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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San Joaquin District
River Management Section

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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 8th, 2002, and was completed on September 6th, 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 23rd, 2003, and was completed around the date of September 8th, 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.
### 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.

<table>
<thead>
<tr>
<th>Particle Size (inches)</th>
<th>Percent Passing</th>
<th>Percent Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>5&quot;</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>2&quot;</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>1&quot;</td>
<td>45%</td>
<td>55%</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>15%</td>
<td>85%</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>5%</td>
<td>95%</td>
</tr>
<tr>
<td>1/8&quot;</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Particle Size (inches)</th>
<th>2002 Percent Passing</th>
<th>2003 Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>5&quot;</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>4&quot;</td>
<td>75%-85%</td>
<td>85%-90%</td>
</tr>
<tr>
<td>2&quot;</td>
<td>40%-50%</td>
<td>30%-35%</td>
</tr>
<tr>
<td>1&quot;</td>
<td>10%-20%</td>
<td>0%-5%</td>
</tr>
<tr>
<td>1/8&quot;</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

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.
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.

<table>
<thead>
<tr>
<th>Task</th>
<th>Phase I 1999</th>
<th>Phase II 2002</th>
<th>Phase II 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline (In-situ)</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cross Sectional Surveys</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pebble Counts</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Bulk Samples</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Flow Model</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>As Built</strong></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cross Sectional Surveys</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Bulk Samples</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Tracer Gravel</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Construction + 1 year</strong></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cross Sectional Surveys</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pebble Counts</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Samples</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map &amp; Replace Tracer Gravel</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Construction + 2 years</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross Sectional Surveys</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pebble Counts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map Tracer Gravel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X - Task completed
* - No Tracer Gravel Movement Exhibited

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.

**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.

![Figure 4. Stockpiles #1 and #2 and bulk sample collection](image-url)
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.

<table>
<thead>
<tr>
<th>Section</th>
<th>2002 post-construction</th>
<th>2003 pre-construction</th>
<th>2003 post-construction</th>
</tr>
</thead>
</table>

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

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.

Figure 5. Gravel Bar (15a)
**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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Stockpile</th>
<th>$D_{50}$ (mm)</th>
<th>$D_{84}$ (mm)</th>
<th>Area of Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1</td>
<td>58</td>
<td>85</td>
<td>11, 12, 13</td>
</tr>
<tr>
<td>2002</td>
<td>2</td>
<td>49</td>
<td>84</td>
<td>15a</td>
</tr>
<tr>
<td>2002</td>
<td>3</td>
<td>52</td>
<td>87</td>
<td>18a</td>
</tr>
<tr>
<td>2003</td>
<td>All</td>
<td>40</td>
<td>70</td>
<td>14, 15b, 16, 18b</td>
</tr>
</tbody>
</table>

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

\( \tau_{ci} \) is the critical shear stress (N/m\(^2\)) required to mobilize particle size \( d_i \). \( \rho_s \) is the density of the sediment (2,650 kg/m\(^3\)), \( \rho_f \) 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, \( \tau = \gamma RS_e \), where \( \tau \) is bed shear stress (N/m\(^2\)), \( \gamma \) 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](image-url)
<table>
<thead>
<tr>
<th>Section</th>
<th>Particle Size (mm)</th>
<th>Critical Shear (N/m²)</th>
<th>HEC-RAS Flow (cfs)</th>
<th>Particle Size (mm)</th>
<th>Critical Shear (N/m²)</th>
<th>HEC-RAS Flow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-1</td>
<td>28</td>
<td>17.4</td>
<td>2,500</td>
<td>28</td>
<td>17.4</td>
<td>2,500</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>19.8</td>
<td>3,200</td>
<td>61</td>
<td>19.8</td>
<td>3,200</td>
</tr>
<tr>
<td>II-3</td>
<td>28</td>
<td>17.4</td>
<td>6,300</td>
<td>28</td>
<td>17.4</td>
<td>6,300</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>19.8</td>
<td>8,300</td>
<td>61</td>
<td>19.8</td>
<td>8,300</td>
</tr>
<tr>
<td>II-6</td>
<td>28</td>
<td>17.4</td>
<td>1,800</td>
<td>61</td>
<td>19.8</td>
<td>3,000</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>19.8</td>
<td>3,500</td>
<td>61</td>
<td>19.8</td>
<td>3,500</td>
</tr>
<tr>
<td>II-8</td>
<td>28</td>
<td>17.4</td>
<td>24,000</td>
<td>62</td>
<td>38.5</td>
<td>30,500</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>19.8</td>
<td>2,700</td>
<td>62</td>
<td>38.5</td>
<td>33,500</td>
</tr>
</tbody>
</table>

(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/m². Figure 8 illustrates average channel shear vs. river station.
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.
REFERENCES


DFG. 2000. *Proposal for the Consideration by the Four Pumps Advisory Committee, Tuolumne River Salmonid Habitat Improvement Project River Mile 49.9 to 50.7*.


APPENDIX A
Monitoring Cross-Section Profile Surveys
APPENDIX B
Pebble Counts & Bulk Analyses
Cross-section II-1

Cross-section II-3

Phase II Monitoring Report
Cross-section II-4

Cross-section II-5
Cross-section II-6

Cross-section II-7
APPENDIX C
Hec-Ras Map and Sections
La Grange Grand Addition 2002 - Plan, Plan 24

Graph 1

2182

Graph 2

2552

Graph 3

2765

Graph 4

2820

Phase II Monitoring Report
APPENDIX D
Tuolumne River Flow Frequency