A ripping bar mounted to a bulldozer was drawn through the gravel. Treatment occurred during summer low-flow conditions (1/2 bankfull discharge, 11.3 cms)	N/A	Ripping appeared to increase subsequent spawning activity.	Treatment increased turbidity for 40-50 miles downstream.	0.7
Shackle et al. 1999	Kennet River, Coln River, Windrush River, and Leach River in southern England	The treatment involved rotovating with a Dowdeswell Powervator 35 (rotary tiller) pulled behind a Ford 1220 four wheel drive tractor.	0.42	Freeze core samples taken before and after treatment indicated a 1.5% to 3.5% reduction (by weight) in silt content. Significant increases in the number of living eggs recovered from egg boxes were found in 2 of 5 treated reaches compared to untreated reaches . Treated gravel was noticeably looser than adjacent uncleaned reaches.	Increased bed erosion and spawner avoidance may occur in cleaned areas where stream gravels are out of equilibrium with streamflow conditions. Short-term increases in turbidity and suspended sediment can be expected downstream of cleaning operations.	0.7

Notes:

N/A = not applicable or not available

Table 3 - Ranking of Gravel Cleaning Methods Reviewed by Cost, Effectiveness and Ecological Disturbance

Reference	Method	cost[2]			effectiveness		impact		ranking[1]
		$/m²	rating	Score	rating	Score	rating	Score	
Mih and Bailey 1981, Allen et al. 1981	Hydraulic (water jet/vaccuum)	N/A	N/A	N/A	moderate	2	low	3	0.83
Shields 1968, Meehan 1971, Mih 1979	Hydraulic (water jet/vaccuum)	N/A	N/A	N/A	moderate	2	low	3	0.83
Mih 1979	Hydraulic (water jet)	N/A	N/A	N/A	high	3	moderate	2	0.83
Shackle et al. 1999	Hydraulic (water jet)	N/A	N/A	N/A	high	3	moderate	2	0.83
Hall and Baker 1982, Gerke 1990	Mechanical (ripping, tilling)	N/A	N/A	1	moderate	2	moderate	2	0.83
West 1984	Mechanical (ripping, tilling)	$ 0.30	low	3	moderate	2	moderate	2	0.78
Andrew 1981	Hydraulic (water jet)	$ 0.61	low	3	moderate	2	moderate	2	0.78
Heiser 1971	Mechanical (excavation/replacement)	$ 0.72	low	3	moderate	2	moderate	2	0.78
TID/MID 1992	Mechanical (ripping); Hydraulic (jet/vaccuum)	$ 3.26	moderate	2	high	3	moderate	2	0.78
Shackle et al. 1999	Mechanical (tilling)	$ 0.42	N/A	N/A	high	3	high	1	0.67
Einstein 1965	Hydraulic (weir/baffle gate)	N/A	N/A	N/A	low	1	low	3	0.67
Mih 1978	Hydraulic (weir/baffle gate)	N/A	N/A	N/A	low	1	low	3	0.67
Hampton 1990	Mechanical (ripping)	N/A	N/A	N/A	moderate	2	moderate	2	0.67
Painter 1990	Mechanical (ripping)	N/A	N/A	N/A	moderate	2	moderate	2	0.67
Andrew 1981	Mechanical (excavation/cleaning)	$ 1.44	moderate	2	moderate	2	high	1	0.56
Mih 1978	Mechanical (excavation/cleaning)	$ 4.10	moderate	2	moderate	2	high	1	0.56
EA 1989	Mechanical (ripping)	N/A	N/A	N/A	low	1	moderate	2	0.50
Stemple 1990	Mechanical (ripping)	N/A	N/A	N/A	low	1	moderate	2	0.50
Mundie and Mounce 1978	Hydraulic (water jet)	N/A	N/A	N/A	low	1	moderate	2	0.50
Wilson 1976	Mechanical (excavation/replacement)	$ 47.57	high	1	low	1	high	1	0.33

notes:

1. Ranking is based on the fraction of the points received over the total score available (9 where units costs are identified, 6 where N/A). Scores are assigned as follows:

cost: low=3, moderate=2, high=1
effectiveness: high=3, moderate=2, low=1
impacts: low=3, moderate=2, high=1

2. Costs adjusted for inflation to year 2001 basis and normalized to unit area cleaned.

N/A = not applicable or not available

Table 4. Gravel quality statistics for all processed gravel-quality samples from 1993 Tuolumne River gravel-cleaning test.

Samples From Upstream Fifty Feet Of Cleaning Test Area

Pre-Cleaning Samples					Post-Cleaning Samples				
Sample	Tappel-Bjornn	Fraction Fines	dG (mm)	Fredle	Sample	Tappel-Bjornn	Fraction Fines	dG (mm)	Fredle
91-01C	0.88	0.073	17	8.1	92-01C	0.94	0.001	43	22.7
91-02C	1.02	0.021	88	34.5	92-01C	0.94	0.032	24	12.1
91-04C	0.81	0.076	57	15.8	92-01C	0.95	0.010	66	26.2
91-05C	0.98	0.042	27	15.5	92-01C	0.65	0.153	13	4.3
91-07C	0.85	0.138	15	7.3	92-01C	0.94	0.003	112	32.6
91-08C	0.96	0.078	30	14.8	92-01C	0.94	0.007	28	17.5
91-10C	0.98	0.038	27	16.6	92-01C	0.94	0.001	36	18.6
91-14C	1.02	0.037	61	27.4	92-01C	0.93	$< 5x10^{-4}$	56	41.3
91-18C	0.92	0.092	20	10.4	92-01C	0.94	0.002	82	25.6
91-19C	0.96	0.007	53	30.7	92-01C	0.94	$< 5x10^{-4}$	123	52.3
91-26C	0.93	0.079	26	12.1	92-01C	0.92	0.018	163	28.0
91-36C	0.95	0.029	41	16.7	92-01C	0.94	$< 5x10^{-4}$	50	32.1
91-38C	0.88	0.066	49	15.7	92-01C	0.94	$< 5x10^{-4}$	47	23.3
91-41C	0.84	0.115	16	6.5	92-01C	0.94	0.001	48	21.0
91-42C	0.98	0.019	36	23.2	92-01C	0.94	0.003	32	17.8
91-43C	0.94	0.073	29	13.6	92-01C	0.93	0.001	26	15.6
91-44C	0.98	0.025	51	28.6	92-01C	0.94	$< 5x10^{-4}$	57	31.8
91-46C	0.98	0.047	40	18.2	92-01C	0.93	$< 5x10^{-4}$	59	47.7
91-48C	0.96	0.081	22	11.9	92-01C	0.94	0.012	41	16.7
91-50C	0.89	0.066	22	9.7	92-01C	0.94	$< 5x10^{-4}$	35	20.9

Samples From Downstream Fifty Feet Of Cleaning Test Area

Pre-Cleaning Samples					Post-Cleaning Samples				
Sample	Tappel-Bjornn	Fraction Fines	dG (mm)	Fredle	Sample	Tappel-Bjornn	Fraction Fines	dG (mm)	Fredle
91-03C	0.57	0.106	42	9.9	92-01C	0.83	0.115	13	5.3
91-09C	0.71	0.160	10	3.7	92-01C	0.94	0.018	40	17.7
91-12C	0.85	0.098	54	20.2	92-01C	0.94	0.004	43	21.8
91-20C	0.97	0.014	42	28.0	92-01C	0.95	0.031	30	14.7
91-21C	0.72	0.156	11	4.2	92-01C	0.94	0.029	21	11.4
91-28C	0.49	0.192	9	3.0	92-01C	0.96	0.026	37	20.2
91-30C	0.31	0.260	5	1.6	92-01C	0.62	0.159	7	3.6
91-31C	0.77	0.130	12	6.0	92-01C	0.82	0.085	26	9.1
91-32C	0.95	0.066	37	15.7	92-01C	0.91	0.057	23	9.8
91-34C	0.73	0.110	22	7.5	92-01C	0.62	0.178	11	3.6
91-37C	0.91	0.084	24	10.9	92-01C	0.71	0.135	17	5.8
91-40C	0.57	0.186	9	3.0	92-01C	0.89	0.071	15	8.1

Samples From Control Area

Pre-Cleaning Samples					Post-Cleaning Samples				
Sample	Tappel-Bjornn	Fraction Fines	dG (mm)	Fredle	Sample	Tappel-Bjornn	Fraction Fines	dG (mm)	Fredle
93-01C	0.98	0.060	44	19.0	92-01C	0.97	0.011	48	30.1
93-02C	0.95	0.014	33	16.8	92-01C	0.93	0.043	30	13.3
93-03C	0.75	0.141	12	5.1	92-01C	0.94	0.102	28	13.8
93-04C	0.97	0.019	70	27.3	92-01C	0.83	0.141	17	7.4
93-05C	1.03	0.053	31	19.5	92-01C	0.97	0.012	45	25

Table 5. Two-sample two-sided heteroscedastic t-tests for changes to gravel quality parameters.

Samples From Cleaning Test Area (All Samples)

	Change in mean index value				**95% confidence interval for increase**	
	before	**after**	**increase**	**p**	**lower**	**upper**
Tappel-Bjornn	0.85	0.89	0.04	0.24	-0.11	0.03
Fines	0.086	0.036	-0.05	$<10^{-3}$	0.022	0.079
dG	31	45	13	0.061	-27	1
Fredle	14	20	6	0.031	-11	-1

Samples From Cleaning Test Area (Upstream Samples)

	Change in mean index value				**95% confidence interval for increase**	
	before	**after**	**increase**	**p**	**lower**	**upper**
Tappel-Bjornn	0.94	0.92	-0.01	0.48	-0.03	0.05
Fines	0.060	0.012	-0.048	$<10^{-4}$	0.026	0.070
dG	36	57	21	0.035	-40	-2
Fredle	17	25	9	0.011	-15	-2

Samples From Cleaning Test Area (Downstream Samples)

	Change in mean index value				**95% confidence interval for increase**	
	before	**after**	**increase**	**p**	**lower**	**upper**
Tappel-Bjornn	0.71	0.84	0.13	0.066	-0.28	0.01
Fines	0.130	0.076	-0.055	0.043	0.002	0.107
dG	23	24	1	0.91	-13	12
Fredle	9	11	1	0.63	-8	5

Samples From Control Area

	Change in mean index value				**95% confidence interval for increase**	
	before	**after**	**increase**	**p**	**lower**	**upper**
Tappel-Bjornn	0.94	0.93	-0.01	0.88	-0.12	0.14
Fines	0.057	0.062	0.004	0.90	-0.084	0.075
dG	38	34	-5	0.69	-22	31
Fredle	18	18	0	0.94	-13	12

Appendix G

Tuolumne River Phase II Gravel Introduction Technical Memorandum (Draft)

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TUOLUMNE RIVER PHASE II GRAVEL INTRODUCTION TECHNICAL MEMORANDUM

Prepared on Behalf of
Tuolumne River Technical Advisory Committee

for

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February 28, 2001

Background

The Tuolumne River Technical Advisory Committee developed the *Habitat Restoration Plan for the Lower Tuolumne River Corridor* (McBain and Trush 2000) to guide restoration activities on the river. A primary recommendation in the Restoration Plan was to restore coarse sediment conditions in the Gravel-bedded Zone, first by adding large volumes of gravel and cobble to rapidly improve the coarse sediment storage in the channel, then by periodically adding coarse sediment approximately at the rate it is transported downstream during high flows. This gravel introduction program began in 1999 with implementation of the DFG/DWR Phase I Gravel Addition Project at La Grange, which introduced approximately 12,500 cubic yards of gravel at riffle 1A below La Grange Bridge. Phase II of the Spawning Gravel Introduction Project was funded by AFRP and the Tracy Mitigation Program to continue spawning gravel introduction in the upper reaches of the Tuolumne River. The AFRP program also funded McBain and Trush to prepare a Coarse Sediment Management Plan that would provide additional detail on high priority gravel introduction sites, refined volume estimates, methods for gravel introduction, and specific monitoring guidelines. Because the Sediment Management Plan will not be complete before the DFG/DWR Phase II project is implemented, McBain and Trush have prepared this technical memorandum to help guide the implementation of the Phase II project.

