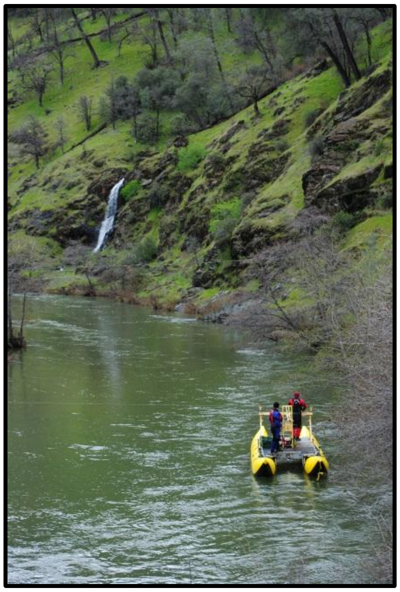

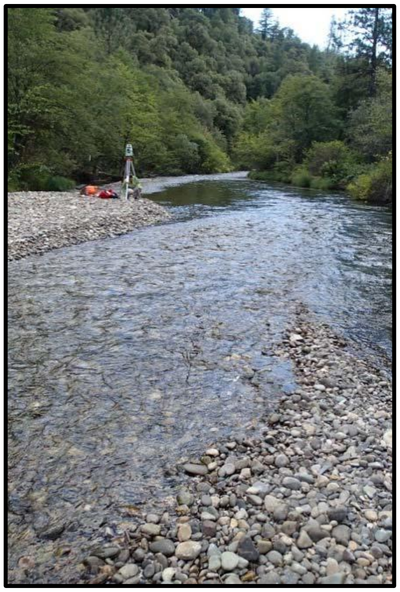

2010-2013 CLEAR CREEK GEOMORPHIC MONITORING:

Bedload sampling and gravel injection evaluation.

Shasta County, California

FINAL REPORT

Prepared for:

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ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT:

California Department of Water Resources (DWR)

Central Valley Project Improvement Act (CVPIA)

Cubic foot per second (cfs)

Cubic yard (cy)

Digital Terrain Model (DTM)

Graham Matthews and Associates (GMA)

McBain and Trush, Inc (M&T)

National Park Service (NPS)

US Bureau of Land Management (BLM)

US Bureau of Reclamation (USBR)

US Fish and Wildlife Service (USFWS)

US Geological Survey (USGS)

Western Shasta Resource Conservation District (WSRCD)

EXECUTIVE SUMMARY

Introduction

The purpose of this 2010-2013 Clear Creek Geomorphic Monitoring Project for US Bureau of Reclamation (USBR) is to evaluate sediment-related geomorphic issues (e.g. transport rate, distribution and abundance of spawning gravel) which govern key biological and ecological criteria (e.g. quality and quantity of salmon spawning habitat) and relate them to specific management objectives such as achieving complete coarse sediment routing. The specific goal of this project is to increase understanding of one of the key physical limiting factors: gravel transport through Reach Two (the 7 mile bedrock gorge between Paige Bar Road and Clear Creek Road). The sediment deficit and spawning habitat degradation below Whiskeytown Dam have been addressed with channel/floodplain restoration projects and gravel injections of various types since 1996. Over 172,000 tons of spawning gravel has been added along Clear Creek below Whiskeytown Dam at 15+ different locations.

Approach

Bedload sampling and stream gaging near NEED Camp and near Igo were employed to assess transport rates (annual loads were computed) and to assess sediment texture (size gradations). The USGS record for Clear Creek gaging station near Igo (USGS 11372000) was used to compute sediment loads at the downstream site and to provide supporting historical data for the project -- for statistical examination of the hydrologic record (USGS 1982, Gordon et al, 1992). Gravel injection sites in the two miles below Whiskeytown Dam comprise most of the source of spawning gravel into Reach Two. Repeat topographic surveys were performed at the Reach One gravel injection sites and at the Guardian Rock site located at the beginning of Reach Two. Injection volumes were compared to volume changes in reaches below injections. Injected gravel reaches were reconnoitered following high flows and qualitative assessments of geomorphic response were performed.

Key Findings

Hydrology

During the study period (Water Year [WY] 2011-2013), Clear Creek below NEED Camp encountered two types of peak flows: spring pulse flows of 600 to 1,100 cfs, (no Glory Hole spills) and storm-driven winter peaks of up to 1,870 cfs on December 2, 2012. At the USGS gaging station near Igo, peak flows were much higher and generally corresponded to peaks measured near NEED Camp. Five storm events over the three year period exceeded the sampling threshold trigger of 2,000 cfs and only two of these exceeded 3,000 cfs (March 26, 2011 and December 2, 2012). Flood frequency analysis revealed recurrence intervals of 2.5 and 4.3 years respectively. The 4.3 year peak (provisional, 4,920 cfs) was of extremely short duration. The period exceeding 2,000 cfs lasted only five hours from 12/2/2012 02:30 to 12/2/2012 07:30. At NEED Camp, the period exceeding 1,000 cfs lasted six hours, from 01:00 to 07:00 on the same day.

Sediment Transport

Due to the infrequency and short duration of high flows, sediment transport data collected do not fully describe the range of observed flows. Spring pulse flows provided most of the opportunity for bedload sampling, though they were of lower magnitude (800-1,000 cfs) than target threshold flows (3,000 cfs at USGS Igo gage). Where possible, historic relations were used to shape transport curves and/or to assess relative rates of transport.

- NEED Camp
    - Annual bedload totals were very low (0.4-11.7 tons) compared to typical gravel injection volumes (1,000-3,000 tons).
    - The fraction of bedload >8mm ranged from 3.1 to 17 percent, thus the delivery of spawning sized gravel into Reach Two was only (at most) about 2 tons.
    - The critical threshold for significant spawning sized gravel transport appeared to be around 900 cfs

    - Bedload discharge increased in 2013, potentially signifying partial routing of spawning gravel from upstream injections.
    - In dry years (2012, 2013), 82-95 percent of the load was transported during pulse flows.
    - In the wettest year (2011) 36 percent of the annual load was transported by pulse flows.

- Clear Creek near Igo
    - The fraction of the bedload samples finer than 2mm ranged from 52-99 percent but averaged 70-76 percent.
    - The >8mm component is very small and does not appear in many samples – the highest percentage of >8mm was 2 percent.
    - The D50 of all samples is smaller than 2mm and the largest D90 is only 4mm, compared to D90s of over 50mm at NEED Camp.
    - Annual loads ranged from 637-1,054 tons
    - In dry years (WY2012-2013), 23-38 percent of the >2mm load was transported during pulse flows.
    - In the wettest year (WY2011) 13 percent of the >2mm load was transported by pulse flows.
    - Suspended sediment samples collected during WY2011-2012 winter storms did not show an increase over background (pre-Moon Fire, 2004-2008) levels: concentrations plotted mostly within the cloud of historic sample data collected prior to the 2008 Moon Fire.
    - Bedload samples collected during a winter storm on the South Fork Clear Creek may indicate a slight increase in unit bedload discharge over mainstem values.
    - Suspended sediment samples collected during pulse flows show the fairly strong hysteresis common to tailwater flow releases (fine sediment is gradually removed from the channel during steady flows).
    - The observed suspended sediment and bedload transport rates seem to indicate that the increase in sediment transport observed after the Moon Fire may be returning to background levels.

Gravel Injection Performance

- Above Paige Boulder Creek, spring pulse flows (and spills, if they happen) perform all of the geomorphic work on gravel injections.
- WY2012 spring pulse flows mobilized most Reach One injections, redepositing the gravels into complex bedforms 570-3,000 feet downstream.
- Winter storms of up to 1,870 cfs generally evacuate all of the Guardian Rock gravel placement site (downstream of Paige Boulder Creek), though spring pulse flows (~800 cfs) continue the advancement of the leading edge by as much as 850 feet.
- Given the current rates of replenishment, similar transport conditions, and a similar flow regime, spawning gravel could route completely through Reach two in about 62 years.
- 51 percent of Reach One is recharged with injected gravel and another 15 percent is charged with other gravels. Thus at similar rates of injection and a similar flow regime, Reach One could be completely charged in as little as 8 years.

Channel Response to Gravel Injection

- In addition to creating spawning habitat, in Reach One gravel injections have induced positive geomorphic changes which represent a change in the trajectory of Clear Creek's geomorphic response to impoundment (e.g. reduced channel dynamism, riparian confinement, reduced habitat quality):
    - Enhanced alluvial form and function
        - Highly dynamic complex bar sequences developing along the body and downstream fronts of gravel "waves" exhibit the following attributes:
            - They discourage riparian colonization which can enhance confinement and increase velocities thereby reducing storage capacity and juvenile salmonid habitat quality.
            - Riparian colonization can also "lock up" gravels available for transport, such as when Himalayan blackberry colonizes a gravel bar.

        - Complex flow patterns across depositional bedforms benefit numerous aquatic organisms by promoting a variety of hydraulic conditions: increased hyporheic flow, changes to depth, velocity and flow direction.
    - Mechanical disruption of established confining riparian vegetation decreases riparian confinement and increases woody debris delivery. Gravel lobes cause longitudinal disruption ("bulldozing" effect) as well as divert flow (as a function of bar height) toward banks causing undercutting and lateral scour.
- Increased mobility of armored riffles occurs as finer particles infiltrate and "lubricate" fossilized features. Large (>200mm) particles, covered in periphyton are often observed "floating" on exposed bars or gravelly riffles.
- Increased floodplain connectivity occurs as the result of gravel lobes decreasing channel capacity and forcing stream flow up out of the channel to flood low lying adjacent surfaces. Raising the water table also seems to increase the rate of alder mortality, again reducing riparian confinement and increasing woody debris loading.

Recommendations

The focus of this project was to evaluate sediment transport through Reach Two, the section of Clear Creek most limiting to achieving complete coarse sediment routing (GMA 2009, 2011). Gravel injection recommendations are specifically provided for the supply reach (Reach One) and the transport reach (Reach Two). Gravel injection recommendations for all sites downstream of Clear Creek Road (where the channel is more completely recharged within the less confined, more alluvial Central Valley Province and where extensive floodplain and channel restoration has occurred) is regularly discussed by the Clear Creek Technical Team. The team made 2014 recommendations for Clear Creek Road, Phase 3A, Tule Backwater, Phase 3C and Phase 3B during the June 2013 meeting. Additional gravel injection is planned as part of the Clear Creek Mercury Abatement project at the proposed Cloverview site (Lower Clear Creek Aquatic Habitat and Waste Discharge Improvement Project) just downstream from Reading Bar.

Spawning Gravel Injections

Whiskeytown

- The primary gravel supply into Reach One. As the upstream-most site, offers the potential to yield the most benefit as gravel deposits slowly migrate downstream.
- Volume (tons) – 3,000
- Frequency – as frequently as pulses/spills evacuate the cone – approximately every two years

Below Dog Gulch

- The original design volume has been met here but the gravel has not routed to Peltier. Though Whiskeytown gravel is beginning to arrive at this site, we strongly suggest replenishing Below Dog as a boost to the leading edge of Whiskeytown and to foster the positive geomorphic channel response described in Section 6.2.1.
- Volume (tons) – 2,000
- Frequency – every 1-2 years

Peltier Bridge

- Slope and channel distance will facilitate one more placement similar to the 2011 effort. The next placed riffle will likely backwater the next native riffle upstream which might slow the advancement of Below Dog gravels. Thus, this site is a lower priority than Below Dog.
- Volume (tons) – 1,000
- Frequency – once more, then only if deemed necessary after extremely high flows (e.g. >3,000 cfs).

Paige Bar

- When gravel from this site connects with the Paige Boulder delta riffle, (assuming full routing has been established upstream) full routing will likely be achieved from Whiskeytown to NEED Camp Bridge (see below). Once-buried bedrock fins within the body of the injection are re-emerging after the second flow season following the last placement, indicating ongoing gradual scour and highlighting the need for ongoing replenishment.

- Volume (tons) – 1,000
- Frequency – every 2 years

Above NEED Camp Bridge

At this time, we do not see a benefit to adding more gravel here as the feature is relatively immobile and by the time Paige gravels arrive, the placed gravels here may be routing through the pool and on into Reach Two.

- Volume (tons) - 0
- Frequency – 0

Guardian Rock

- A critical and highly efficient site for achieving complete routing through the system.
- Volume (tons) – 2,000-3,000
- Frequency – every 1-2 years

The Squeeze (“The Narrows”)

- This is a new site proposed by GMA in 2011 after several reconnaissance trips through the gorge. It is located 1.55 miles below the leading edge of Guardian rock gravels and 2.25 miles downstream of Paige Bar Road on Mule town Road (approximate location in Google Earth: 40°33’4.46”N, 122°31’48.95”W)
- Volume (tons) – 5,000
- Frequency – to be determined

Placer Road

- Gravel transport has increased dramatically (GMA 2011) since the increase in sand delivery from the South Fork. While habitat quality may be diminished (fines in spawning gravels), the sand has provided an unexpected boost toward achieving coarse sediment continuity by advancing the leading edge from 2,800 to 3,600 feet in one year (GMA 2011). This site was not mapped as part of this 2010-2013 project.
- Volume (tons) – 4,000

Frequency – every 2 years

Spring Pulse Flows

While the intent of the annual spring pulse flows on Clear Creek have more to do with fish (e.g. attraction flows for spring Chinook), they achieve a high degree of channel maintenance value as well, mobilizing injections and providing the driver for the positive geomorphic response described in Section 6.2.1.

Recommend continuing spring pulse flows (more important in drier years), but increasing magnitude to at least 1,000 cfs (at the dam base) to promote coarse sediment transport past the NEED Camp Gage.

Geomorphic Monitoring

Much of the future geomorphic monitoring for Clear Creek sediment-related phenomena has been proposed under the ongoing efforts to implement *The Environmental Water Program,* an ecological restoration strategy involving high flow spills through Clear Creek. Monitoring suggestions included here may (or may not) be covered by the EWP monitoring plan. We deem them relevant as they arose from the 2010-2013 efforts and relate to Reaches 1 and 2. In order of descending priority:

- Detailed topographic mapping at and below injection sites, after placement and after high flows.

- Integrate surveyed datasets with USFWS spawning habitat mapping data to expand utility (valuation of gravel placements versus fish use) and scope (the USFWS surveys remote, difficult to reach areas) of geomorphic assessments.
- Continued operation of NEED Camp streamgage – provides the only streamflow data for Reach One. Utility would be improved by the operation of a continuous stage recorder above or within Paige Boulder Creek to provide flow information for injections located above Paige Boulder Creek.
- Continued bedload sampling at both locations during very high flow events and pulse flows will improve predictive capability and can provide insight into sediment routing status (e.g. if the percentage of >8mm gravel in bedload samples increases, it may imply that routing has been achieved through the pool above NEED Camp Bridge; the <2mm fraction of bedload measured at Igo may indicate decreased sand production within the South Fork Clear Creek.
- Continue qualitative assessments of geomorphic response below gravel injections. Add a quantitative component (e.g. facies mapping, cross section surveys with water surface elevations, tracer gravel mobility studies, sediment transport capacity modeling, habitat mapping) to quantify and thus predict the effect of gravel injections as a passive restoration tool to achieve secondary restoration goals.

Potential Impact of Environmental Water Program Flows

The Clear Creek Environmental Water Program (EWP) could provide more frequent high flows by manipulating Whiskeytown Dam operations to facilitate mid-range peaks with a target magnitude of 3,250 cfs (as the 1 day average at the dam base) at a target frequency of not less than 4 of 10 years and up to 7 of 10 years (Stillwater 2013, *draft*). The last event of similar magnitude and duration was the 2003 Glory Hole spill which initiated numerous positive geomorphic effects in the lower reaches such as: floodplain deposition, channel migration, development of new alluvial features, bed mobilization and gravel transport (GMA 2003). Restored channels and floodplains generally functioned as designed and degraded channel segments were not recaptured (GMA 2003). As of 2003, little restoration work had occurred in the upper reaches (1 and 2), other than gravel injection at the base of Whiskeytown Dam. Since 2003, nearly 60,000 tons of gravel has been added in reaches One and Two (Table 7), leading to a substantial increase in spawning habitat (GMA 2011) and the variety of positive geomorphic changes described in this 2013 report (see section above).

While a thorough assessment of potential positive geomorphic impacts is well beyond the scope of this report, the data collected for this project suggest that some benefits EWP flows could provide might be:

- Increasing coarse sediment transport which might reduce the cost and effort to achieve complete routing.
- Enhance riparian scour both by mechanical disruption by entrained debris and by fluvial cutting at the toes of banks.
- Increased transport of injection gravels may increase the mobility of armored, previously immobile features.
- Spawning gravels distributed by natural flows tend to develop into more complex depositional features which exhibit a wider range of hydraulic conditions than can be achieved by mechanical placement (as in the case of channel evolution Below Dog Gulch).
- For Reach Two in particular, the limiting segment for complete routing of coarse sediment, EWP flows could greatly shorten the time to achieve complete routing.

While EWP flows could conceivably evacuate stored gravels from some productive areas (such as spawning riffles), the ecological cost of these impacts would likely be offset by the creation of new habitats. The restoration costs should also be lowered by the reduced effort required to maintain sediment routing once it is achieved: gravel could be placed in fewer locations along a stream that is fully supplied and experiences periodic high flows.

1. INTRODUCTION

1.1 Project Description

The purpose of this 2010-2013 Clear Creek Geomorphic Monitoring Project for US Bureau of Reclamation (USBR) is to evaluate sediment-related geomorphic issues (e.g. transport rate, distribution and abundance of spawning gravel) which govern key biological and ecological criteria (e.g. quality and quantity of salmon spawning habitat) and relate them to specific management objectives such as achieving complete coarse sediment routing. In response to US Bureau of Reclamation's Solicitation Number R10PS23016, Graham Matthews and Associates (GMA) proposed a study plan for 2010-2012 Clear Creek Geomorphic Monitoring -- Gravel Transport and Analysis. Funding was provided by the USBR under Order Number R10PX23016. Modification 001 provided an extension to the period of performance until September 30, 2013.

This report follows and builds upon numerous relevant studies focusing on Clear Creek sediment-related impacts, notably:

Clear Creek Geomorphic Monitoring Reports (GMA 2003-2007, 2011a);
Clear Creek Geomorphic Monitoring 2009-2011 (GMA 2011);
Clear Creek Gravel Injection Monitoring 2007-2009 (GMA 2009);
2006 Update to the Clear Creek Gravel Management Plan (GMA 2007a);
Dog Gulch Gravel Injection Design (GMA 2006a);
Final Report: Geomorphic Evaluation of Lower Clear Creek, downstream of Whiskeytown Reservoir (McBain and Trush 2001); and
Clear Creek Gravel Management Plan: Final Technical Report (McBain and Trush 2001).

The specific goal of the project is to increase understanding of one of the key physical limiting factors on Clear Creek: gravel transport through Reach Two (the seven mile bedrock gorge between Paige Bar Road and Clear Creek Road). The objectives are centered on sediment sampling, computing annual loads, making predictions regarding gravel recharge and providing recommendations for future gravel augmentation in Clear Creek. Tasks, objectives and deliverables are provided in Table 1.

Table 1. Objectives for 2010-2013 Clear Creek Bedload Sampling and Analysis.

TASK	OBJECTIVES	DELIVERABLES
Sediment Sampling	Conduct bedload sampling near NEED Camp and near Igo	Three hard copies of Final Report
	Determine grain size, compute transport rates and annual loads	
		A PDF of the report
Stream Gaging	Upgrade and operate a continuous stream gage at NEED Camp	
	Maintain with discharge measurements and compute annual records	A WORD 2003 copy of the report
Modeling	Expand upon previous studies and predicitons of time to recharge	
		Excel and Powerpoint files
Spawning Gravel Recommendations	Provide recommendations on volumes, frequency	
	and locations of gravel injections.	Seminal data on six CDs
Reporting	Produce (this) 2013 Final Report	
		All GIS files
Project Management	Attend meetings, provide geomorphic consultation	
	Submit progress reports	Maps provided as JPEG and PDF formats

1.2 Background

1.2.1 Physical Setting and Historic Impacts

Clear Creek originates on the eastern slope of the Trinity Mountains, and flows into Whiskeytown Lake (Elevation 1,210 ft), 11 miles west of Redding (Figure 1). The lower section of Clear Creek flows south from Whiskeytown Lake for approximately 9 miles, and then flows east for 8.5 miles before joining the Sacramento River five miles south of Redding. The drainage area of Clear Creek upstream of the USGS gaging station near Igo, CA (11372000) is 228 mi^2, most of which is regulated by Whiskeytown Dam. The below-dam drainage area above the Igo gage is 28.5 mi^2. Clear Creek is part of the Trinity River Division of the Central Valley Project, and Whiskeytown Dam has regulated streamflows since May 1963. The majority of natural inflow into Whiskeytown Reservoir from the upper Clear Creek watershed is diverted through the Spring Creek tunnel into the Sacramento River to generate power. Only a small percentage of the annual runoff (~38%) is released into Clear Creek downstream of Whiskeytown Dam (McBain & Trush 2001).

