Tuolumne River
La Grange Gravel Addition Project
PHASE II
Geomorphic Monitoring Report

California Department of Water Resources

San Joaquin District

River Management Section

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Report Prepared by:

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Report prepared under the supervision of

Kevin J. Faulkenberry P.E., Senior Engineer,

by

Robert C. Lampa P.E., Engineer, Water Resources,

and

David S. Encinas P.E., Engineer, Water Resources

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Gravel addition has been used as a common solution for rivers with dams that prohibit spawning material from being transported downstream. Although dams are essential for producing water supply, hydropower, irrigation, recreation, and flood control, they also pose a problem when they prohibit the recruitment of gravel from upstream sources. This in turn forces the river to erode the channel bed and banks for material, resulting in degradation of conditions and creating unsuitable habitat for species downstream.

Considered to have the largest naturally reproducing Chinook salmon population in the San Joaquin Valley, the Tuolumne River is an example of this situation. The Tuolumne River has several dams that block the recruitment of coarse material and regulate the flows to the lower reaches of the river. In order to maintain anadromous fish populations and combat the degradation to the river, gravel augmentation has been implemented to enhance the quality and quantity of spawning habitat.

Site Description

Part of the Tuolumne River Salmonid Habitat Improvement Project (DFG, 2000), the Tuolumne River La Grange Gravel Addition Project site is located near the town of La Grange between River Mile (RM) 50 and 51 of the Tuolumne River (Figure 1). In the center of the site is the historic La Grange Bridge. Upstream of the bridge are remnants of the steep canyon-like features found in the upper watershed of the Tuolumne River. However, downstream of the bridge, the floodplains begin to widen, forming a gently sloping alluvial valley. Prior to augmentation, much of the reach had been scoured of its gravel beds and banks due to the lack of gravel recruitment since La Grange Dam was built.

Figure 1. Site Location Map

History

In 1999, the California Department of Fish and Game (DFG) constructed Phase I of the Tuolumne River La Grange Gravel Addition Project, resulting in 11,000 tons of gravel added just downstream of the Old La Grange Bridge (DWR, 2000). The Department of Water Resources (DWR) agreed to monitor the physical changes in the reach where Phase I was to be constructed as part of an interagency agreement (Agreement) between DWR and DFG originally signed on April 1, 1999. The Agreement was amended to include Phase II monitoring on December 28, 2001.

In anticipation of Phase II implementation, McBain and Trush prepared a draft technical memorandum for DWR and DFG in 2001. The purpose of the memorandum was to help guide the implementation of the project, and summarized data collected and recommendations made for actions in the reach. In it, they recommended a high priority for action at site 15a (riffle 1A), and riffles A7 and 1B (Figure 2). Elements of riffle A7 include sites 11, 12, 13, 14a, and 14b. Elements of riffles 1A and 1B include sites 15a, 15b, 16, 18a, and 18b. These sites were chosen by DFG, DWR, and USFWS as the best sites for Phase II work.

Phase II Construction and Augmentation

Approximately 14,400 tons of gravel was added in 2002 for Phase II of the project (Table 1). Construction was funded by the Anadromous Fish Restoration Program (AFRP) and the Tracy Mitigation Program. Funded by the Four-Pumps Agreement, approximately 8,000 tons of gravel was added again in 2003, expanding the project reach from RM 50.1 to RM 50.7. Unlike the gravel addition in 1999 where the gravel was placed in one location at riffle 1A, the last two additions were in multiple locations both upstream and downstream of the Bridge. Primary monitoring funding was directed toward the 2002 work, and data in this report are primarily focused on that portion of Phase II, although data from 2003 work is also included.

Construction for initial Phase II work began on July 8^{th}, 2002, and was completed on September 6^{th}, 2002. The work was done by DFG, who used rubber-tired loaders to place gravel at sites 11, 12, 13, 15a, and 18b. Trucks brought in the gravel the previous year (2001) from Merced River Mining near Snelling, California and deposited it in three stockpiles located for their proximity to the augmentation sites. The stockpiles were sampled for later sieve analyses. Total cost for construction was $162,600 including gravel purchase and placement.

The additional work in 2003 began on July 23^{rd}, 2003, and was completed around the date of September 8^{th}, 2003. The work was also done by DFG with the same equipment and procedures, and cost about $162,000. DWR monitored the import material for cleanliness as it was delivered and took samples from the stockpiles for later sieve analyses. Table 1 summarizes the quantities of gravel placed at each Phase II site as provided by DFG.

Year	Funding Agency	Location	Quantity (tons)	Cost	Notes
1999	CalFed	D/S Old La Grange Bridge	**11,000**	**$ 250,975.00**	Phase I gravel addition project
2002	AFRP, Tracy	11	1,800		Portion of Phase II gravel addition project. Limited to funding availability. Gravel was purchased in 2001 but was not placed until 2002. $98,575.46 - Tracy Funds $64,074.06 - AFRP
		12	900		
		13	4,650		
		15a	5,250		
		18a	1,800		
		total	**14,400**	**$ 162,649.52**	
2003	4 Pumps	14a	2,000		Phase II continued. Gravel added to areas of higher priority due to higher than anticipated gravel costs.
		14b	2,500		
		15b	500		
		16	1,700		
		18b	1,300		
		total	**8,000**	**$ 161,812.50**	

Source: Doug Ridgeway, DFG

Table 1. Gravel Addition Summary

DFG planned to implement Phase II with the McBain and Trush recommended volume estimates for each area, but in 2003, higher than anticipated gravel costs forced a reduction in total quantity. The idea was to maximize the amount of gravel that could be purchased with available funds. Therefore, placement was concentrated in the areas shown in the table to the exclusion of a few other sites in the reach. Plans for gravel purchase are set for the fall of 2004, and placement is planned for 2005. Gravel quantities and placement locations for 2005 have not yet been decided.

Gravel Sizes and Specifications

Adding the correct gravel size is important for both biological suitability and mobility purposes. In addition, it is necessary for the import material to be free from deleterious material, consist of smooth river rock, be free of fines, and originate preferably from the Tuolumne River Basin. The gravel gradation recommended by McBain and Trush (2001) is shown in Table 2.

Particle Size (inches)	Percent Passing	Percent Retained
5"	100%	0%
2”	80%	20%
1”	45%	55%
3/4”	15%	85%
1/2”	5%	95%
1/8”	0%	100%

Table 2. Recommended Gravel Composition

The recommended composition was based on optimum salmon spawning gravel size cited in numerous literature sources, but when faced with a limited purchasing budget, the specifications may need to be modified based on typical screen sizes gravel plants use and the gradation of available source material to bring costs down. The more stringent the gravel specifications, the more the gravel costs to purchase. The percentages in Table 3 represent the compositions ordered for the 2002 and 2003 work. They were derived from knowledge of available sources in the area based on previous gravel purchases and consideration for costs required to meet the recommended composition in Table 2. The 2002 gradation closely mirrors that which was recommended, but gravel costs rose considerably in 2003, so specifications had to be adjusted to bring costs down. In that case, specified sizes were developed in cooperation with the supplier based on the material source. An effort was made to develop a specification that could be met with the source available by simply screening with top and bottom end screens to save money (in this case a 0.5 and 4 inch screen was eventually used, although the specification originally ordered was up to 5 inch as shown in the table). Later in processing, the material size was improved by selectively choosing the source material and by augmenting the processed material with smaller rock located on-site. The compositions are also shown graphically in Appendix B.

Particle Size (inches)	2002 Percent Passing	2003 Percent Passing
5"	100%	100%
4"		85%-90%
2”	75%-85%	30%-35%
1”	40%-50%	
3/4”	10%-20%	
1/2”	0%	0%-5%
1/8”		0%

Table 3. Gravel Compositions Used for Phase II

Purpose

The purpose of this report is to summarize the monitoring data and help satisfy the requirements set forth in the Agreement, which include:

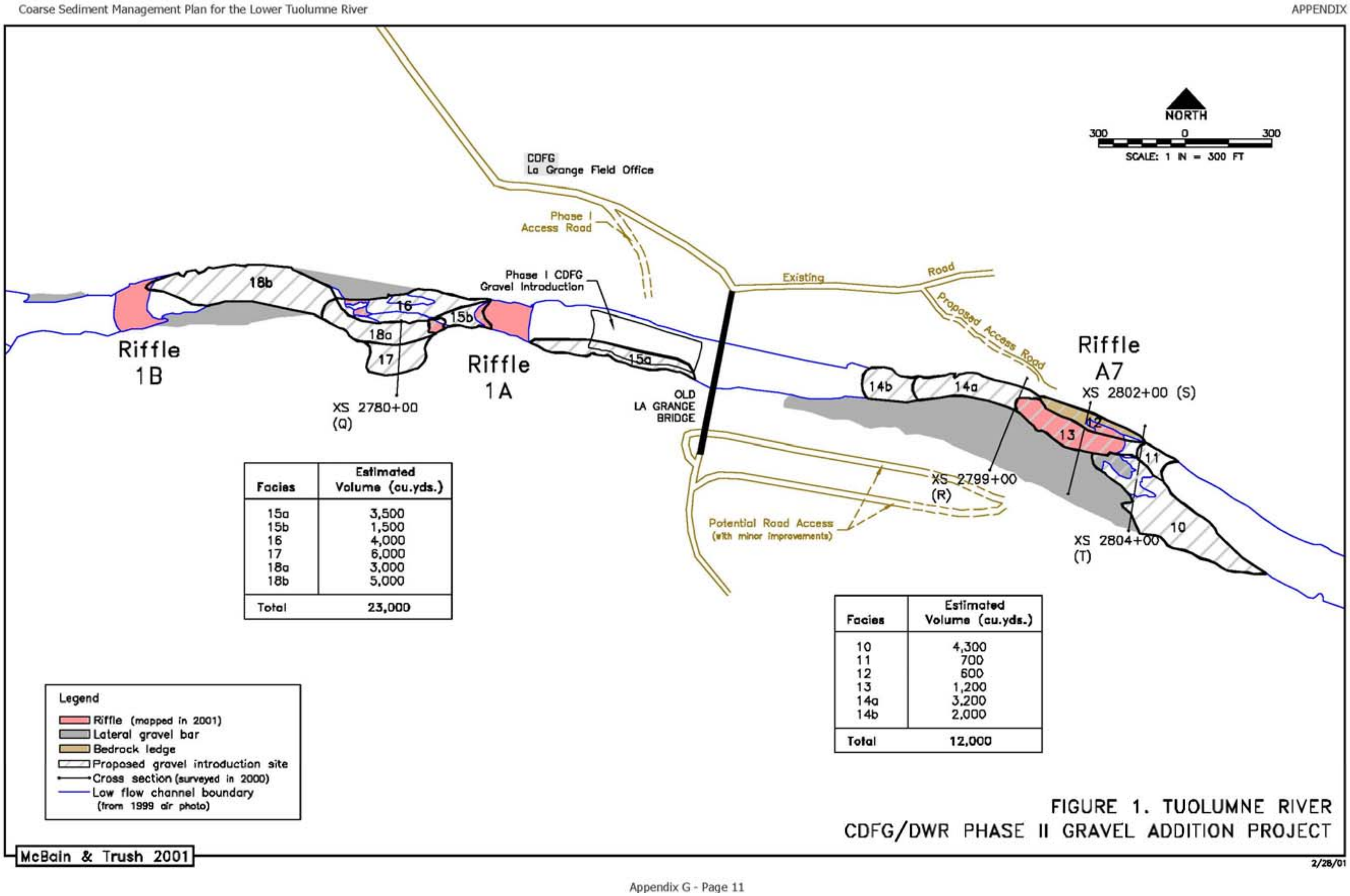
1. pre-project and as-built surveyed cross-sections,
2. determine the flow threshold that begins to mobilize introduced gravel,
3. estimate the changes to alluvial storage at all transects,
4. evaluate changes to gravel quality at all transects,
5. provide recommendations for future gravel additions in the reach, and
6. document whether or not project objectives in the CalFed Monitoring Report were met.

The Agreement only pertains to Phase II work funded and completed in 2002. Work in 2003 was funded by Four-Pumps without any monitoring component, though Four-Pumps completely funded the creation of this report. Cross-sectional surveys, pebble counts, bulk sampling, and tracer gravel experiments are tools we used in an effort to help address the above requirements. We assumed the "CalFed Monitoring Report" mentioned in the Agreement was the 2001 draft master's thesis by Erin Lutrick titled, in part, "A Review of Gravel Addition Projects". The thesis made several recommendations to CalFed including standardized monitoring of gravel addition projects. Cited monitoring parameters relevant to the project and listed in CMARP appendix VII (Lutrick, 2001) include:

- Gravel size distribution (surface and subsurface), reported as gravel sizes relevant to specific biotic responses

- Bed mobility, measured using tracer gravels

This is a partial list and only includes geomorphic monitoring parameters. Several other parameters listed pertain to biological monitoring.



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 2. Gravel Addition Areas

GOALS AND OBJECTIVES

Project Goals

The purpose of Phase II of the project (DFG, 2000) was to begin restoration of the coarse sediment supply in the upper portion of the Tuolumne River's designated salmon spawning area by introducing clean, spawning size gravels into the river. The primary goal was to improve the quality and quantity of spawning habitat for Chinook salmon. Additional objectives of the gravel augmentation include:

- Increase instream storage of spawning sized gravels by developing a long-term gravel infusion program;
- Improve chinook salmon productivity by increasing the quality and quantity of habitat;
- Encourage marginal fluvial transport of these gravels for replenishing downstream alluvial deposits and channel formation, ultimately improving downstream chinook salmon spawning and rearing habitat;
- Utilize the project as an indicator of instream gravel movement and subsequent gravel additions in this reach.

Monitoring Goals

The goal of the monitoring program is to collect data so that the requirements listed earlier in this report in the Purpose section can be satisfied. Data collection through the various tools should allow us to evaluate the gravel and channel conditions so that we can answer the geomorphologic questions of gravel quality, mobility, and quantity in the project reach. The goal of the monitoring report is to present the data, address the requirements mentioned, and make further recommendations.

GEOMORPHIC MONITORING ACTIVITIES

As previously mentioned, the monitoring methods used to evaluate the gravel addition are cross-section surveys, Wolman pebble counts, bulk sample analyses, and the placement of painted rocks for tracer gravel experiments. Table 4 illustrates the monitoring schedule performed by DWR. Each column represents a gravel addition, with Phase II being split according to the two construction dates.

Task	Phase I 1999	Phase II 2002	Phase II 2003
Baseline (In-situ)			
Cross Sectional Surveys	X	X	X
Pebble Counts	X	X	X
Bulk Samples	X		
Flow Model	X	X	X
As Built			
Cross Sectional Surveys	X	X	X
Bulk Samples	X	X	X
Tracer Gravel	X	X	X
Construction + 1 year			
Cross Sectional Surveys	X	*	*
Pebble Counts	X	*	*
Bulk Samples	X	*	*
Map & Replace Tracer Gravel	X	*	*
Construction + 2 years			
Cross Sectional Surveys	*	*	
Pebble Counts	*	*	
Bulk Samples	*	*	
Map Tracer Gravel	*	*	

X - Task completed
* - No Tracer Gravel Movement Exhibited

Table 4. Phase I and II Monitoring Schedule

The guidelines were initially set in the Agreement for both Phase I and Phase II by DFG. An "x" signifies the work was completed, and an asterisk indicates that no tracer gravel movement was detected, so the task was not necessary as per the Agreement.

Cross-Section Surveys

Several monitoring sections were established, with at least one per gravel addition site, by placing 3-foot long, 0.5-inch rebar as pins to mark them. These sections have been used to record baseline (pre-construction), as-built, and post-event conditions used for comparisons. Figure 3 illustrates the locations of these monitoring cross-sections established for Phase II of the project. Where the sections also correspond to Phase I monitoring sections, the Phase I transect number is in parentheses. Two additional proposed sections are also illustrated and are discussed in the conclusions and recommendations section. The cross-sections that were used for full monitoring include II-1, II-3, II-4, II-5, II-6, II-7, II-8, II-9, and II-10. Although the survey points are not illustrated in the figure, substantial amounts of survey data were collected in the area bounded by points approximately 2,800 ft upstream and 1,900 ft downstream of the Bridge. The upstream-most data were collected specifically to be used in the HEC-RAS model discussed later in the report.

Figure 3. Existing and Additional Proposed Monitoring Cross-Section Locations (Phase I Designations in Parentheses)

Pebble Counts

A common monitoring technique used on this type of project is the Wolman pebble count (Wolman, 1954). It is used for characterizing the stream bed surface by documenting the particle size distribution of gravels within the monitoring section. Samples are randomly selected, measured along the intermediate axis, and tallied according to typical sieve sizes. Pebble counts are one of the most efficient and simplest monitoring techniques.