Data Collection

To date, we have collected the following information for the Sediment Management Plan:

- habitat mapped, using recent aerial photos (Dec 1999) and methods developed for other Tuolumne River projects; mapping includes pool-riffle-run units, gravel bars, and chinook spawning habitat as indicated by recent redd construction;
- surveyed several potential sites that would benefit from spawning gravel or coarse sediment augmentation, and assessed logistical opportunities/constraints (road construction needs, land ownership, etc.);
- installed and surveyed 19 new cross sections between La Grange Dam and Basso, monumented with rebar pins and tied to real elevation control where possible; cross sections are numbered according to longitudinal stationing from the San Joaquin River, similar to other Tuolumne River project reaches; cross sections and other survey data were used to estimate gravel volumes at specific proposed sites;
- performed pebble counts of existing and proposed sediment conditions;
- compared pre-1990's habitat data with recent data to document spawning habitat attrition at specific riffles, in order to aid in prioritizing the selection of gravel introduction sites for 2001 and for future projects;
- assessed historical conditions at selected sites from early aerial photo sequences;

The primary focus of the Sediment Management Plan is in the reach between La Grange Dam and Basso Bridge. We mapped the available spawning habitat in this reach in December 2000, to compare to previous spawning habitat assessments conducted by the Districts in 1988 (EA 1992). Our assessment in the upper reach indicates that spawning habitat has decreased by as much as 44% compared to the 1988 data, likely a result of steady gravel attrition from annual bedload transport and lack of upstream supply, as well as from the catastrophic degradation from the January 1997 flood. Based on spawning habitat availability, channel widening and downcutting, and chinook spawning preferences (redd densities), the most evident impacts are generally in the riffles upstream of New La Grange Bridge (NLGB), compared to riffles between NLGB and Basso Bridge. For example, spawning habitat at riffle A3/4 has been reduced from 22,000 ft2 in 1988 to approximately 3,700 ft2 in 2000; Riffle A5 is nearly completely scoured away, with water depths of 5 to 6 ft, coarse substrate, and very little velocity; Riffle A6 supported only one or two redds in 2000/01 spawning season.

Site Selection, Methods, and Volumes

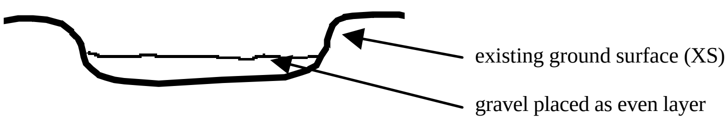
During the Feb 13 meeting, the TRTAC agreed that sites upstream of New La Grange Bridge were highest priority. This reach receives the highest concentration of spawners, and gravel placed here will not only provide immediate benefit to salmon, but will continue to benefit salmon in future years as the gravel is routed downstream. Our selection of preferred sites for 2001 implementation was therefore prioritized as follows (see Figure 1 for site locations):

- the section of channel between riffles A7 and 1B (upstream and downstream of the Phase I project site) was recommended as a preferred site for implementation in 2001. In addition, the TRTAC discussed supplementing the riffle 1A Phase I site with a gravel bar extending from the left bank, with the objective of increasing channel confinement, providing better velocities in the riffle, and introducing a somewhat finer gravel mixture.

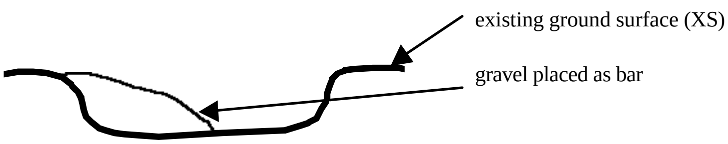
- riffles A1 and A2 were not recommended because of the limited long-term benefits to be gained at these sites, both located upstream of a deep pool that would prevent gravel from routing downstream in future events;
- riffle A3/4 would require construction of a new access road on TID property, and was recommended as a project for implementation by the Districts;
- riffles A5 and A6 are high priority, but access is limited to a single location at the USGS Cableway;

Early implementation of gravel introduction (prior to completion of the Coarse Sediment Management Plan) provides an excellent opportunity to experiment with gravel placement techniques to maximize . We propose several different techniques for gravel placement (Figure 3):

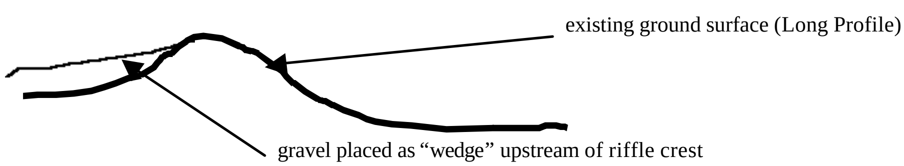
1. Riffle supplementation: this method entails placing clean, well-sorted gravel onto the existing channelbed in an even layer of specified depth;



2. Point bar supplementation: this method would place gravel as a lateral bar to increase confinement and provide long-term supply;



3. Pool tail supplementation: this method would increase spawning habitat area on overly-steep pool-tails;



4. Riffle wedge: this method would layer gravel increasing in depth moving downstream to reduce the riffle slope and increase spawning habitat;

5. Recruitment pile: this method would place a quantity of gravel on or near the channel margin, available for downstream transport at high flows; long-term recruitment locations could be identified for routine (annual) supplementation;

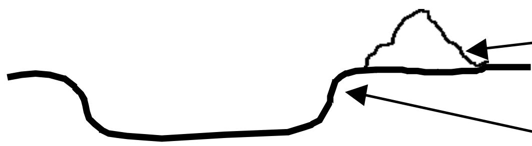


Figure 3. Suggested gravel introduction methods that can be used to address different channel conditions.

In addition to placement of large quantities of gravel directly in the channel for immediate spawning habitat supplementation, our assessment of coarse sediment storage conditions below La Grange Dam concluded that gravel could be placed in a natural gravel bar morphology in several locations to increase coarse sediment storage for eventual downstream transport, to improve channel confinement, and to increase water velocities during spawning flows. Restoring a more natural alternate bar morphology will improve bedload transport continuity, and therefore better downstream routing of introduced gravels during high flows. Importantly, this strategy will discourage future riffle loss by providing instream sediment storage to replace gravels transported from riffles during high flows. In addition, the large backwater dredging pit should be filled to reconstruct bankfull channel confinement. A coarser (unprocessed) gravel composition can potentially be used to construct bars and fill backwaters.

Figure 1 shows recommended spawning gravel and coarse sediment introduction sites from riffle A7 to riffle 1B. We delineated discrete gravel introduction polygons (numbered 10 to 18) to provide gravel volume estimates and flexibility in gravel addition methods and particle size composition. These polygons were digitized to estimate the surface area, and combined with the recommended depth of gravel placement, yielded the estimated gravel volumes. We used cross section surveys to estimate the appropriate depth of gravel placement in the riffle A7 section. We have not installed cross sections in the portion of channel below riffle 1A, and estimates of gravel depth should be refined with additional surveys.

In addition to the planview map of the gravel introduction sites (Figure 1), we provide the 1999 aerial photo of the proposed gravel introduction reach upstream and downstream of Old La Grange Bridge (Figure 2),cross sections with "proposed channel contours" sketched onto cross section plots. These contour lines were used to estimate recommended gravel depths/volumes. Placement of gravel into the channel during implementation may be simplified, with less topographic detail than is reflected in the sketched contour lines.

Below we describe each gravel introduction polygon, the main objective for gravel placement, and provide a rough volume estimate.

Polygon 10: Impacts of bank scour and lack of supply from upstream sources are clearly evident in recent air photos and field visits. Spawning habitat in adjacent portions of the channel will benefit from increased confinement in the upper portion of the riffle, by increasing velocities in the pool tail spawning areas at spawning flows (~300 cfs). Additionally, this material will be available for transport at high flows to maintain spawning gravel supply at downstream riffles. Recommended gravel introduction volume at polygon 10 is approximately 4,300 yd^3. A coarser, heterogeneous mix of unwashed gravel and cobble could be used here. Figure 4 (XS-2804+00) shows the proposed gravel introduction morphology on the left bank bar.

Polygon 11: The pool tail at the head of riffle A7 emerges from a deep pool, and has an unnaturally steep longitudinal morphology (Figure 4), and bedrock has become exposed within the channel. Introducing gravel in the pool tail downstream to the riffle crest will increase available spawning habitat. Gravel should be placed so the riffle crest elevation is not increased at this site. Recommended volume = 700 yd^3. Figure 4 (XS-2804+00) shows the proposed pool tail morphology.

Polygon 12: The direction of flow entering the riffle causes frequent scour of the bedrock outcropping on the right bank. We recommend placing a small volume of gravel on this bedrock ledge for future transport during high flows to maintain spawning gravel at downstream riffles. Recommended volume = 600 yd^3. This material should be relatively clean, fine gravel (1-4 inch) to facilitate mobilization and downstream transport. Figure 5 shows the proposed right bank bar morphology.

Polygon 13: The main portion of the riffle provides usable spawning habitat, but the spawning area could be improved and increased by reducing the riffle slope. Measured slope from the riffle crest to XS-R is 0.0070. Raising the channelbed approximately 2.0 ft at XS 2802+00 would reduce slope to 0.0020. Gravel should be placed so the riffle crest elevation is not increased at this site. This would require a gravel "wedge" of increasing depth from 0.0 ft at the upstream riffle crest to 2.0 ft at XS 2802+00. Recommended volume = 1,200 yd^3. Figure 5 shows the proposed riffle cross section contour.

Polygon 14a,b: The riffle ends abruptly into a pool with depths increasing in the downstream direction up to 11 ft. By adding gravel at the downstream end of the riffle, the entire riffle length can be extended and substantially increase the available spawning habitat. Gravel should be placed contiguous with polygon 13 and extend approximately 300-500 ft downstream (depending on the volume of material available), with constant slope of approximately 0.0020. Recommended volume = 5,200 yd^3. Figure 5 shows the proposed cross section contour extending downstream from the riffle tail.

Subtotal gravel volume for introduction at riffle A7 = 12,000 yd^3

Polygon 15a: The CDFG Phase I gravel addition at riffle 1A below the Old La Grange Bridge substantially increased the volume of coarse sediment in this portion of channel, replacing much of the material scoured downstream during the 1997 flood. The channel is over-widened in this reach, however, contributes to water velocities below the usable range for salmonid spawning. Additionally, the material appears somewhat coarser than the preference range for chinook salmon. The TRTAC Subcommittee agreed that the Phase I project would likely be improved by further supplementing riffle 1A with gravel placed as a left bank bar to slightly increase confinement and velocities during spawning flows, and with finer gravels sprinkled throughout the riffle. Recommended volume = 3,500 yd^3. Figure 1 shows the proposed location and extent of gravel placement.

Polygon 15b: The section of channel between riffles 1A and 1B was extensively altered during the 1997 flood. The large right bank bar opposite the left bank backwater was nearly entirely scoured away, and a small side-channel formed. Very little spawning was observed in this reach in 2000-01. This gravel introduction polygon would extend riffle 1A further downstream and eliminate the small scour pool. Recommended volume = 1,500 yd^3. Figure 1 shows the proposed location and extent of gravel placement.

Polygon 16: The former right bank bar that was scoured during the 1997 flood should be replaced to restore high flow (<5,000 cfs) confinement through this section of channel. Replacing the bar would eliminate the right side channel and backwater areas where velocities were too low for salmon spawning. This bar will also provide in-channel gravel storage available to maintain downstream spawning riffles and reduce/prevent future losses. Recommended volume = 4,000 yd^3. Figure 1 shows the proposed location and extent of gravel placement.

Polygon 17: The large backwater pond on the left bank is a remnant dredger mining pit. Backwater areas provide habitat for bass during summer when water temperatures are higher, trap and store fine sediments (sand), and eliminate the bankfull channel confinement that allows bedload transport continuity through the reach. Filling in this backwater pond (Figure 7) will significantly improve spawning habitat and geomorphic conditions in this reach. A coarser, heterogeneous mix of gravel and cobble could be used here. Recommended volume = 6,000 yd^3. Figure 1 shows the proposed location and extent of gravel placement.

Polygon 18a: The section of channel between the backwater pond and right bank bar was also significantly scoured during the 1997 flood. Water depths exceed 6-8 ft. By placing gravel back into this portion of the channel, riffle 1A could be extended further downstream to increase the amount of spawning habitat available. Additional surveying would be necessary here to refine the estimate of gravel depths appropriate to restore a suitable riffle slope. Recommended volume = 3,000 yd^3. Figure 1 shows the proposed location and extent of gravel placement.

Polygon 18b: If enough gravel is available (within funding constraints) during Phase II, then riffle 1A can be extended further downstream by supplementing the channel between polygon 18a and riffle 1B with approximately 2 ft of clean spawning gravel. Additional surveying would be necessary here to refine the estimate of gravel depths appropriate to restore a suitable riffle slope. Recommended volume = 5,000 yd^3. Figure 1 shows the proposed location and extent of gravel placement.

Subtotal gravel volume for introduction at riffle 1A/B (including 18b) = 23,000 yd^3

Total gravel volume recommended for Phase II introduction = 35,000 yd^3

Site Access

During the Feb 13th TRTAC meeting, we discussed access to the riffle A7 and 1A/B sites. Access to riffle A7 from the south bank would require trucks passing through downtown La Grange, then down the Old La Grange Bridge road and onto the floodplain via a steep, unimproved dirt road on the west (downstream) side of the bridge. Trucks would then pass under the bridge and upstream on the floodplain where access is relatively straightforward. Access to riffles 1A/B would be relatively easy here. An abandoned dirt road leads from the Old La Grange Bridge road to riffle A7, but this road would require substantial improvements (grading and brush/tree limb clearing) to provide access for dump trucks. This property is owned by Stanislaus County.