The impoundment-induced coarse sediment deficit and concomitant reduction in habitat quality in Clear Creek below Whiskeytown Dam has been well documented by various investigators (Coots 1971 as cited in McBain and Trush 2001, GMA 2003-2007, 2011). Effects of reduced coarse sediment supply include: riffle coarsening, fossilization of alluvial features, reduced rates of channel migration, loss of fine sediments available for overbank deposition and riparian re-generation, and a reduction in the amount and quality of spawning gravels available for anadromous salmonids.

Most of the reach from the dam to Clear Creek Road exhibits typical inner-gorge, bedrock-dominated morphology with a high degree of confinement and little alluvial storage. However, the upper-most two mile section from the dam down to NEED Camp is less steep, less confined, exhibits remnant alluvial features and hence, demonstrates potential for alluvial forms and processes to develop. Tributary sources of coarse sediment for the first 1.8 miles below the dam are extremely limited and contribute coarse sediment only during highly infrequent stochastic events. Colluvial sources (canyon walls) contribute virtually nothing within practical management timeframes and such material is of limited ecological value until it is transported and rounded over longer distances. Heavily vegetated gravel bars, coarse-cobble riffles and (post-dam) abandoned floodplains alternate with deep scour pools and bedrock-constricted chutes. Most spawning riffles in the reach have coarsened and appear relatively immobile as intermittent high flows from dam-spills and releases winnow, but lacking sediment input, do not replace finer material. Below Clear Creek Road, where the creek enters the reduced confinement and lower gradient of the Central Valley, the combination of gravel mining over-extraction and reduced coarse sediment supply led to channel down-cutting and a loss of channel dynamism and floodplain connectivity.

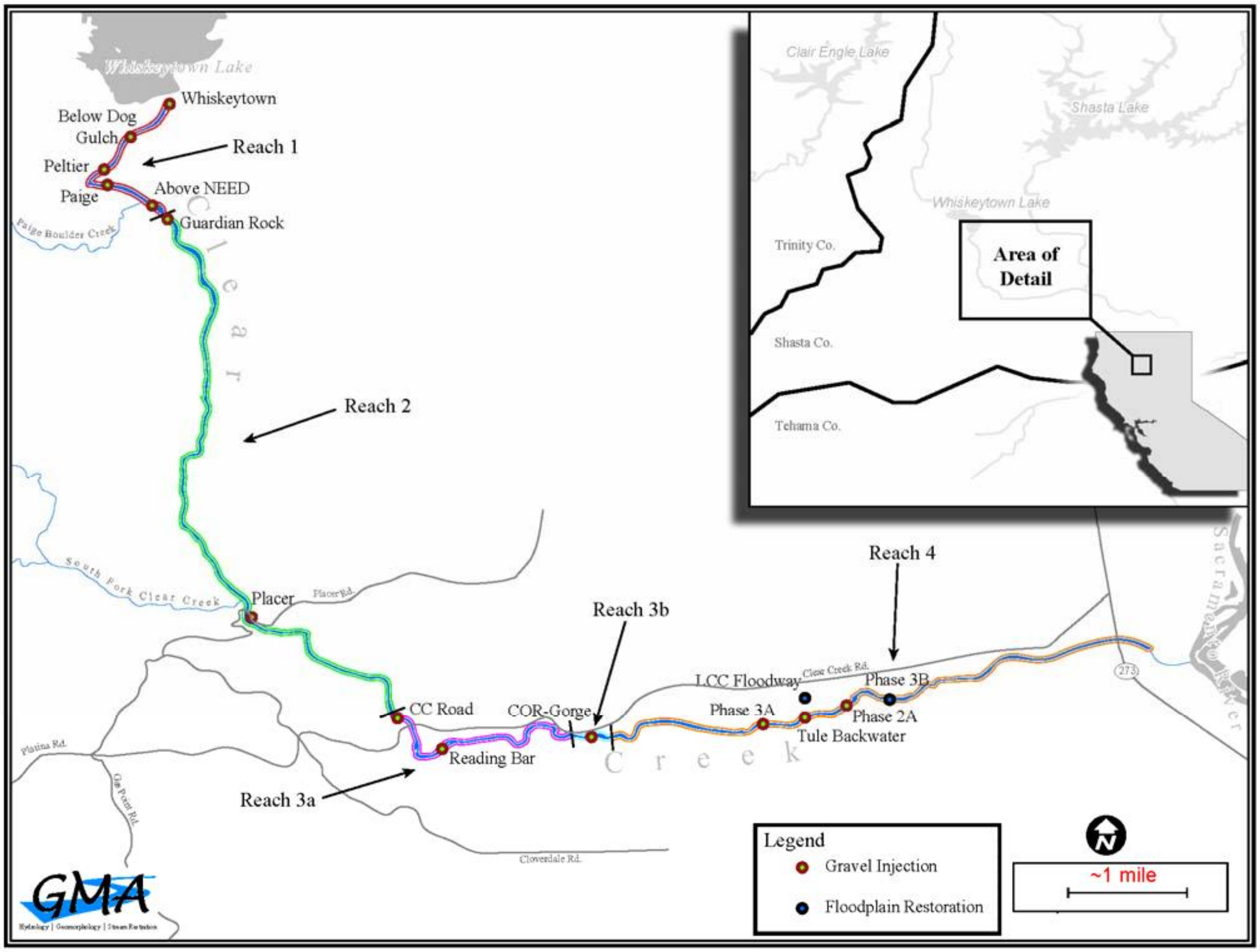

Figure 1. Clear Creek reach maps showing gravel injection locations*. In this report, we use the McBain and Trush geomorphic reach delineations.

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*Two sites which appear in USFWS gravel injection maps do not appear here:

NEED Camp Bridge -- was a pad of gravel associated with the construction of the bridge.

"Dino Pool" – was originally considered a separate site from Paige Bar, but immediately merged with Paige Bar gravel, so now generally considered the same site.

McBain & Trush (2001) summarized the effects of flow regulation and historic impacts on channel morphology in the lower river, as follows:

> *Downstream of Clear Creek Road, alluvial features were first placer mined, then dredged for gold. Mining in the 1800's destroyed most of the morphological features of the natural channel and floodplains. In 1903, flow and sediment regulation followed with construction of Saeltzer Dam (removed in 2001), and continued with completion of Whiskeytown Dam in 1963.*
>
> - *riparian encroachment along the low flow channel, and partial or complete fossilization of alluvial deposits downstream of Clear Creek bridge;*
> - *reduced very fine sediment supply and high flows to suspend them, reducing silt deposition on floodplains and reduced natural riparian floodplain regeneration, and floodplain formation processes;*
> - *reduced high flow regime that decreased the ability of the Clear Creek channel downstream of Clear Creek Bridge to migrate or avulse, transport bedload, form floodplains, and keep riparian vegetation from maturing along the low flow water edge;*
> - *channel incision to clay hardpan in many locations, general bed coarsening, and loss of alluvial storage in the reach downstream of Clear Creek Bridge, resulting from riparian confinement, lost coarse sediment supply from the upper watershed, and downstream aggregate mining.*

The reach delineations utilized for this study are those proposed by McBain and Trush 2001 (Figure 1):

1. Upstream alluvial reach from Whiskeytown Dam to just below the Paige Bar Bridge (2.1 miles),
2. Canyon Reach, upper bedrock gorge extending down to Clear Creek Road (7 miles),
3. Saeltzer Dam Reach is divided into two sub-reaches:
    - 3a. Low gradient alluvial reach from Clear Creek Road to Saeltzer Dam site (1.6 miles),
    - 3b. Saeltzer Gorge: 1,500 feet of confined bedrock gorge (0.3 miles)
4. Unconfined alluvial reach from Saeltzer Gorge to Sacramento River (6.5 miles).

River mile estimates vary according to the method of measurement, the alignment used and the planform existing at that particular time. In general, the Sacramento River is zero and the base of Whiskeytown Dam is Mile 17.5 to 18.

1.2.2 Restoration of the Physical Setting

Restoration efforts to address habitat degradation include actions ranging from temperature-control flow releases to relic dam destruction to exotic species removal. The focus for many project is on geomorphic restoration efforts such as higher flow releases, gravel injection and floodplain lowering, with a particular emphasis on gravel injection. The Lower Clear Creek Floodplain Restoration Project was designed to restore 1.7 miles of stream impacted by instream gravel mining and 0.5 miles of stream impacted by gold dredging. The project was designed to initiate rehabilitation by restoring a natural channel and floodplain morphology, and native riparian vegetation: (1) eliminate juvenile stranding mortality in off-channel mining pits, (2) improve adult migration through the mining reach, and (3) improve spawning and rearing habitat quantity and quality. The project was divided into four phases and included restoration of floodplains (Phases 1-3) and upland habitats upstream of the project (Reading Bar) where borrow activities were planned. Phase 1 of the project was completed in 1998 with funds provided through the Central Valley Project Improvement Act (CVPIA) and included construction of a natural bar (plug) to reduce stranding of juvenile salmon and improve passage conditions for adult salmon migrating upstream. Phase 2, completed in 2000 and 2001, initiated restoration of floodplains by filling aggregate extraction pits within the stream channel and floodplain. Phase 3A, completed in 2002, was the first portion of the project to involve active stream channel rehabilitation, improving floodplain connectivity, and revegetation of natural riparian communities. Phase 3B was completed in 2007 and diverted the channel away from a highly degraded and incised reach of exposed claypan. Later phases of the project are planned to continue moving downstream from Phase 3B, completing channel rehabilitation, floodplain construction, and finally, restoring flow into a section of historic stream channel diverted by aggregate extraction.

Restoration of a natural channel and floodplain, in combination with gravel injection and appropriate flow releases, should in theory initiate and sustain natural sediment transport processes thereby enhancing ecological function of the riverine ecosystem. Outside the Floodplain Restoration Project footprint, geomorphic restoration activities include gravel injections, pulse flow releases and floodplain lowering (at Reading Bar). Gravel injection sites have been developed at no less than 15 locations, most of which exist outside the floodplain project footprints.

Pulse flows have been limited to approximately 1,300 cfs by the dam’s outlet works. Until quite recently, such flows were believed to provide minimal geomorphic function (e.g. scour and re-deposition of coarse sediment). Following the development of the Guardian Rock (Below NEED) gravel injection site in 2005 however, it became apparent that these relatively minor flows (much smaller than the average annual post-dam peak flow) were capable of fulfilling a vital function in the restoration of Clear Creek: the mobilization and redistribution of injected gravel (GMA 2006a, 2009, 2011a).

In 2009, five new projects were developed in Reach One, within the Whiskeytown Natural Recreation Area (NRA), which placed gravel directly into the channel as riffle supplements of various types. The theory was that such placement would (1) provide short term benefit should the gravel not move for a long time (fish could spawn the gravel in-situ), and (2) that if spills or pulse flows did occur, the gravel prisms would provide a source for fluvial redistribution into more bars and riffles and that (3) these features would eventually become hydraulically linked to achieve complete coarse sediment routing through the reach.

By early 2010, over half of Reach One was “recharged” and the areal extent of spawning gravel had increased by 500 percent over 2001 levels (GMA 2009). While habitat conditions in Reach One have been vastly improved by gravel injections and mid-level pulse flows, gravel transport through Reach Two remains a major limiting factor impeding complete coarse sediment routing through Clear Creek (GMA 2009). Determining rates of coarse sediment transport into and out of Reach Two can aid in quantifying the deficit, inform predictions of recharge, and guide gravel injection efforts, which comprise the focus of this study.

1.2.3 Hydrologic Setting

The hydrologic setting for Clear Creek below Whiskeytown has been described extensively elsewhere (McBain and Trush 2001, GMA 2007a, 2011a) and is briefly summarized here.

In 1963, closure of Whiskeytown Dam cut off all but the highest flows which the dam passed as spill. Normal releases to the river were reduced to a very steady, very low flow (often < 100 cfs). The average annual peak at the USGS gaging station near Igo (11372000) was reduced from roughly 9,000 cfs to 4,000 cfs. The 2 year flood was reduced from 7,300 cfs to 2,800 cfs (Figure 2).

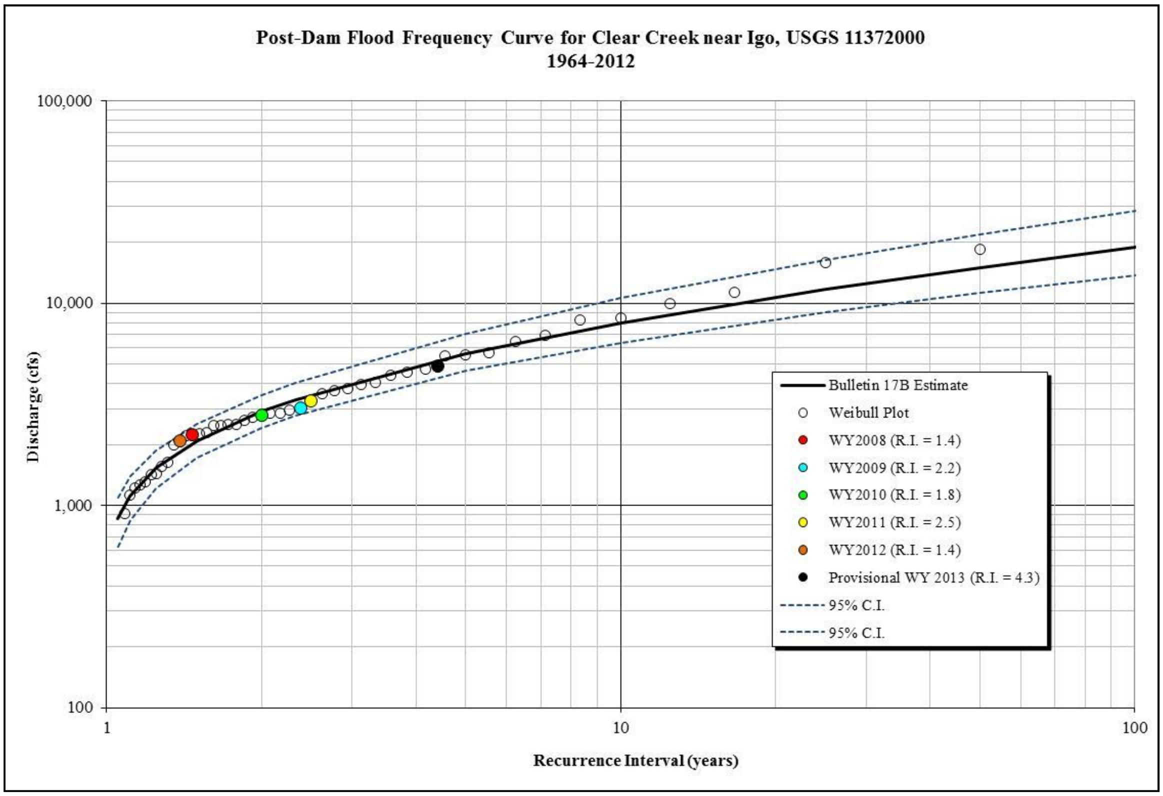


Figure 2. The flood frequency curve (post-dam) for USGS 11372000.

Three very different types of flood peaks exist in the post-dam regime:

1. Pulse flow releases create peaks which travel to the Igo gaging station (generally) unaffected by tributary accretion;
2. Peak flows resulting from below-dam runoff drive most of the peak events at the Igo gaging station though they generally have very little effect on Reach One (as the only large tributary enters near the downstream end of the reach); and
3. Highly infrequent Glory Hole spills from Whiskeytown Reservoir which range widely in duration and magnitude.

Therefore, the relative effect of pulse flows and spills is greater in Reach One, which rarely encounters flows greater than 200 cfs. At the Igo gaging station, peaks generated by pulse flows and spills are typically similar in magnitude to storm-generated peaks (often 1,000-3,000 cfs).

2. METHODS

2.1 TASK 1 – Sediment Sampling

The objective for this task was to quantify coarse sediment transport rates into and out of Reach Two. The upstream site was located just below the NEED Camp Bridge, adjacent to the stream gage which GMA installed for geomorphic monitoring purposes (Figure 3). The downstream boundary of Reach 2 (Clear Creek Road) offers a poor sampling opportunity, so the downstream site was located near the USGS gaging station near Igo (Figure 4). The cableway was initially anchored to the USGS anchors but was later moved 50 feet upstream.

Figure 3. Sampling location below the NEED Camp Bridge. Flow is from right to left in both 2010 photos.

Figure 4. Sediment sampling location near the USGS near Igo gaging station. Downstream and upstream views (2010 and 2011).

Triggers for sampling were flow predictions of:

>2,000 cfs at the Igo gage (http://www.cnrfc.noaa.gov/graphicalRVF.php?id=RDGC1) or

>1,000 cfs at NEED Camp based on Quantitative Precipitation Forecasts for rainfall in the upper Clear Creek basin (http://www.cnrfc.noaa.gov/awipsProducts/RNOHD6RSA.php).

Bedload sampling utilized a 12 inch TR-2 pressure difference bedload sampler deployed from a crane on a cataraft. The TR-2 is widely used for bedload sampling and offers performance superior to that of the better known Helley-Smith for river systems exhibiting bi-modal loads (large particles and high sand loads) in transport (Childers 1999, Pittman 2005). Mesh sampler bags utilized a 0.5mm mesh.Some wading samples were collected with a handheld Elwha, a 2/3 scale TR-2 bedload sampler.

An initial point (I.P.) was established on the stream bank and was used to anchor the tape for all measurements (Figure 5). Standard methods, as developed by the USGS and described in Edwards and Glysson (1998), were used. Beginning and end stations, sample interval, sample duration, start time and end time, beginning and end gage height, and pass number were recorded. Bedload samples were processed for total mass and a half-phi grain size analysis at the GMA coarse sediment laboratory in Placerville, California. A laboratory QAPP is available to interested parties.

Figure 5. Views of the Toutle River Number Two (TR-2) bedload sampler.

Depth-integrated suspended sediment sampling was performed at the Igo site. Sampling was performed using either a US DH-48 Depth-Integrating Suspended Sediment Sampler (for wadeable flows), a US DH-59 Depth-Integrating Suspended Sediment Sampler (rope-deployed from the cataraft at un-wadeable flows), or a D-74 Depth-Integrating Suspended Sediment Sampler (cable-deployed from a cataraft at un-wadeable flows). Standard methods, as developed by the USGS and described in Edwards and Glysson (1998) and in the GMA QAPP (GMA 2002), were used for sampling.

Suspended sediment concentrations were computed in the GMA sediment laboratory following USGS and ASTM D-3977 protocols. A laboratory QAPP is available to interested parties.

2.2 TASK 2 – Stream Gaging

A gaging station was developed at the NEED Camp site with permission from the National Park Service. Staff plates, crest gages and a continuous data collection platform (Campbell CR200 and Design Analysis H-310 pressure transducer). The purpose of gaging at this location is to quantify streamflow exiting Reach 1 and to be used in sediment load computations. Streamflow measurements were generally collected according to standard USGS protocols using wading or boat techniques and Price AA current meters. The gage was downloaded monthly and checked for drift periodically. Gage height records are converted to 15 minute discharge as follows.

All discharge measurements were entered and catalogued using a modified USGS-type 9-207 discharge measurement summary form. Stage/discharge relationships (rating curves) were developed and applied to the adjusted continuous-stage records to generate 15 minute discharge records. Discharge records were computed in the WISKI software suite, a comprehensive hydrologic time-series database management system developed by Kisters AG. The WISKI Suite incorporates complete USGS standards for surface water streamflow computations which utilize methods according to WSP 2175, Measurement and Computation of Streamflow vols.1 and 2 (Rantz 1982). The USGS Clear Creek gaging station near Igo (USGS 11372000) was used to compute sediment loads at the downstream site and to provide supporting historical data for the project -- for statistical examination of the hydrologic record (USGS 1982, Gordon et al, 1992).