Bulk Samples

Bulk samples are also used to characterize channel bed composition. Samples of the bed surface and subsurface materials are analyzed via sieves and plotted on gradation curves. However, in our case, the bulk sample method was used to monitor the import material sizes to control material quality. Samples were taken from the import stockpiles for both 2002 and 2003.

For the augmentation in 2002, a total of twelve 5-gallon buckets were used to collect the samples from three stockpiles (Figure 4) placed along the La Grange reach. The first stockpile was located upstream of the Bridge to be used for areas 11, 12, and 13 (Figure 2). A second stockpile for area 15a was placed on the right floodplain immediately downstream of the Bridge, and the last stockpile, used for area 18a, was situated at the lower limit of the reach. In 2003, all stockpiles were combined into one analysis, and covered areas 14a, 14b, 15b, 16, and 18b.

Figure 4. Stockpiles #1 and #2 and bulk sample collection

Tracer Gravel

This monitoring technique was used to document channel bed surface mobility on pools, riffles, and point bars. The placement and monitoring of tracer gravel helps determine at what stream flow gravel moves, which features are mobilized, and how far the rocks move. This monitoring task was used as a trigger for most other monitoring activity on the site, as was previously mentioned in the monitoring schedule (Table 4). Tracer gravel was placed on monitoring sections II-1, II-7, and II-10 in 2002.

DATA RESULTS & ANALYSIS

Cross-Section Surveys

Baseline and as-built surveys of each of the active monitoring cross-sections are shown in Appendix A along with baseline surveys of additional proposed sections. Baseline data was collected prior to the addition of gravel, and as-built data was collected after completion. The monitoring plan called for surveys on each of the two years following construction if tracer gravel exhibited movement, but because there has been no movement, no surveys have been performed beyond the as-builts. The proposed sections are discussed in the Conclusions and Recommendations section.

Pebble Counts

Once the 2002 gravel placement was complete, the as-built pebble counts were performed. Gradation curves were generated from the data and can be found in Appendix B. Table 5 below illustrates the D_{50} and D_{84} determined at each monitoring section. These values are used to calculate sediment transport, which will be discussed later in the report.

	2002 post-construction								2003 pre-construction		2003 post-construction			
	II-1		**II-3**	**II-6**	**II-7**		**II-10**		**II-4**	**II-9**	**II-4**	**II-5**	**II-8**	**II-9**
	9/18/2002	7/16/2003	9/8/2004	9/8/2004	8/7/2002	7/18/2003	9/18/2002	7/18/2003	7/16/2003	7/22/2003	9/8/2004	9/8/2004	9/8/2004	9/8/2004
D_{50}	72	78	64	74	82	73	67	75	43	77	60	66	51	62
D_{84}	103	119	105	120	125	113	104	119	84	110	87	93	100	91

Table 5. Pebble Count Particle Sizes for Monitoring Cross-Sections

Figure 5. Gravel Bar (15a)

The values in Table 5 and the gradation curves in Appendix B indicate some small changes may have taken place. The data shows the bed to have slightly coarsened over the year in sections II-1 and II-10, with about 10% larger D_{50} and 15% larger D_{84} for each. However, the trend for section II-7 is the opposite, with the bed being finer than previously observed, for an approximate drop of 10% in both classes. Since there is evidence that flows had not been large enough to mobilize the gravel in these sections, we assume that the differences in pebble counts are the result of sampling variations.

Bulk Samples

Gradation curves developed from the sieve analyses of the bulk samples are presented in Appendix B. Table 6 contains a summary of the D_{50} and D_{84} from the bulk sample analyses. The values represent the averages for each stockpile. The 2002 D_{50} and D_{84} values were similar for each pile as expected, since the material originated from the same source. The bulk sample data were used in sediment transport computations as well as for other comparisons discussed later in the report.

Year	Stockpile	D_{50} (mm)	D_{84} (mm)	Area of Placement
2002	1	58	85	11, 12, 13
2002	2	49	84	15a
2002	3	52	87	18a
2003	All	40	70	14, 15b, 16, 18b

Table 6. Particle Sizes for Stockpile Bulk Sample Data

Looking at the bulk sample gradation curve in Appendix B, all three stockpiles seem similar in gradation. Also shown is the specification range for the import material, which shows the material delivered was larger than what was ordered in 2002. However, the import material is still much smaller in size than the previously exposed bed material. The consequences of using gravel larger than specified would likely include a higher required flow to induce mobility. Calculations of the flows required to move the native bed and import materials are discussed in the sediment transport section below.

Tracer Gravel

The particle sizes placed on sections II-1, II-7, and II-10 were determined using the D_{50} and D_{84} values of the 2002 pebble counts shown in Table 5. Fourteen samples of each size for each cross-section (84 total particles) were brightly painted and spaced evenly across the monitoring sections. The sections were revisited after one year; however, since flows were relatively low during that period, none of the rocks moved. Most of the rocks were retrieved, repainted, and replaced until the next event. The hydrograph in Figure 6 shows daily flows since before Phase I construction, and the dates of Phase I and Phase II construction. It shows that between the 2002 and 2003 construction, no more than 1,340cfs occurred in the reach, and since the 2003 construction the maximum flow has been about 2,800cfs.

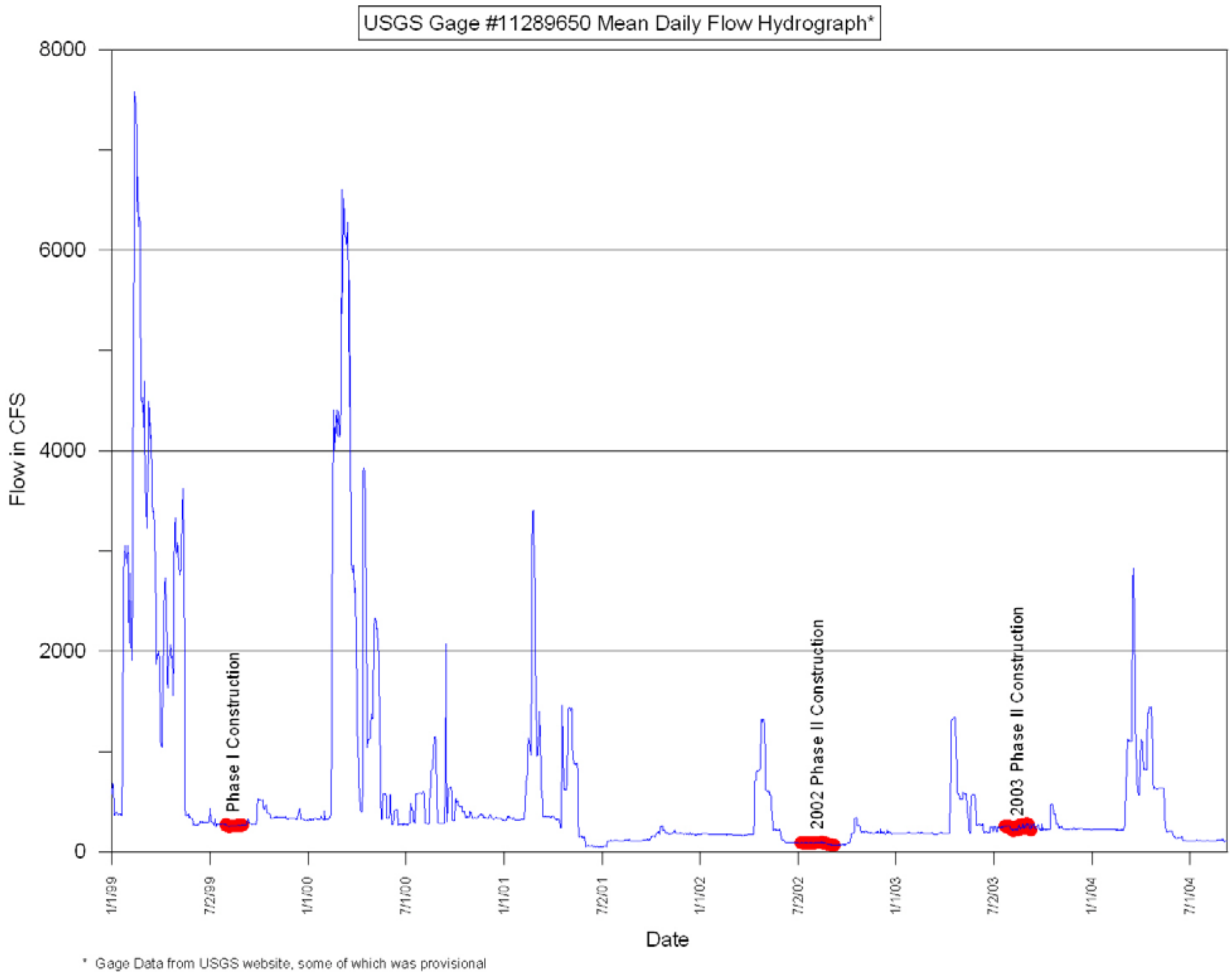


Figure 6. La Grange Hydrograph 1999-present

Sediment Transport

Critical Shear Calculations

As mentioned in previous sections, the survey, pebble count, and bulk sample data were all used to estimate sediment transport. Several equations were used to determine the shear forces necessary to mobilize the gravel.

The Andrews equation (Andrews, 1994),

$$\tau^*_{ci} = 0.0384(D_i/D_{50})^{-0.887},$$

was used to determine the critical dimensionless shear, τ^*_{ci}, which is used in the Shields equation. In this case, D_i pertains to the d_{84} particle size identified from the bulk samples.

In order to estimate the force required to mobilize given particle sizes, the following Shields equation was used,

$$\tau_{ci} = \tau^*_{ci} (\rho_s - \rho_f) g d_i .$$

τ_{ci} is the critical shear stress (N/m^2) required to mobilize particle size d_i, ρ_s is the density of the sediment (2,650 kg/m^3), ρ_f is the density of water, and d_i is the particle diameter. After calculating the shear force using Shields equation, the forces applied to the channel bed by the flow were calculated using the formula, $\tau = \gamma R S_e$, where τ is bed shear stress (N/m^2), γ is the unit weight of water, R is the hydraulic radius, and S is the energy slope. The resulting critical shear values were used to determine critical flows at each section by comparing them to the results of a HEC-RAS water profile model. Table 7 summarizes the critical shear calculation results for the pebble counts, bulk samples, and design specifications for each cross-section.

Hydraulic Model

We developed an HEC-RAS model, a one-dimensional channel hydraulics model that simulates flow through a channel, to support the analysis of the sediment transport calculations. Information from USGS quad maps, topographic surveys, and high water mark surveys were used in the model to develop several profiles (flow events). Assumptions were made for the “n” values, slopes, and starting water surface elevations. In order to calibrate the model, water surface elevation surveys were used along with the data provided by the gage set on the Bridge. A plot of the HEC-RAS map and sections can be found in Appendix C.

The results of the calculated water surface elevations at flows of 6,000 to 10,000cfs were within 0.2ft of the observed water elevation at the gage (River Sta 2820). The channel shear values vs. flow generated from the model at each section are shown in Figure 7.

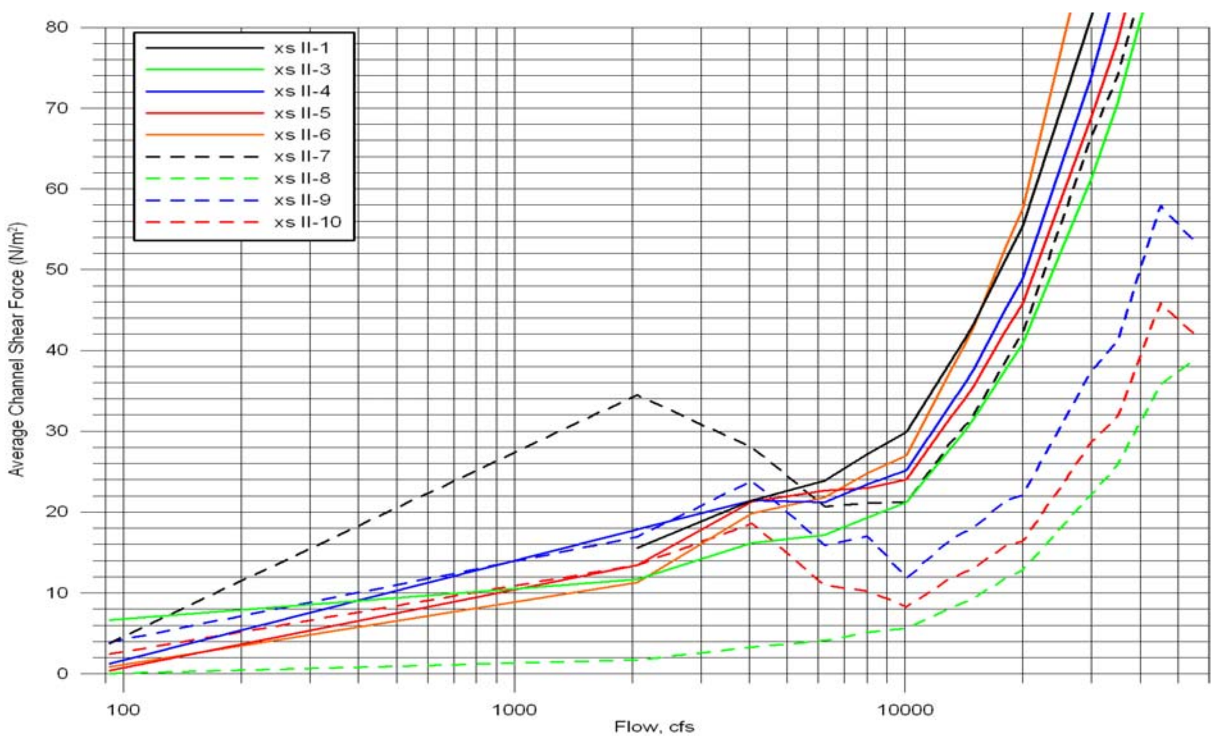


Figure 7. Average Channel Shear vs. Flow

			Recommended			Design Spec			Pebble count data									Bulk Sample data (1)		
			(McBain & Trush)			(average)			2002 (as-built)			2003			2004			2002		
	section	size	particle size	critical shear	hec-ras flow	particle size	critical shear	hec-ras flow	particle size (2)	critical shear	hec-ras flow	particle size(2)	critical shear	hec-ras flow	particle size(2)	critical shear	hec-ras flow	particle size	critical shear	hec-ras flow
			(mm)	(N/m2)	(cfs)	(mm)	(N/m2)	(cfs)	(mm)	(N/m2)	(cfs)	(mm)	(N/m2)	(cfs)	(mm)	(N/m2)	(cfs)	(mm)	(N/m2)	(cfs)
2002 Construction	II-1	d_{50}	28	17.4	2,500	28	17.4	2,500	72	44.5	15,500	78	48.9	17,200				58	35.8	12,100
		d_{84}	61	19.8	3,200	61	19.8	3,200	103	46.4	16,200	119	50.9	18,000				85	37.4	12,600
	II-3	d_{50}	28	17.4	6,300	28	17.4	6,300	(3)						64	39.8	19,000	58	35.8	17,000
		d_{84}	61	19.8	8,300	61	19.8	8,300	(3)						105	42.1	20,500	85	37.4	18,000
	II-6	d_{50}	28	17.4	3,300	28	17.4	3,300	(3)						74	46.0	15,500	49	30.4	11,000
		d_{84}	61	19.8	4,000	61	19.8	4,000	(3)						120	48.6	16,500	84	32.3	12,000
	II-7	d_{50}	28	17.4	350	28	17.4	350	82	50.9	23,600	73	45.4	21,300				49	30.4	1,300
		d_{84}	61	19.8	450	61	19.8	450	125	53.4	24,600	113	47.7	22,300				84	32.3	1,700
	II-10	d_{50}	28	17.4	3,400	28	17.4	3,400	67	41.4	41,000	75	46.6	>45,000				52	32.4	35,000
		d_{84}	61	19.8	22,000	61	19.8	22,000	104	43.8	42,000	119	49.1	>45,000				87	34.4	37,000
2003 Construction (4)															2004			2003		
															particle size(2)	critical shear	hec-ras flow	particle size	critical shear	hec-ras flow
															(mm)	(N/m2)	(cfs)	(mm)	(N/m2)	(cfs)
	II-4	d_{50}	28	17.4	1,800	62	38.5	15,400							60	37.3	15,000	40	24.9	9,800
		d_{84}	61	19.8	3,000	98	40.6	17,000							87	38.9	15,500	70	26.5	10,600
	II-5	d_{50}	28	17.4	2,900	62	38.5	17,000							66	41.0	17,500	40	24.9	10,400
		d_{84}	61	19.8	3,500	98	40.6	17,500							93	42.6	18,000	70	26.5	10,800
	II-8	d_{50}	28	17.4	24,000	62	38.5	>50,000							51	31.7	40,000	40	24.9	33,000
		d_{84}	61	19.8	28,000	98	40.6	>50,000							100	34.2	42,000	70	26.5	35,000
	II-9	d_{50}	28	17.4	2,100	62	38.5	30,500							62	38.5	30,500	40	24.9	21,800
		d_{84}	61	19.8	2,700	98	40.6	33,500							91	40.2	33,000	70	26.5	22,800

(1) - bulk samples taken from delivered stockpiles (see Table 6)
(2) - see Table 5
(3) - pebble count monitoring began in 2004
(4) - 2003 Phase II project included no monitoring funding, but pebble counts were performed in 2004 to provide baseline for future monitoring.