Access from the north bank appears preferable. Haul trucks would avoid having to pass through downtown La Grange, and very little road improvement would be necessary. The existing improved dirt road leading past the DFG La Grange Field Office, past La Grange Bridge, then up-river along the hillside would provide access to riffle A7. A small section of road grading and placement of a temporary culvert to cross the small swale would be required to descend the hill to the introduction site. Improving this access would also provide a future long-term gravel introduction site for routine maintenance (by placing small quantities of gravel on the right bank bedrock bar). Access to the sites downstream of Old La Grange Bridge already exists along the north bank from the Phase I project. All property on the north bank is owned either by Stanislaus County or the State of California.

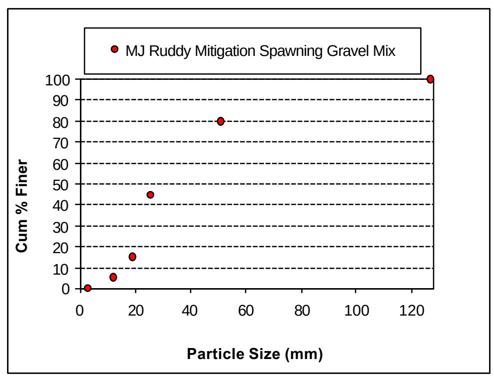
Gravel Composition

Gravel size requirements vary with a fish's life stage. For spawning adult chinook salmon, considerable research has been conducted to describe suitable spawning gravel size compositions. For example, Raleigh (et al. 1986) reported the optimal mix for chinook salmon ranging from 20 to 106 mm. Chambers (1956) reported suitable gravel mixes of: 21% for 3 to 12.5 mm; 41% for 12.5 to 60 mm; 24% for 60 to 100 mm; and 14% for 60 to 150 mm. Allen and Hassler (1986) developed profiles of habitat requirements for chinook salmon in the Pacific Southwest, and site Bell's (1973) findings that optimal gravels range from 13 to 102 mm, and that 80% of the particles should range from 13 to 51 mm, and the remaining 20% from 51 to 103 mm. This size range also agrees with Thompson (1972) as cited in Bjornn and Reiser for fall chinook salmon. Platts et al. (1979) reported spawning gravel mixes from the South Fork Salmon River, Idaho containing 84% of 10 to 76 mm, and the remaining greater than 76 mm. Finally, Kondolf and Wolman (1993) compiled published and original reports containing spawning gravel size distribution data for salmonids, and noted a large range of spawning gravel sizes used by chinook salmon. Describing the ideal or definitive spawning gravel mixture is thus not possible.

Previous spawning gravel improvement projects on the Tuolumne River (TFC 1990) used literature information to develop a gravel composition suitable for chinook salmon spawning riffles specifically for the Tuolumne River. They recommended (and used) the following gravel mixture at riffle 36A in the Santa Fe Aggregates (formerly MJ Ruddy) Mining Reach:

Table 1. Gravel composition used at MJ Ruddy (riffle 36A) for spawning gravel mitigation in 1989.

Percent of Total	*Particle Size (mm)*	*Particle Size (inches)*
5%	3 to 12.5 mm	1/8 " to 1/2"
10%	12.5 to 19.1 mm	1/2" to3/4"
30%	19.1 to 25.4 mm	3/4" to 1"
35%	25.4 to 51 mm	1" to 2"
20%	51 to 127 mm	2" to 5"



This gravel mixture equates to approximately 80% finer than 51 mm (2 inches), with D_{50} = 28 mm and D_{84} = 60 mm. We recommend using a spawning gravel mixture that conforms as closely as is practical to the above mixture, but that does not exceed the 20% recommended for the larger 2" to 5" component.

We performed surface pebble counts at several riffle sites in the reach between New La Grange Bridge and Basso Bridge, at locations with good spawning gravel-sized gravel distributions. Table 2 shows the particle sizes of the most recent pebble count data. This data conforms well with the recommended gravel mixture above, since the surface particle composition is generally coarser than the subsurface bulk sample.

Table 2. Particle sizes from recent pebble count data.

Pebble Ct Location	D_{50}	D_{84}	*Type of Facies*
Riffle 3B	52	83	Low water margin of lateral bar
Riffle 4A	40	70	Low water margin of lateral bar
Riffle 4B	45	68	Surface of shallowly inundated medial bar surrounded by numerous redds
Riffle 5A	58	106	Coarser facies representative of riffle and run thalweg

Literature Cited

Allen, M.A., and T.J. Hassler. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) –chinook salmon. U.S. Fish and Wildlife Service Biological Report 82(11.49). US Army Corp of Engineers, Tuolumne River EL-82-4. 26 p.

Bell, M.C. 1973. Fisheries handbook of fisheries requirements and biological criteria. U.S. Army Corp of Engineers, Fish Eng. Res. Program. Portland Oregon.

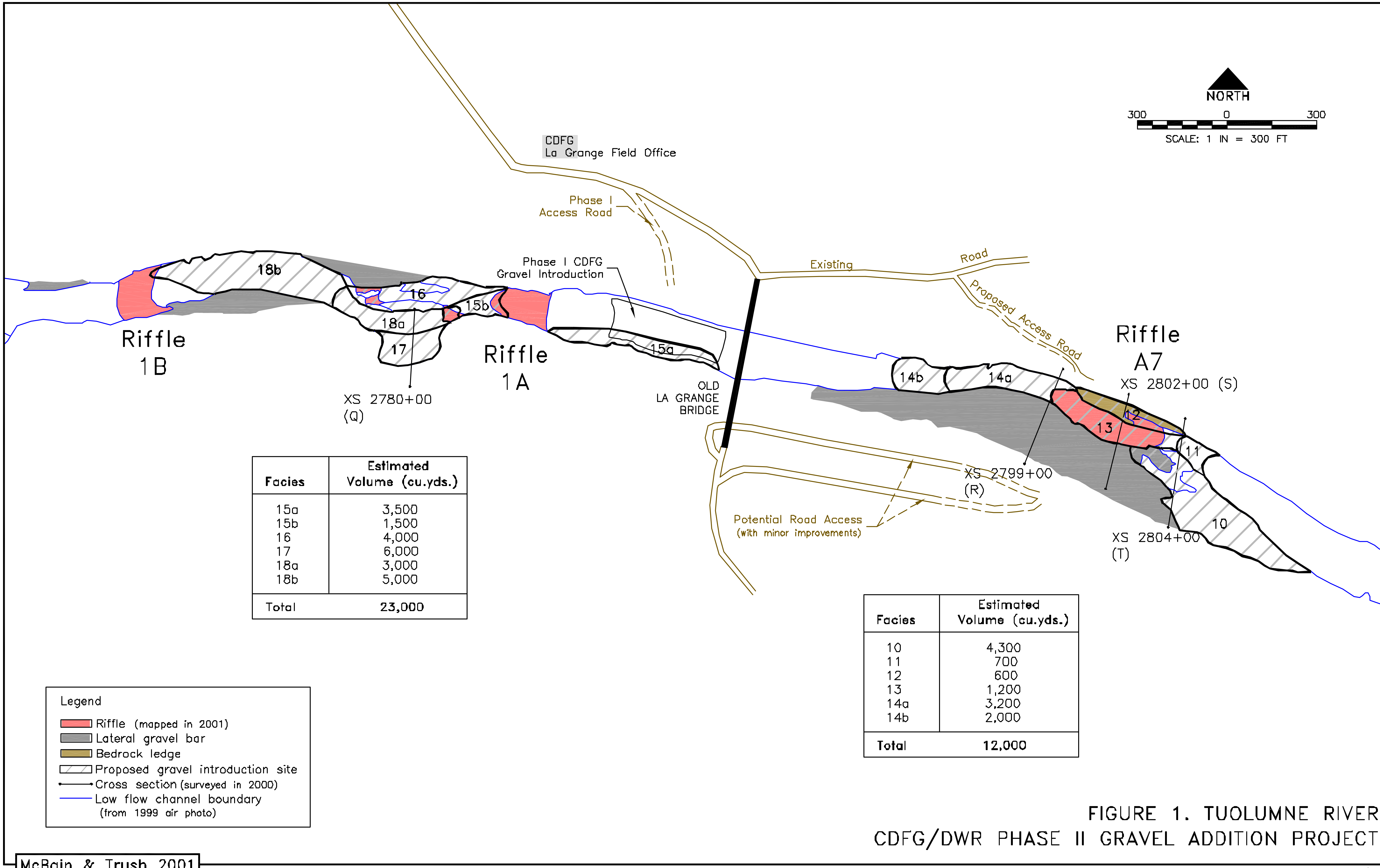
Chambers, J.S. 1956. Research relating to study of spawning grounds in natural areas. U.S. Army Corp of Engineers, North Pacific Division, Fish Eng. Res. Program. p 88-94.

Kondolf, G.M., and M.G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research, 29(7): 2275-2285.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA Forest Service, Intermountain Forest and Range Experimental Station, General Technical Report INT-138

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. U.S. Fish and Wildlife Service Biological Report 82(10.122). 64 p.

Trinity Fisheries Consulting: Anadromous Fisheries Restoration. 1990. Draft Report on gravel quality monitoring of MJ Ruddy, Inc. 1989 salmon spawning restoration projects on the Tuolumne River. Arcata Ca.



Facies	Estimated Volume (cu.yds.)
15a	3,500
15b	1,500
16	4,000
17	6,000
18a	3,000
18b	5,000
Total	23,000

Facies	Estimated Volume (cu.yds.)
10	4,300
11	700
12	600
13	1,200
14a	3,200
14b	2,000
Total	12,000