2.3 TASK 3 – Modeling

The original intent of this task was to expand upon previous modeling efforts by Northern Hydrology and Engineering (NHE) to predict bed evolution and sediment transport into Reach Two. Upon consultation with NHE and USBR, it was determined that the task was under-funded and that other empirical monitoring and modeling techniques should be repeated (GMA 2006, 2009, 2011), specifically, the repeated topographic surveys of the primary source of gravel into Reach 2, the Reach 1 gravel injections. Such data provides the basis for volume change estimates and the computation of translation rates (the rate of downstream migration of the leading edge of gravel – an index of the rate of gravel recharge).Topographic surveys and aerial photographs provide the first level of resolution for planform monitoring. Channel trends relative to hydrologic events, design parameters and valley-scale features can be quickly assessed. Detailed topographic maps of the Reach 1 injection sites were developed. Cut-fill analyses, using the grid method, were performed for various purposes. Where possible, GMA surveyed relative to horizontal (NAD83) and vertical (NGVD29) control set by others.

Benchmark surveying was completed using the Trimble R8 Model 3 RTK (GPS) System. Mapping was completed using Leica 1201 Robotic Total Station, referenced to local benchmarks (Figure 6). The depth sounder used for bathymetry was the Ohmex Sonarmite V3 Echosounder. In the field, terrestrial topography points were surveyed in a rough grid fashion with an average approximate point density 15 feet apart, although actual point locations are chosen by topographic breaks rather than a set distance. The more topographically complex a section of ground or stream channel, the more points were required to accurately document topography. During field mapping, points were classified using the following point codes; bedrock, control monuments, other control points, project boundary, edge of water, tops, toes, normal ground surface shots, wet shots, gravel deposits, and thalweg.

All topographic point data were exported from Leica Geomatics Office software and incorporated into a Trimble Business Center project file where any necessary control adjustments were made. Additionally, projects were divided into distinct point groups based on standard survey practices and as modified for this specific project. The following list includes most of the point groups: control, temporary control, topography, and topography check points. The point groups and their associated breaklines define triangulated irregular network (TIN) surfaces which were developed for surveyed areas using Arc GIS 3D Analyst software.

Depending on point density and complexity, the TIN surfaces were then converted to either 1 or 2 foot DEM (Digital Elevation Model), which is a uniformly gridded representation of the data at a chosen resolution, to perform surface differencing (cut-fill) analysis. Raster calculator was used to develop isopachs to visually display areas of scour and aggradation which occurred between topographic surveys. A Spatial Analyst Cut-Fill tool was used to generate volume change amounts in cubic feet, which were then converted to cubic yards (then to tons using a 1.5 ton/CY multiplier) for comparison with injection amounts.

Figure 6. Total station and cataraft-based (GPS/RTK and depth sounder) survey platforms.

2.4 TASK 4 – Spawning Gravel Recommendations

Most of the other six tasks contributed to the completion of Task 6, and thus comprise the Methods for Task 6. Primarily, the survey data and the streamflow data facilitated evaluations of how much gravel was entrained by a given hydrologic event and how it was transported and distributed.

2.5 TASK 5 – Reporting

This report was produced in Microsoft WORD 2010 and Microsoft Excel 2010. All seminal files are included on a CD included with this report.

2.6 TASK 6 – Project Management

GMA senior staff attended numerous Clear Creek Technical Working Team (CCTT) meetings and field visits. GMA senior staff also responded to various phone conversations with CCTT team and core agency members, providing consultation for gravel injection and other restoration actions.

3.0 RESULTS

Tasks are re-ordered in this section to provide the logical discussion of:

Hydrology → Sediment Transport → Physical Change → Interpretation → Prediction

3.1 Streamflow

The below dam drainage area for the NEED Camp gage is 7.55 mi^2 versus 28.5 mi^2 for the USGS gage near Igo. Dog Gulch (0.9 mi^2) and Paige Boulder Creek (4.5 mi^2) contribute to the NEED Camp gage, while the USGS site receives flow contributions from several more creeks including Orofino, Stony, Salt, Kanaka and the South Fork of Clear Creek. The South Fork is the largest below-dam tributary with a drainage area of 9 mi^2.

The streamgage at NEED Camp provided a nearly continuous stage record for the entire study period with the following gaps due to battery failure or pressure transducer malfunction:

- October 1, 2010 0:00 – December 6, 2010 2:15
- January 28, 2011 12:15 – March 3, 2011 13:45

Staff height readings were compared to recorded gage height values and the stage height record was adjusted as follows:

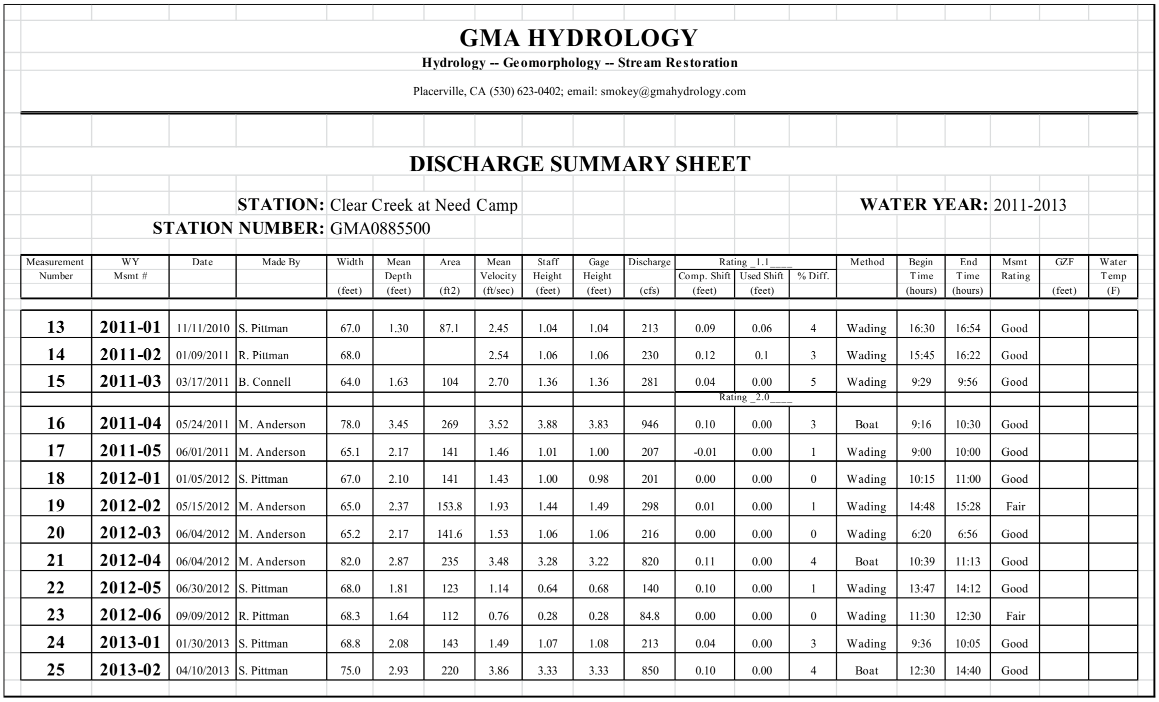
- From November 29, 2010 through March 3, 2011 a Global Water Level Logger was installed at the site and appeared to be drifting for unknown reasons. The gage height record was shifted to all staff height observations during that time period.
- On March 3, 2011 a Design Analysis H-310 pressure transducer and Campbell CR200 Data Collection Platform were installed. For the remainder of the computational period the H-310 remained fairly consistent and a consistent gage height correction was applied to the record.
- During periods of high stage (>4ft), there appears to be a difference between the water surface elevation at the staff plate location (left bank) and the pressure transducer location (right bank). To account for this difference, a slightly higher gage height correction was applied to the gage height for stages greater than 4 ft.

Thirteen discharge measurements were collected during the study period (140-946 cfs, Table 2) in addition to twelve measurements that were collected as part of a previous project from 2007-2010 (140-1,310 cfs). Rating 1.0 was developed in Microsoft Excel (for the previous project) and was inserted into SKED, a rating curve development program, for use in the WISKI Hydrologic Database system. Rating 1.0 wasmodified to Rating 1.1 and used to compute a portion of the instantaneous discharge record from the 15 minute stage data. Rating 2.0 was developed in SKED for the second portion of the project period. Shifts and assumptions were employed as follows:

- A hydrographic comparison of that record with USGS gage Clear Creek near Igo, CA indicated that Rating 1.0 was under predicting discharge below a stage of 0.8 ft (approximately 130 cfs). Rating 1.0 was modified to Rating 1.1, which was used from October 1, 2010 through March 26, 2011 at 01:30.
- Measurements 12 and 13, taken on February 22, 2010 and November 11, 2010 indicate a low end shift to Rating 1.1, which likely occurred during the January 22, 2010 storm event. A positive stage variable shift was applied to Rating 1.1 from January 22, 2010 until December 28, 2010.
- Measurements 14 and 15, taken on January 9, 2011 and March 17, 2011 indicate that a new shift occurred to Rating 1.1. A second positive stage variable shift was applied to Rating 1.1 from December 28, 2010 until March 26, 2011.
- Measurements collected after the March 26, 2011 storm event show a new stage versus discharge relationship. Measurements 16 through 23, taken from May 24, 2011 through September 9, 2012 were used to develop Rating 2.0.

Rating 2.0 was used to compute discharge from March 26, 2011 through the end of the project period (Figure 7). A rating table was developed for field use and is provided in Appendix 1. The aforementioned gaps in the stage record were filled as “estimated” using scaled discharge from the USGS near Igo station’s final approved record (Figure 8).

Table 2. Discharge measurement summary for Clear Creek below NEED Camp WY2011-2013.



GMA HYDROLOGY

Hydrology -- Geomorphology -- Stream Restoration

Placerville, CA (530) 623-0402; email: smokey@gmahydrology.com

DISCHARGE SUMMARY SHEET

STATION: Clear Creek at Need Camp

STATION NUMBER: GMA0885500

WATER YEAR: 2011-2013

Measurement Number	WY Msmt #	Date	Made By	Width (feet)	Mean Depth (feet)	Area (ft2)	Mean Velocity (ft/sec)	Staff Height (feet)	Gage Height (feet)	Discharge (cfs)	Rating _1.1____ Comp. Shift (feet)	Used Shift (feet)	% Diff.	Method	Begin Time (hours)	End Time (hours)	Msmt Rating	GZF (feet)	Water Temp (F)
13	**2011-01**	11/11/2010	S. Pittman	67.0	1.30	87.1	2.45	1.04	1.04	213	0.09	0.06	4	Wading	16:30	16:54	Good		
14	**2011-02**	01/09/2011	R. Pittman	68.0			2.54	1.06	1.06	230	0.12	0.1	3	Wading	15:45	16:22	Good		
15	**2011-03**	03/17/2011	B. Connell	64.0	1.63	104	2.70	1.36	1.36	281	0.04	0.00	5	Wading	9:29	9:56	Good		
											Rating _2.0____								
16	**2011-04**	05/24/2011	M. Anderson	78.0	3.45	269	3.52	3.88	3.83	946	0.10	0.00	3	Boat	9:16	10:30	Good		
17	**2011-05**	06/01/2011	M. Anderson	65.1	2.17	141	1.46	1.01	1.00	207	-0.01	0.00	1	Wading	9:00	10:00	Good		
18	**2012-01**	01/05/2012	S. Pittman	67.0	2.10	141	1.43	1.00	0.98	201	0.00	0.00	0	Wading	10:15	11:00	Good		
19	**2012-02**	05/15/2012	M. Anderson	65.0	2.37	153.8	1.93	1.44	1.49	298	0.01	0.00	1	Wading	14:48	15:28	Fair		
20	**2012-03**	06/04/2012	M. Anderson	65.2	2.17	141.6	1.53	1.06	1.06	216	0.00	0.00	0	Wading	6:20	6:56	Good		
21	**2012-04**	06/04/2012	M. Anderson	82.0	2.87	235	3.48	3.28	3.22	820	0.11	0.00	4	Boat	10:39	11:13	Good		
22	**2012-05**	06/30/2012	S. Pittman	68.0	1.81	123	1.14	0.64	0.68	140	0.10	0.00	1	Wading	13:47	14:12	Good		
23	**2012-06**	09/09/2012	R. Pittman	68.3	1.64	112	0.76	0.28	0.28	84.8	0.00	0.00	0	Wading	11:30	12:30	Fair		
24	**2013-01**	01/30/2013	S. Pittman	68.8	2.08	143	1.49	1.07	1.08	213	0.04	0.00	3	Wading	9:36	10:05	Good		
25	**2013-02**	04/10/2013	S. Pittman	75.0	2.93	220	3.86	3.33	3.33	850	0.10	0.00	4	Boat	12:30	14:40	Good		

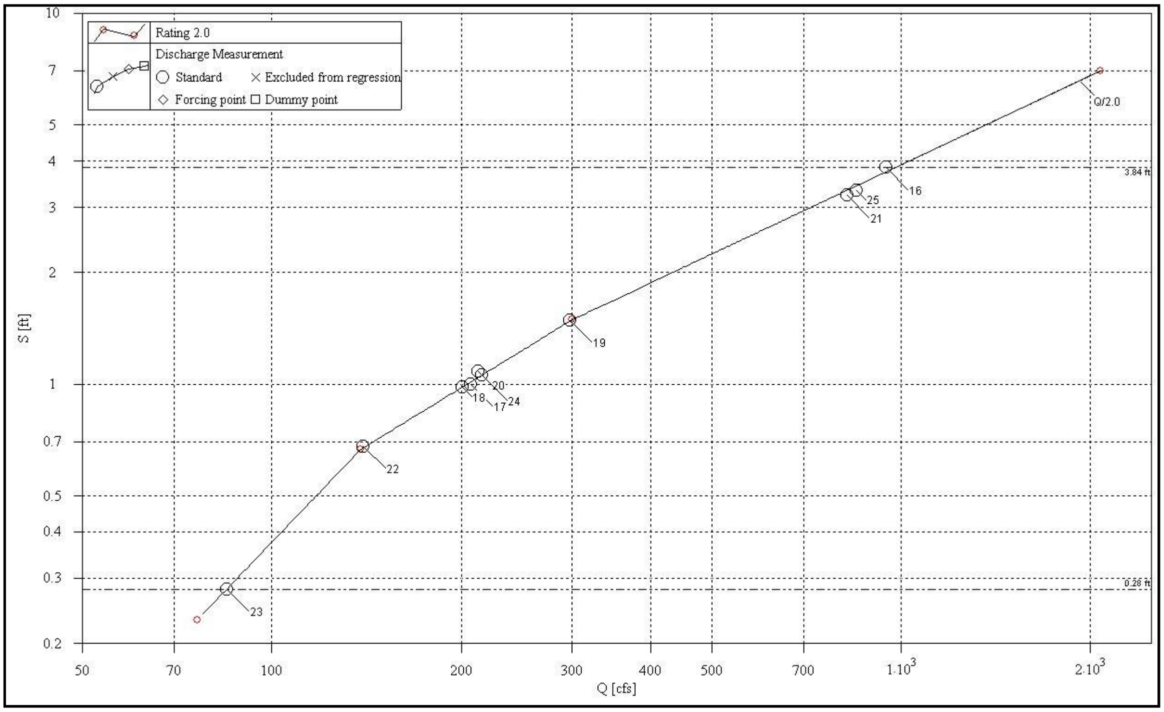


Figure 7. Rating 2.0 for Clear Creek below NEED Camp.

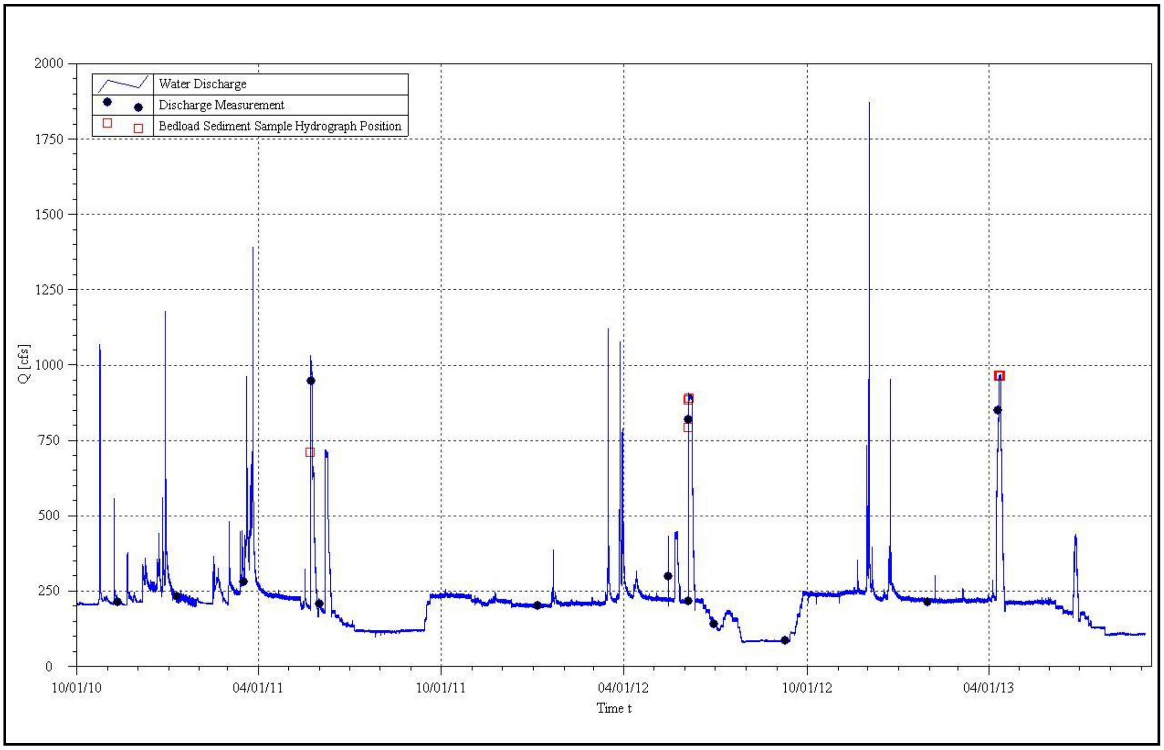


Figure 8. WY2011-2013 hydrograph for Clear Creek below NEED Camp.

During the study period (WY 2011-2013), Clear Creek below NEED Camp encountered two types of peak flows: spring pulse flows of 600 to 1,100 cfs, (no Glory Hole spills) and storm-driven winter peaks of up to 1,870 cfs on December 2, 2012. Readings from a crest stage recorder located on Paige Boulder Creek, applied to the historic NPS rating, indicate that the largest peak flows are routed down Paige Boulder Creek (~1/4 mile upstream) and thus have little influence on Reach 1. The importance of the NEED Camp discharge record is that it:

- Provides a check on Whiskeytown dam release magnitude;
- For Pulse Flows, describes streamflow through Reach 1;
- Provides the discharge record for sediment load computation out of Reach 1;
- In conjunction with flows from Orofino Gulch (just below the NEED Camp gage):
    - describes streamflow which mobilizes the Guardian Rock (Below NEED) injection;
    - describes streamflow into Reach 2.

At the USGS gaging station near Igo, peak flows were much higher and generally corresponded to peaks measured near NEED Camp (Figure 9). Five storm events over the three year period exceeded the sampling threshold trigger of 2,000 cfs and only two of these exceeded 3,000 cfs (March 26, 2011 and December 2, 2012). The flood frequency analysis (Figure 2) reveals recurrence intervals of 2.5 and 4.3 years respectively. The 4.3 year peak (4,920 cfs) was of extremely short duration. The period exceeding 2,000 cfs lasted only five hours from 12/2/2012 02:30 to 12/2/2012 07:30. At NEED Camp, the period exceeding 1,000 cfs lasted six hours, from 01:00 to 07:00 on the same day.