Table 7. Sediment Transport Calculations Summary

Mobilizing Flows

The HEC-RAS model results and critical shear calculations were used to predict the flows required to move the D_{50} and D_{84} particles (Table 7). Shear values calculated at each section represent average channel shear in the sections, so actual boundary shear in portions of the channel could exceed those values.

2002 Construction Areas

Using 2002 bulk sample data, the model predicts that flows over 12,000cfs are necessary to mobilize the material at the upper end of the reach (area 11, section II-1), while flows of over 17,000cfs are needed at area 12 and 13 (section II-3) for mobilization. Just below the bridge, at area 15a, a borderline situation exists where shears just begin to reach magnitudes necessary for mobilization on section II-7 at 1,300cfs before subsiding at higher flows, but at the section immediately upstream (section II-6) flows greater than 11,000cfs are needed. Flows on area 18b (section II-10) spread out widely on the floodplain before shears are high enough to move the gravel, so no movement was predicted below 35,000cfs.

Using the 2002 pebble count data, flows from 15,500 to 42,000cfs were needed to mobilize the bed at sections II-1, II-7, and II-10, but those predictions rose to a minimum of 17,200cfs after the 2003 pebble counts at those sections.

2003 Construction Areas

Using 2003 bulk sample data, movement was predicted at areas 14a and 14b (sections II-4 and II-5) above the 10,000cfs range. At areas 18a and 18b (sections II-8 and II-9), flows have to be 33,000cfs and 22,000cfs respectively.

Pebble count data recorded in 2004 for the areas constructed in 2003 indicate a minimum mobilizing flow at the upstream areas of 14a and 14b of 15,000cfs, while the downstream areas of 18a and 18b would need at least 30,500cfs before gravel begins to move.

The only results for areas constructed in 2002 or 2003 that show a chance of movement at the flows experienced in the reach over the last two years would be the bulk sample data figures for section II-7; however, since no movement was recorded by tracer gravel, it seems that pebble count data was the more accurate measure on that section. Figure 7 illustrates that just a slight increase in critical shears due to particle size increase at section II-7 would require a much higher flow for mobilization.

Because sections II-1, II-3, II-4, II-5, and II-6 are situated in a narrow, confined reach, forces steadily increase as flows increase. Sections II-7, II-8, II-9, and II-10 are similar, but are in a location where the floodplain begins to widen. As flows overtop the banks and flow onto the floodplains, energy begins to dissipate causing the average channel shear force to drop. In the higher flows (>10,000cfs), the floodplain begins to fill and the channel shear force again begins to rise. For sections II-8, II-9, and II-10, the floodplains are much wider, which dissipates more flow and energy and keeps shears relatively low. At all three sections, more than 20,000cfs is required to reach 30 N/m^2. Figure 8 illustrates average channel shear vs. river station.

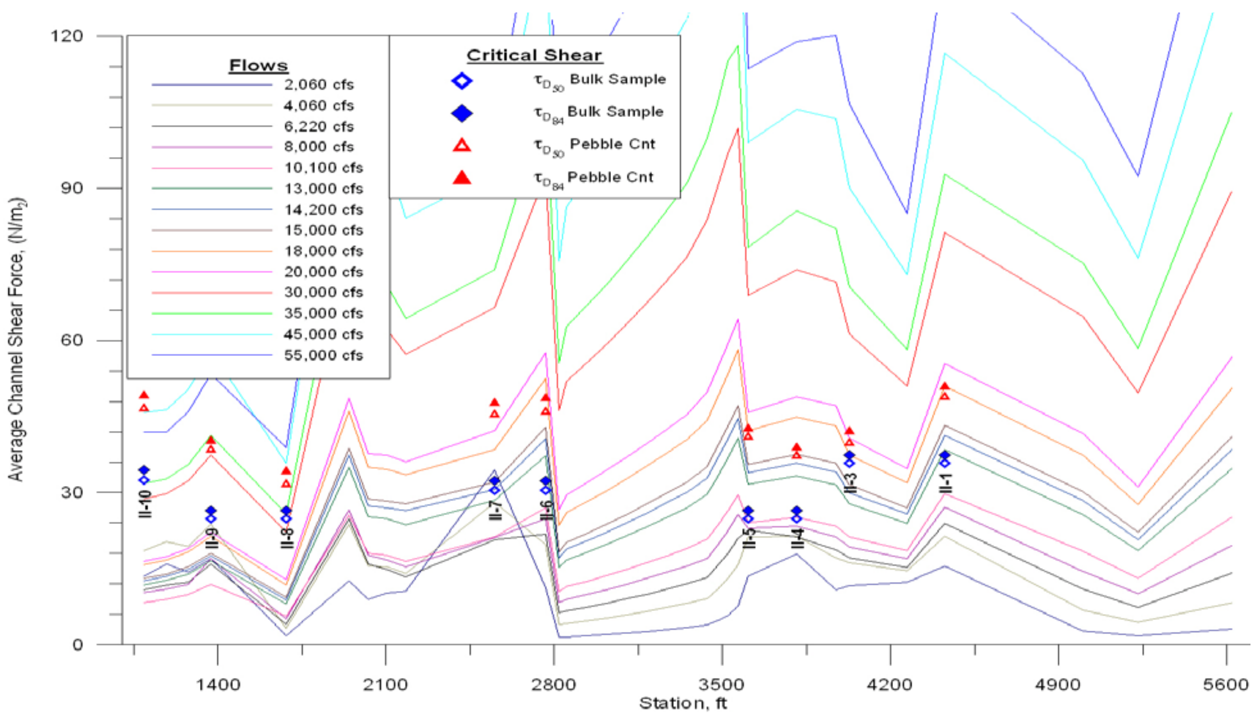


Figure 8. Particle Shears

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This report summarized the cross-section survey, pebble count, bulk sample, and tracer gravel data collected. The addition of 22,400 tons of gravel in this reach has improved the quality and quantity of spawning habitat by reducing the degraded features such as the deep incised channels and by improving the lack of recruitment from upstream resources.

The goals and objectives of Phase II gravel augmentation that can be addressed by this monitoring program included improving the quality and quantity of spawning habitat, increasing instream storage of spawning sized gravels through a long-term infusion program, encouraging marginal fluvial transport of gravels, and utilizing the project as an indicator of instream gravel movement. We conclude that spawning habitat quality and quantity have been improved, instream storage of spawning gravel has been increased, and that the project monitoring program would be able to indicate instream gravel movement. However, the objective of encouraging marginal fluvial transport of gravels has not yet been achieved. Gravel sizes placed in the river were too large for the current flow regime and current channel widths to be mobilized within a suitable amount of time, although it is clear that the gravel placed was smaller than much of the previously existing substrate. This is evident when reviewing pebble count data taken at cross-section II-7 (Phase I transect 3), where the pre-Phase I D_{50} was 135mm (DWR, 2000), but that value has been reduced to 73mm post-Phase II construction.

The monitoring program and this report also strove to meet the requirements mentioned in the "Purpose" section for 2002 Phase II work. The first requirement was to produce pre-project and as-built surveys. Limited funding constrained surveys to cross-sections mostly due to the increase in project size in Phase II, with several monitoring cross-sections put in place and surveyed at various times during the monitoring period.

The second requirement was to determine the flow threshold for gravel mobility. This requirement was met with sediment transport calculations detailed in the "results" section of this report. Based upon those analyses, it is estimated that flows in excess of 10,000cfs are required for mobilization of the imported gravel at most of the monitoring sections. This flow corresponds to about a 17 year event (Appendix D), and has been exceeded only twice since New Don Pedro Dam began operation in 1971 (USGS Station 11289650 records from 1971 to 2002). The target flow for mobilization of gravel should be closer to 5,500cfs, or about the 2.8 year event, according to the DFG 1998 Monitoring Plan for the reach (Lutrick, 2001).

The third requirement stated that we must document the changes to alluvial storage at all transects. While storage volumes are difficult to accurately determine from a few surveyed cross-sections, we already know the quantities brought in to the site, which are listed in Table 1. Changes in the volumes due to bed movement by flows has been shown to be insignificant based on tracer gravel data, but when the tracers eventually show movement, surveys will be necessary to provide data for volume estimation. Current monitoring activities probably will need to be expanded to fulfill that goal, and recommendations listed below (such as additional monitoring sections) should improve our ability to monitor volume changes.

The fourth requirement is that changes in gravel quality are documented at all transects. This was accomplished by both bulk sample analyses of the import stockpiles and by pebble counts on the transects themselves. Minor changes have been recorded to-date, but are probably the result of sampling variations because no other evidence exists of the gravel being mobilized.

Fifth on the requirement list is the need for recommendations for future gravel additions in the reach. These recommendations follow in the next section.

The last listed requirement of the Agreement is that DWR document whether or not project objectives discussed in the CalFed Monitoring Report were met. The listed objectives included monitoring gravel size distribution and tracer gravel bed mobility, both of which were covered in the sections above.

Recommendations

The following are recommendations intended to improve both future monitoring and future gravel augmentation in the reach:

- **Maintain and expand the existing monitoring program**. No flows of a sufficient magnitude to induce movement of tracer gravel or the introduced gravel in the reach were recorded during the monitoring period. As a result, performance of the Phase I and Phase II gravel augmentations are still largely unknown. We recommend the monitoring program period be extended so that resources will be available for response if flows able to induce changes in the channel are experienced in the future. In addition, funding constraints have required that a minimal monitoring program be implemented for this project. For example, while several monitoring sections for Phase II are fully monitored at this point, with multiple surveys and pebble count data gathered at them, more are needed because of the length of the reach that has been augmented. We recommend an expansion of the program to add the proposed cross-sections shown in Figure 3, as well as topographic surveys of the areas, so that a more complete picture of the project will be attainable and requirements to determine changes in alluvial storage are able to be fulfilled. In addition, although monitoring funding only covered the 2002 Phase II construction, it should be expanded to include the 2003 construction and any future work on the reach.
- **Strike a better balance between geomorphic/biologic needs for import gravel composition and cost to produce the gravel**. The original recommendations by McBain and Trush for gravel composition in the reach were based on an ideal sizing for salmon spawning. The composition also would produce movement at lower flows than current conditions predict (Table 7). In 2002, planners attempted to use the recommended composition when ordering gravel, but producers were evidently not able to meet the specification affordably, so larger material was placed in the channel. In 2003, planners attempted to use available materials to formulate a composition that would be affordable and producible, but the gravel delivered proved to be too large for frequent mobility by the current flow regime even though it was closer to the recommended composition. A better balance between costs and needs should be attained for future augmentation, with either more funding available for the higher cost of smaller

gravel, or lower expectations for the quantities that available funding will buy, unless new, cheaper sources become available. Future added gravel should be mobile at flows much lower than the flows at which mobility is predicted for the gravel placed so far in Phases I and II.

- **Improve import material delivery monitoring for adherence to specifications**. DFG monitored 2001/2002 gravel delivery, and DWR monitored the gravel delivered in 2003. Although much effort was made to make sure cleanliness specifications were met, gravel size was not well monitored for the 2003 gravel until after it was delivered. This resulted from the way the gravel was purchased, with the order placed very close to delivery, which required samples be taken and analyzed from delivered stockpiles. Analysis takes several days, so monitors did not have the opportunity to alert the producers that specifications were not being met until after the material was delivered. Future composition and specification monitoring should be completed on stockpiles prior to delivery by making sure that the material is ordered well in advance of delivery. This should help ensure that gravel introduced to the channel will be sized more appropriately for mobility and spawning.
- **Future gravel additions should be placed on the remaining unaugmented sites and a layer of smaller gravel should be placed on previous Phase I and Phase II sites**. The sites identified in Figure 2 that have not yet been filled, particularly sites 10, 17, and portions of 16 and 18a, should be next in line for gravel addition. In addition, as a result of the sediment transport calculations summarized in this report, we recommend that a layer of gravel from 0.5 to 1 foot deep that meets the composition illustrated in Table 2 be placed on riffle sections of the Phase I and Phase II constructed sites. This will help ensure the desired bed mobility apparently still lacking.

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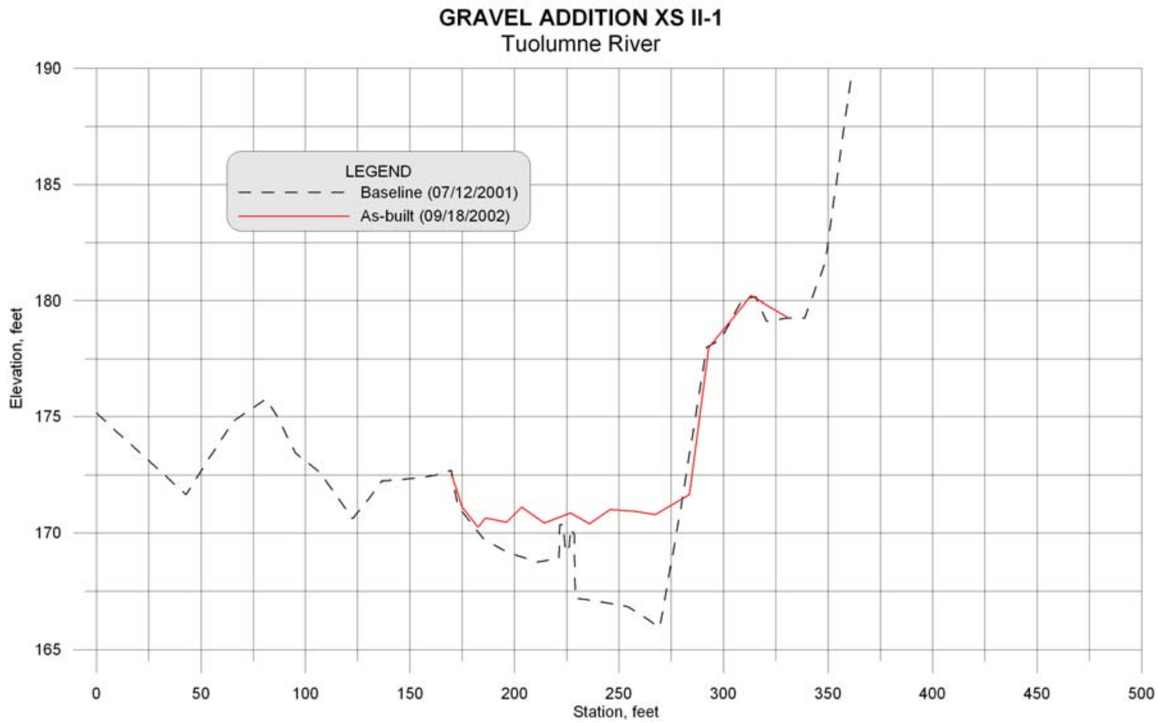
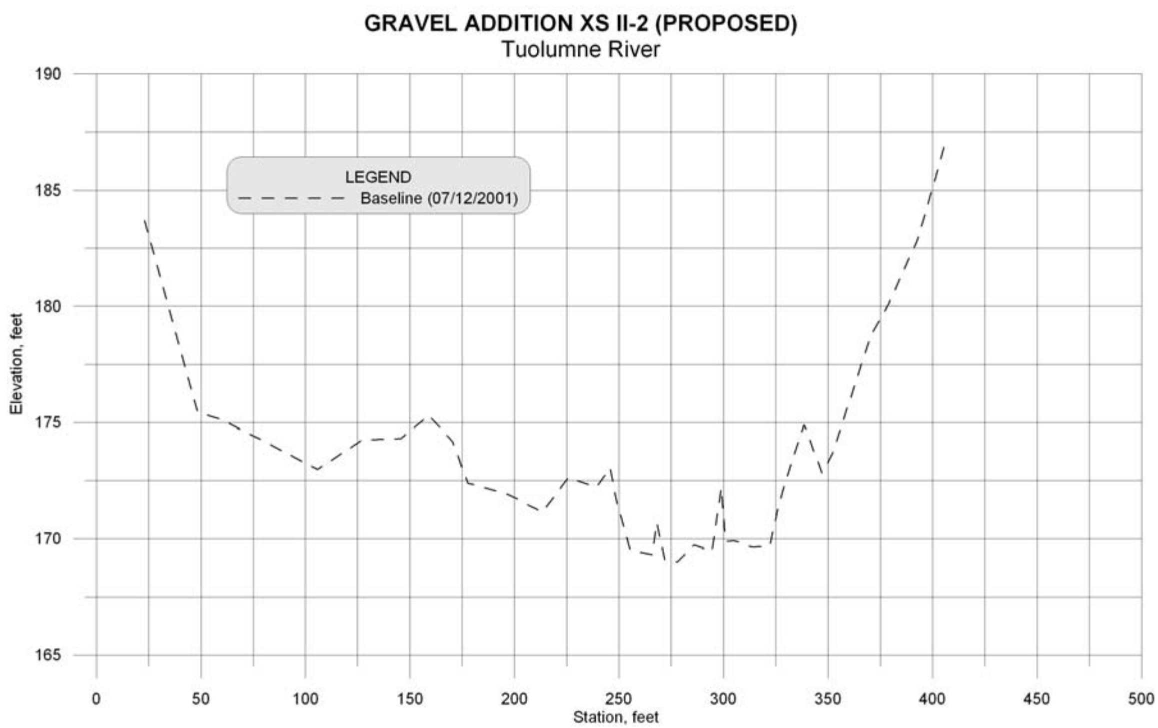
APPENDIX A
Monitoring Cross-Section Profile Surveys