FIGURE 1. TUOLUMNE RIVER
CDFG/DWR PHASE II GRAVEL ADDITION PROJECT

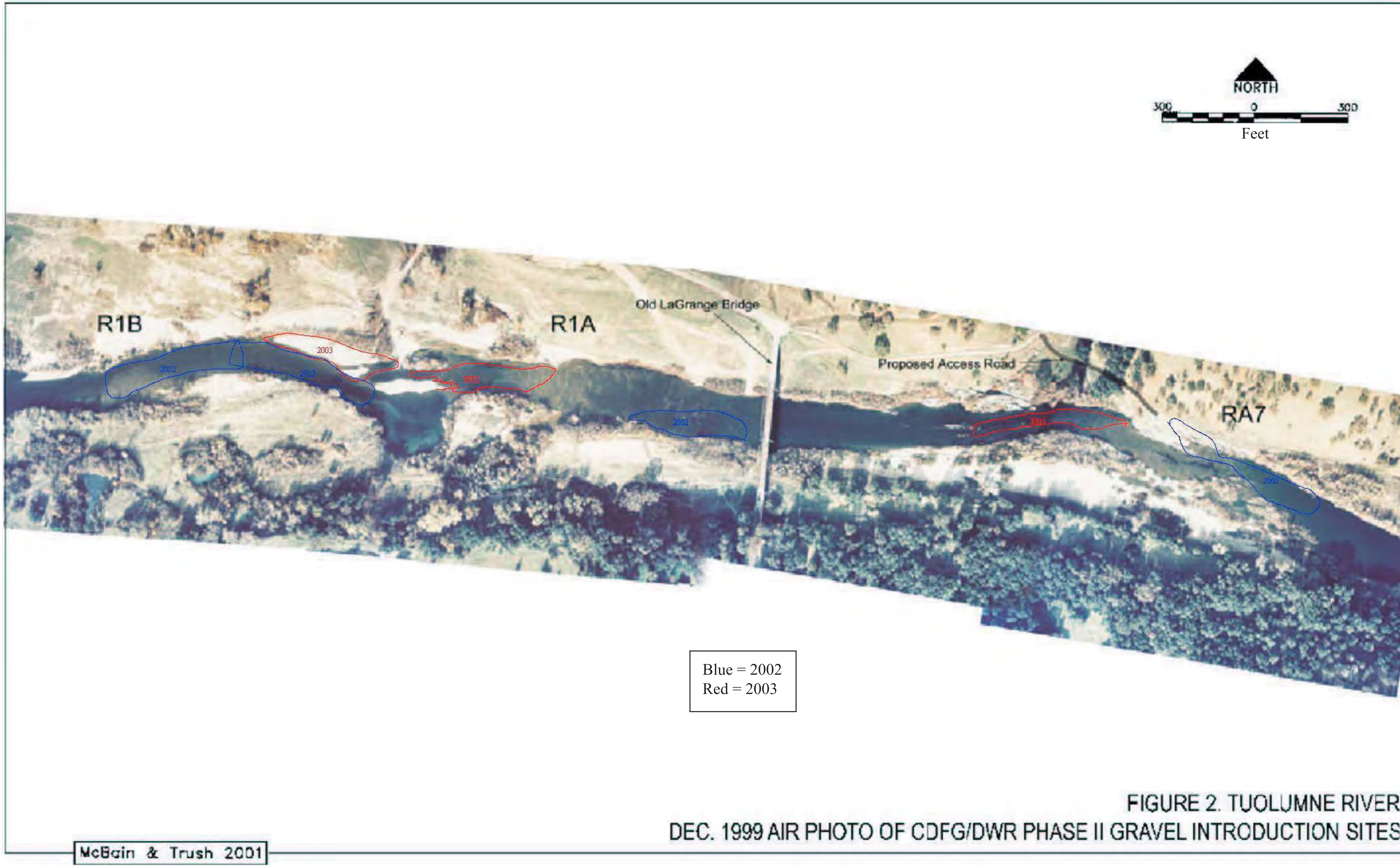


FIGURE 2. TUOLUMNE RIVER
DEC. 1999 AIR PHOTO OF CDFG/DWR PHASE II GRAVEL INTRODUCTION SITES

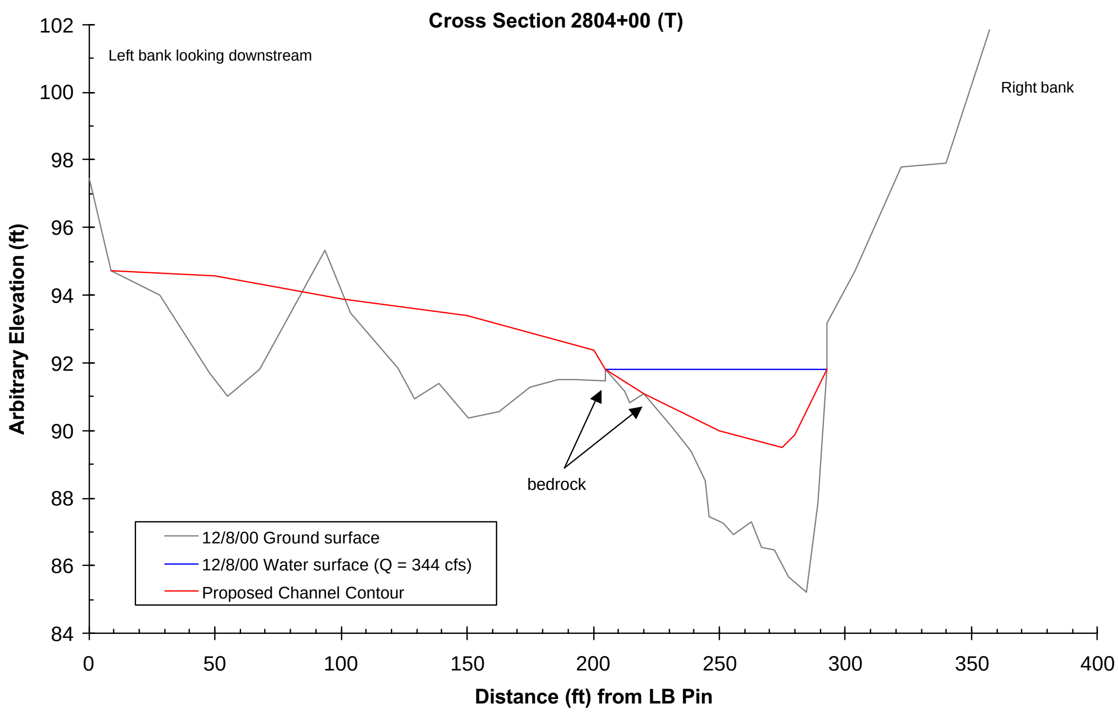


Figure 4. Cross Section 2804+00 traversing pool-tail at the head of riffle A7. The left bank lateral bar has been scoured and depleted of most coarse sediment stored on the bank. The right bank has become incised to bedrock, and the face of the pool-tail steepened.

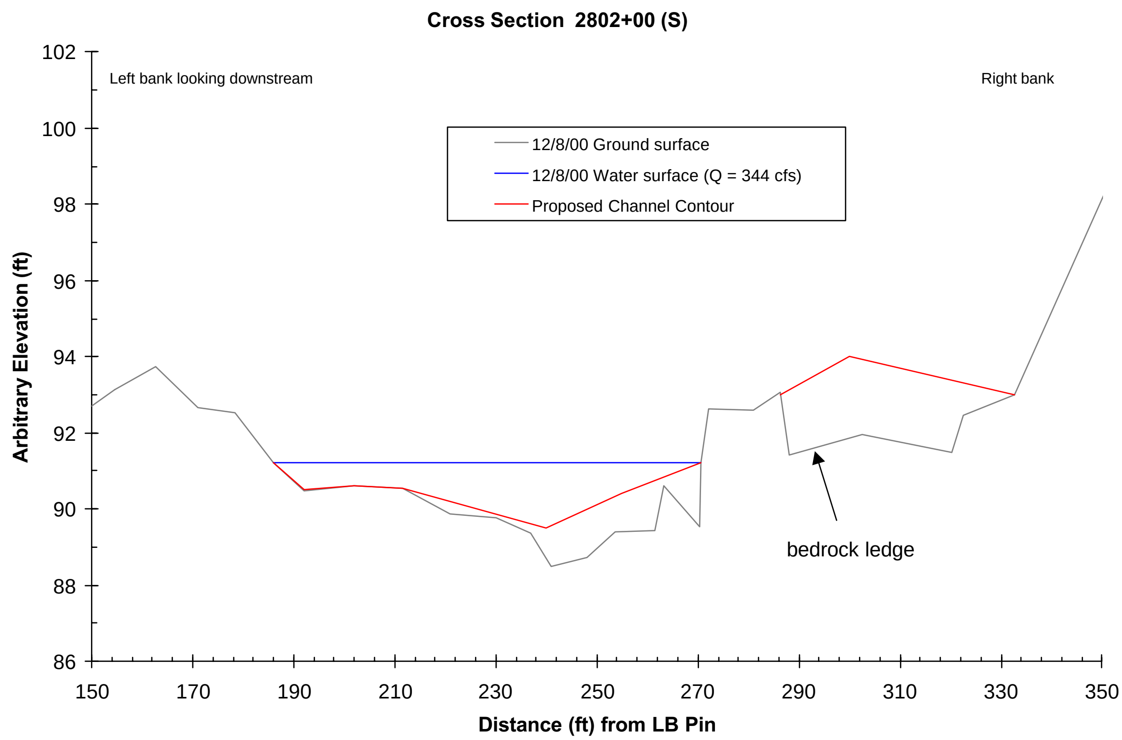


Figure 5. Cross Section 2802+00 traversing the middle portion of riffle A7. The left side of the riffle provides good spawning habitat, but the right half has higher velocities that exceed the suitable range for chinook spawning. Additionally, the right bank bedrock ledge is an ideal site to re-supply gravel storage.

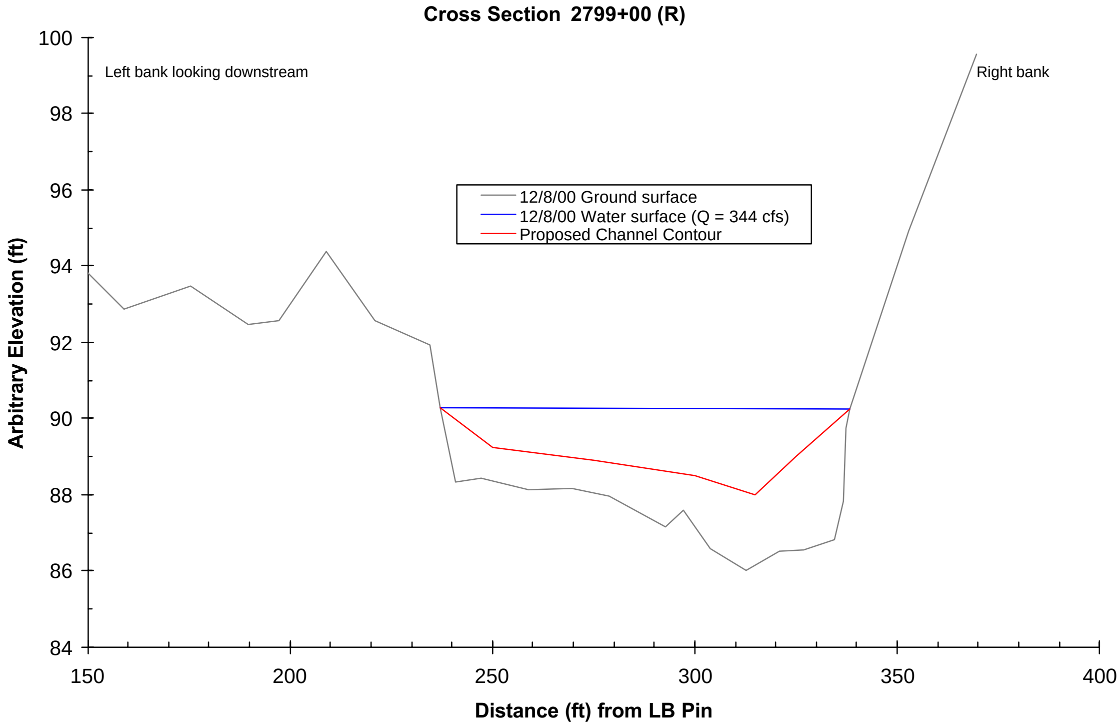


Figure 6. Cross Section 2799+00 traversing the downstream end of riffle A7. beyond this cross section the channel deepens to 6-8 ft.

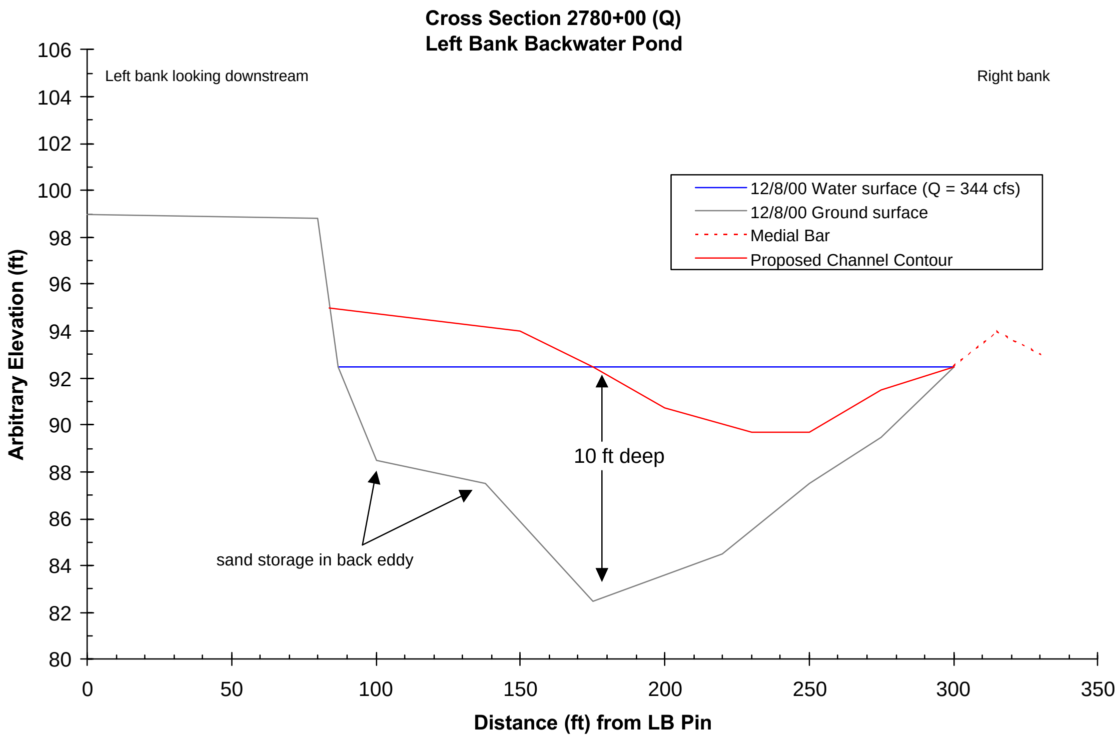


Figure 7. Cross Section 2780+00 traversing the left bank backwater pit that was left from dredger mining operations. Filling the pit would reconfine the low water channel.

Appendix H

Informal Consultation with regards to Steelhead for Phase II Gravel Introduction at La Grange on the Tuolumne River, CA.

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Stockton Fish and Wildlife Office
4001 North Wilson Way, Stockton, CA 95205-2486
209-946-6400 (Voice) 209-946-6355 (Fax)

July 7, 2003

To: Madelyn Martinez, NOAA Fisheries

From: Jeff McLain, Anadromous Fish Restoration Program

Subject: Informal Consultation with regards to Steelhead for Phase II Gravel Introduction at La Grange on the Tuolumne River, CA.