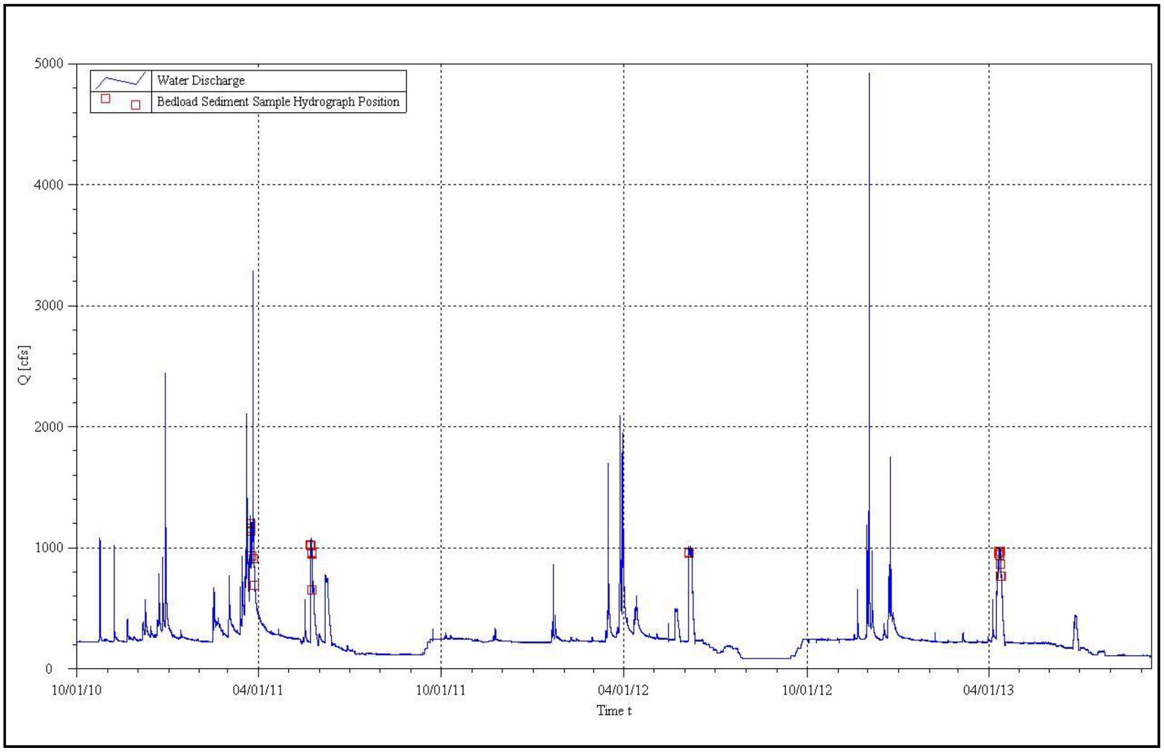


Figure 9. The WY2011-2013 discharge hydrograph for USGS Clear Creek near Igo (#11372000).

3.2 Sediment Transport

Definitions useful for this section:

> *Sediment discharge: an instantaneous sediment transport rate, expressed in mass or volume per unit time (tons/day). For example, "a bedload discharge of 12 tons/day was measured at the NEED camp monitoring station, measurement #8 at 12:15 on 5/4/11"; and*
>
> *Sediment load: a mass or volume of sediment transported over a pre-defined period of time (tons) – this is the rate (sediment discharge) integrated over a period of time. For example, "3 tons of bedload were transported past the NEED camp monitoring station during the WY 2011 Spring Flow Release."*

Typically, sediment discharge describes sediment that was measured while in transport, and load describes the amount collected or computed over a given time period. A useful comparison is with streamflow: discharge is the instantaneous rate (cfs) and yield is the volume over time (acre feet).

3.2.1 Introduction

Within the original contract period, only four events exceeded 2,000 cfs and two events were of sufficient duration to be considered a potential sampling event. GMA responded to one of these events as well as the 2011-2013 spring pulse flows (Figure 9). Further, a glory hole Spill was forecast for the late-March 2011 storm and GMA staffed a large response effort – the spill however did not occur. During the only event to exceed 3,000 cfs, the USGS occupied the Igo sampling section (the USGS cableway at Igo) precluding sediment data collection efforts (the GMA sampling cableway was subsequently relocated). The contract period was extended for another sampling season in the hopes that WY2013 would provide additional sampling opportunities. The only potential sampling event that occurred in WY2013 was the poorly forecasted December 2 storm, which came and went at night in 6 hours. Thus, sampling efforts for the three year period describe flows under 2,000 cfs at both stations.

The emphasis of this study was to examine rates of spawning gravel transport, thus the <2mm fraction was not computed at NEED Camp. At the Igo sampling location, where the stream channel has been impacted by sand transport from the South Fork of Clear Creek (GMA2011a), both greater-than and less-than 2mm bedload was computed.

3.2.2 Sediment Transport at NEED Camp

Bedload sediment data derived from particle-size analysis are presented here in various forms:

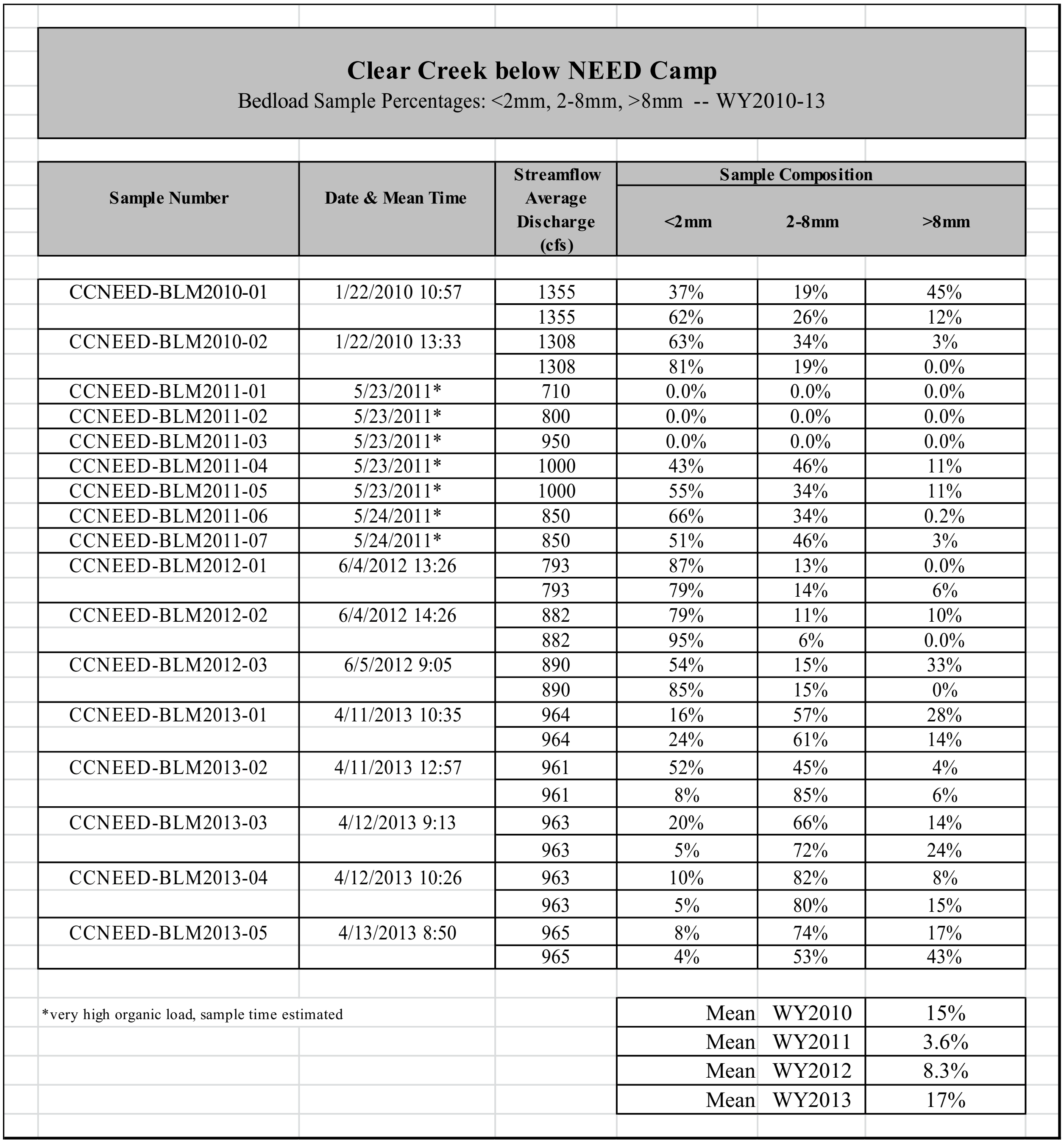
- Sample composition describes the relative percentages of various sizes classes contained in individual samples but does not include transport rate information (Table 3),
- Bedload discharge (tons/day) greater and less than 2mm describes transport rates of sand and everything larger than sand for each sample (Table 4),
- Sample particle size analyses are presented as curves of cumulative percent finer-than (Figure 10) and computed size fractions (e.g. D50) are presented numerically (Table 5),
- Equations relating stream discharge to sediment transport (Figure 11) are developed from the bedload discharge data (Table 4), and
- These equations are integrated over the continuous discharge record to compute loads (in tons) for various time periods (Table 6).

Twenty-seven bedload passes were completed between January 2010 and May 2013 at flows up to 1360 cfs. Samples were collected during three spring pulse flows and two winter storms (Figure 9). Numerous zero-transport samples were measured, indicating that bedload transport appears to begin at flows in the range of 700-800 cfs (Table 4). Some WY2011 samples were omitted from sediment load computations as the meta-data was not recovered and bedload discharge could not be computed from these samples. The 2011 samples are however included in the particle size analyses of sample composition (Table 3) which breaks out bedload sample percentages into <2mm, 2-8mm and >8mm, providing an examination of the relative abundance of sand, pea gravel and spawning-sized gravel in the load. Looking at the average >8mm component within each water year yields (Table 3):

- WY2010 = 15%
- WY2011 = 3.1%
- WY2012 = 8.3%
- WY2013 = 17%

Samples collected within the WY2011-2013 study period were collected at similar flows and though the sample sizes are small, the data may indicate that the >8mm fraction is increasing. The 2010 data represents a single high flow event, a storm/spill and may be biased by the inclusion of a single large particle in the first pass.

Table 3. Bedload sample composition, Clear Creek below NEED Camp: 2010-2013.



Clear Creek below NEED Camp

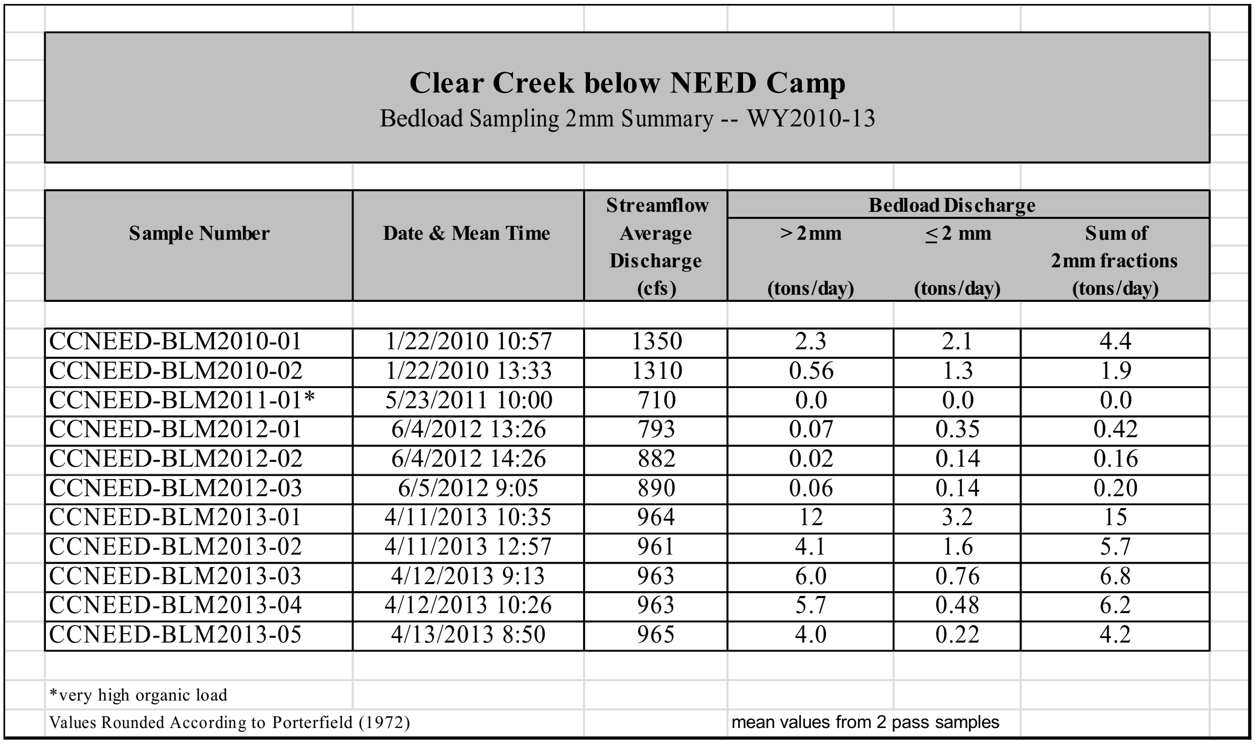
Bedload Sample Percentages: <2mm, 2-8mm, >8mm -- WY2010-13

Sample Number	Date & Mean Time	Streamflow Average Discharge (cfs)	Sample Composition		
			<2mm	2-8mm	>8mm
CCNEED-BLM2010-01	1/22/2010 10:57	1355	37%	19%	45%
		1355	62%	26%	12%
CCNEED-BLM2010-02	1/22/2010 13:33	1308	63%	34%	3%
		1308	81%	19%	0.0%
CCNEED-BLM2011-01	5/23/2011*	710	0.0%	0.0%	0.0%
CCNEED-BLM2011-02	5/23/2011*	800	0.0%	0.0%	0.0%
CCNEED-BLM2011-03	5/23/2011*	950	0.0%	0.0%	0.0%
CCNEED-BLM2011-04	5/23/2011*	1000	43%	46%	11%
CCNEED-BLM2011-05	5/23/2011*	1000	55%	34%	11%
CCNEED-BLM2011-06	5/24/2011*	850	66%	34%	0.2%
CCNEED-BLM2011-07	5/24/2011*	850	51%	46%	3%
CCNEED-BLM2012-01	6/4/2012 13:26	793	87%	13%	0.0%
		793	79%	14%	6%
CCNEED-BLM2012-02	6/4/2012 14:26	882	79%	11%	10%
		882	95%	6%	0.0%
CCNEED-BLM2012-03	6/5/2012 9:05	890	54%	15%	33%
		890	85%	15%	0%
CCNEED-BLM2013-01	4/11/2013 10:35	964	16%	57%	28%
		964	24%	61%	14%
CCNEED-BLM2013-02	4/11/2013 12:57	961	52%	45%	4%
		961	8%	85%	6%
CCNEED-BLM2013-03	4/12/2013 9:13	963	20%	66%	14%
		963	5%	72%	24%
CCNEED-BLM2013-04	4/12/2013 10:26	963	10%	82%	8%
		963	5%	80%	15%
CCNEED-BLM2013-05	4/13/2013 8:50	965	8%	74%	17%
		965	4%	53%	43%

*very high organic load, sample time estimated

Mean	WY2010	15%
Mean	WY2011	3.6%
Mean	WY2012	8.3%
Mean	WY2013	17%

Table 4. Bedload sampling summary for Clear Creek below NEED Camp: 2010-2013.



Clear Creek below NEED Camp

Bedload Sampling 2mm Summary -- WY2010-13

Sample Number	Date & Mean Time	Streamflow Average Discharge (cfs)	Bedload Discharge > 2mm (tons/day)	Bedload Discharge ≤ 2 mm (tons/day)	Bedload Discharge Sum of 2mm fractions (tons/day)
CCNEED-BLM2010-01	1/22/2010 10:57	1350	2.3	2.1	4.4
CCNEED-BLM2010-02	1/22/2010 13:33	1310	0.56	1.3	1.9
CCNEED-BLM2011-01*	5/23/2011 10:00	710	0.0	0.0	0.0
CCNEED-BLM2012-01	6/4/2012 13:26	793	0.07	0.35	0.42
CCNEED-BLM2012-02	6/4/2012 14:26	882	0.02	0.14	0.16
CCNEED-BLM2012-03	6/5/2012 9:05	890	0.06	0.14	0.20
CCNEED-BLM2013-01	4/11/2013 10:35	964	12	3.2	15
CCNEED-BLM2013-02	4/11/2013 12:57	961	4.1	1.6	5.7
CCNEED-BLM2013-03	4/12/2013 9:13	963	6.0	0.76	6.8
CCNEED-BLM2013-04	4/12/2013 10:26	963	5.7	0.48	6.2
CCNEED-BLM2013-05	4/13/2013 8:50	965	4.0	0.22	4.2

*very high organic load

Values Rounded According to Porterfield (1972)

mean values from 2 pass samples

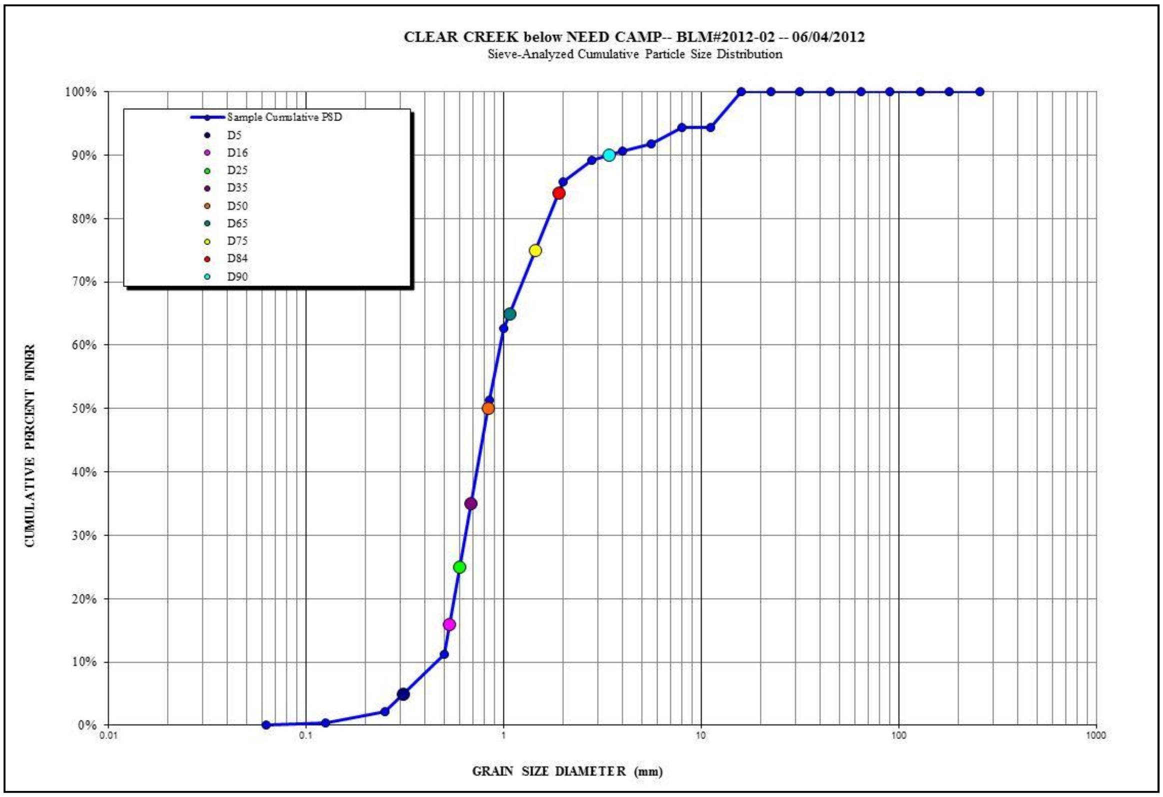


Figure 10. An example particle size distribution developed from sieve data for a bedload sample collected at NEED Camp.

Table 5. Size fractions for bedload samples collected at NEED Camp WY2010-2013.