GRAVEL ADDITION XS II-1
Tuolumne River
LEGEND
Baseline (07/12/2001)
As-built (09/18/2002)
Elevation, feet
Station, feet



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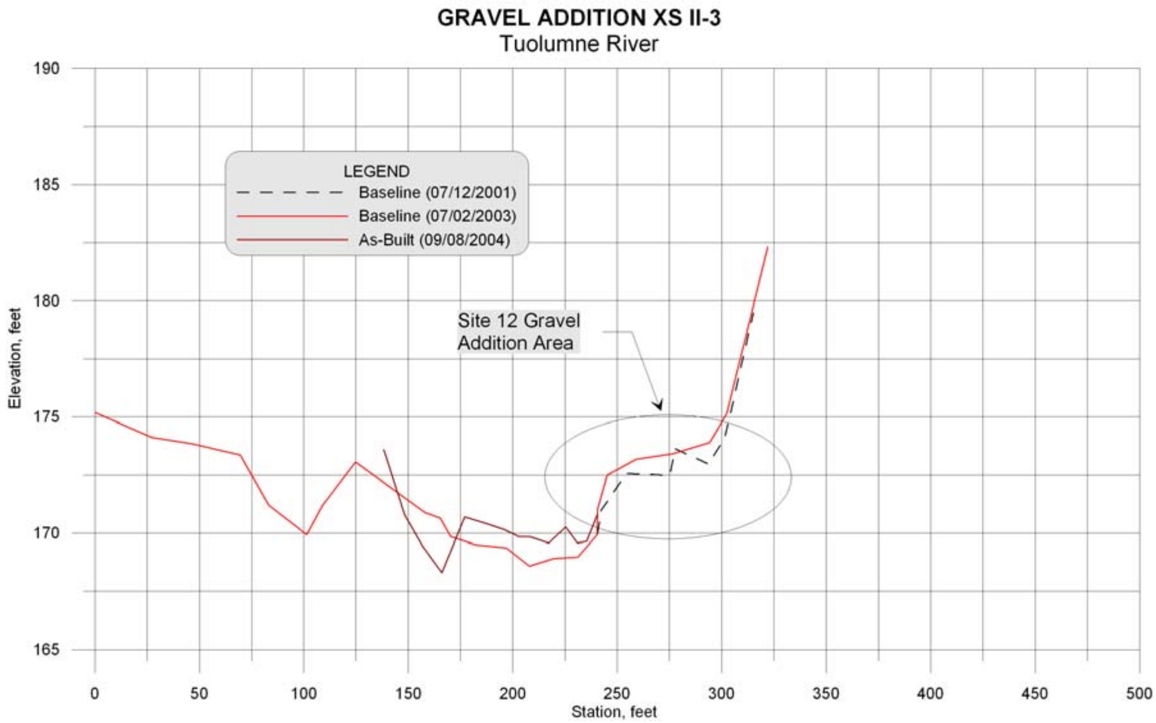
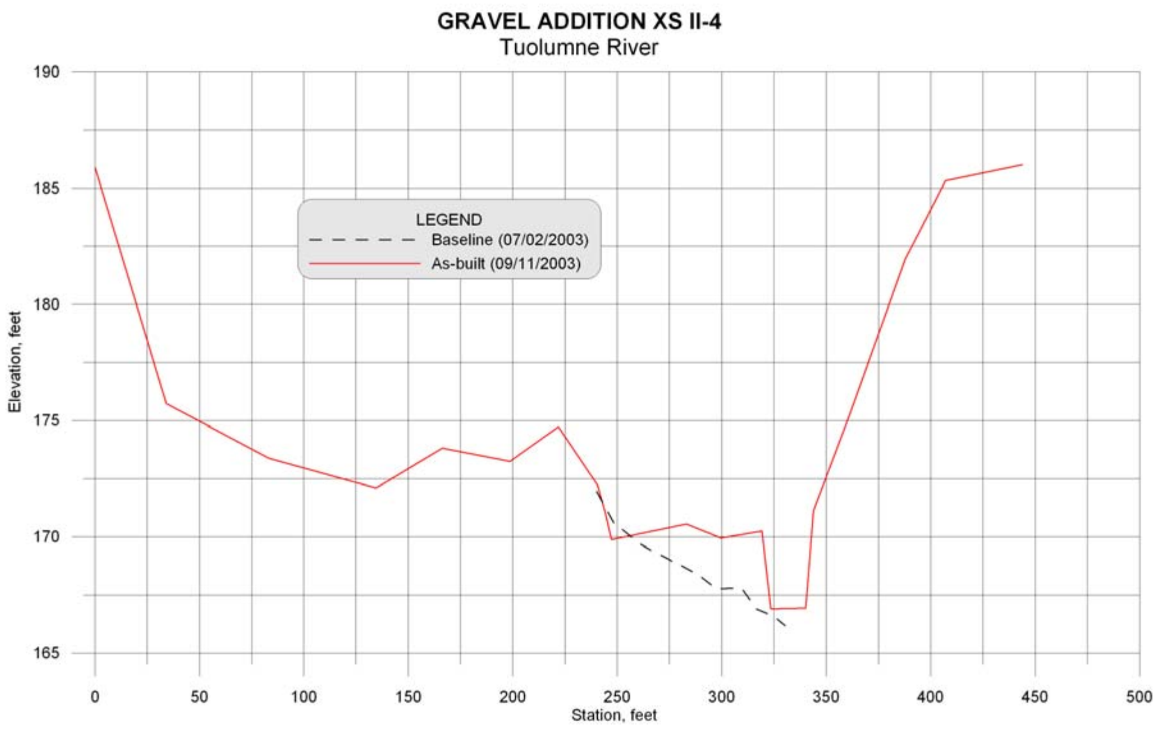
Tuolumne River
LEGEND
Baseline (07/12/2001)
Elevation, feet
Station, feet


GRAVEL ADDITION XS II-3
Tuolumne River
LEGEND
Baseline (07/12/2001)
Baseline (07/02/2003)
As-Built (09/08/2004)
Site 12 Gravel
Addition Area
Elevation, feet
Station, feet
190
185
180
175
170
165
0
50
100
150
200
250
300
350
400
450
500


GRAVEL ADDITION XS II-4
Tuolumne River
LEGEND
Baseline (07/02/2003)
As-built (09/11/2003)
Elevation, feet
Station, feet
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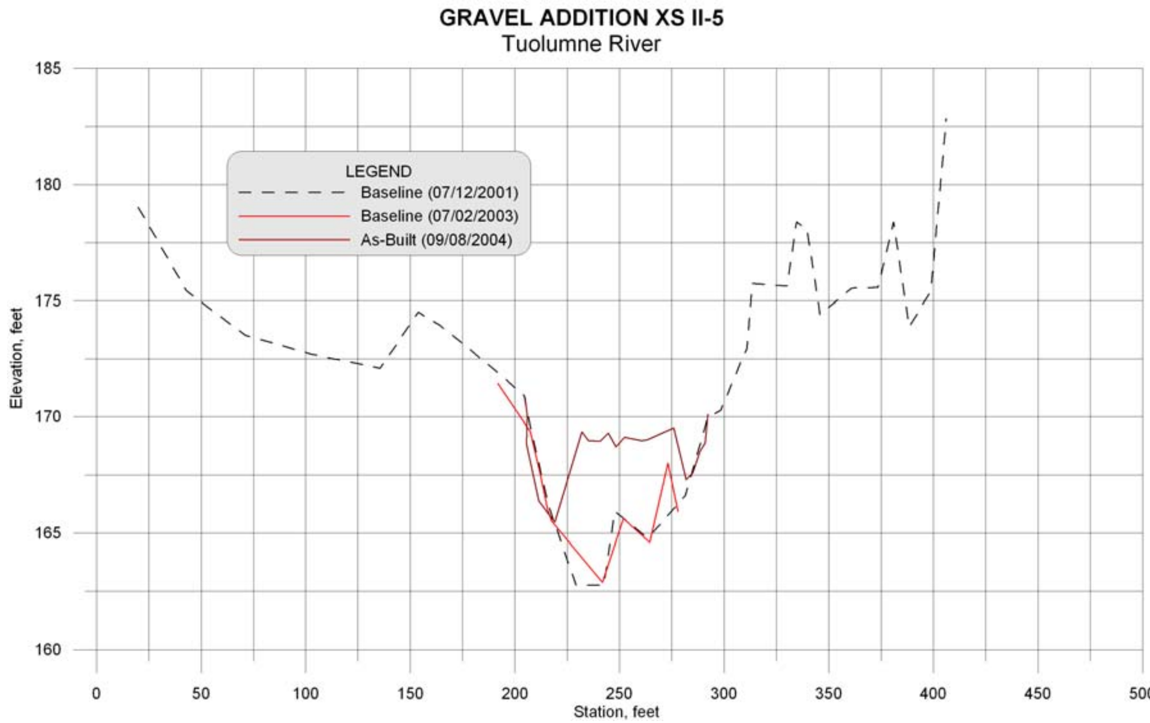
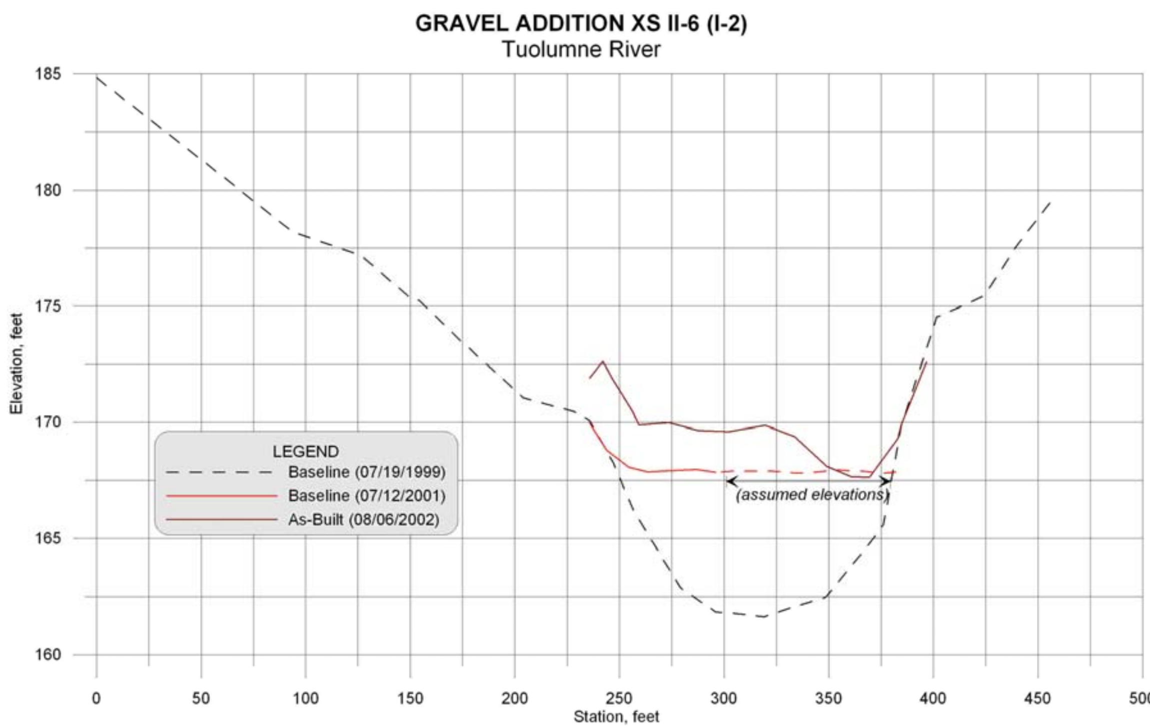
185
180
175
170
165
0
50
100
150
200
250
300
350
400
450
500


GRAVEL ADDITION XS II-5
Tuolumne River
LEGEND
Baseline (07/12/2001)
Baseline (07/02/2003)
As-Built (09/08/2004)
Elevation, feet
Station, feet
185
180
175
170
165
160
0
50
100
150
200
250
300
350
400
450
500


GRAVEL ADDITION XS II-6 (I-2)
Tuolumne River
LEGEND
Baseline (07/19/1999)
Baseline (07/12/2001)
As-Built (08/06/2002)
(assumed elevations)
Elevation, feet
Station, feet
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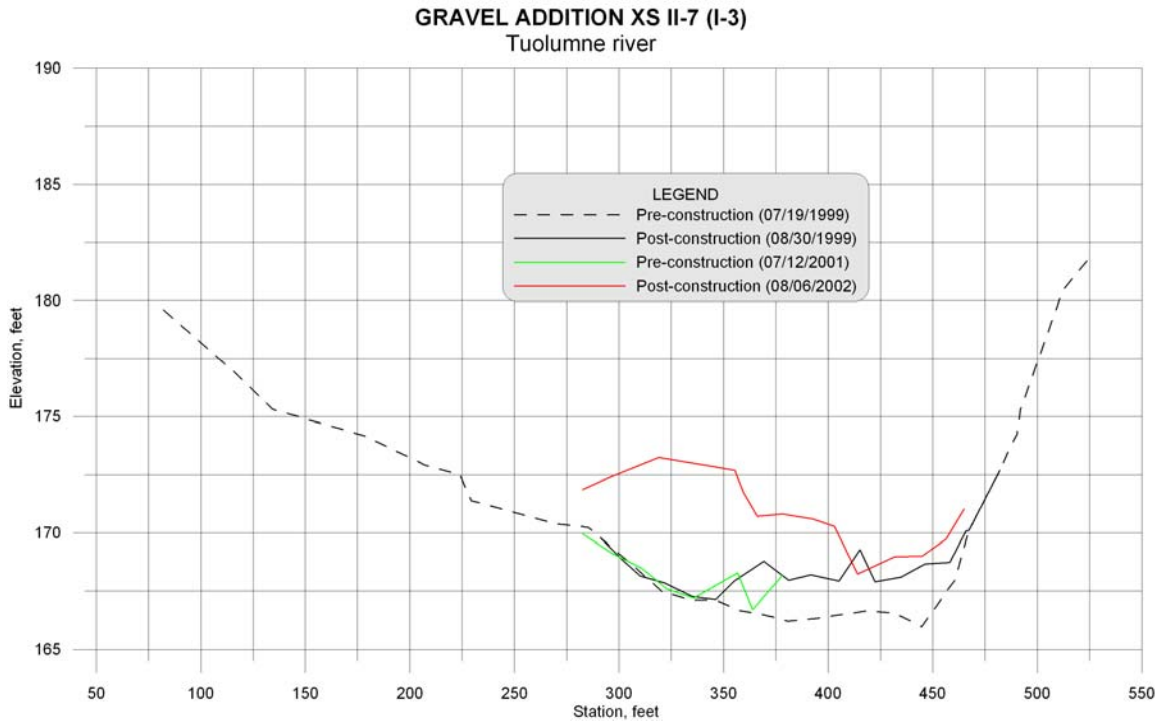
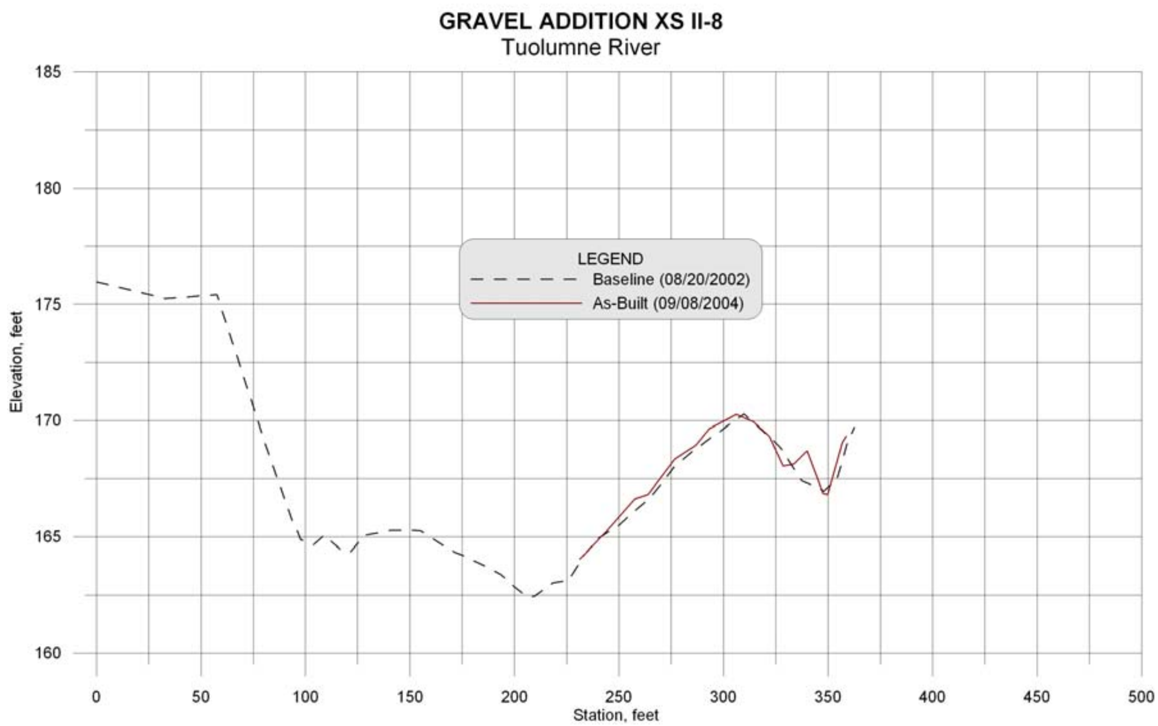
180
175
170
165
160
0
50
100
150
200
250
300
350
400
450
500