Dear Madelyn,

I am sending this letter to you, at your request, to summarize the meeting on June 25, 2003, in La Grange to discuss the impacts of gravel additions for salmon spawning enhancement on ESA listed steelhead/trout habitat. As you know, The Anadromous Fish Restoration Program (AFRP) has contracted a portion of this work to the La Grange habitat improvement shop and feels it fulfills a vital role in restoring Chinook salmon populations on the Tuolumne River. The AFRP wants to ensure steelhead/trout habitat is not adversely effected during this process. The meeting which took place on site was attended by representatives of the Tuolumne River Technical Advisory Committee. The following people attended the meeting:

Doug Ridgeway, California Department of Fish and Game
Dave and Allison Boucher, Friends of Tuolumne River
Dennis Blakeman, California Department of Fish and Game
Jeff McLain, U.S. Fish and Wildlife Service
Madelyn Martinez, NOAA Fisheries
Patrick Koepele, Tuolumne River Preservation Trust
Tim Heyne, California Department of Fish and Game
Wilton Fryer, Turlock Irrigation District

The group visited gravel augmentation sites utilized by the California Department of Fish and Game La Grange office. Dave Boucher, among others present pointed out the favorable steelhead/trout habitat adjacent to these sites and we discussed methods to avoiding impacts to these habitats as well as potential enhancements. Following, is a summary of our discussion at these sites and recommendations for gravel augmentation during 2003.

Introduction Site 15a (Riffle 1A)

The group observed introduction site 15a, which appeared to have good salmon spawning habitat. Previous years gravel introductions at this site have been successful (Figure 1).

Introduction Site 15b (Riffle 1A)

This site had a good steelhead/trout pool on the south bank with good depth, velocity and overhanging vegetation (Figure 2). Previous gravel introductions have remained upstream of this pool, and the group agreed to continue to avoid disturbing this pool that is at the lower end of the riffle. Any introductions in the future should stay at least 20'-30' from the bank.

Figure 1. Gravel introduction site 15a, La Grange.

Figure 2. South bank pool (left) at lower end of gravel introduction site 15b, La Grange.

Introduction Site 16

Introduction site 16 was on a riffle just below a large pool and appeared to have moderate steelhead/trout habitat adjacent to the south bank (Figure 3). The group recommended pushing gravel from the north bank, restricting the channel and concentrating the flow on the south bank.

Figure 3. Gravel introduction site 16, La Grange.

Introduction Site 18b (Riffle 1B)

Site 18b appeared to have good gravel on the slightly large side for both Chinook and steelhead/trout (Figure 4). Top dressing may be beneficial in the future. There were some good pools just downstream of this gravel introduction site on the north side that should be preserved (Figure 5). The group recommended filling the south site of the channel upstream of the bridge to keep the thalweg on the north bank.

Figure 4. Gravel introduction site 18b, La Grange

Figure 5. Pools just below gravel introduction site 18b, La Grange.

<u>Introduction Sites 14a and 14b</u>

Introduction sites 14a and 14b are upstream of the Old La Grange bridge just downstream of Riffle A7 (Figure 6). These sites contained small pools with overhanging vegetation along the north bank but did not have the required topographical heterogeneity for steelhead/trout usage. The suggestion of the group was to add gravel in "bumps" upstream of the pools.

Figure 6. Gravel introduction sites 14a and 14b, La Grange.

Recommendations

Due to increasing gravel costs, only 5,300 cubic yards of gravel will be available for placement during 2003 (see attached letter from Doug Ridgeway, California Department of Fish and Game). In light of the limited gravel supply, the group made the following recommendations:

1) Build new riffles downstream of Riffle A7 in sites 14a and 14b,
2) Create a new gravel bar at site 16 by narrowing the channel,
3) Add contours running diagonally to the rivers flow at 18a,
4) Stay 20’ to 30’ from banks with valuable steelhead habitat, and
5) Conduct pre and post project evaluations.

The group agreed that these actions should be taken to ensure no damage to steelhead/trout habitat. In addition, it appears the existing steelhead habitat could be improved with small adjustments in gravel introduction methods. Please call me if you have any questions.

Sincerely,

Jeff McLain
Fishery Biologist

Attachments

Appendix I

Adult *O. mykiss* Habitat in the Lower Tuolumne River: California Rivers Restoration Fund (2004)

Adult *O. mykiss* Habitat in the Lower Tuolumne River

Produced for

Tuolumne River Technical Advisory Committee

Prepared by

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7523 Meadow Avenue
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8 March 2004

INTRODUCTION

The California Rivers Restoration Fund (CRRF) mapped the locations where they routinely catch adult *Oncorhynchus mykiss* that weigh between 2 and 12 pounds using hook-and-line tackle in the lower Tuolumne River between La Grange Dam and the Robert's Ferry Bridge. Some of these fish are bright silver, which is typical of Central Valley steelhead that have recently migrated into the river (Photo 34, Appendix A).

Adult *O. mykiss* typically utilize short riffle-pool sequences where surface turbulence is present over the riffle and downstream pool habitat (Appendix A). The channels at the pool-tails are usually narrow or constricted, which creates the surface turbulence. The riffles are also steep, quickly transitioning into pool habitat that is at least 4 feet deep. Riffle substrates are typically coarse, but suitable for spawning and juvenile rearing. The bed topography is complex at the best used sites, consisting of multiple rows of ridges formed by Chinook salmon tailspills. These habitats typically occur in narrow sections of the channel that have not been mined for gravel. Riparian vegetation is usually dense along one or both sides of the channel.

The fish usually feed and hold downstream in pool habitat that is within 150 feet of the upstream riffle. They primarily spawn under surface turbulence in the riffle habitat. Juvenile *O. mykiss* typically rear in riffle and run habitats with surface turbulence. In contrast, Chinook salmon, *O. tshawytscha*, primarily spawn in pool tails and infrequently in riffle habitats.

METHODS

The mapping surveys were conducted 21 January 2004 and 23 February 2004 by Dr. Carl Mesick and Mr. Steve Walser. Most of the study area was surveyed from a raft, whereas the areas upstream of the Old La Grange Bridge were surveyed by foot. Site locations were identified with hand-held GPS units and by marking the locations on habitat maps produced by McBain and Trush in 2002. A digital photo was taken at most sites.

RESULTS

A total of 47 sites were identified as adult *O. mykiss* habitat between the La Grange Dam and Robert's Ferry Bridge. Photos of 40 of these sites are presented in Appendix A and the location of all 47 sites are shown on the McBain and Trush (2002) maps in Appendix B. Table 1 provides the site numbers, GPS coordinates, habitat features, and photo number in Appendix A.

Table 1. Map site number and DFG Site # shown on the McBain and Trush (2002) maps in Appendix B, the GPS coordinates (UTM, NAD 27 Datum), Habitat Features, and Photo number shown in Appendix A.

Site #	DFG Site #	Zone	Easting	Northing	Habitat Features	Photo #
1	RA3/4	10S	725545	4171558	Spawning, Feeding, Holding	None
2	RA7	10S	724228	4171556	Degraded by Gravel Augmentation 2003	1
3	R1A UPPER	10S	723715	4171649	Spawning, Feeding, Holding	3
4	R1A LOWER	10S	723586	4171624	Spawning, Feeding, Holding	None
5	PHASE II GRAVEL AUGMENTATION	10S	723334	4171655	Degraded by Gravel Augmentation 2002	None
6	R1B	10S	723274	4171626	Spawning, Feeding, Holding	4
7	J59 BRIDGE	10S	723028	4171619	Holding, Feeding	5
8	R2	10S	722687	4171691	Spawning, Feeding, Holding	6
9	R3A	10S	722560	4171654	Spawning, Feeding, Holding	7
10	R3B UPPER	10S	722162	4171401	Spawning, Feeding, Holding	8
11	R3B MIDDLE	10S	722117	4171219	Spawning, Feeding, Holding	9
12	R3B LOWER	10S	722061	4171136	Spawning, Feeding, Holding	10
13	R4A	10S	721697	4170885	Spawning, Feeding, Holding	11
14	R4B UPPER	10S	721684	4170611	Spawning, Feeding, Holding	12
15	R4B MIDDLE	10S	721604	4170313	Spawning, Feeding, Holding	13
16	R5A	10S	721285	4170071	Spawning, Feeding, Holding	14
17	R5B	10S	721092	4169903	Spawning, Feeding, Holding	15
18	R7 UPPER	10S	720730	4168703	Spawning, Feeding, Holding	16
19	R7 LOWER	10S	720467	4168409	Spawning, Feeding, Holding	17
20	R8	10S	720190	4168296	Spawning, Feeding, Holding	18
21	R8A	10S	720034	4168215	Spawning, Feeding, Holding	19
22	R12	10S	719038	4167563	Spawning, Feeding, Holding	20

Table 1. Continued.

Site #	DFG Site #	Zone	Easting	Northing	Habitat Features	Photo #
23	R13A	10S	718843	4167433	Spawning, Feeding, Holding	21
24	R13C	10S	718342	4167019	Spawning, Feeding, Holding	22
25	R14	10S	717985	4167236	Spawning, Feeding, Holding	None
26	R16	10S	717839	4167200	Spawning, Feeding, Holding	23
27	RUN DOWNSTREAM R16	10S	717683	4167262	Spawning, Feeding	24
28	R17A	10S	717310	4167338	Spawning, Feeding, Holding	25
29	DOWNSTREAM R17A	10S	717252	4167323	Spawning, Feeding, Holding	26
30	R17D NEAR BOULDERS	10S	716790	4167137	Spawning, Feeding, Holding	27
31	FEEDING HABITAT AT SRP-3	10S	716339	4167169	Holding, Feeding	None
32	R18	10S	715986	4167341	Spawning, Feeding, Holding	None
33	R20	10S	715280	4167673	Spawning, Feeding, Holding	28
34	R21 UPPER	10S	715031	4167528	Spawning, Feeding, Holding	29
35	R21 LOWER	10S	715019	4167433	Spawning, Feeding, Holding	30
36	R22	10S	714923	4167386	Spawning, Feeding, Holding	31
37	R23A	10S	714680	4167378	Spawning, Feeding, Holding	32
38	R23B	10S	714105	4167433	Spawning, Feeding, Holding	33
39	R23C UPPER	10S	714048	4167273	Spawning, Feeding, Holding	35
40	R23C LOWER	10S	713635	4167449	Spawning, Feeding, Holding	36
41	R23D	10S	713586	4167570	Spawning, Feeding, Holding	37 & 38
42	R24	10S	713403	4167523	Spawning, Feeding, Holding	39
43	R24B UPPER	10S	713204	4167538	Spawning, Feeding, Holding	40
44	R24B LOWER	10S	713076	4167575	Spawning, Feeding, Holding	41
45	R26	10S	711990	4167981	Spawning, Feeding, Holding	42
46	R27	10S	711386	4168250	Spawning, Feeding, Holding	None
47	R28A	10S	711052	4168223	Holding, Feeding	None

APPENDIX A

Site Photos of *Oncorhynchus mykiss* Habitat
in the lower Tuolumne River
between La Grange Dam and Robert's Ferry Bridge

Photos of Sites 1 through 30 were taken on 21 January 2004
Photos of Sites 32 through 47 were taken on 23 February 2004

Prepared by

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Photo 1. Site #2 (RA7) Phase II Gravel Augmentation 2003

Photo 2. Gravel added at Site #2 (RA7) in 2003

Photo 3. Site #3 (R1A upper)

Photo 4. Site #6 (R1B)

Photo 5. Site #7 (J59 Bridge)

Photo 6. Site #8 (R2)

Photo 7. Site #9 (R3A)

Photo 8. Site #10 (R3B Upper)

Photo 9. Site #11 (R3B Middle)

Photo 10. Site #12 (R3B Lower)

Photo 11. Site #13 (R4A)

Photo 12. Site #14 (R4B Upper)

Photo 13. Site #15 (R4B Middle)

Photo 14. Site #16 (R5A)


Photo 15. Site #17 (R5B)


Photo 16. Site #18 (R7 Upper)

Photo 17. Site #19 (R7 Lower)

Photo 18. Site #20 (R8)

Photo 19. Site #21 (R8A)

Photo 20. Site #22 (R12)


Photo 21. Site #23 (R13A)


Photo 22. Site #24 (R13C)


Photo 23. Site #26 (R16)


Photo 24. Site #27 (Run Downstream of R16)

Photo 25. Site #28 (R17A)

Photo 26. Site #29 (Run Downstream of R17A)

Photo 27. Site #30 (R17D)

Photo 28. Site #33 (R20 Upper)

Photo 29. Site #34 (R21 Upper)

Photo 30. Site #35 (R21 Lower)

Photo 31. Site #36 (R22)

Photo 32. Site #37 (R23A)

Photo 33. Site #38 (R23B)

Photo 34. Fish (~15 inches FL) caught at site #38 (R23B) on 2/23/04

Photo 35. Site #39 (R23C Upper)

Photo 36. Site #40 (R23C Lower)


Photo 37. Site #41 (R23D Upper)


Photo 38. Site #41 (R23D Lower)

Photo 39. Site #42 (R24)

Photo 40. Site #43 (R24B Upper)


Photo 41. Site #44 (R24B Lower)


Photo 42. Site #45 (R26)

APPENDIX B

Oncorhynchus mykiss Habitat in the lower Tuolumne River between La Grange Dam and Robert's Ferry Bridge overlain on the McBain and Trush 2002 maps