	2010-01 (mm)	2010-02 (mm)	2011-04 (mm)	2011-05 (mm)	2011-06 (mm)	2011-07 (mm)	2012-01 (mm)	2012-02 (mm)	2012-03 (mm)	2013-01 (mm)	2013-02 (mm)	2013-03 (mm)	2013-04 (mm)	2013-05 (mm)
D5	0.52	0.43	0.56	0.50	0.50	0.55	0.49	0.3	0.5	0.9	0.9	1.1	1.4	2.0
D16	0.72	0.60	0.91	0.80	0.80	0.87	0.61	0.5	0.7	1.6	1.3	2.1	2.2	2.3
D25	0.93	0.72	1.20	1.00	1.00	1.12	0.71	0.6	0.8	2.1	1.8	2.4	2.4	2.6
D35	1.28	0.87	1.59	1.30	1.20	1.40	0.85	0.7	1.0	2.4	2.2	2.6	2.7	3.1
D50	2.13	1.21	2.34	1.80	1.50	1.95	1.05	0.8	1.4	2.8	2.6	3.3	3.3	4.2
D65	5.00	1.75	3.35	2.50	2.00	2.52	1.40	1.1	1.9	3.8	3.2	4.5	4.2	8.5
D75	16.51	2.33	4.46	3.40	2.40	3.07	1.71	1.4	2.6	5.2	3.8	6.2	5.2	14.0
D84	46.34	3.25	6.28	5.10	2.80	3.86	2.09	1.9	9.1	10.9	4.9	9.7	6.7	22.8
D90	52.31	4.28	8.59	8.80	3.40	4.86	2.79	3.4	25.2	50.2	6.0	14.4	8.7	32.2

Size fractions computed from grain size analyses (Figure 10) for the samples showing greater than zero transport are provided in Table 5. Although the D50 (fraction for which 50 percent of the sample is smaller) is quite small (typically 1-2mm), it appears to be growing coarser in the 2013 samples.

Bedload discharge (tons/day) for each sample was computed (Table 4) using the standard formula relating bedload discharge to sampler width, sample mass, channel width and the amount of time the sampler spends on the bed (Edwards and Glysson 1999):

$$Qb = K \times (WT/tT) \times MT$$

where

Qb	is bedload discharge in tons/day,
K	is a conversion factor (0.095 for a 12 inch sampler)
WT	is the sampled width of the river, in feet,
tT	is the total time in seconds that the sampler was on the bed, and
MT	is the sample mass in grams for the size class being computed.

Annual loads were then computed for all three water years for the >2mm size class. Ten 2-pass composites and one 1-pass zero-transport sample (Table 4) were utilized in annual load computations. Samples collected during 2010 and 2012 were used to develop the generalized regression (Figure 11).

The >2mm bedload discharge (BLD) transport curve is represented by the equation (Figure 11):

$$BLD = 2.9715 * 10^{-8} \left(Discharge - 700 \right)^{2.70262}, \quad r^2 = 0.99$$

Samples collected during 2013 showed higher transport and were not used in transport curve development. The higher transport rate was accounted for in 2013 continuous bedload discharge computations by shifting to measurements as described below.

- Zero transport was estimated at 700 cfs based on field observations and sample BLM2011-01 collected on May 23, 2011, which showed no bed material in transport.
- Once the continuous bedload discharge data had been developed, the sample data were used to adjust the bedload discharge so that it passed through all sample points.
- The continuous bedload discharge curve was adjusted to the samples using fitting and proportional fitting techniques.

Annual loads are provided in Table 6. Un-sampled periods are considered rough estimates. As expected, coarse sediment load exiting Reach One is very low, though transport rates did increase in 2013 resulting in an annual load of 11.7 tons, most of which (95%) was transported during the spring pulse flow (Table 6). The coarse sediment load into Reach Two is thus dominated by the gravel injection below the sampling site near Guardian Rock where 1,000 to 3,000 tons (Table 7) were injected each year during the study.

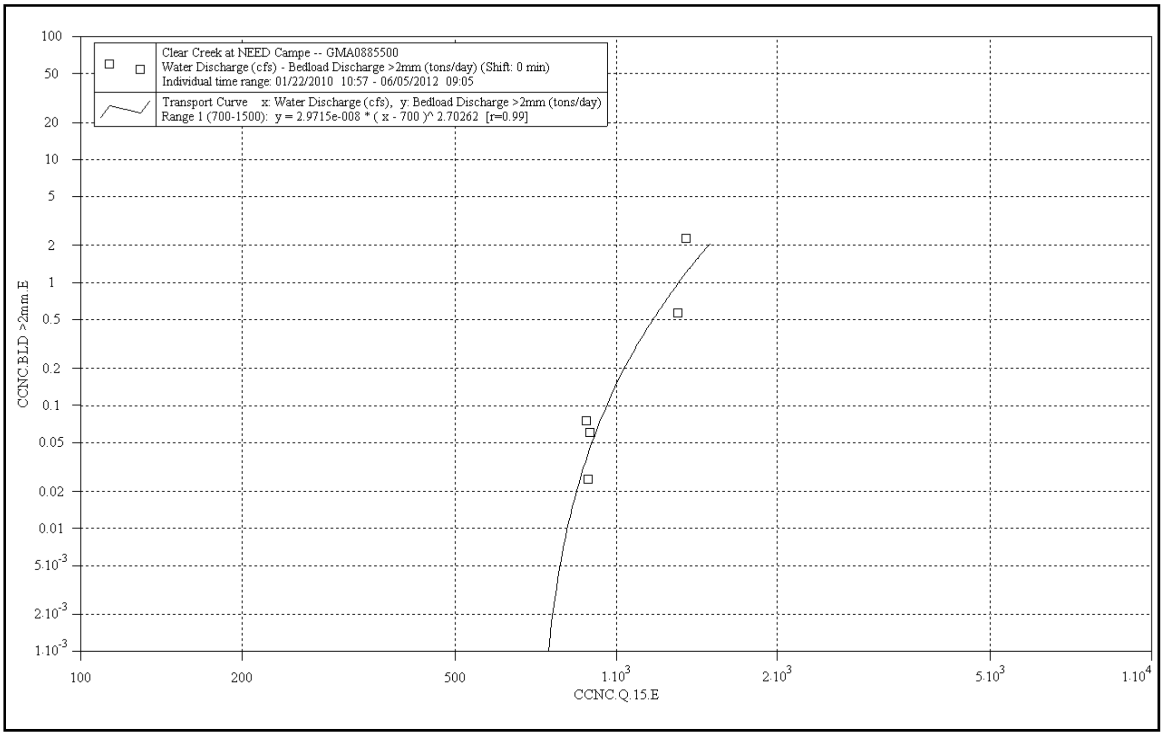


Figure 11. The generalized >2mm sediment transport curve (stream discharge vs bedload discharge) for Clear Creek at NEED Camp: 2010-2013.

Table 6. WY2011-2013 annual bedload sediment loads for Clear Creek below NEED Camp and Igo.

Clear Creek Sediment Loads

Annual Bedload Summary -- WY2011-2013

Clear Creek below NEED Camp -- GMA0885500

Full Water Year	≤2mm (tons)	>2mm (tons)	Sum of Partials (tons)		Pulse Flow	≤2mm (tons)	>2mm (tons)	Percent of annual load
2011	NA	0.45	NA		2011	NA	0.16	36%
2012	NA	0.24	NA		2012	NA	0.20	82%
2013*	NA	11.7	NA		2013	NA	11.2	95%

*WY 2013 computed through September 10, 2013.

Table 7. Clear Creek gravel injection totals (in tons) by site: 1996-2013. Parentheses include other common names. *Source: CCTT working document compiled from USFWS, USBR, WSRCD documents.*

Year	Whiskeytown	Below Dog Gulch (Dog Gulch)	Peltier Sluicing Site	Paige Bar	Above Need Camp (Need)	Below Need Camp (Guardian Rock)	Placer Bridge	Clear Creek Road Bridge	Reading Bar	City of Redding (Gorge)	Phase 3A (North Moon and Pump)	Tule Back water	Phase 2A (Grove)	LCC Floodway	Total
1996	0	0	0	0	0	0	0	0	0	7,500	0	0	0	0	7,500
1997	0	0	0	0	0	0	0	0	0	3,500	0	0	0	0	3,500
1998	4,498	0	0	0	0	0	0	0	0	4,501	0	0	0	0	8,999
1999	3,500	0	0	0	0	0	0	0	0	4,501	0	0	0	0	8,001
2000	3,500	0	0	0	0	0	3,001	0	0	4,500	0	0	0	0	11,001
2001	2,500	0	0	0	0	0	3,000	0	0	7,001	0	0	0	0	12,501
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	13,125	13,125
2003	0	0	0	0	0	0	4,799	1,001	1,000	3,448	0	0	0	0	10,248
2004	4,258	0	0	0	0	0	4,999	1,000	0	2,001	0	0	0	0	12,258
2005	2,000	0	0	0	0	1,001	4,003	1,002	0	0	1,729	0	0	0	9,735
2006	0	0	0	0	0	2,601	0	0	0	0	0	0	0	0	2,601
2007	3,000	0	0	0	0	0	5,000	0	0	0	2,000	0	0	20,350	30,350
2008	1,000	0	0	0	0	0	2,997	0	0	0	1,483	0	3,005	0	8,485
2009	0	1,003	769	1,786	981	1,228	0	0	0	0	0	0	0	0	5,767
2010	0	1,000	0	0	0	1,000	0	1,450	0	0	3,000	1,200	640	0	8,290
2011	3,000	2,000	1,000	1,000	0	3,000	0	0	0	0	0	0	0	0	10,000
2012	0	0	0	0	0	2,018	4,471	1,498	0	0	0	1,987	0	0	9,974
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**27,256**	**4,003**	**1,769**	**2,786**	**981**	**10,848**	**32,270**	**5,951**	**1,000**	**36,952**	**8,212**	**3,187**	**3,645**	**33,475**	**172,335**
2010-2012	**3,000**	**3,000**	**1,000**	**1,000**	**0**	**6,018**	**4,471**	**2,948**	**0**	**0**	**3,000**	**3,187**	**640**	**0**	**28,264**

3.2.3 Sediment Transport at Igo

Forty eight bedload passes were collected at the Igo site between May 2010 and April 2013 at flows of 253-1,190 cfs. The fraction of the samples finer than 2mm ranged from 52-99 percent but averaged 70-76 percent in Water Years 2011-2013 (Table 8). The >8mm component is very small and does not appear in many samples – the highest percentage of >8mm was 2 percent in two of the 2013 samples (Table 8). Passes were composited into the 25 samples in Table 9 and bedload discharge was computed from the greater and less than 2mm sample data.

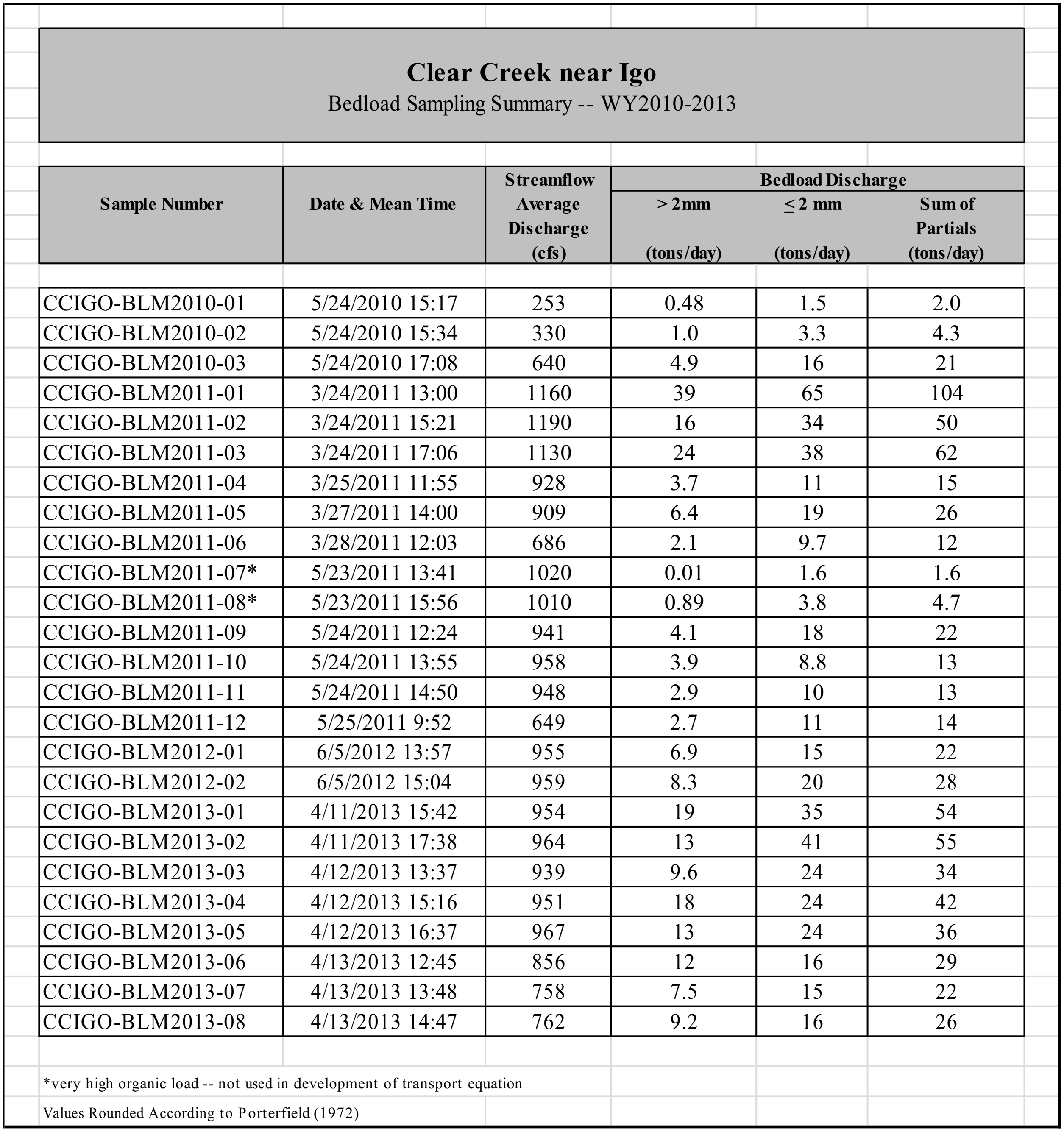
Size fractions computed from grain size analyses (Figure 10) for the bedload samples are provided in Table 10. The D50 of all samples is smaller than 2mm and the largest D90 is only 4mm, compared to D90s of over 50mm at NEED Camp (Table 5).

Table 8. Bedload sample composition for Clear Creek near Igo: WY2010-2013.

Clear Creek near Igo
Bedload Sample Percentages: <2mm, 2-8mm, >8mm -- WY2010-2013

Sample Number	Date & Mean Time	Streamflow Average Discharge (cfs)	Sample Composition		
			<2mm	2-8mm	>8mm
CCIGO-BLM2010-01	5/24/2010 15:17	253	76%	24%	0%
CCIGO-BLM2010-02	5/24/2010 15:34	330	76%	24%	0%
CCIGO-BLM2010-03	5/24/2010 17:08	640	76%	24%	0%
CCIGO-BLM2011-01	3/24/2011 13:00	1160	63%	36%	1%
			68%	31%	0%
			58%	40%	1%
CCIGO-BLM2011-02	3/24/2011 15:21	1190	70%	30%	0%
			68%	32%	0%
CCIGO-BLM2011-03	3/24/2011 17:06	1130	63%	37%	0%
			84%	16%	0%
			55%	44%	1%
CCIGO-BLM2011-04	3/25/2011 11:55	928	73%	27%	0%
			75%	25%	0%
			76%	24%	0%
CCIGO-BLM2011-05	3/27/2011 14:00	909	74%	25%	0%
			76%	24%	0%
CCIGO-BLM2011-06	3/28/2011 12:03	686	82%	18%	0%
CCIGO-BLM2011-07	5/23/2011 13:41	1020	98%	2%	0%
			99%	0%	0%
CCIGO-BLM2011-08	5/23/2011 15:56	1010	94%	4%	1%
			75%	25%	0%
CCIGO-BLM2011-09	5/24/2011 12:24	941	80%	20%	0%
			81%	18%	0%
CCIGO-BLM2011-10	5/24/2011 13:55	958	90%	10%	0%
			63%	37%	0%
CCIGO-BLM2011-11	5/24/2011 14:50	948	78%	22%	0%
CCIGO-BLM2011-12	5/25/2011 9:52	649	83%	17%	0%
			79%	20%	0%
CCIGO-BLM2012-01	6/5/2012 13:57	955	64%	36%	0%
			76%	24%	0%
CCIGO-BLM2012-02	6/5/2012 15:04	959	73%	27%	0%
			66%	33%	1%
CCIGO-BLM2013-01	4/11/2013 15:42	954	70%	29%	1%
			58%	40%	2%
CCIGO-BLM2013-02	4/11/2013 17:38	964	77%	23%	0%
			74%	25%	0%
CCIGO-BLM2013-03	4/12/2013 13:37	939	70%	30%	0%
			76%	24%	0%
CCIGO-BLM2013-04	4/12/2013 15:16	951	52%	47%	1%
			60%	38%	1%
CCIGO-BLM2013-05	4/12/2013 16:37	967	68%	32%	0%
			61%	38%	0%
CCIGO-BLM2013-06	4/13/2013 12:45	856	56%	42%	2%
			57%	41%	1%
CCIGO-BLM2013-07	4/13/2013 13:48	758	62%	36%	1%
			69%	31%	0%
CCIGO-BLM2013-08	4/13/2013 14:47	762	69%	31%	0%
			59%	41%	1%
	Mean	WY2011	76%	24%	0%
	Mean	WY2012	70%	30%	0%
	Mean	WY2013	70%	29%	1%

Table 9. Bedload sampling summary for Clear Creek near Igo, WY2010-2013.



Clear Creek near Igo

Bedload Sampling Summary -- WY2010-2013

Sample Number	Date & Mean Time	Streamflow Average Discharge (cfs)	Bedload Discharge > 2mm (tons/day)	Bedload Discharge ≤ 2 mm (tons/day)	Bedload Discharge Sum of Partials (tons/day)
CCIGO-BLM2010-01	5/24/2010 15:17	253	0.48	1.5	2.0
CCIGO-BLM2010-02	5/24/2010 15:34	330	1.0	3.3	4.3
CCIGO-BLM2010-03	5/24/2010 17:08	640	4.9	16	21
CCIGO-BLM2011-01	3/24/2011 13:00	1160	39	65	104
CCIGO-BLM2011-02	3/24/2011 15:21	1190	16	34	50
CCIGO-BLM2011-03	3/24/2011 17:06	1130	24	38	62
CCIGO-BLM2011-04	3/25/2011 11:55	928	3.7	11	15
CCIGO-BLM2011-05	3/27/2011 14:00	909	6.4	19	26
CCIGO-BLM2011-06	3/28/2011 12:03	686	2.1	9.7	12
CCIGO-BLM2011-07*	5/23/2011 13:41	1020	0.01	1.6	1.6
CCIGO-BLM2011-08*	5/23/2011 15:56	1010	0.89	3.8	4.7
CCIGO-BLM2011-09	5/24/2011 12:24	941	4.1	18	22
CCIGO-BLM2011-10	5/24/2011 13:55	958	3.9	8.8	13
CCIGO-BLM2011-11	5/24/2011 14:50	948	2.9	10	13
CCIGO-BLM2011-12	5/25/2011 9:52	649	2.7	11	14
CCIGO-BLM2012-01	6/5/2012 13:57	955	6.9	15	22
CCIGO-BLM2012-02	6/5/2012 15:04	959	8.3	20	28
CCIGO-BLM2013-01	4/11/2013 15:42	954	19	35	54
CCIGO-BLM2013-02	4/11/2013 17:38	964	13	41	55
CCIGO-BLM2013-03	4/12/2013 13:37	939	9.6	24	34
CCIGO-BLM2013-04	4/12/2013 15:16	951	18	24	42
CCIGO-BLM2013-05	4/12/2013 16:37	967	13	24	36
CCIGO-BLM2013-06	4/13/2013 12:45	856	12	16	29
CCIGO-BLM2013-07	4/13/2013 13:48	758	7.5	15	22
CCIGO-BLM2013-08	4/13/2013 14:47	762	9.2	16	26

*very high organic load -- not used in development of transport equation

Values Rounded According to Porterfield (1972)

Table 10. Size fractions for bedload samples collected at Clear Creek near Igo: WY2010-2013.