GRAVEL ADDITION XS II-7 (I-3)
Tuolumne river
LEGEND
Pre-construction (07/19/1999)
Post-construction (08/30/1999)
Pre-construction (07/12/2001)
Post-construction (08/06/2002)
Elevation, feet
Station, feet
190
185
180
175
170
165
50
100
150
200
250
300
350
400
450
500
550


GRAVEL ADDITION XS II-8
Tuolumne River
LEGEND
Baseline (08/20/2002)
As-Built (09/08/2004)
Elevation, feet
Station, feet
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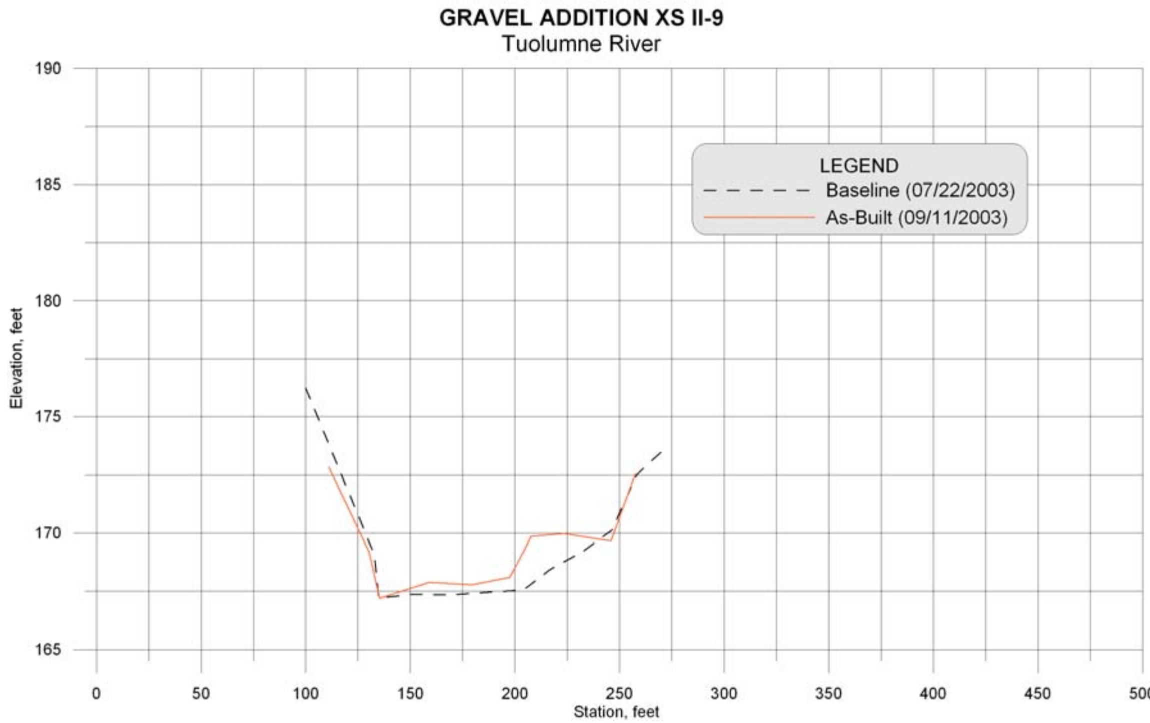
180
175
170
165
160
0
50
100
150
200
250
300
350
400
450
500


GRAVEL ADDITION XS II-9
Tuolumne River
LEGEND
Baseline (07/22/2003)
As-Built (09/11/2003)
Elevation, feet
Station, feet
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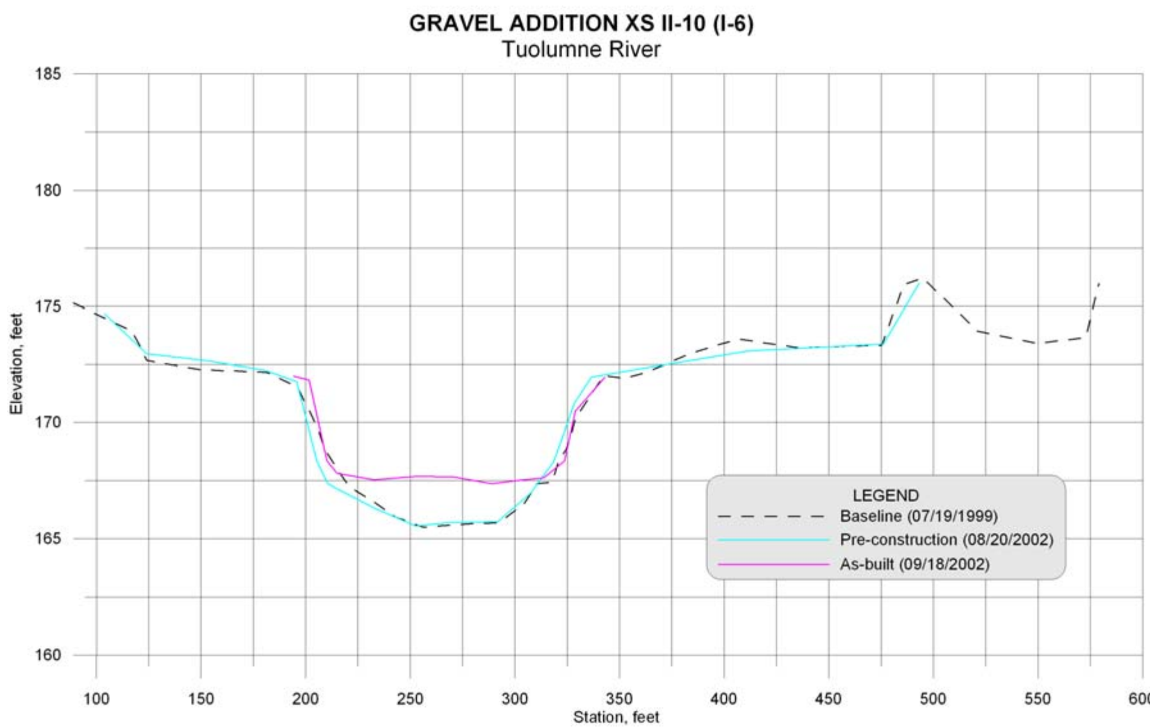
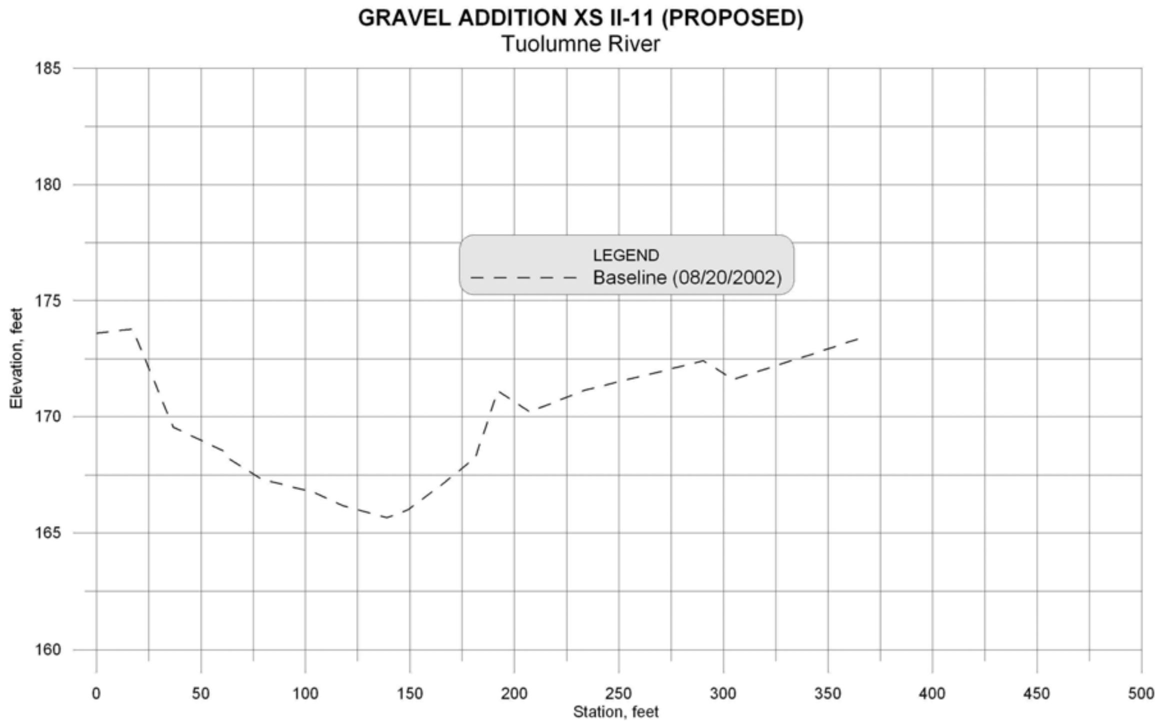
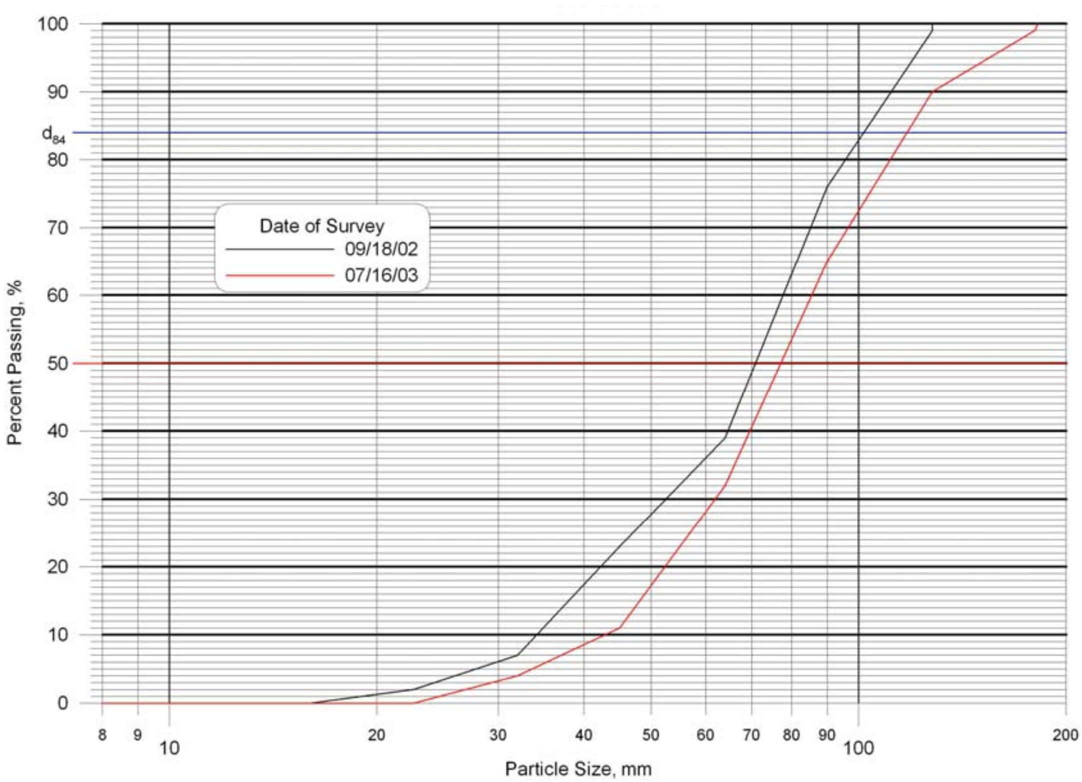
185
180
175
170
165
0
50
100
150
200
250
300
350
400
450
500

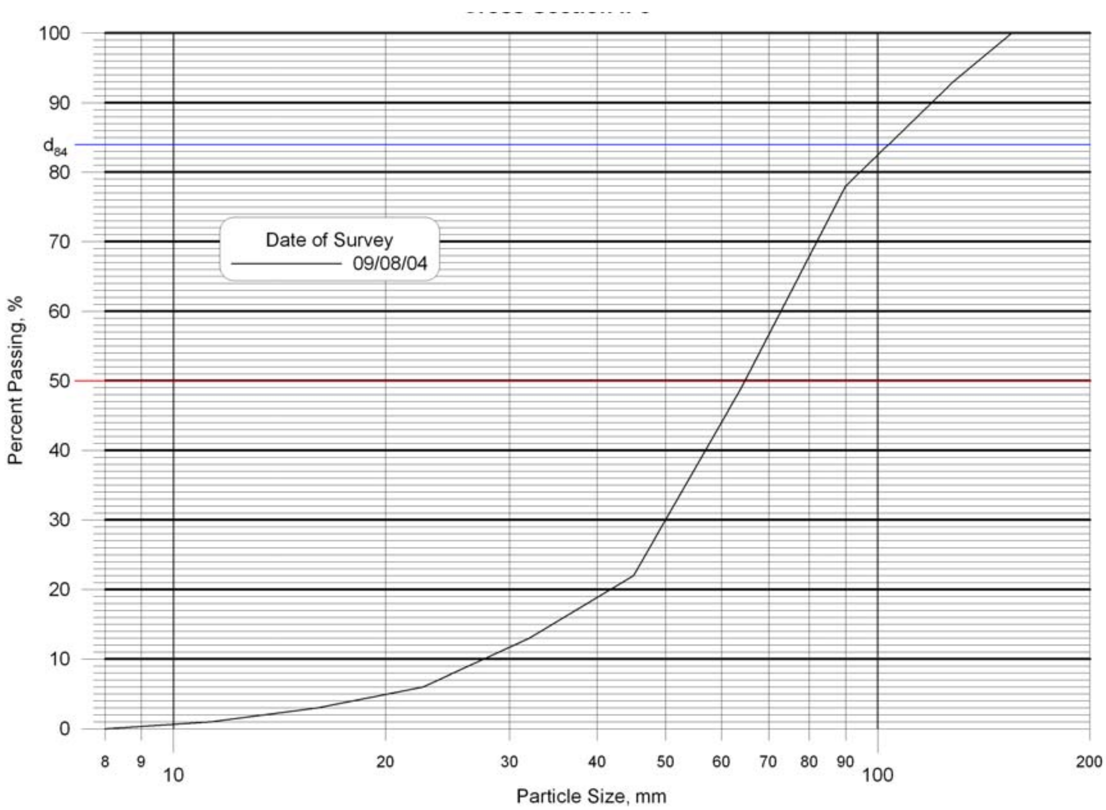

GRAVEL ADDITION XS II-10 (I-6)
Tuolumne River
LEGEND
Baseline (07/19/1999)
Pre-construction (08/20/2002)
As-built (09/18/2002)
Elevation, feet
Station, feet
185
180
175
170
165
160
100
150
200
250
300
350
400
450
500
550
600


GRAVEL ADDITION XS II-11 (PROPOSED)
Tuolumne River
LEGEND
Baseline (08/20/2002)
Elevation, feet
Station, feet
185
180
175
170
165
160
0
50
100
150
200
250
300
350
400
450
500