Prepared by

California Rivers Restoration Fund
P.O. Box 236
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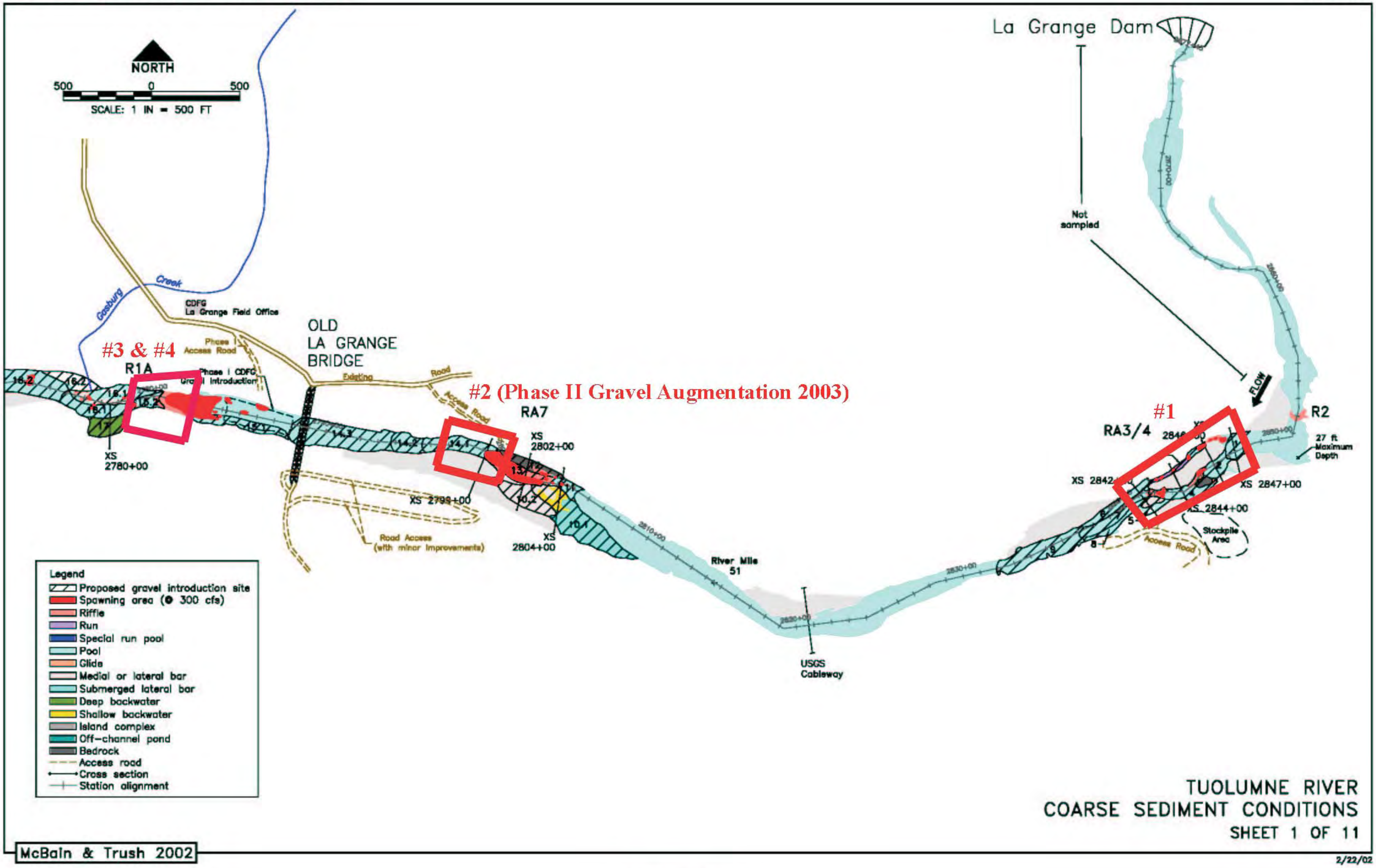
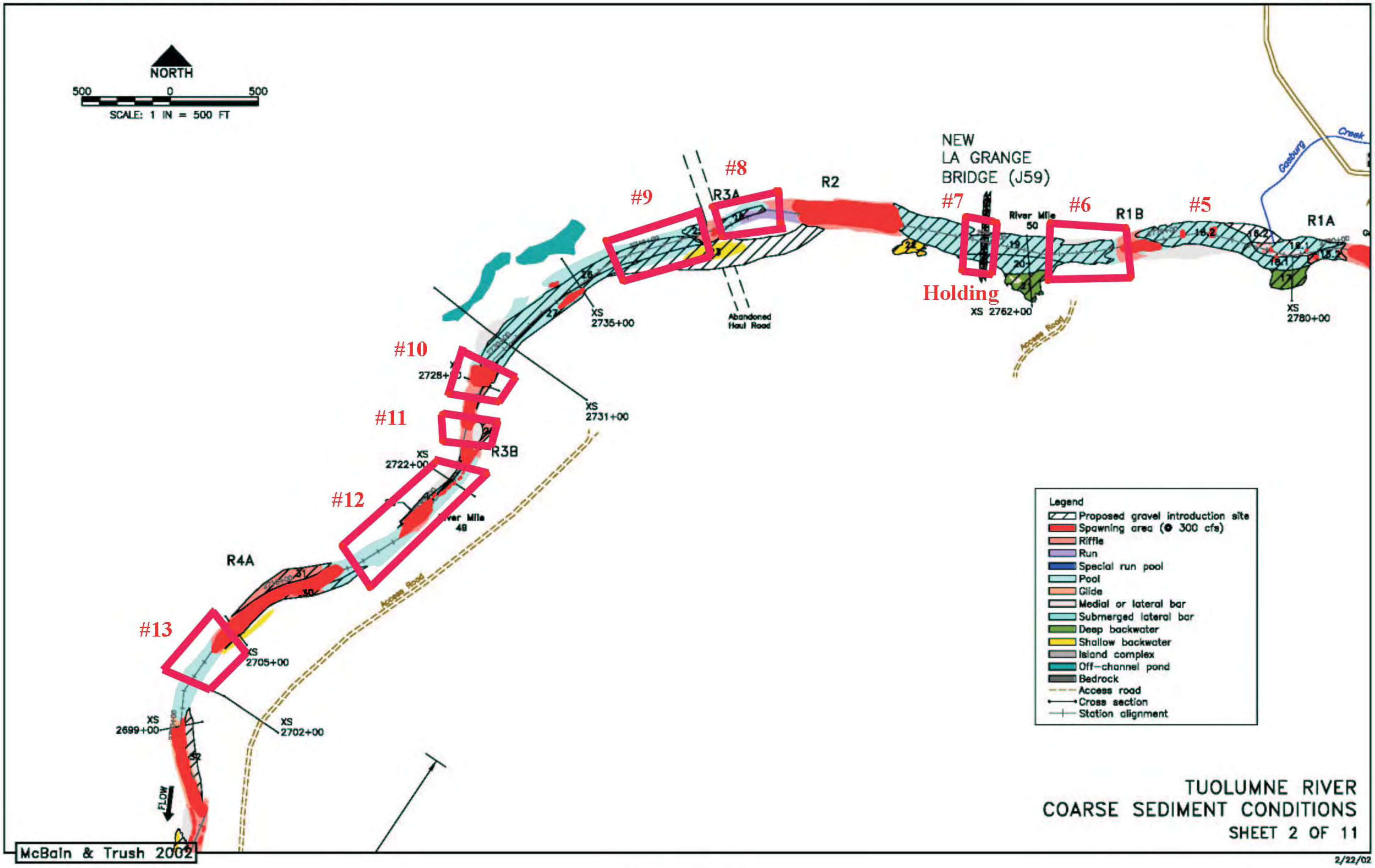