	2011-01 (mm)	2011-02 (mm)	2011-03 (mm)	2011-04 (mm)	2011-05 (mm)	2011-06 (mm)	2011-07 (mm)	2011-08 (mm)	2011-09 (mm)	2011-10 (mm)	2011-11 (mm)	2011-12 (mm)
D5	0.6	0.5	0.6	0.5	0.6	0.6	0.1	0.2	0.5	0.5	0.5	0.6
D16	0.9	0.7	0.8	0.8	0.8	0.8	0.3	0.4	0.7	0.7	0.7	0.8
D25	1.1	0.9	1.0	0.9	1.0	1.0	0.3	0.5	0.9	0.9	0.8	0.9
D35	1.3	1.1	1.2	1.1	1.1	1.1	0.4	0.7	1.0	1.1	1.0	1.1
D50	1.6	1.5	1.6	1.4	1.4	1.3	0.6	1.0	1.3	1.4	1.3	1.3
D65	2.1	1.9	2.2	1.7	1.7	1.6	0.8	1.4	1.6	1.9	1.6	1.6
D75	2.5	2.2	2.6	2.0	2.0	1.8	1.1	1.7	1.8	2.2	1.9	1.8
D84	3.0	2.6	3.2	2.4	2.4	2.1	1.3	2.2	2.2	2.7	2.3	2.2
D90	3.6	3.1	3.8	2.7	2.7	2.5	1.6	2.6	2.5	3.2	2.6	2.5

	2012-01 (mm)	2012-02 (mm)	2013-01 (mm)	2013-02 (mm)	2013-03 (mm)	2013-04 (mm)	2013-05 (mm)	2013-06 (mm)	2013-07 (mm)	2013-08 (mm)
D5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.6
D16	0.7	0.7	0.8	0.7	0.7	0.9	0.9	0.9	0.7	0.9
D25	0.9	0.9	1.0	0.9	0.9	1.1	1.0	1.1	0.9	1.1
D35	1.1	1.1	1.2	1.0	1.1	1.3	1.2	1.3	1.1	1.3
D50	1.4	1.4	1.5	1.3	1.4	1.7	1.6	1.8	1.5	1.7
D65	1.9	1.8	2.0	1.7	1.8	2.3	2.0	2.3	1.9	2.2
D75	2.3	2.2	2.5	2.0	2.2	2.7	2.4	2.7	2.4	2.6
D84	2.8	2.7	3.0	2.5	2.6	3.3	2.9	3.4	3.0	3.2
D90	3.5	3.4	3.7	2.9	3.2	3.8	3.5	4.0	3.6	3.7

Annual loads were computed for all three water years for the >2mm and <2mm size classes. Ten 2-pass composites and one 1-pass zero-transport sample (Table 4) were utilized in annual load computations. Samples collected during 2010 and 2013 were used to develop the generalized regressions (Figures 12 and 13):

$$\leq 2\text{mm} \quad BLD = 0.0194197 * \left(Discharge - 200\right)^{1.05619}, \quad r^2 = 0.86$$

$$>2\text{mm} \quad BLD = 7.9859e-005 * \left(Discharge - 351.8\right)^{1.82898}, \quad r^2 = 0.83$$

- For ≤2mm, zero transport was estimated at 200 cfs based on field observations. For >2mm, the zero transport was determined by the trajectory of the transport curve.
- Samples BLM2011-07 and 2011-08 were not used in transport curve development because they showed a very high organic load which may have occluded the sampler bag and biased the measurement. However, they were used to adjust the bedload discharge record during that time period.

Once the continuous bedload discharge data had been developed, the sample data were used to adjust the bedload discharge so that it passed through all sample points, using fitting and proportional fitting techniques.

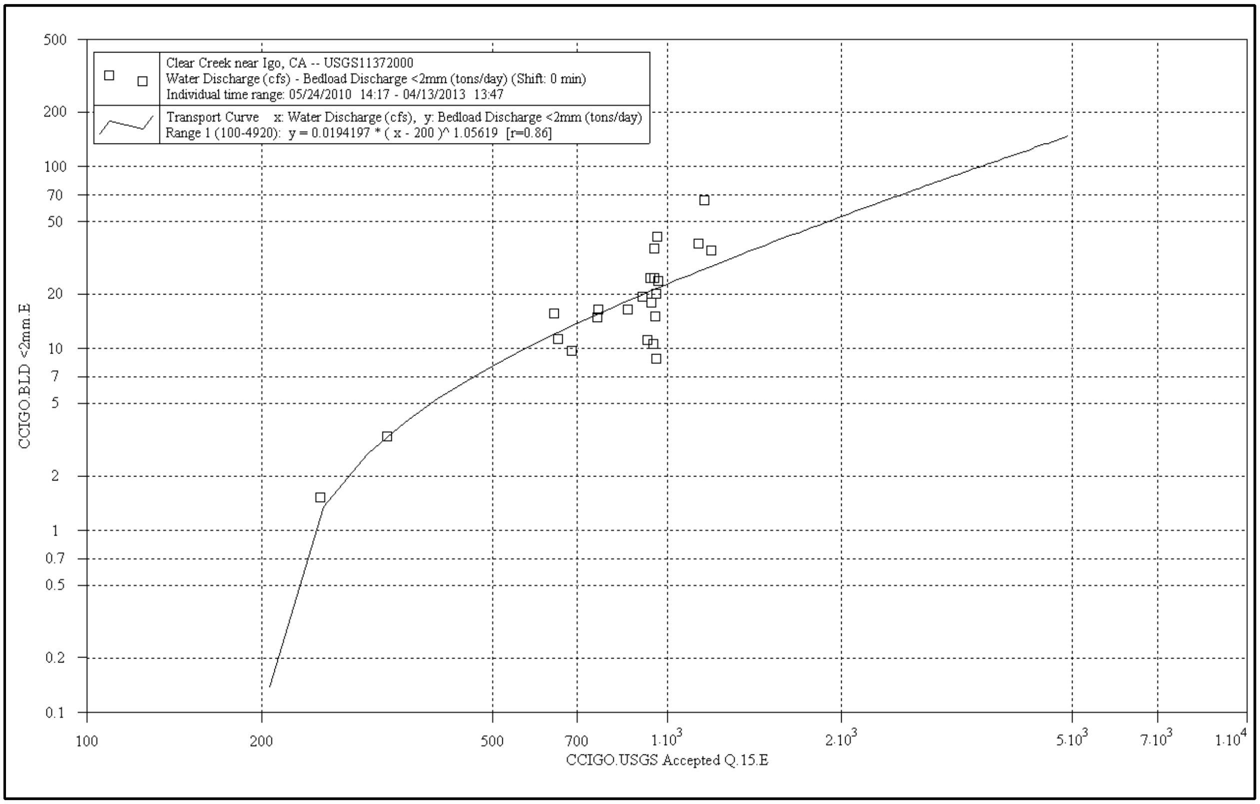


Figure 12. The generalized <2mm bedload transport curve (stream discharge vs bedload discharge) for Clear Creek near Igo.

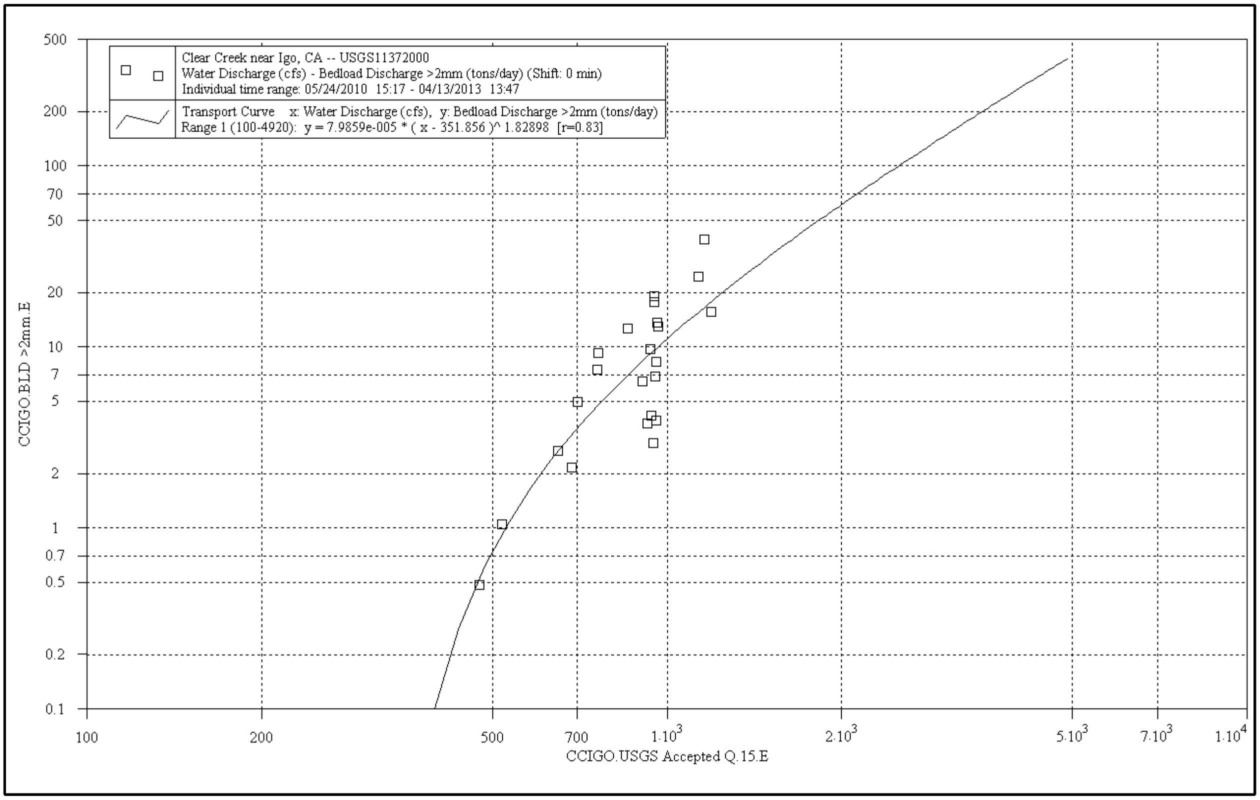
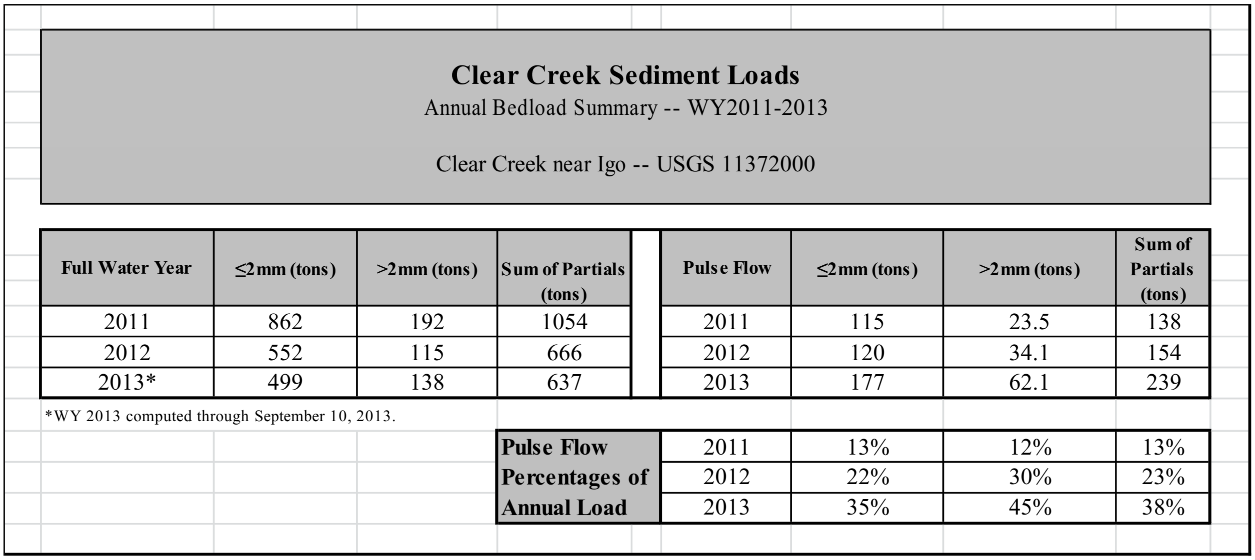


Figure 13. The generalized >2mm bedload transport curve (stream discharge vs bedload discharge) for Clear Creek near Igo.

Bedload annual loads are presented in Table 11. The relatively wet 2011 showed the highest load totals in both size classes. During dry years such as WY2012 and 2013, the spring pulse flow transports a higher percentage of the annual load: 22-35 percent of the sand and 30-45 percent of the >2mm.

Table 11. WY2011-2013 annual bedload sediment loads for Clear Creek near Igo: <2mm and >2mm.



Clear Creek Sediment Loads
Annual Bedload Summary -- WY2011-2013

Clear Creek near Igo -- USGS 11372000

Full Water Year	≤2mm (tons)	>2mm (tons)	Sum of Partials (tons)
2011	862	192	1054
2012	552	115	666
2013*	499	138	637

Pulse Flow	≤2mm (tons)	>2mm (tons)	Sum of Partials (tons)
2011	115	23.5	138
2012	120	34.1	154
2013	177	62.1	239

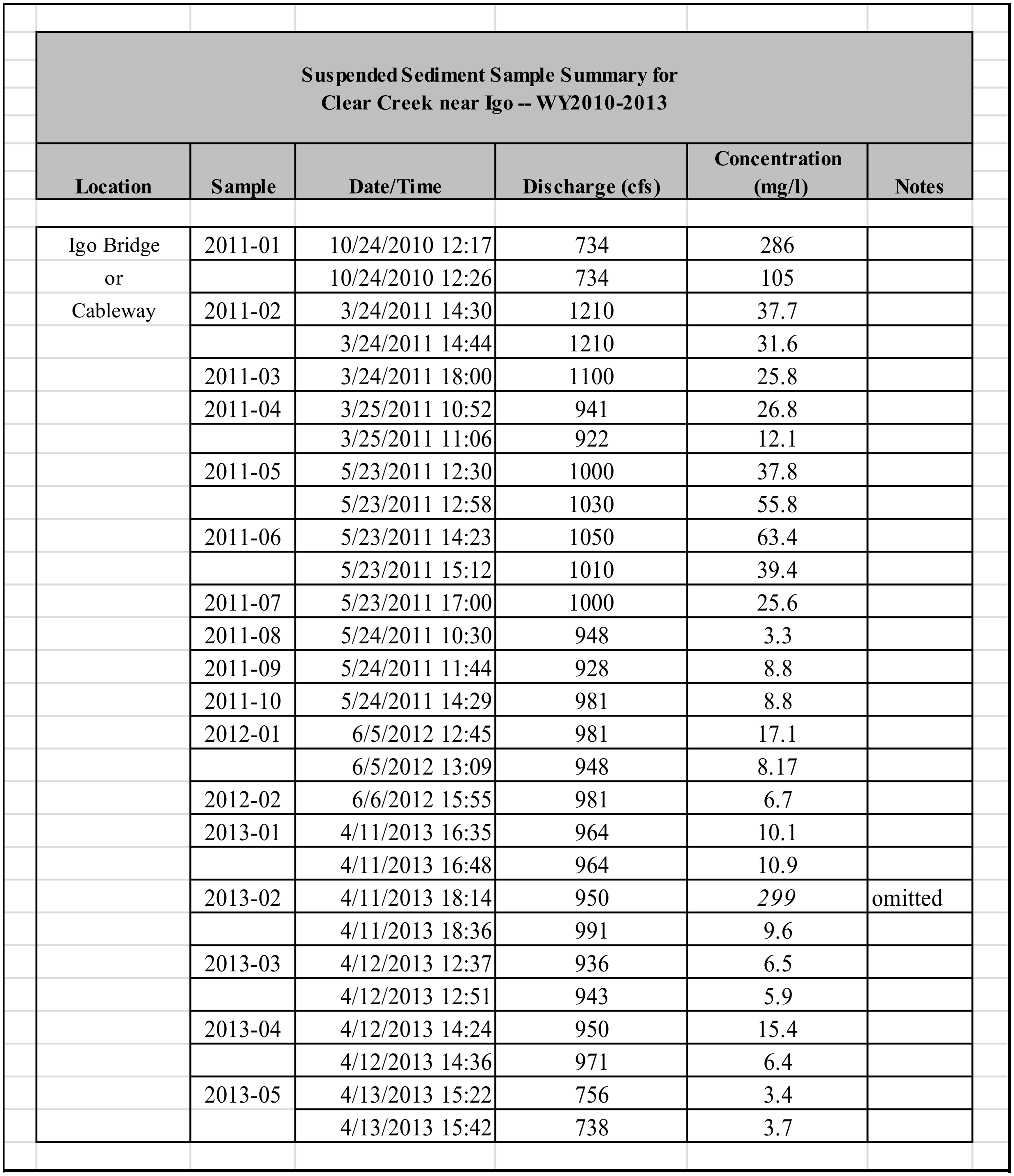
*WY 2013 computed through September 10, 2013.

Pulse Flow Percentages of Annual Load	2011	13%	12%	13%
	2012	22%	30%	23%
	2013	35%	45%	38%

Since much of the sediment delivered to the mainstem (from the South Fork) is fine sediment, we also collected a limited number of suspended sediment samples to examine how the transport rates during the study period compared to historic datasets (Table 12). The data collected before the Moon Fire of 2008 (and the subsequent increase in sediment delivery to the mainstem) were used to develop the general equation in Figure 14. WY2010-2011 storms seem to plot within the same cloud of points as do the 2004-2008 data. The 2011-2013 Pulse Flow data show a very poor relation with discharge which may be a function of hysteresis (differences in sediment transport dependent upon hydrograph position and sediment supply). One sample was censored (2013-02), as it appeared to be an outlier. In general, storms seem to transport higher suspended sediment loads than do pulse flows, because during rainstorms the South Fork (and other tributaries) are actively delivering higher suspended sediment loads (Figure 15).

During the March 27, 2011 storm, we also collected bedload samples (two passes) from the South Fork at the old gaging location approximately 100 yards upstream of the confluence (Figure 16). When transport rate and discharge are scaled by drainage area, the South fork samples sit slightly above and to the left of the cloud of WY2011-2013 points for the Igo sampling station. This suggests that for a flow of the same relative magnitude (cfs/mi^2), the South Fork produces a slightly higher bedlload discharge/mi^2. This analysis is somewhat confounded by the facts that virtually the entire sand load measured at the Igo station comes down the South Fork (visual observations of channel condition), and the Igo station is scaled by the below-dam drainage area. A better comparison would be the annual loads for each site scaled by drainage area (allowing a comparison of sediment yield), but the South Fork was not monitored for this project and such a comparison is not possible. Particle size analysis (Table 13) shows the median grain size for South Fork bedload (1.3mm) to be comparable to that for Igo (1.4mm) and the minima (0.1 and 0.4mm) and maxima (3.8 and 3.1mm) are also similar in magnitude. This agreement further indicates that the load measured at Igo is comparable to the South Fork both in texture (Tables 10 and 13) and rate of transport (Figure 17).

Table 12. Suspended sediment sample summary for Clear Creek near Igo, WY2010-2013.