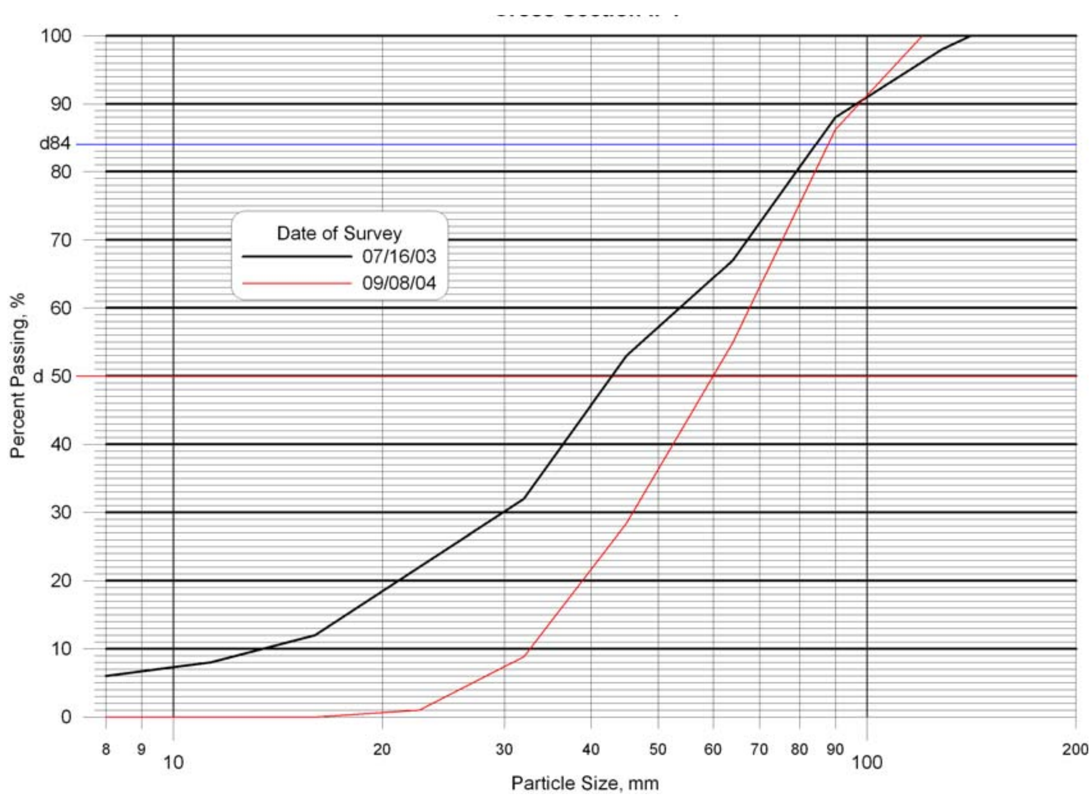
APPENDIX B
Pebble Counts & Bulk Analyses



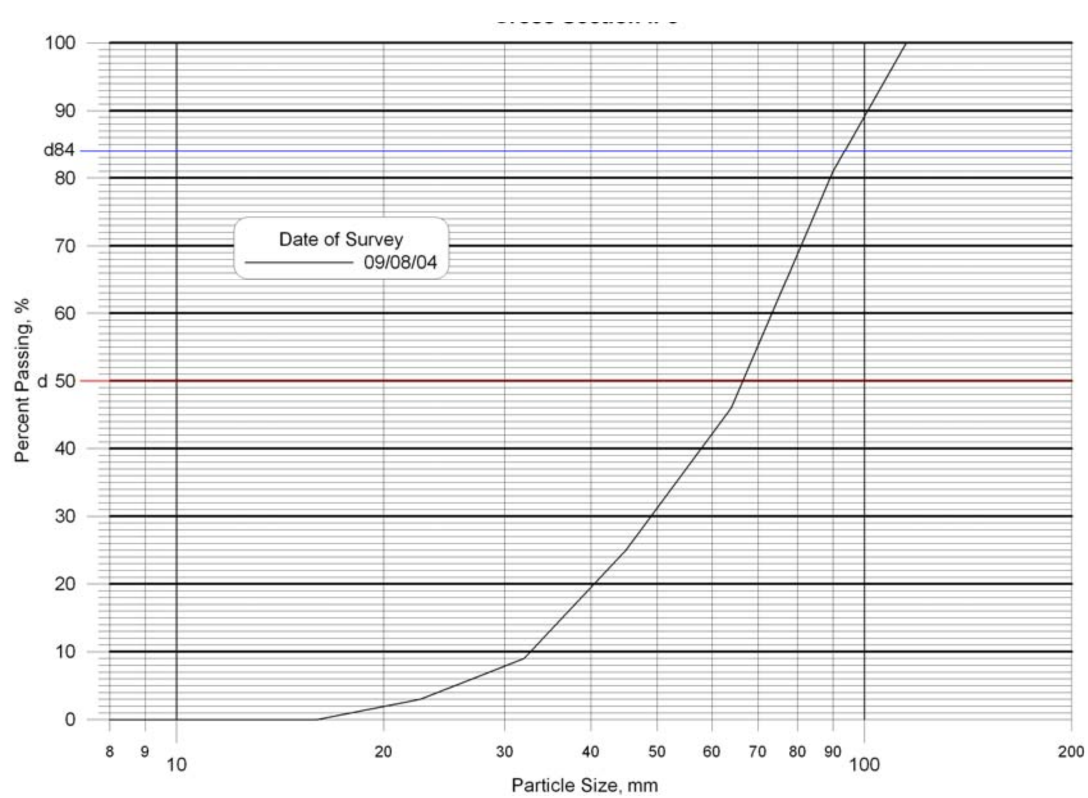
Cross-section II-1



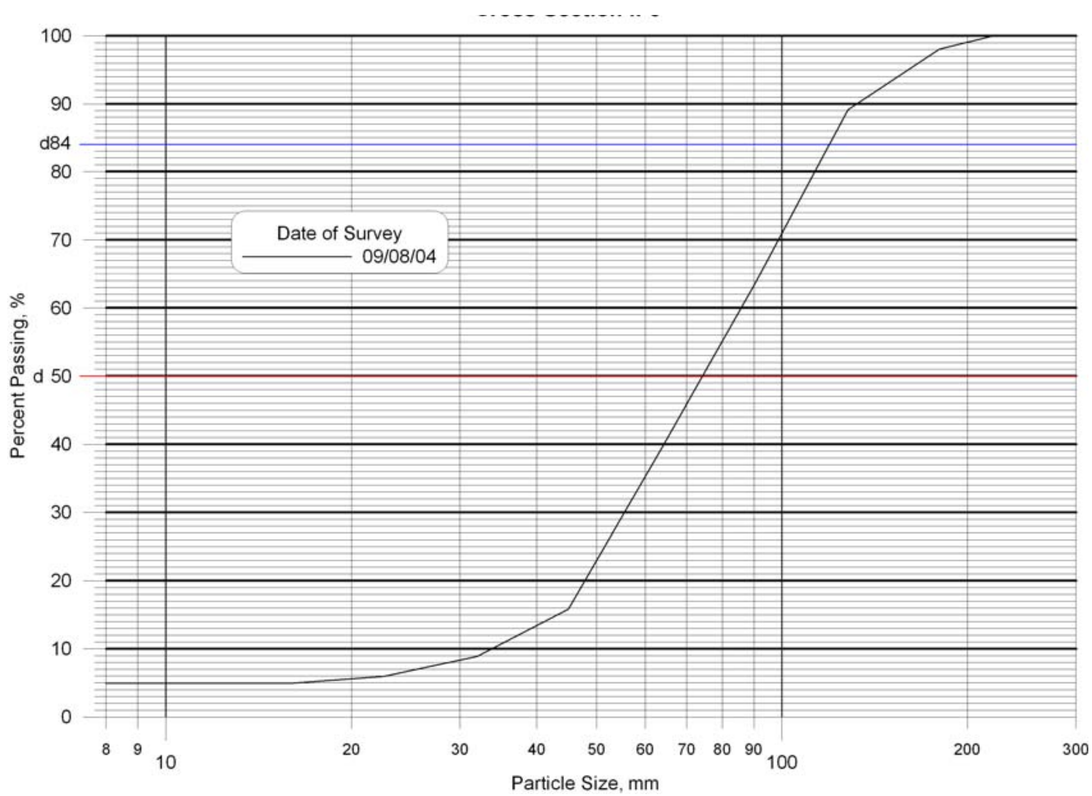
Cross-section II-3



Cross-section II-4



Cross-section II-5



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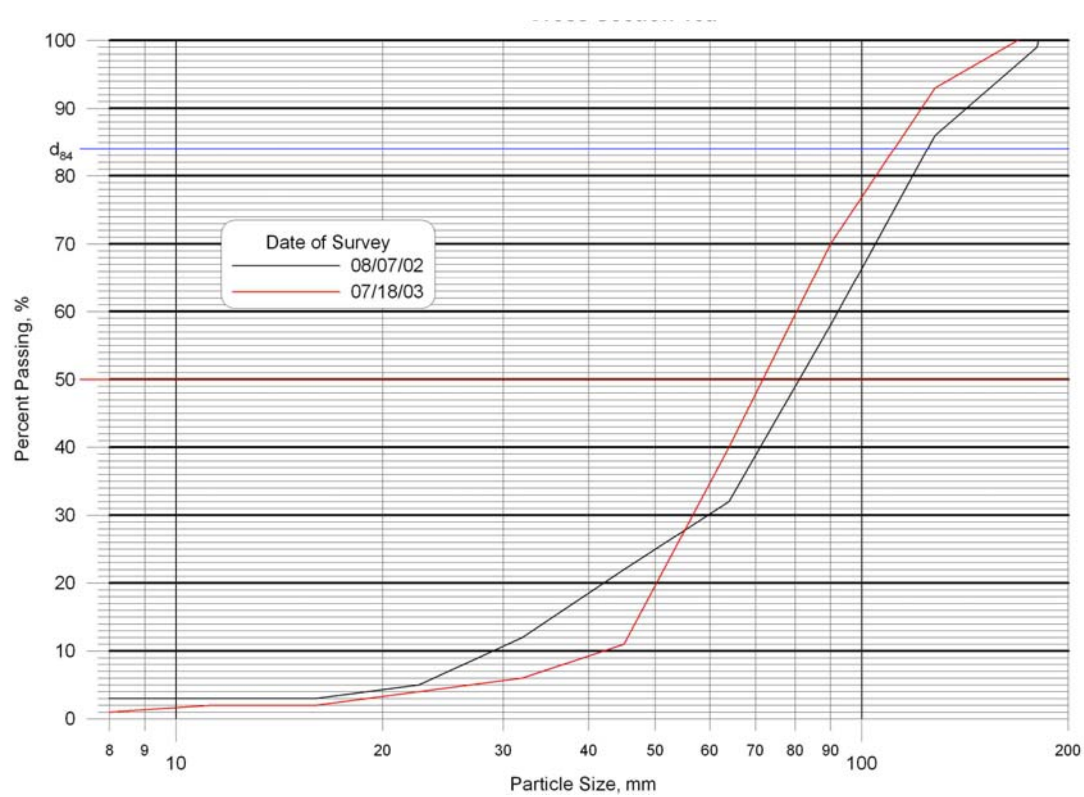

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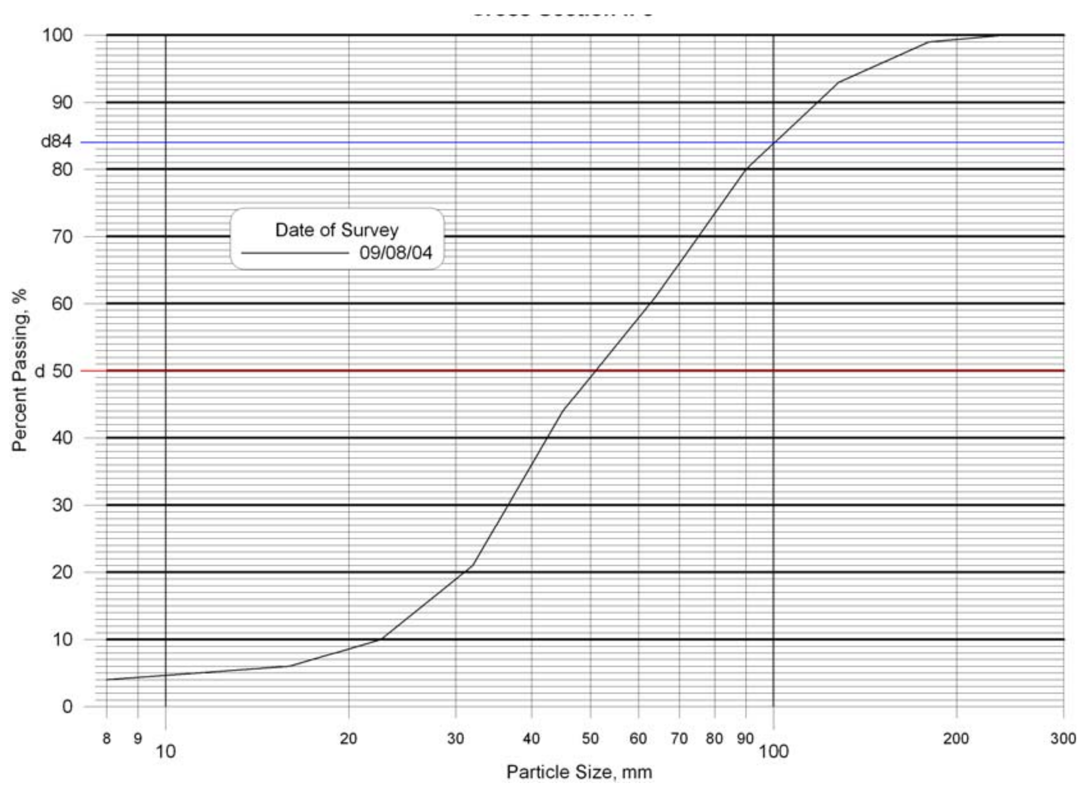
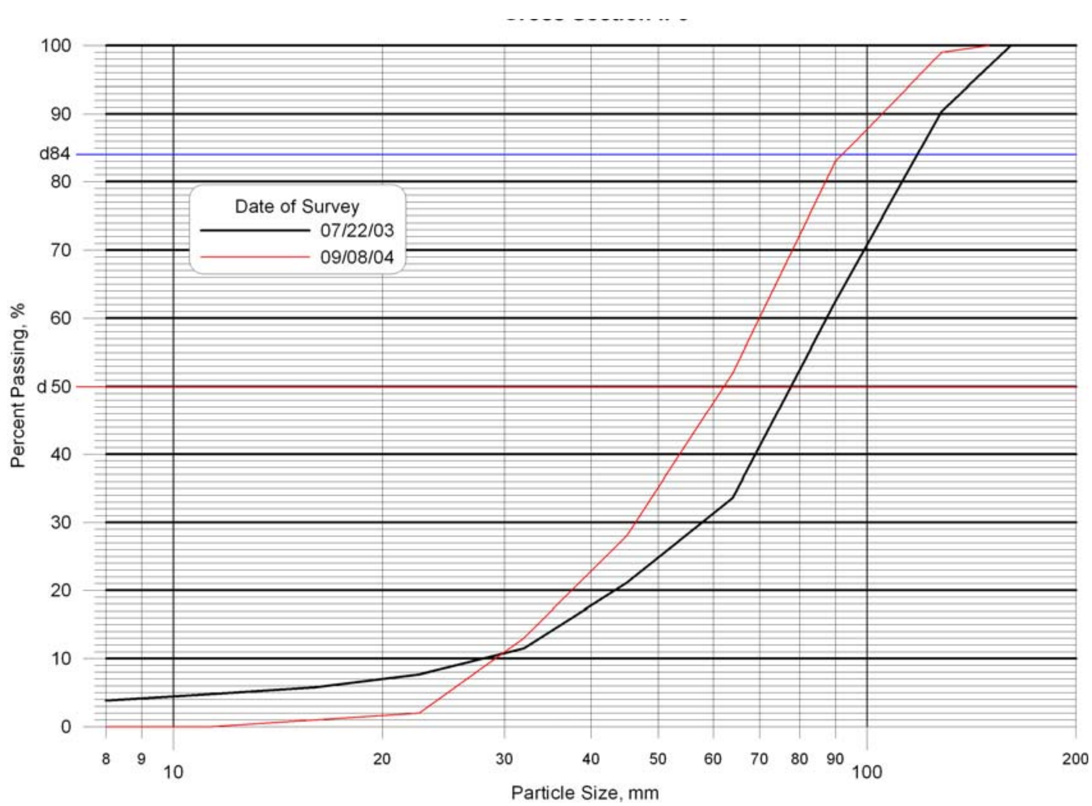
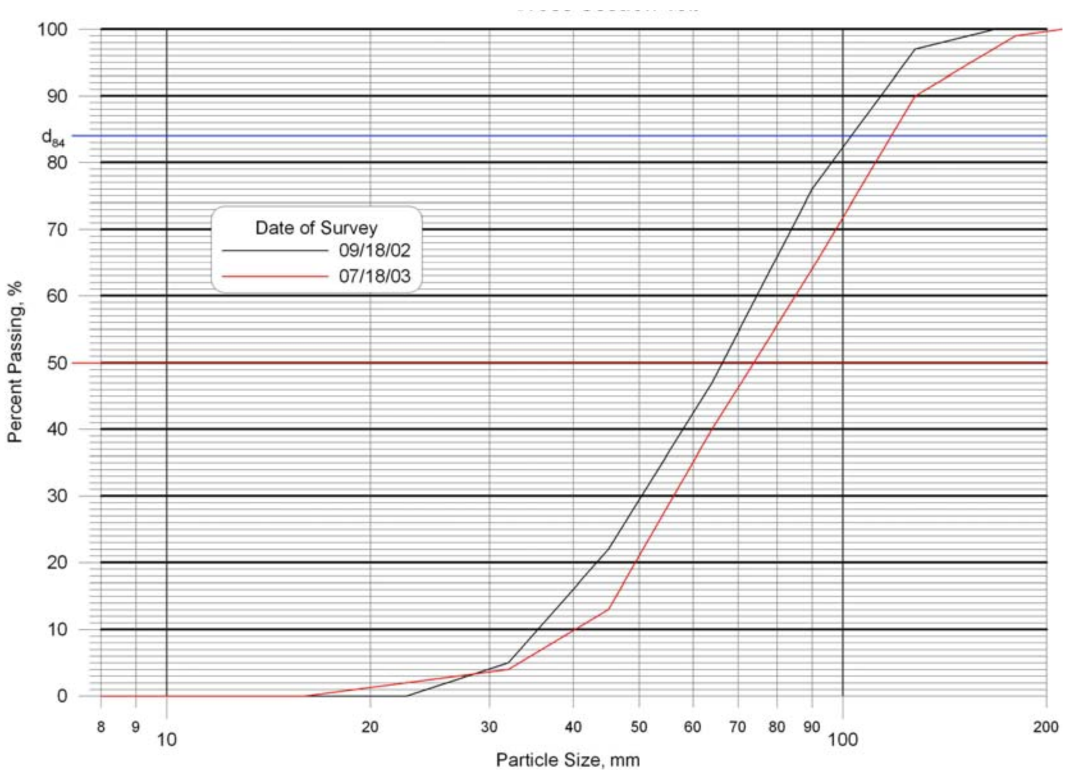