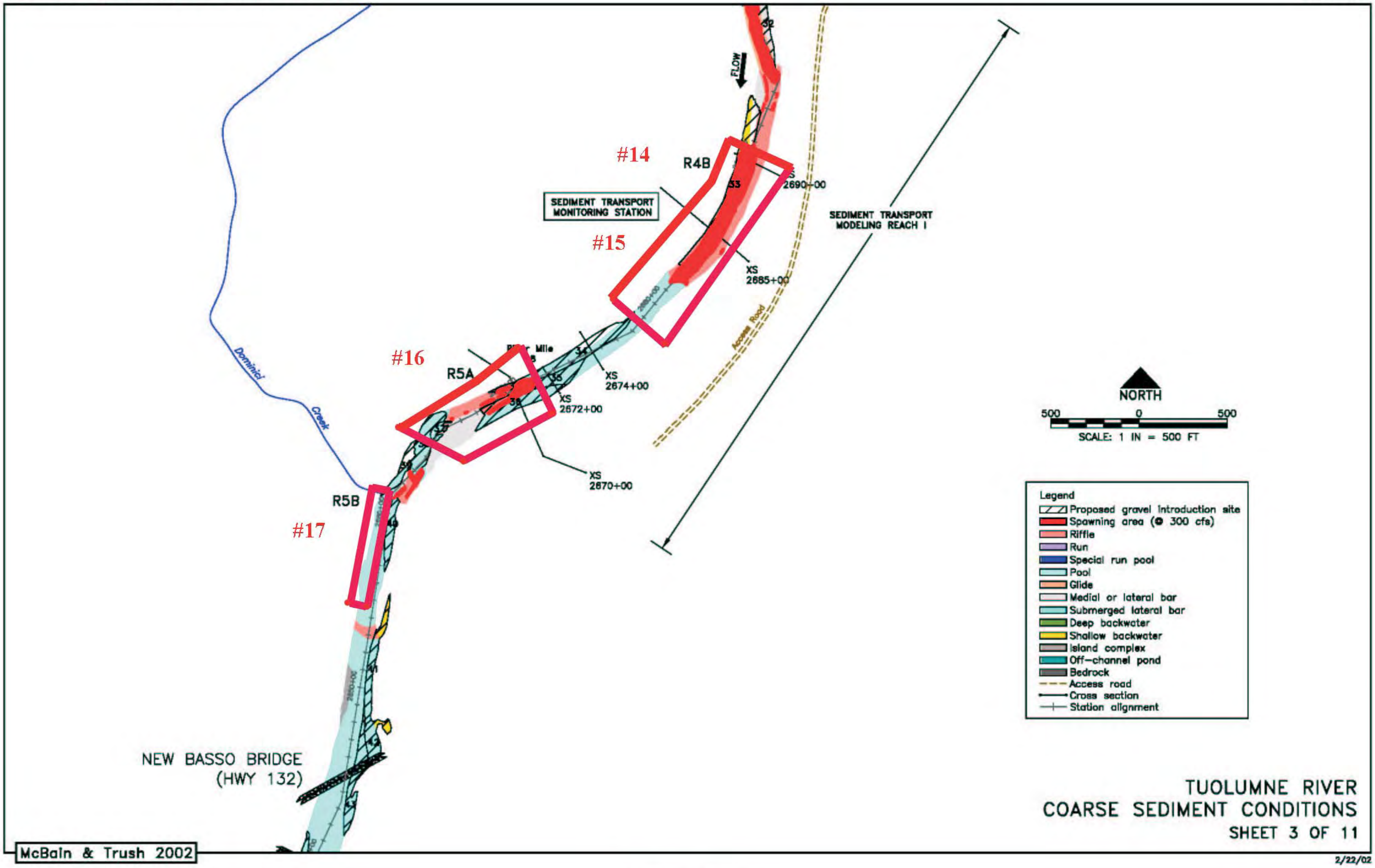
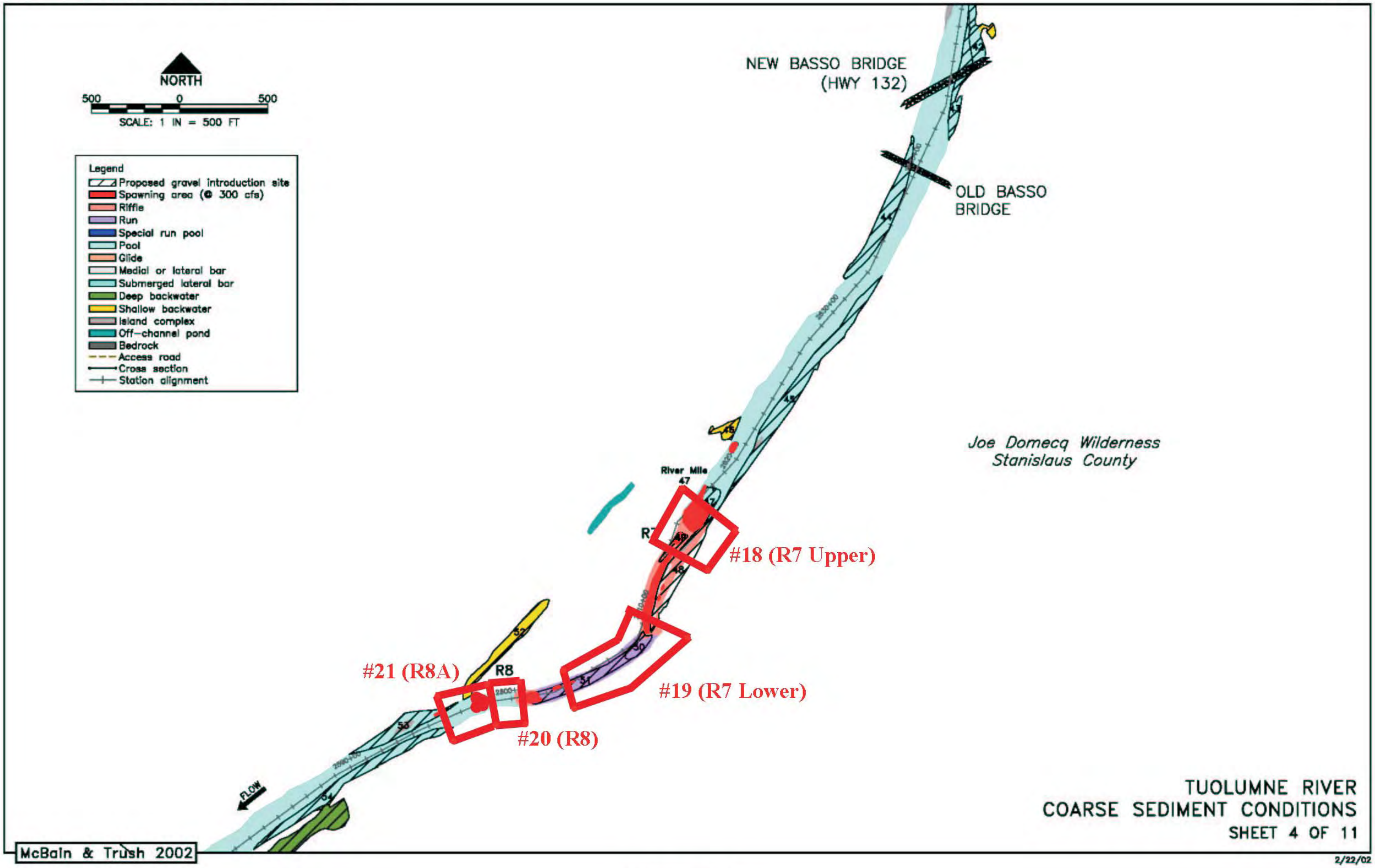
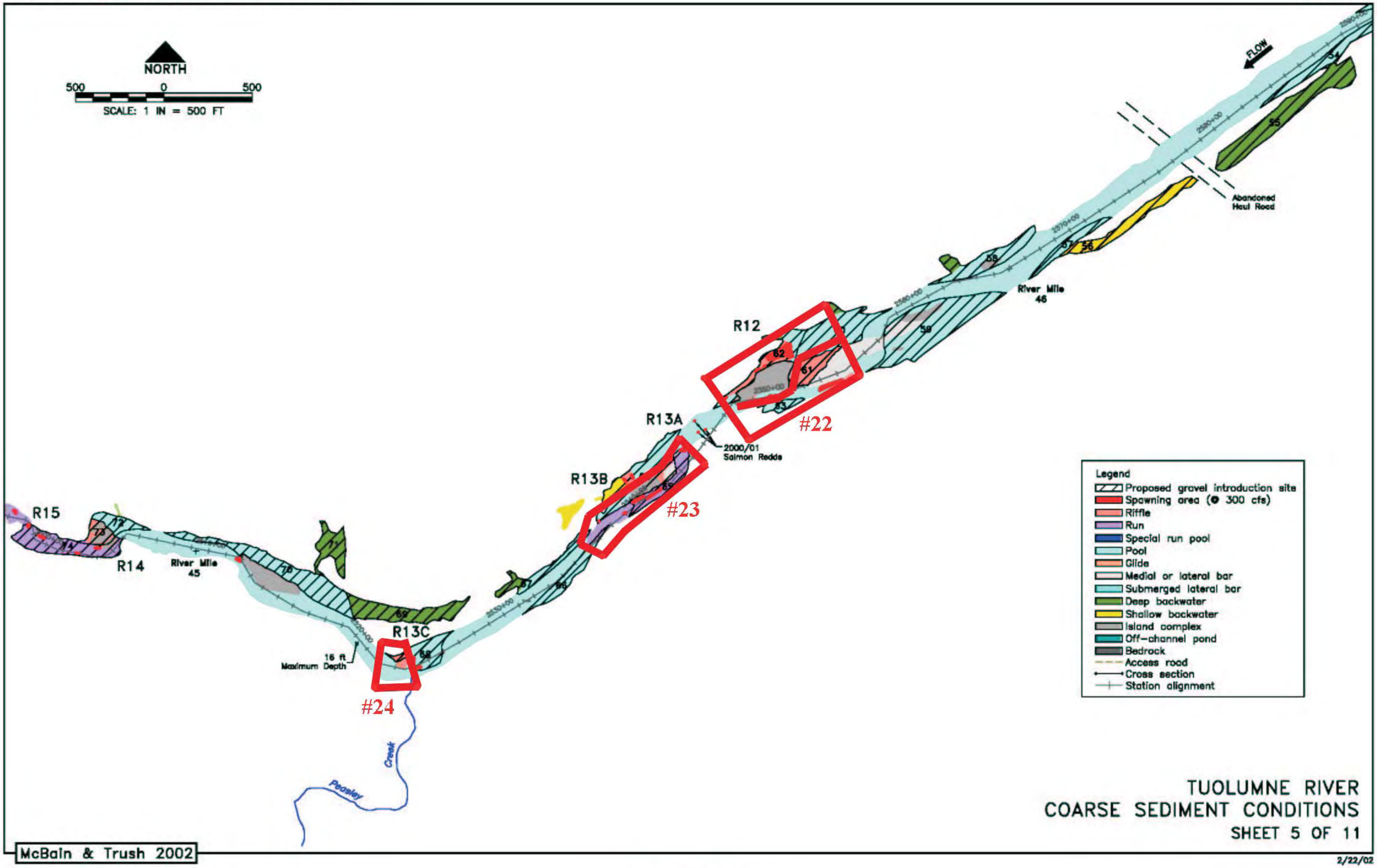
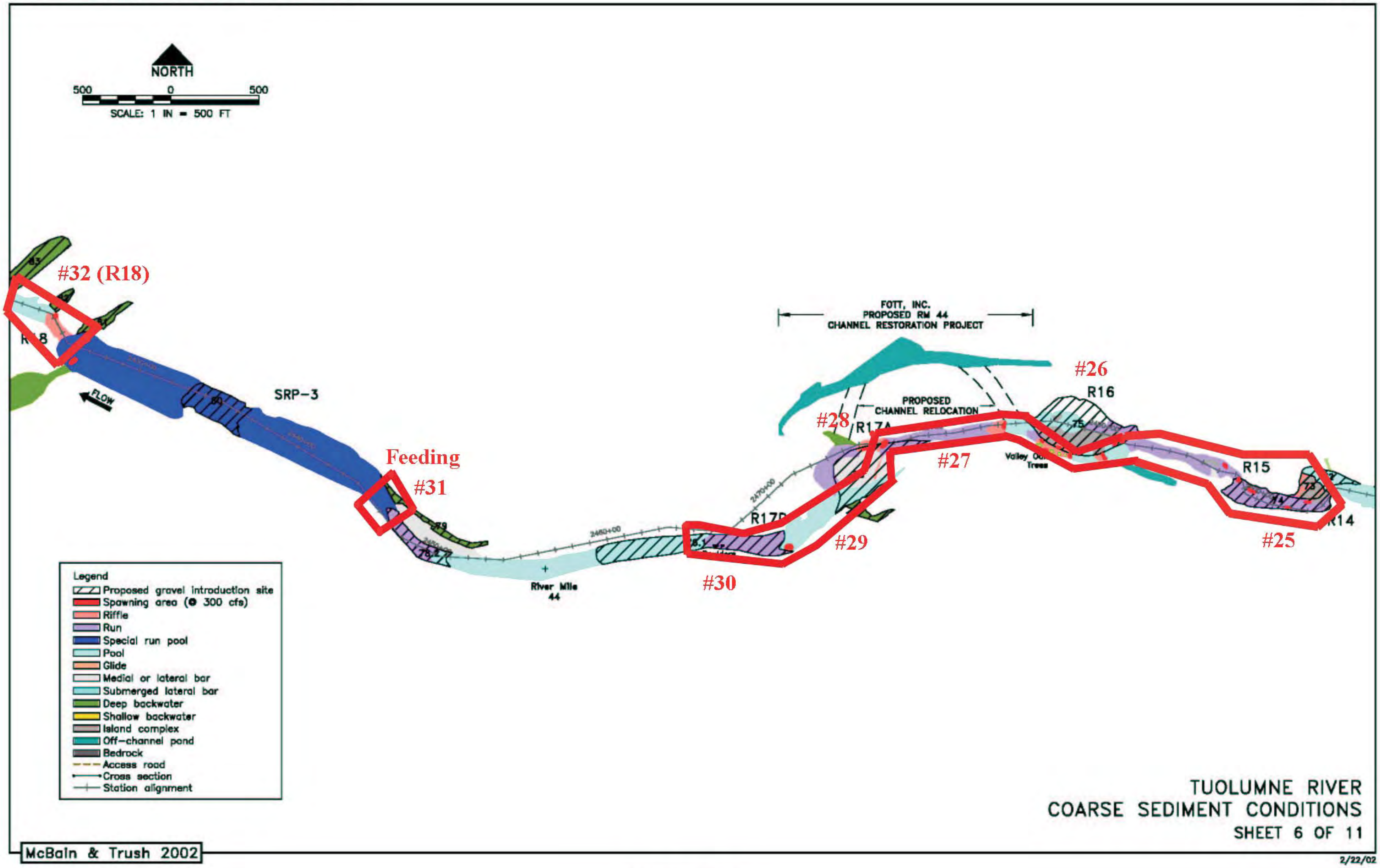