Suspended Sediment Sample Summary for
Clear Creek near Igo -- WY2010-2013

Location	Sample	Date/Time	Discharge (cfs)	Concentration (mg/l)	Notes
Igo Bridge or Cableway	2011-01	10/24/2010 12:17	734	286	
		10/24/2010 12:26	734	105	
	2011-02	3/24/2011 14:30	1210	37.7	
		3/24/2011 14:44	1210	31.6	
	2011-03	3/24/2011 18:00	1100	25.8	
	2011-04	3/25/2011 10:52	941	26.8	
		3/25/2011 11:06	922	12.1	
	2011-05	5/23/2011 12:30	1000	37.8	
		5/23/2011 12:58	1030	55.8	
	2011-06	5/23/2011 14:23	1050	63.4	
		5/23/2011 15:12	1010	39.4	
	2011-07	5/23/2011 17:00	1000	25.6	
	2011-08	5/24/2011 10:30	948	3.3	
	2011-09	5/24/2011 11:44	928	8.8	
	2011-10	5/24/2011 14:29	981	8.8	
	2012-01	6/5/2012 12:45	981	17.1	
		6/5/2012 13:09	948	8.17	
	2012-02	6/6/2012 15:55	981	6.7	
	2013-01	4/11/2013 16:35	964	10.1	
		4/11/2013 16:48	964	10.9	
	2013-02	4/11/2013 18:14	950	*299*	omitted
		4/11/2013 18:36	991	9.6	
	2013-03	4/12/2013 12:37	936	6.5	
		4/12/2013 12:51	943	5.9	
	2013-04	4/12/2013 14:24	950	15.4	
		4/12/2013 14:36	971	6.4	
	2013-05	4/13/2013 15:22	756	3.4	
		4/13/2013 15:42	738	3.7	

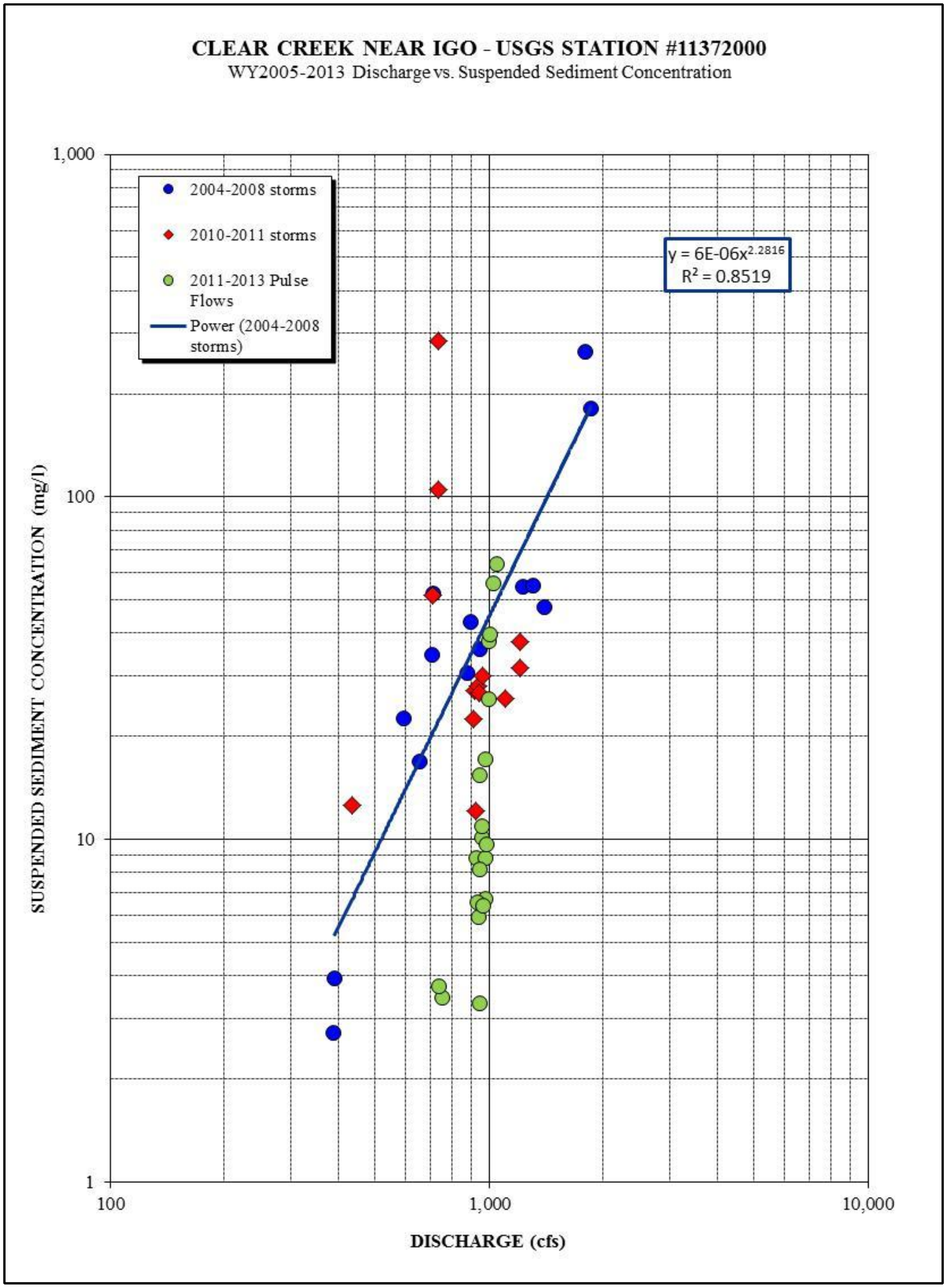


Figure 14. Suspended sediment concentration vs discharge for Clear Creek near Igo, 2008-2013.

Figure 15. Storm of March 27, 2011 photograph of the confluence of South Fork and mainstem Clear Creek showing the visible increase in turbidity and (by inference) suspended sediment concentration from the South Fork. Flow in Clear Creek is left to right. View is looking down South Fork into Clear Creek.

Figure 16. South Fork Clear Creek March 27, 2011 showing (clockwise from top left): sampling section, staff plate near old gage, hand held Elwha sampler, two passes bedload samples.

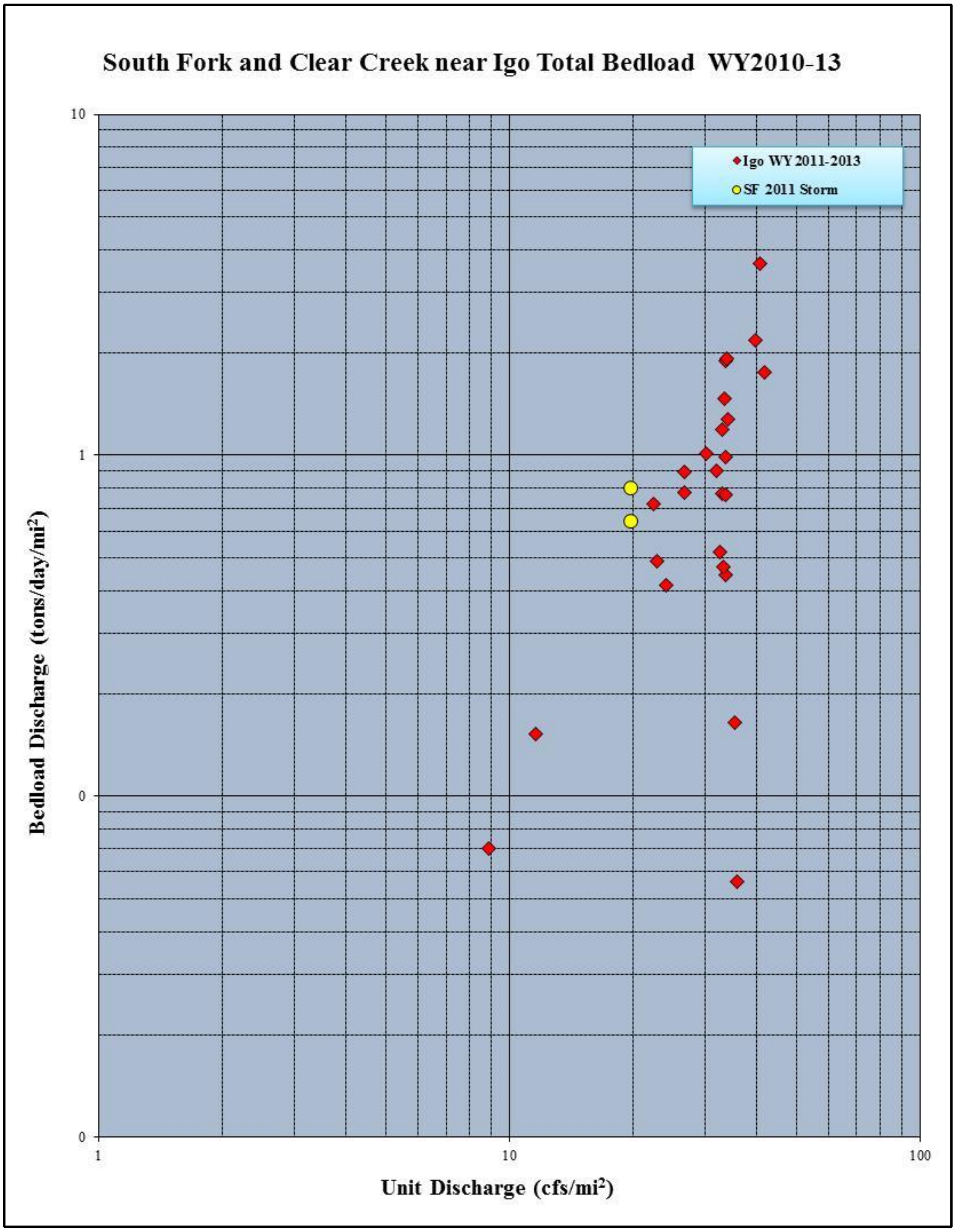


Figure 17. Total bedload discharge for SF Clear Creek and mainstem at Igo, both axes scaled by drainage area.

Table 13. Particle size analysis results for South Fork Clear Creek WY2011 bedload samples.

	2011-01a (mm)	2011-01b (mm)
D5	0.4	0.7
D16	0.6	0.9
D25	0.7	0.9
D35	0.8	1.0
D50	1.0	1.7
D65	1.4	2.2
D75	1.7	2.5
D84	2.2	2.7
D90	2.8	3.1

3.3 Reach 1 Gravel Injections

3.3.1 Introduction

The gravel injection locations in Figure 1 correspond sequentially to the site names delineated in Table 7. For clarity, from upstream to downstream, the Reach 1 injections are:

- Whiskeytown (dam base)
- Below Dog Gulch (~3,300 feet below the dam)
- Above Peltier Bridge (begins ~1,000 feet upstream of bridge)
- Paige Bar (at the upstream end of the bar)
- Above NEED Camp Bridge
- Guardian Rock (below NEED Camp Bridge, entrance to Reach 2, the gorge)

The focus of this project was to evaluate bedload transport through Reach Two. Since the coarse sediment supply for Reach Two is comprised almost entirely of the gravel injections in Reach One (plus the Guardian Rock site), the modeling task for this project focused on examining the injections relative to flow events, replenishment and rate of downstream translation:

- Reach One injections were surveyed for topography in May 2012, September 2012 and September 2013.
- For the sites above Paige Boulder Creek (Below Dog Gulch, Peltier Bridge and Paige Bar), the only significant flow events between WY2011 and 2013 were the annual pulse flows (Figure 18) which ranged in magnitude from ~800-1,100 cfs.
- For the Guardian Rock site, located downstream of the Paige Boulder confluence, at least six events >1,000 cfs occurred during the study period in addition to the annual spring pulse flows (Figure 18).
- Surface models were developed from the survey data and volume change computations were performed for:

- May 2012-September 2012 (assumption: the June 2011 as-built ground surface is represented by the May 2012 survey, as no intervening flows occurred – this applies to all but Above NEED and Guardian Rock) – describes changes from 2012 pulse flow.
- September 2012-September 2013 (describing change from the 2013 pulse flow).

The following definitions will prove helpful for this section:

> *Geomorphic processes (erosion/deposition -- cut/fill) are discussed here in "tons" to facilitate comparison with injection quantities, which are commonly discussed in units of mass, not volume (Table 14).*
>
> *"Channel Recharge" is subjectively defined here as "reaches dominated by the presence of gravel and associated alluvial properties: unvegetated gravel bars, mobile riffles and limited bedrock and boulder exposure."*
>
> *"Translation Rate" is a rough method to compute time-to-recharge which simply examines feet/year of recharge to date and applies that rate to the remaining channel length. Assumptions for this method are too many to list and estimates are provided as coarse, planning-level predictions.*

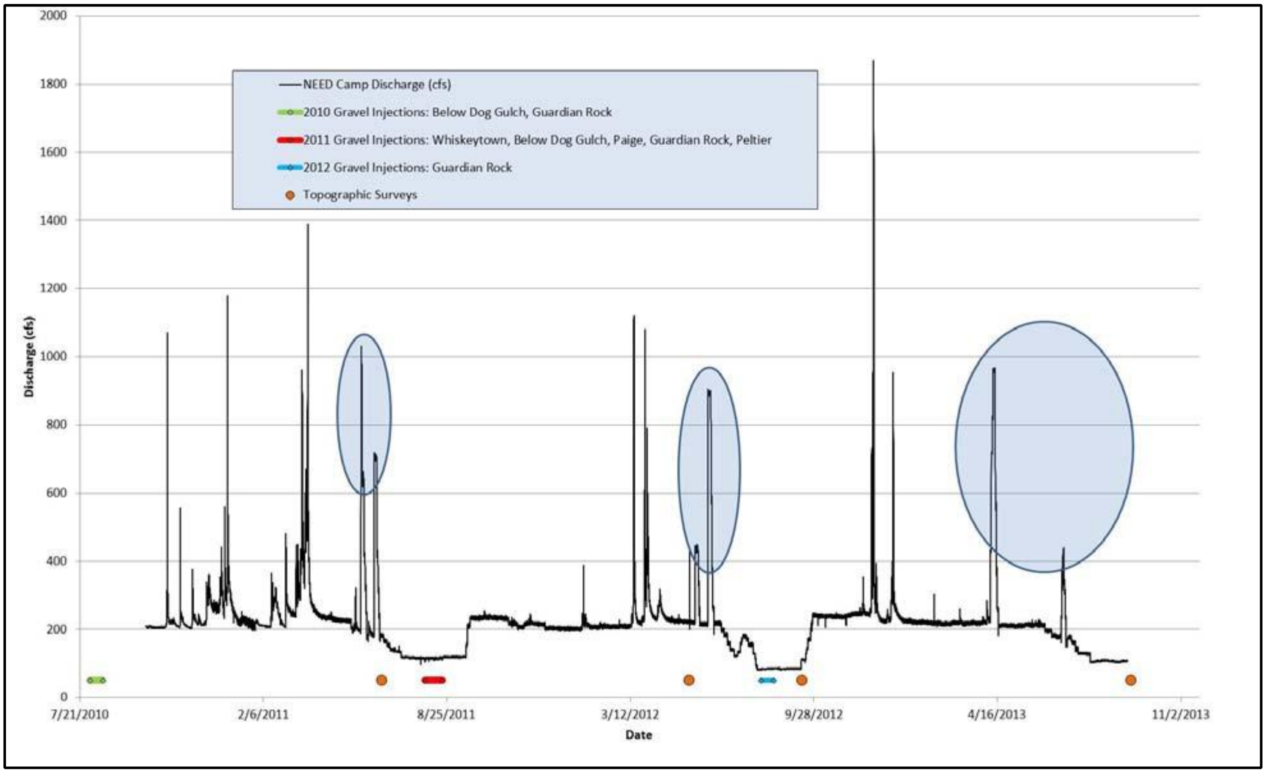


Figure 18. Gravel injections and survey dates relative to NEED Camp gage hydrograph. Note that the pulse flows indicated by blue ovals are the primary geomorphic drivers for all but two Reach 1 injections (Above NEED and Guardian Rock), which lie below Paige Boulder Creek, the driver for all the other peaks.

Table 14. Volumes derived from WY2012-2013 topographic surveys and surface differencing for Reach 1 injection sites.

Sheet	Site	Period	Cut (CY)	Cut (ton)	Fill (CY)	Fill (ton)	Net (CY)	Net (ton)	Net Process	Event
B1	Below Dog	5/12-9/12	651	977	368	552	-283	-425	CUT	August 2011 Injection + 2012 Spring Pulse
	Below Dog	9/12-9/13	265	398	140	210	-125	-188	CUT	2013 Spring Pulse
B3	Above Peltier Bridge	5/12-9/12	101	152	139	209	38	57	FILL	August 2011 Injection + 2012 Spring Pulse
	Above Peltier Bridge	9/12-9/13	73	110	64	96	-9	-14	CUT	2013 Spring Pulse
B5	Paige Bar	5/12-9/12	225	338	124	186	-101	-152	CUT	August 2011 Injection + 2012 Spring Pulse
	Paige Bar	9/12-9/13	109	164	90	135	-19	-29	CUT	2013 Spring Pulse
B7	Guardian Rock	9/12-9/13	1271	1907	0	0	-1271	-1907	CUT	12/2/2012 storm + 2013 Spring Pulse

Whiskeytown

Type: Talus Cone

Year Initiated: 1998

Last Replenished: 2011

Tons Injected at Site: 27,256

Volume (CY) Injected at Site: 18,171

Linear Feet of Channel Recharged: 3,000

Over 27,000 tons of gravel has been added at the Whiskeytown Dam site since 1998 (Table 7). Though the injection has not been charged since 2011, it appears to have routed all the way to the next injection site at Below Dog Gulch (GMA 2011). The 2011 pulse flow resulted in 99 CY of gravel fill in the bedrock pool separating the leading edge of the Whiskeytown gravel and the site Below Dog Gulch (GMA 2011). Any evidence of gravel routing through the pool and depositing in the reach below would be masked by the Below Dog injection. Since no significant aggradation occurs on the pool tail, it appears unlikely that gravel is yet completely routing through the pool. The 2011 ispopach shows positive change in the upper two thirds of the pool and close to zero change near the tail, implying that gravel flows into the pool faster than it flows out (GMA 2011).

Below Dog Gulch

Type: Riffle Supplement

Year Initiated: 2009

Last Replenished: 2011

Tons Injected at Site: 4,000

Volume (CY) Injected at Site: 3,000

Linear Feet of Channel Recharged: 1,200

This project was intended to boost the leading edge of the Whiskeytown gravel injection by adding gravel just below a deep bedrock pool (roughly 3,000 ft downstream of the Whiskeytown injection) which was inhibiting routing of gravel (Figure 19). The site is at the upstream end of a long, coarse riffle which exhibited considerable potential for developing spawning habitat: lee deposits and relic lateral bars have retained small amounts of spawning gravel through the 48 year impoundment period (first picture, Figure 20).

As designed (GMA 2006), the project would have nearly connected with downstream injection projects above Peltier Bridge. Budgetary and logistical constraints precluded building the injection to the design scale and 1,000 of the prescribed 3,600 tons were injected as a riffle supplement in 2009. The injection was completely mobilized by the 2010 Glory Hole spill and was recharged in the exact same manner in 2010. In 2011 the volume was doubled and 2,000 tons were placed (Figure 20). Though the injection takes the initial form of a placed riffle (over bedrock), due to channel geometry and riparian confinement, sediment transport capacity is very high and pulse flows quickly rearrange the riffle supplement into a series of alternate bars and riffles extending 200-1,200 feet downstream of the injection site (Figure 21 and Figure 22)). The channel length that has been recharged by this injection has more than doubled since 2011, from 500 feet to 1,200 feet below the injection site.

Cut-fill ispoachs and 2013 topography are provided in Appendix B1 and B2. Cut-fill volumes and computed masses are provided in Table 14. The 2012 pulse flow peaked at 902 cfs at NEED camp and resulted in nearly half of the injected gravel scouring from the placement location (977 tons, Table 14). 552 tons were redeposited in the downstream bar sequence and the remainder (425 tons net cut) was transported beyond the survey extent. The area below the 2012 survey extent was surveyed in September 2013 (Appendix B2) and can be compared to future surveys.

The 2013 spring pulse flow (967 cfs at NEED Camp) eroded another 188 tons of gravel. The isopach analysis (Appendix B1) indicates that during the 2013 pulse, scour occurred not only on the remnants of the original injection site, but also on the downstream bar complex. Thus, the net cut to the original computational unit (placement site and bar sequence below) is 612 tons, or approximately 1/3 of the 2011 placement volume. Based upon field observations during the September 2013 surveys, the entire 2009-2011 volume (4,000 tons) is likely represented by the 2013 topography (1,200 feet of channel).