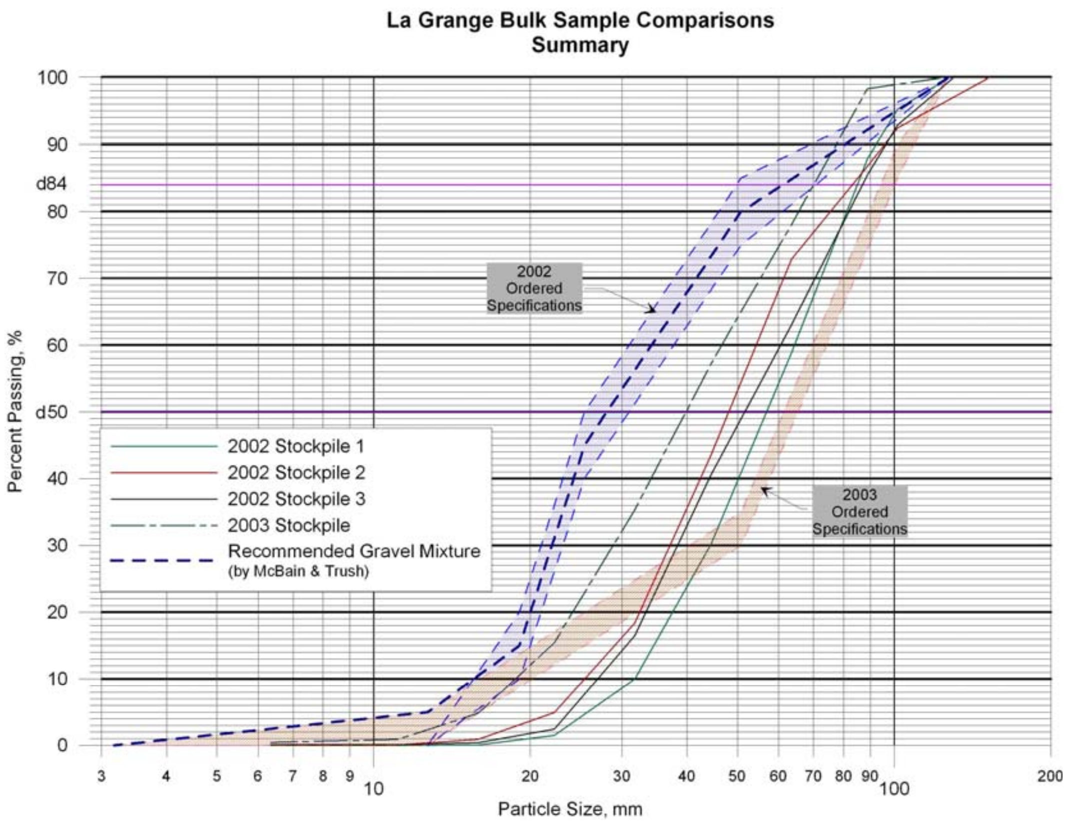
Cross-section II-8



Cross-section II-9

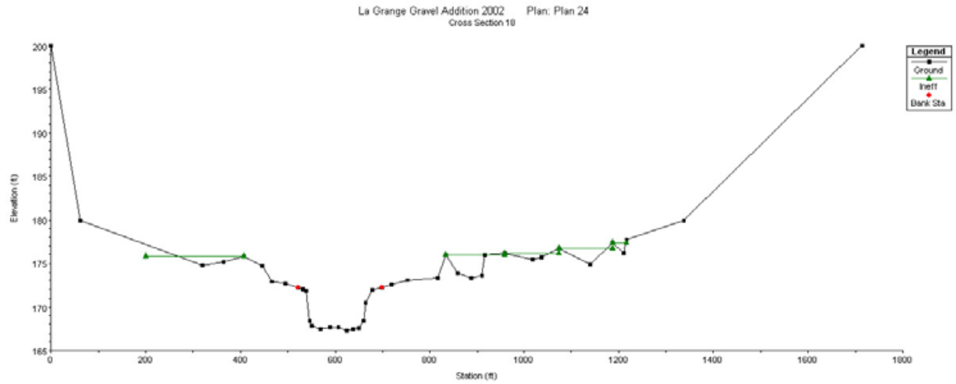


Cross-section II-10



APPENDIX C
Hec-Ras Map and Sections


1093
1370
1685
1947
2182
2552
2765
2820
2850
3437
3608
3810
3972
4030
4270
4425
5000
5230
5620
XS II-10 (I-6)
XS II-9
XS II-8
XS II-7 (I-3)
XS II-6 (I-2)
XS II-5
XS II-4
XS II-3
XS II-1



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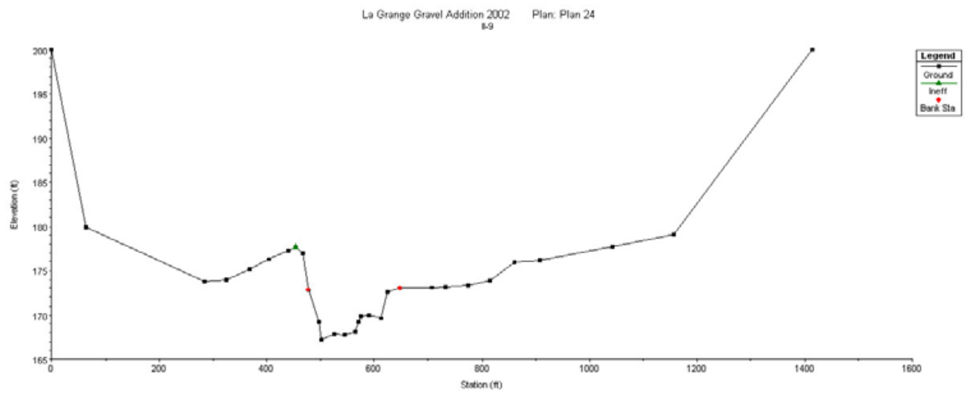

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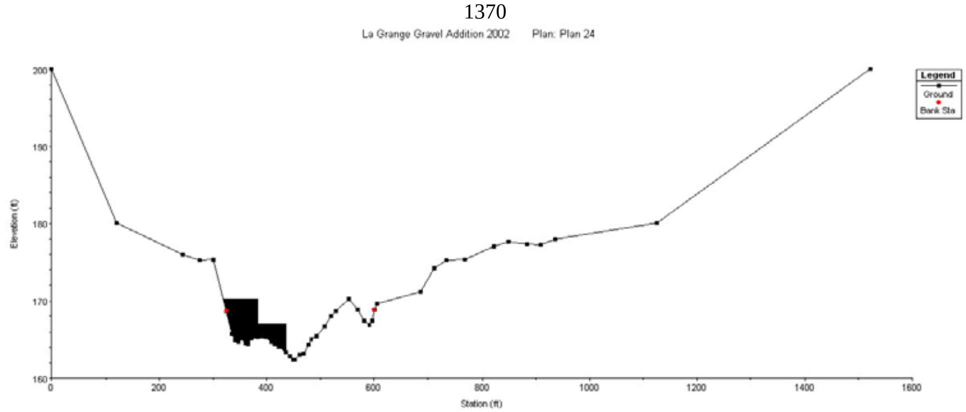

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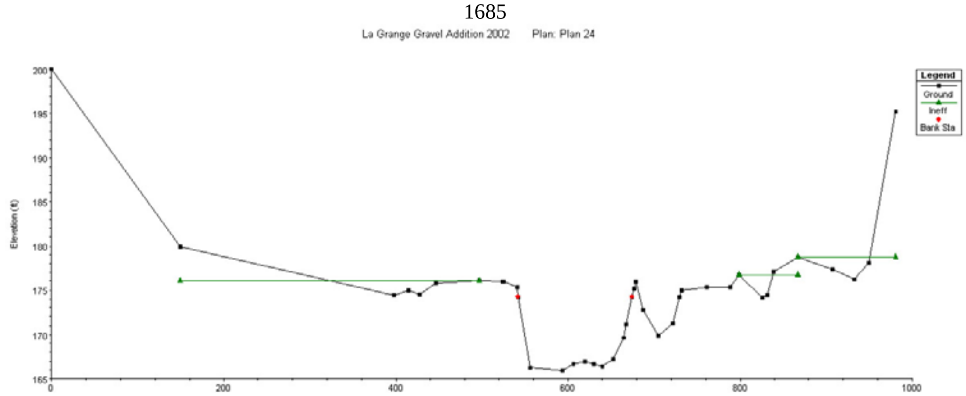

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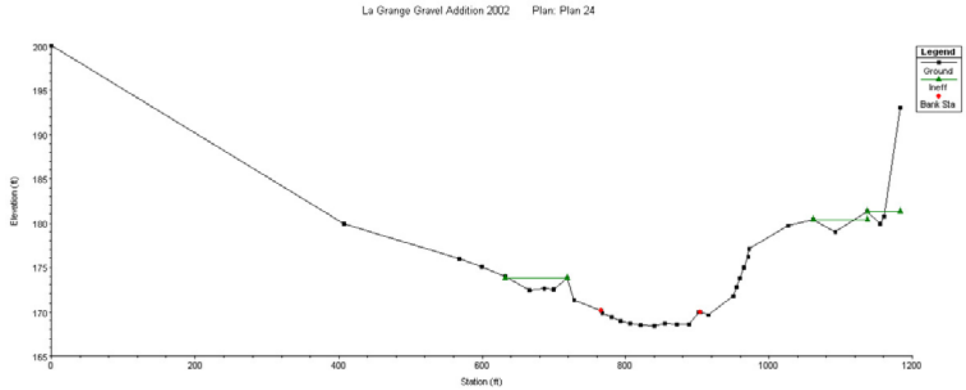

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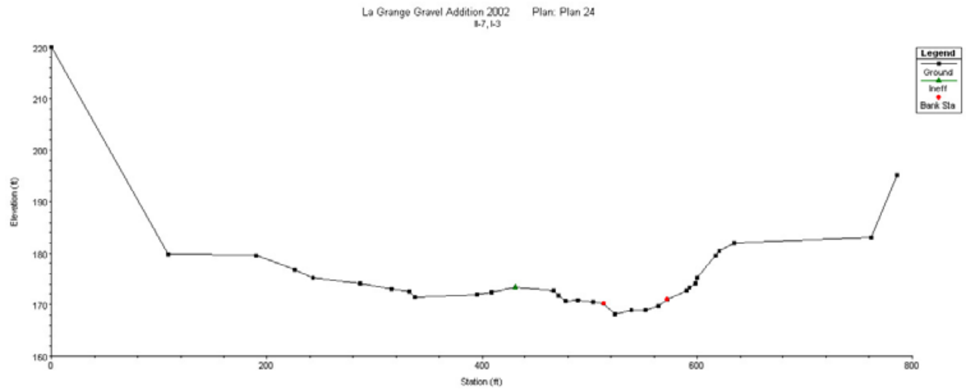

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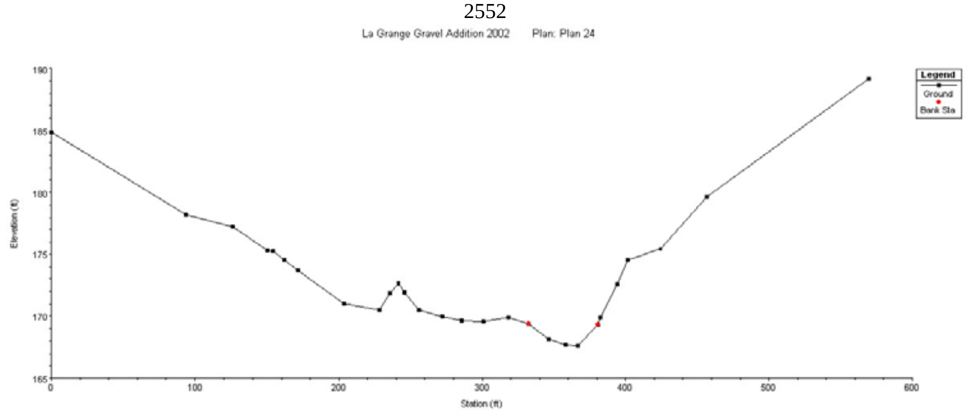

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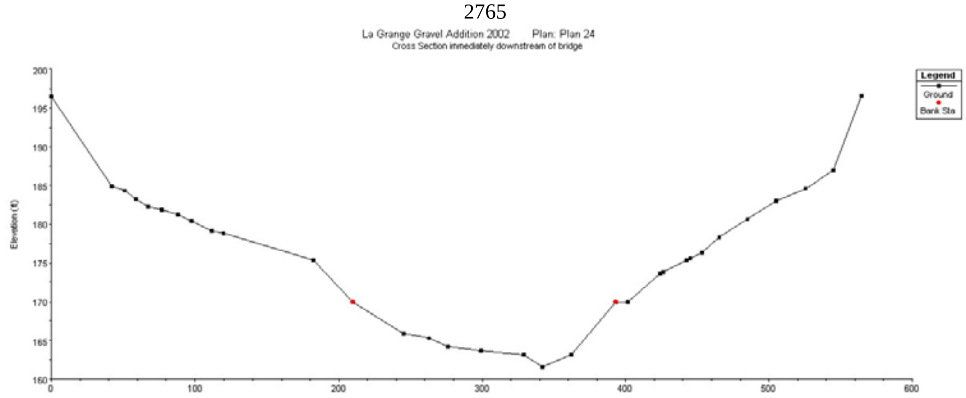

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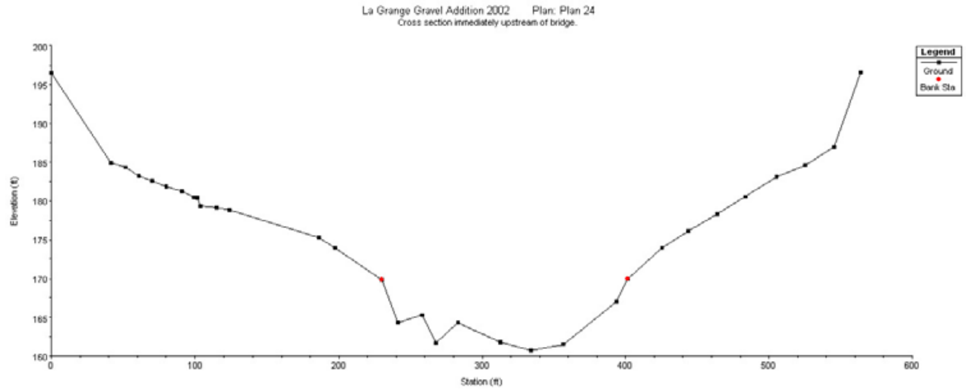