NORTH
500 0 500
SCALE: 1 IN = 500 FT
La Grange Dam
Not sampled
Gasburg Creek
CDFG La Grange Field Office
OLD LA GRANGE BRIDGE
#3 & #4
R1A
#2 (Phase II Gravel Augmentation 2003)
RA7
#1
RA3/4
R2
FLOW
27 ft Maximum Depth
XS 2780+00
XS 2799+00
XS 2802+00
XS 2804+00
XS 2847+00
XS 2844+00
Stockpile Area
Access Road
Road Access (with minor Improvements)
River Mile 51
USGS Cableway
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 1 OF 11
McBain & Trush 2002
2/22/02


NORTH
500 0 500
SCALE: 1 IN = 500 FT
NEW LA GRANGE BRIDGE (J59)
#5
#6
#7
#8
#9
#10
#11
#12
#13
Holding
R1A
R1B
R2
R3A
R3B
R4A
River Mile 50
River Mile 49
XS 2780+00
XS 2762+00
XS 2735+00
XS 2731+00
XS 2722+00
XS 2705+00
XS 2702+00
XS 2699+00
Abandoned Haul Road
Access Road
Gasburg Creek
FLOW
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 2 OF 11
McBain & Trush 2002
2/22/02

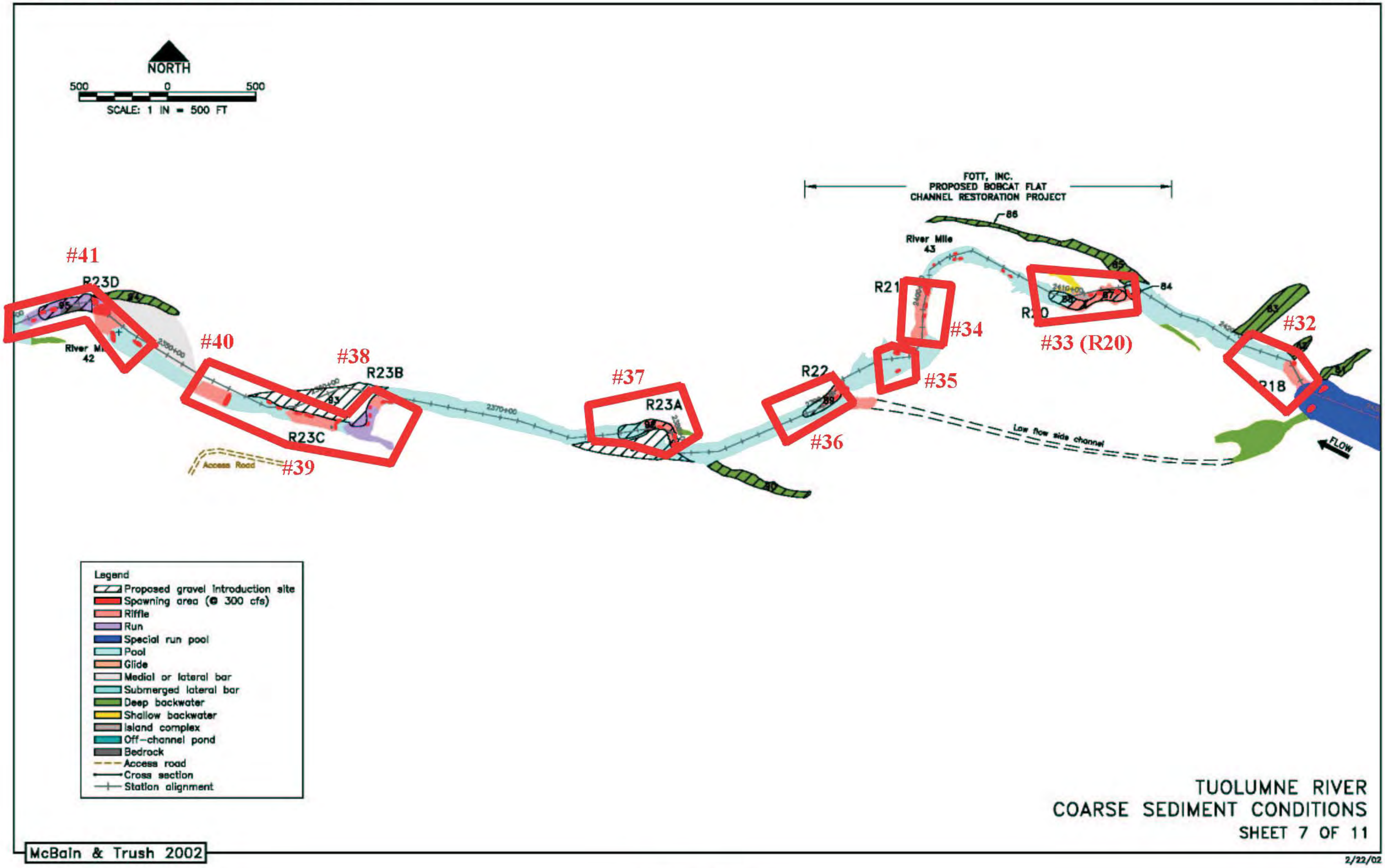

FLOW
#14
R4B
#15
#16
R5A
R5B
#17
SEDIMENT TRANSPORT MONITORING STATION
SEDIMENT TRANSPORT MODELING REACH I
XS 2690+00
XS 2685+00
XS 2674+00
XS 2672+00
XS 2670+00
Access Road
Dominici Creek
NORTH
500 0 500
SCALE: 1 IN = 500 FT
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
NEW BASSO BRIDGE (HWY 132)
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 3 OF 11
McBain & Trush 2002
2/22/02

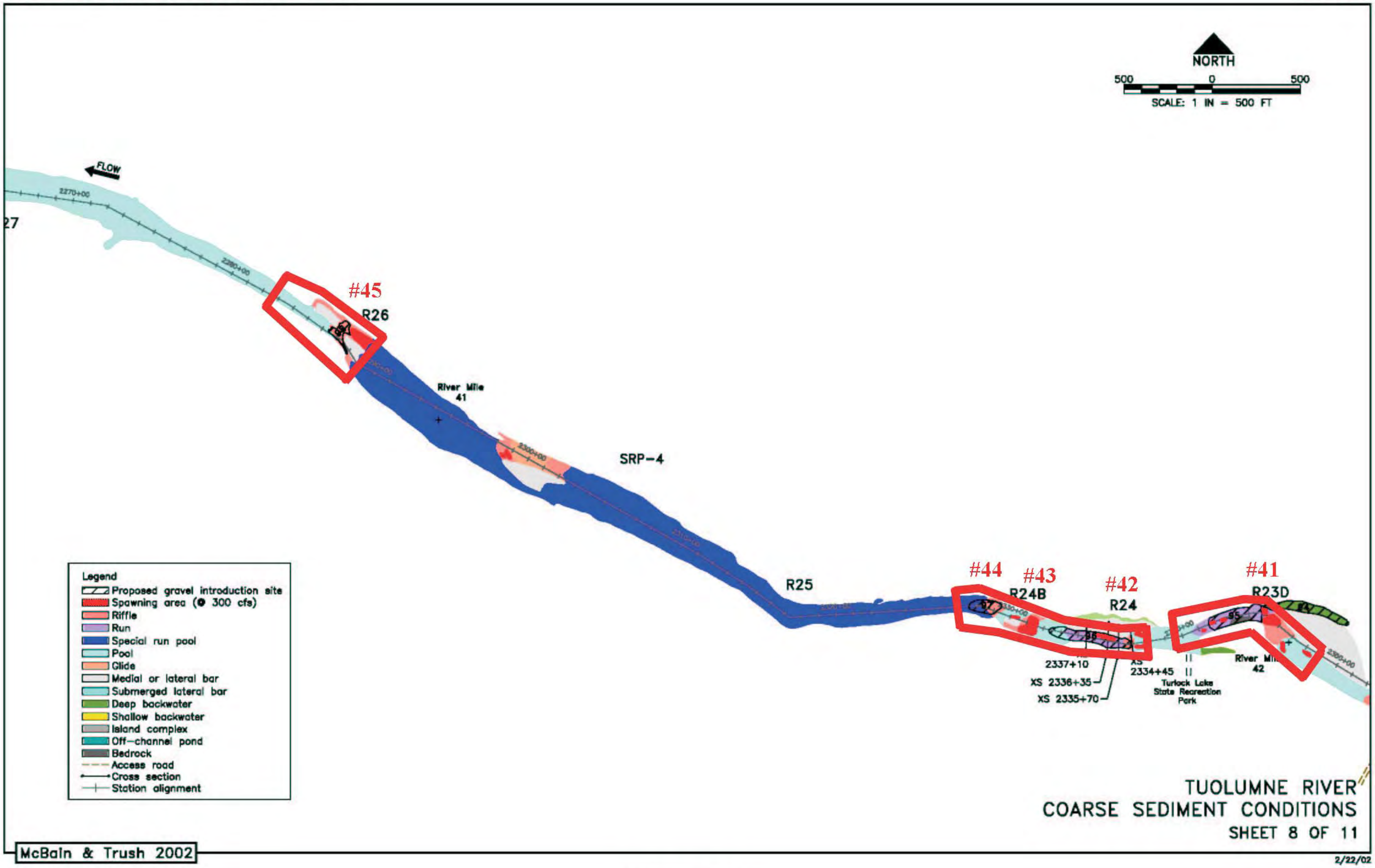

NORTH
500
0
500
SCALE: 1 IN = 500 FT
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
NEW BASSO BRIDGE
(HWY 132)
OLD BASSO
BRIDGE
Joe Domecq Wilderness
Stanislaus County
River Mile
47
R7
#18 (R7 Upper)
#19 (R7 Lower)
#20 (R8)
#21 (R8A)
R8
FLOW
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 4 OF 11
McBain & Trush 2002
2/22/02

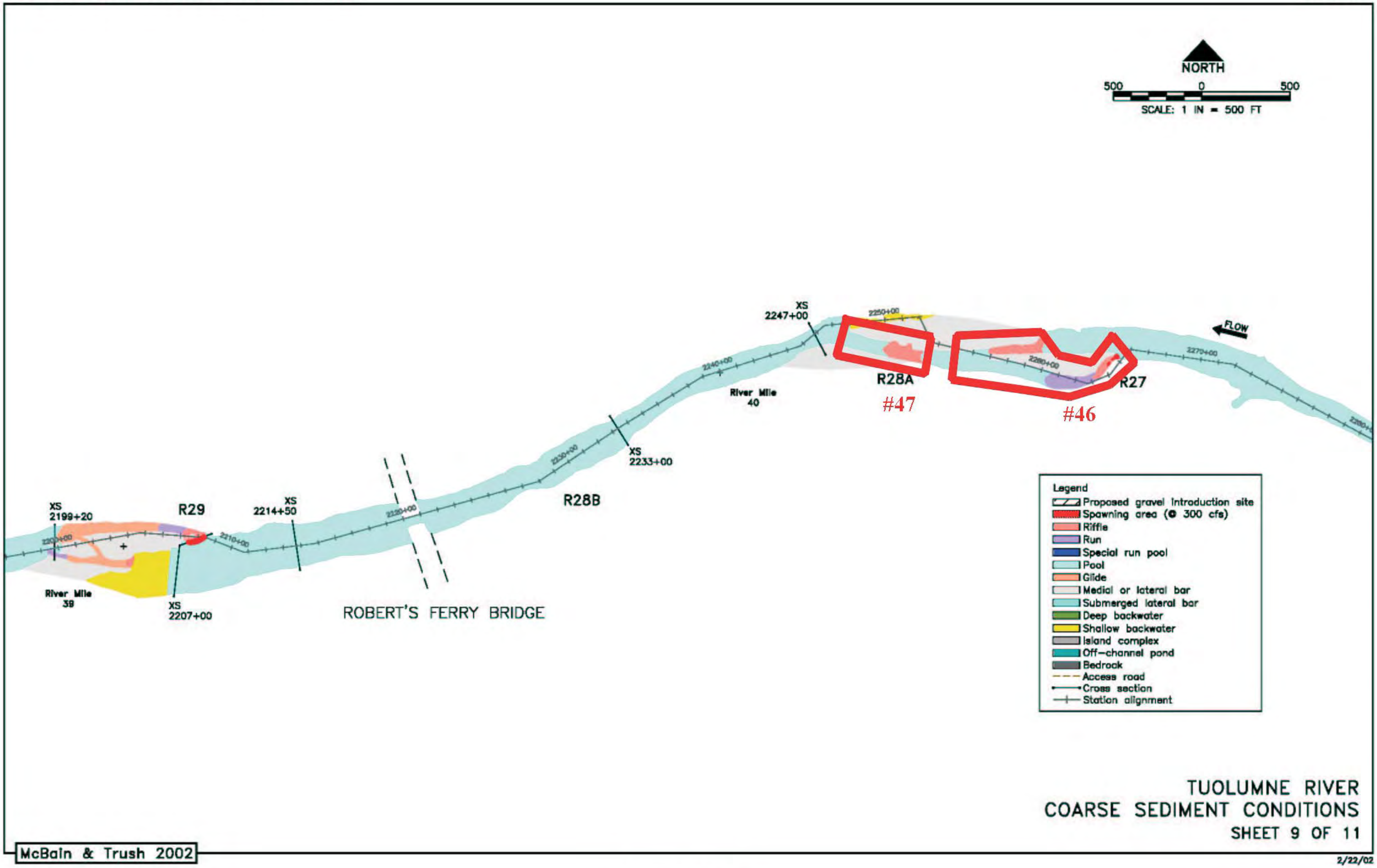

NORTH
500 0 500
SCALE: 1 IN = 500 FT
FLOW
Abandoned Haul Road
River Mile 46
River Mile 45
R12
R13A
R13B
R13C
R14
R15
#22
#23
#24
2000/01 Salmon Redds
16 ft Maximum Depth
Peasley Creek
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 5 OF 11
McBain & Trush 2002
2/22/02



NORTH
500 0 500
SCALE: 1 IN = 500 FT
#32 (R18)
SRP-3
FLOW
Feeding
#31
River Mile
44
#30
#29
#28
R17A
FOTT, INC.
PROPOSED RM 44
CHANNEL RESTORATION PROJECT
PROPOSED
CHANNEL RELOCATION
#27
#26
R16
R15
#25
R14
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 6 OF 11
McBain & Trush 2002
2/22/02


NORTH
500
0
500
SCALE: 1 IN = 500 FT
FOTT, INC.
PROPOSED BOBCAT FLAT
CHANNEL RESTORATION PROJECT
River Mile
43
River Mile
42
#41
R23D
#40
#38
R23B
R23C
#39
Access Road
#37
R23A
R22
#36
R21
#34
#35
#33 (R20)
#32
R18
Low flow side channel
FLOW
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 7 OF 11
McBain & Trush 2002
2/22/02


NORTH
500
0
500
SCALE: 1 IN = 500 FT
FLOW
27
#45
R26
River Mile 41
SRP-4
R25
#44
#43
R24B
#42
R24
#41
R23D
2337+10
XS 2336+35
XS 2335+70
2334+45
Turlock Lake State Recreation Park
River Mile 42
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 8 OF 11
McBain & Trush 2002
2/22/02


NORTH
500 0 500
SCALE: 1 IN = 500 FT
FLOW
XS 2199+20
R29
XS 2214+50
River Mile 39
XS 2207+00
ROBERT'S FERRY BRIDGE
R28B
XS 2233+00
River Mile 40
XS 2247+00
R28A
#47
R27
#46
Legend
Proposed gravel introduction site
Spawning area (@ 300 cfs)
Riffle
Run
Special run pool
Pool
Glide
Medial or lateral bar
Submerged lateral bar
Deep backwater
Shallow backwater
Island complex
Off-channel pond
Bedrock
Access road
Cross section
Station alignment
TUOLUMNE RIVER
COARSE SEDIMENT CONDITIONS
SHEET 9 OF 11
McBain & Trush 2002
2/22/02