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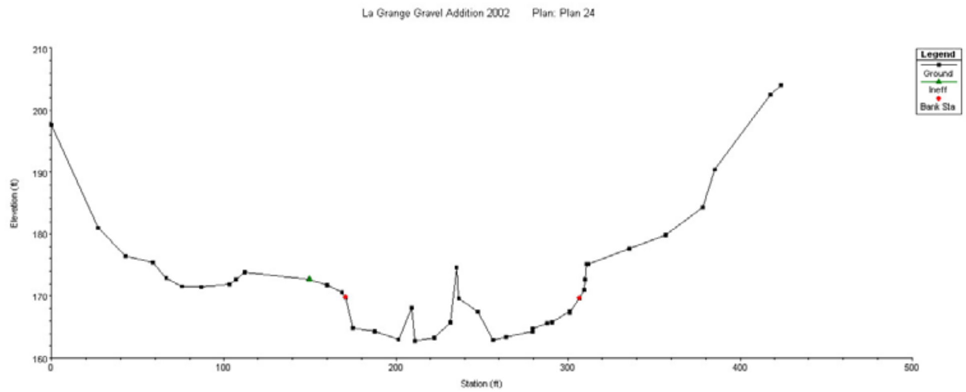

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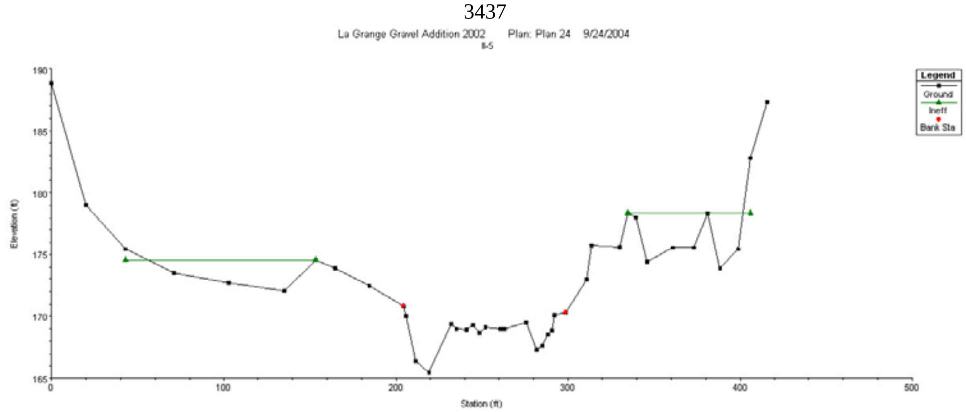

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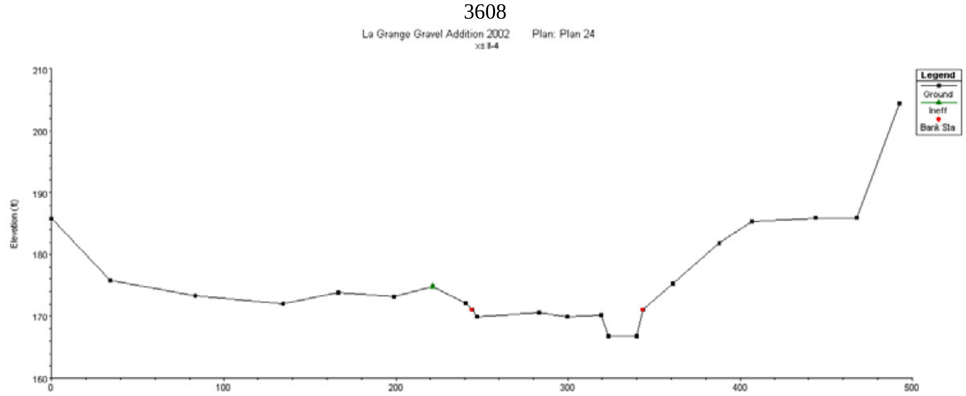

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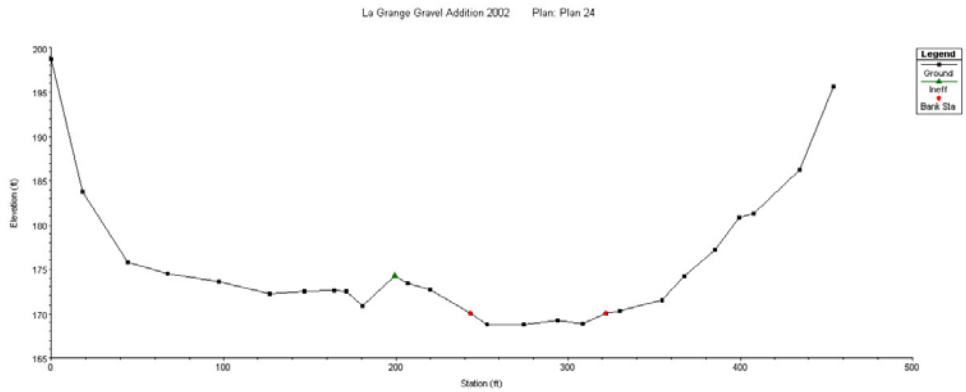

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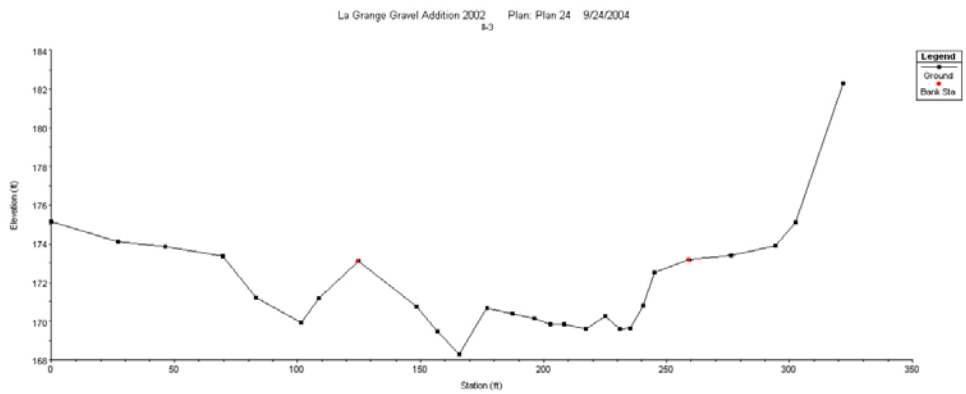

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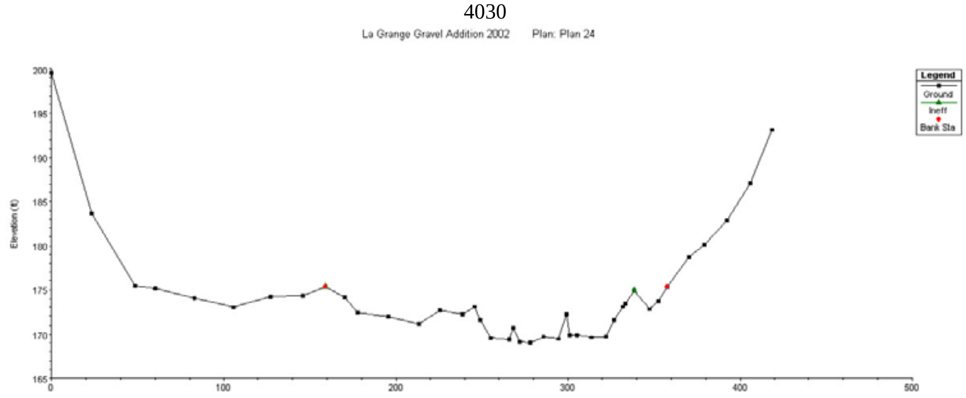

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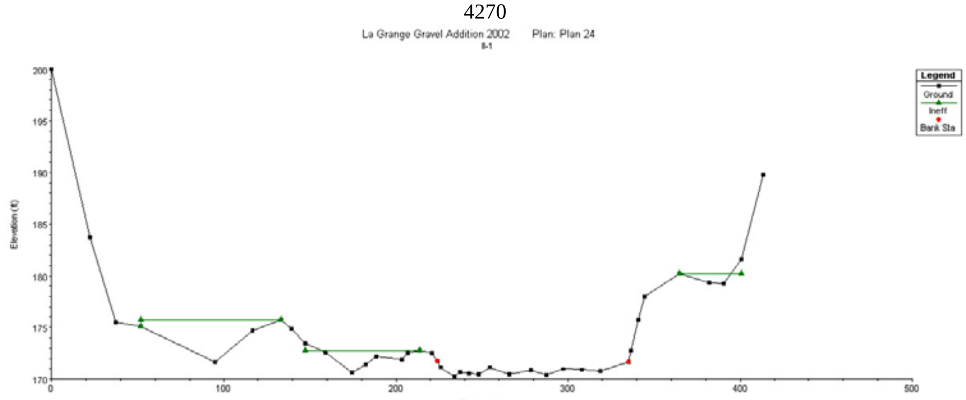

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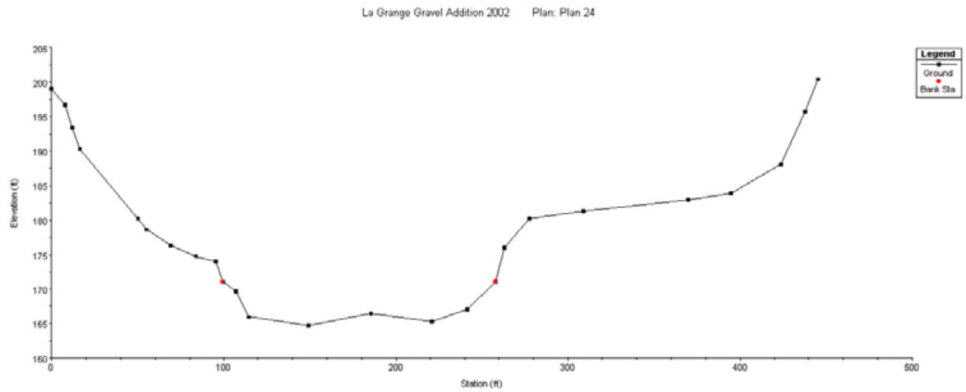

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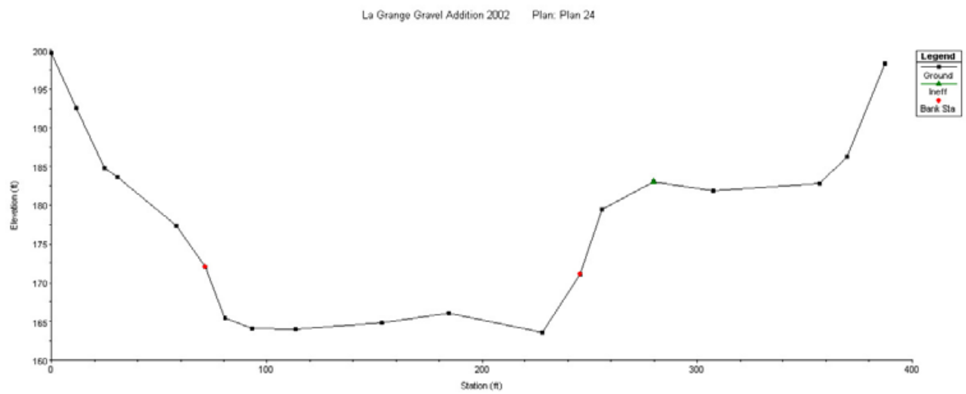

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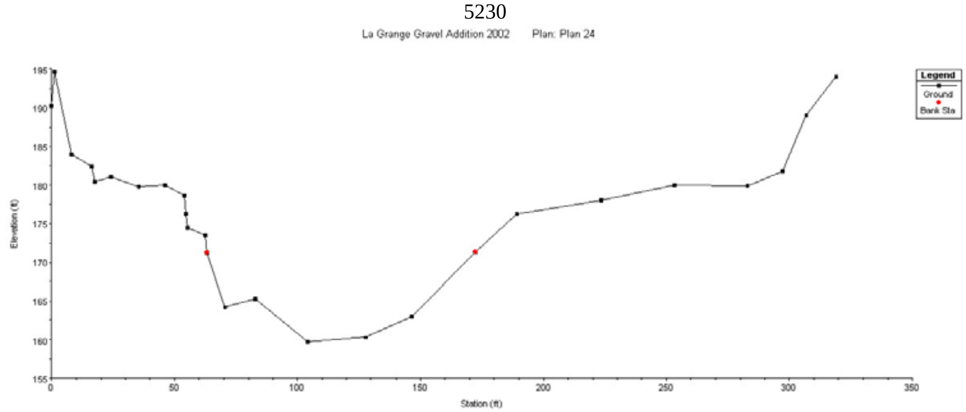
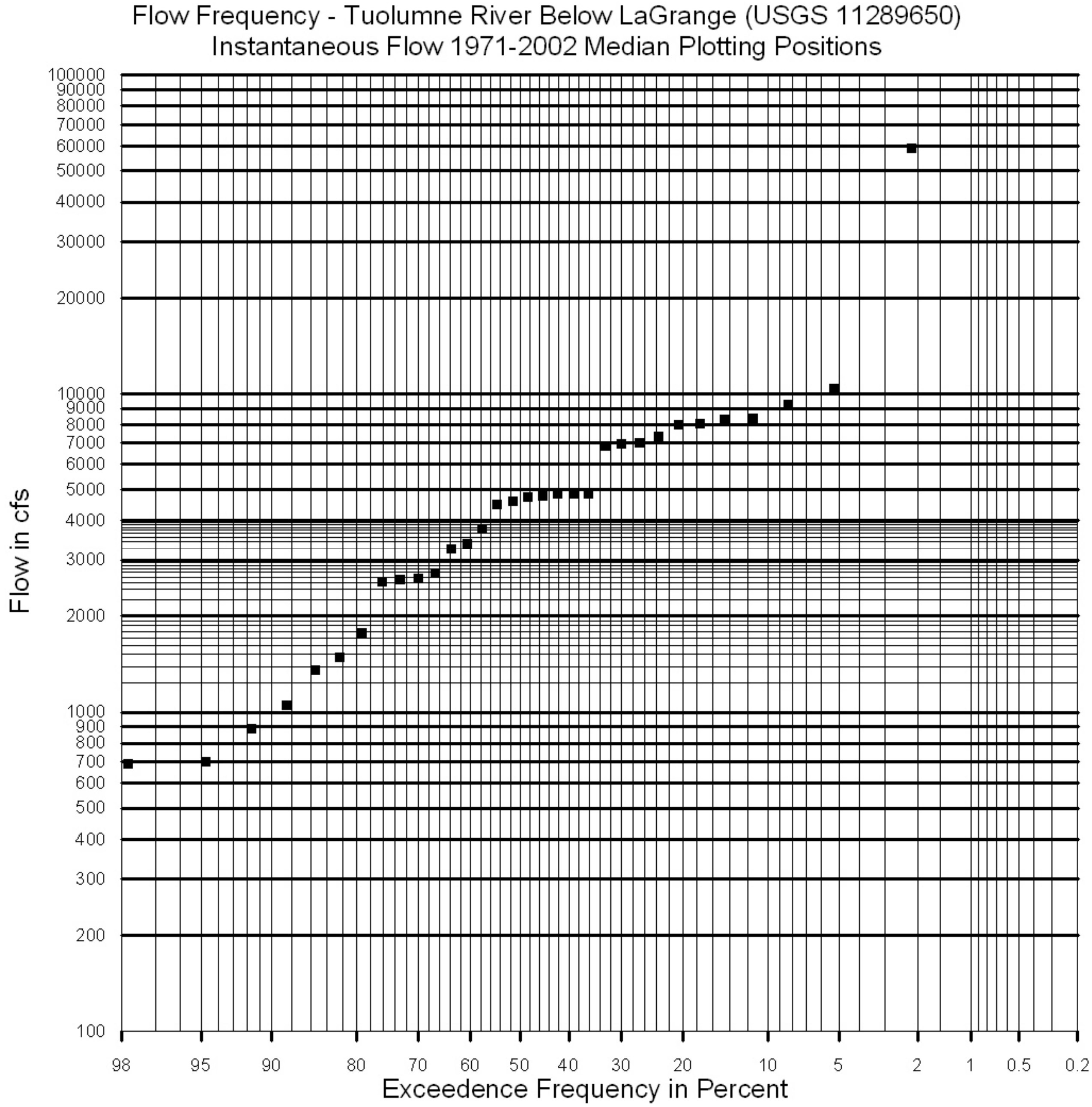


5620

APPENDIX D
Tuolumne River Flow Frequency


Flow Frequency - Tuolumne River Below LaGrange (USGS 11289650)
Instantaneous Flow 1971-2002 Median Plotting Positions
Flow in cfs
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
Exceedence Frequency in Percent