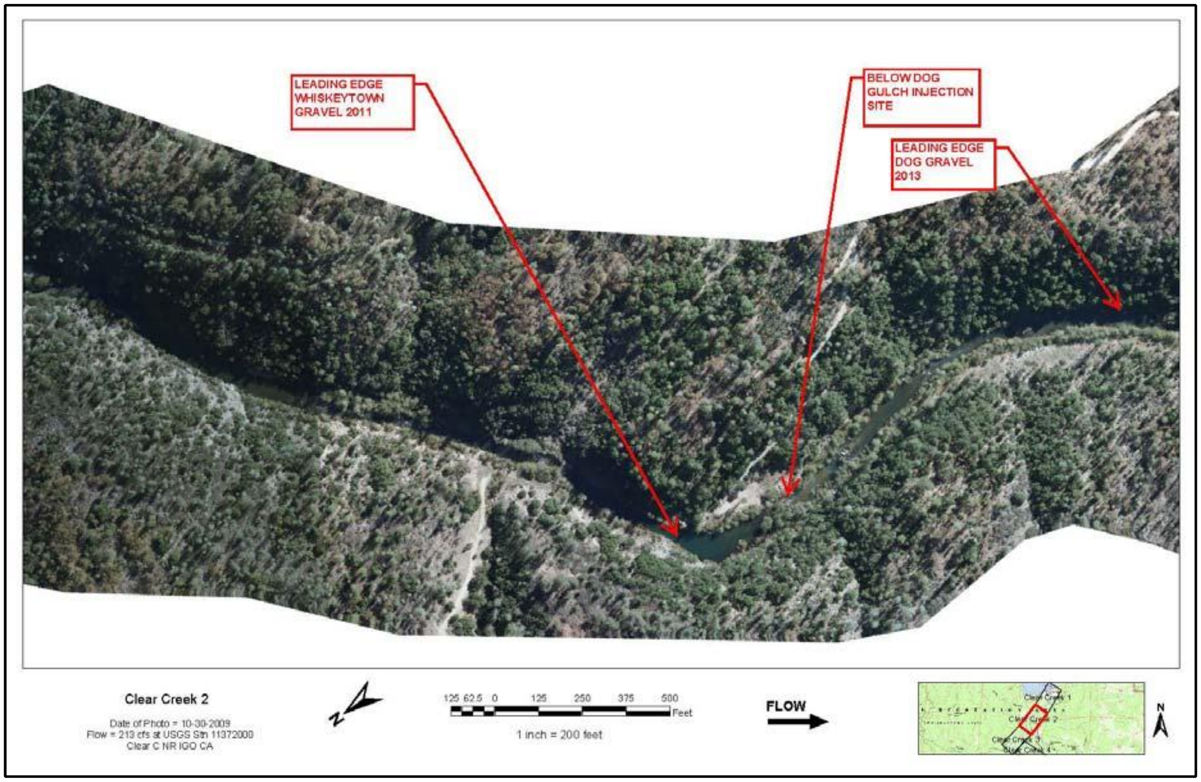


Figure 19. Annotated excerpt from 2009 Clear Creek Atlas (GMA 2011) showing bedrock pool upstream of "Below Dog" site.

Pre and post May 2009 implementation – view from upstream end.

Following the January 22, 2010 spill (~914 cfs), and following the August, 2010 recharge.

Following the May 2011 Pulse Flow (~1,000 cfs) and August 2011 recharge (last photo, Tehama Environmental Solutions).

Figure 20. Below Dog Gulch gravel injection site showing site conditions relative to peak flow and gravel recharge events. Flow is <100 cfs in all photos.

Pre-2009 channel condition vs. June 2011 – downstream view 250 feet downstream of injection site.

2013 channel condition - downstream view 250 feet downstream of injection site.

Figure 21. Incipient bars developing into alternate bar sequences 250 feet downstream of the Below Dog injection site: pre-2009 condition (~200 cfs); June 2011 (~75 cfs); September 2013 (~75 cfs).

Figure 22. Upstream view from the 2013 leading edge 1,200 feet downstream of the Below Dog injection site. Note the complex form of the lateral bar/riffle migrating through the bedrock pool: high velocity gravel bed on the left side photo; deep, slow bedrock/boulder pool on the right side; riparian disturbance (uprooted alder); transverse flow across the bar. The alignment and trajectory is keyed to the mid-channel bedrock island at the top of the photo (~75 cfs).

Above Peltier Bridge

Type: Riffle Supplement

Year Initiated: 2009

Last Replenished: 2011

Tons Injected at Site: 1,769

Volume (CY) Injected at Site: 1,179

Linear Feet of Channel Recharged: 570

The channel condition prior to gravel injection at both Peltier Bridge and at Paige Bar reflects the combined impact of sediment transport impairment and flow regulation:

1. surface armoring from winnowing of fines,
2. near-absence of spawning-sized gravel,
3. a degree of confinement from riparian encroachment,
4. lack of complexity, and
5. a disconnect between active channel and floodplain.

The *Paige Bar and Above Peltier Bridge Gravel Injection Designs* (GMA 2007b) provided a gravel sluicing plan for the site above the bridge. The design called for 3,750 tons of gravel to be sluiced into the reach to a uniform depth, with raised gravel prisms (riffle crests) sculpted at inflections in the long profile, where bar sequences appear on pre-dam aerial photographs. Ultimately, 769 tons were injected at the site in 2009, along the downstream-most of the riffle crest inflections identified in the 2007 design report. In 2011, another 1,000 tons were sluiced into the next remnant-riffle upstream, creating 570 feet of combined riffle (Figure 23).

The upstream boundary of the constructed riffle was originally located 2,000 feet downstream of the Below Dog leading edge, but with the downstream migration of Below Dog and with the upstream expansion in 2011 of Peltier, the two sites are now separated by only 1,025 feet. The 2012 spring pulse flow rearranged the placement, with some of the gravel moving into the run separating the two injection sites (Appendix B3). The dominant processes were scour to the thalweg in the as-built riffle surface and deposition in the deeper, slower run below. The net fill of 57 tons (5 percent of all the gravel injected) is likely due to slight inconsistencies between the surveys (e.g. the upstream edge was not mapped as thoroughly in the second survey) and the overall change is probably closer to zero; based upon field observations, it appears highly unlikely that new gravel entered the site.

The 2013 pulse resulted in some minor topographic change following the same pattern as was observed in 2012 though on a smaller scale (Appendix B3). The two injections now comprise one riffle/bar, with steep faces on both ends. The surveys and the 2013 topographic surface (Appendix B4) indicate that only minor advancement has occurred at the leading edge since its original advance of 50 feet in 2010.

Looking upstream from Peltier Bridge at gravel sluicing implementation 2009 and geomorphic monitoring bathymetric survey 2010.

2011 construction of the upper portion and a downstream view of the final product.

Figure 23. Views of the sluiced riffles upstream of Peltier Valley Bridge.

Paige Bar

Type: Riffle Supplement

Year Initiated: 2009

Last Replenished: 2011

Tons Injected at Site: 2,786

Volume (CY) Injected at Site: 1,857

Linear Feet of Channel Recharged: 975

The original conceptual design for Paige Bar included options for harvesting gravel from an onsite fossilized gravel deposit, lowering the floodplain, reducing riparian confinement and raising the invert of the stream channel with spawning gravels to enhance floodplain connectivity. Lateral berms (recruitment piles) were included to insure long term coarse sediment supply. The 2009 effort implemented two components of the design: a lateral berm and a riffle supplement (Figure 24) at the upstream end of the project area. Hydraulic conditions prevented berm development for the upper site, so the site was modified into a riffle supplement. At the downstream location, where an active spawning area along the right bank was avoided (Figure 24), the riffle supplement extended downstream two hundred feet. In 2009, 1,786 tons (1,191 CY) of gravel was injected at the two sites.

In the first winter following injection, 33 percent (596 tons) of the injected gravel moved from where it was placed (GMA 2011) and the “recharged” section extended another 500 feet downstream, filling interstitial voids in the coarse riffle below. The next year’s pulse flow (WY2011) removed another 189 tons from the reach which was corroborated by GMA field crew observations of discontinuous lateral deposits below the leading edge. As of 2013, the large lobe of gravel (2009 attempt at berm construction) remains in the pool above the riffle supplement which apparently requires more than 1,400 cfs (2010 spill) to move it into the riffle below.

Another 1,000 tons was added to the downstream riffle supplement in 2011. The 2012 spring pulse moved 152 tons beyond the former leading edge (survey extent). The survey was extended in September 2012 to accommodate change beyond the 2011 leading edge (Appendix B5) and the 2013 pulse induced minor change (29 tons cut) to the 975 foot long riffle. In September 2013, the gravel in the pool above and the entire length of downstream replenished riffle were surveyed (Appendix B6) to facilitate future monitoring.

Looking downstream at the 2011 riffle supplement and upstream at the 2009 gravel lobe (transverse riffle in 2013) remaining in the pool above.

Figure 24. Views of the Paige Bar injection.

Above NEED Camp Bridge

Type: Placed Riffle

Year Initiated: 2009

Last Replenished: 2009

Tons Injected at Site: 981

Volume (CY) Injected at Site: 654

Access and ecological considerations precluded the development of the site as described in the 2007 conceptual design included in the 2007 report. Access was easily developed near an existing roadway along the left bank and 981 tons of gravel was end-dumped adjacent to the streambed then graded into a riffle form with a bulldozer (Figure 25). Flow compression resulting from channel filling and backwatering an upstream riffle (transferring water surface slope) transformed the low gradient pool head into a riffle, thus providing potentially immediate spawning habitat. The placement has changed little in four years, prograding to a small degree downstream into the pool (GMA 2011, Survey Atlas). Beyond casual observations, this site was not monitored for this 2011-2013 project.

Figure 25. Gravel injection above NEED Camp Bridge occurring through a gap in the left bank vegetation. The 2009 as-built injection showing the upstream end and a November 2010 view downstream showing the increased water surface slope through the pool.

Guardian Rock (previously known as "NEED Camp," located below NEED Camp Bridge)

Type: Lateral Berm

Year Initiated: 2005

Last Replenished: 2012

Tons Injected at Site: 10,848

Volume (CY) Injected at Site: 7,232

Linear Feet of Channel Recharged: 3,270

This site is located at the beginning of Reach Two, the entrance to the gorge. The site was charged in 2005 and 2006 with 1,000 and 2,600 tons respectively. The 2008 peak of ~2,000 cfs moved most of the 2006 injection. 1,228 tons were added in 2009 and another 1,000 tons in 2010 (Figure 18). The site is very efficient at entraining gravel with flows as low as 600 cfs. Flows over 1,500 cfs remove virtually all of the gravel.

3,000 tons were placed at the site in 2011. The March 2012 storm with a peak of 1,120 cfs at NEED Camp mobilized ~75 percent of the injection (S. Pittman, visual estimate) (Figure 26). The injection was charged again with 2,000 tons in the summer of 2012. The December 2, 2012 storm with a peak of 1,870 cfs (plus approximately 200 cfs from Orofino Gulch) and the 2013 pulse flow mobilized 1,907 tons – virtually the entire injected volume (Appendix B7). While the injection site was mostly evacuated during the first event, the leading edge of gravel continued to advance into Reach 2 during both events (USFWS 2013 data):

- Prior to the 2013 spring pulse flow, the leading edge was approximately 2,420 feet downstream of the injection site, and
- On April 24, 2013, the gravel front advanced another 850 feet to a location 3,270 feet below the injection site.
- Since injections began in 2005, this equates to a mean translation rate of approximately 410 feet per year.
- Since the Placer Road injection site is approximately 28,500 feet downstream of the Guardian Rock injection site, assuming the Placer gravel will reach Clear Creek Road before the Guardian gravel arrives at Placer, at 410 feet per year gravel will reach completely through Reach 2 in about 62 years. *Again, these estimates are very coarse and many unknowns remain regarding the actual time to recharge (e.g. frequency and duration of floods, actual replenishment rates, sediment transport attributes of deep pools within the gorge).*

3,000 tons August 2011

Following March 2012 storm -- 1,120 cfs

2,000 tons Sept. 2012

Following Dec. 2012 storm -- 1,870 cfs

Figure 26. Looking upstream at the Guardian Rock injection site below NEED Camp Bridge: four views WY2011-2013.

6. DISCUSSION

6.1 Sediment Transport

Five storm events over the three year period exceeded the sampling threshold trigger of 2,000 cfs at USGS Igo. Only two of these events exceeded 3,000 cfs (March 26, 2011 and December 2, 2012). GMA responded to the March 2011 event but was unable to sample the peak due to a conflict with USGS occupation of the cableway. The flood frequency analysis (Figure 2) reveals recurrence intervals of 2.5 and 4.3 years respectively for the two peaks. The 4.3 year peak (4,920 cfs) was of extremely short duration: the period exceeding 2,000 cfs lasted only five hours and occurred at night. At NEED Camp, the period exceeding 1,000 cfs lasted six hours, from 01:00 to 07:00 on the same day. Thus, sampling efforts primarily describe pulse flow events, though some storms were sampled as well: up to 1,190 cfs at Igo and up to 1,355 cfs at NEED Camp.

6.1.1 Sediment Loads at NEED Camp

The annual sediment loads computed during the study period are trivial compared to the gravel injection volumes (1,000-3,000 tons/year) at the Guardian Rock site just downstream. The fraction >2mm ranged from 0.24 to 11.7 tons per year during the study period (Table 6). During years with large storms like WY2011, the relative percentage of the >2mm load transported by pulse flows is lower (36 percent). In relatively dry years however, pulse flows transported 82-95 percent of the >2mm load.

Bedload sieve data show the range of D50 to be 0.8-4.2mm (Table 5), suggesting either a very low supply of spawning sized gravel or a lack of flows high enough to move the coarser gravels. The bedload >8mm best describes spawning-sized gravel transport and the data suggest that ~900 cfs is an important threshold for increasing the transport of this size class (Figure 27). After 2010 (with flows up to 1360 cfs), the percent of >8mm (in samples collected at 710-1,000 cfs) increases each year, essentially doubling from 2011-2012 and again from 2012-2013 (Table 3).

However, the actual magnitude of >8mm load is still quite low (e.g. the highest during the study period would be 17 percent of 11.7 tons in 2013 – about two tons). Again, the annual injections at Guardian Rock are critical for maintaining gravel routing in Reach Two, until Reach One routes gravel from Whiskeytown to Guardian Rock.

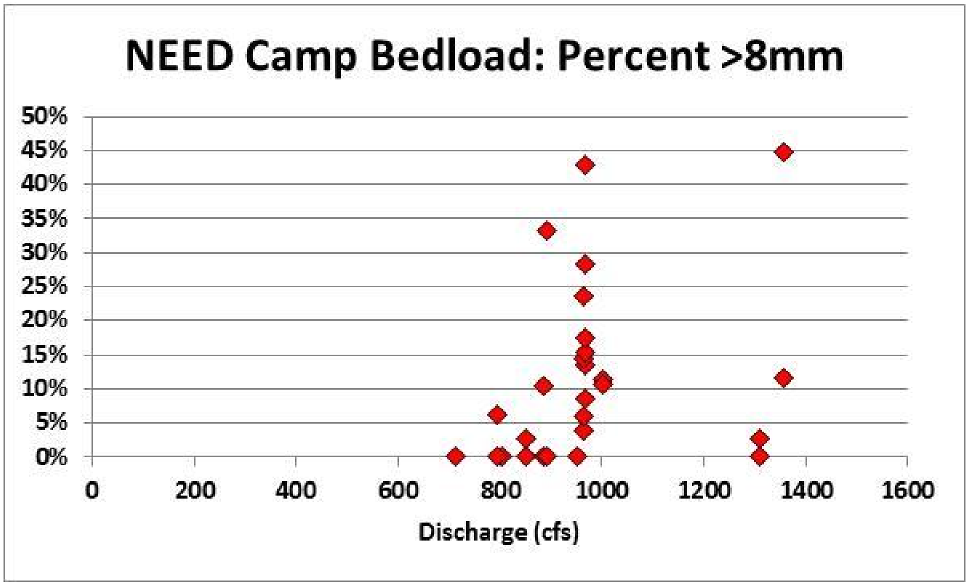


Figure 27. >8mm bedload fraction as a function of discharge at NEED Camp WY2010-2013.

Gravel injections have recharged 5,945 feet of channel length in Reach One, and the Reach is approximately 11,125 feet long (from Whiskeytown injection to the Guardian Rock injection), so 51 percent of the channel length is recharged by injected gravel. Examination of the 2010 USFWS habitat mapping data reveals another 15 percent of the total channel length is composed of gravels other than injections (remnant fluvial deposits, bridge construction activities etc). Thus, approximately 66 percent of Reach One is currently recharged with gravel.

The length of channel not yet recharged is 3,480 feet and the rate of recharge to date is ~ 450 feet per year. Assuming the flow and injection schedule continues as it has over the last 17 years since injection began (and assuming transport conditions are similar in charged and uncharged sub-reaches) Reach One could be 100 percent recharged in as little as 8 years.

6.1.2 Sediment Loads near Igo

The 2013 peak flow was roughly three times larger than the highest flow sampled at the Igo site. Bedload samples were collected up to 1,190 cfs and the load was computed up to 4,920 cfs, an extrapolation greater than three orders of magnitude. However, the errors associated with extrapolating the sediment transport curve beyond the range of observations are constrained by the very short duration of the event .

Annual bedload totals at Igo ranged from 637 to 1,054 tons per year (Table 11). Pulse flows accounted for 23-38 percent of the load in dry years and only 13 percent of the load in wet years like WY2011 (Table 11). Less than 1 percent (on average) of bedload samples were composed of material >8mm (Table 8). While spawning sized gravel may be present in the bedload near Igo (Figure 28), its relative abundance is overshadowed by the large volume of sand in the reach. Watershed area-scaled discharge versus bedload discharge shows the South Fork transporting only slightly higher unit rates than the mainstem (Figure 17). This may suggest that both systems are well-supplied and are transporting at capacity. WY2011-2013 suspended sediment discharge during storm periods did not appear to differ greatly from historic datasets implying that the South Fork may have returned to pre-Moon Fire fine sediment delivery conditions (Figure 14). Pulse flows clearly show lower suspended sediment discharges than storm events as tributary contribution is typically lower during pulse flows. Visual observations indicate that a large portion of the sediment load delivered to the mainstem is probably coarse sand that does not transport well in suspension (Figure 28).

Figure 28. March 2011 views of the South Fork Clear Creek delta above the Igo sampling station. 3 inch knife for scale – left photo.

6.2 Gravel Injection Evaluations

6.2.1 Geomorphic Response to Injections

The leading edge of the Whiskeytown injection was not evaluated as part of this project. The 2011 evaluation (GMA 2011) showed ~100 CY fill in the pool just above the Below Dog site which indicated that spawning gravel was beginning to route through this pool. In 2013, the pool was resurveyed but the data were not available at the time this report was produced. Gravel condition and abundance at the tailout suggests gravel is still routing through the pool.

All of the Reach One injection sites (except Above NEED and Whiskeytown) are currently empty (at placement locations) and channels are heavily charged with gravel for 570-3,000 feet below the injection sites. In addition to increasing the areal extent of spawning gravel, numerous other secondary and highly beneficial effects of gravel injection were observed during the study period:

1. Enhanced alluvial form and function
    a. Highly dynamic complex bar sequences developing along the body and downstream fronts of gravel “waves” exhibit the following attributes:
        i. They discourage riparian colonization which can enhance confinement, increase velocities thereby reducing storage capacity and juvenile salmonid habitat

    quality. Riparian colonization can also “lock up” gravels available for transport, such as when Himalayan blackberry colonizes a gravel bar (Figure 21).

    ii. Complex flow patterns across depositional bedforms features benefit numerous aquatic organisms by promoting a variety of hydraulic conditions: increased hyporheic flow, changes to depth, velocity and flow direction (Figure 22).

2. Mechanical disruption of established confining riparian vegetation decreases riparian confinement, increases woody debris delivery. Gravel lobes cause longitudinal disruption (“bulldozing” effect) as well as divert flow (as a function of bar height) toward banks causing undercutting and lateral scour (Figure 29).
3. Increased mobility of armored riffles occurs as finer particles infiltrate and “lubricate” fossilized features. Large (>200mm) particles, covered in periphyton are often observed “floating” on exposed bars or gravelly riffles (Figure 29).

Increased floodplain connectivity occurs as the result of gravel lobes decreasing channel capacity and forcing streamflow up out of the channel to flood low-lying adjacent surfaces. Raising the water table also seems to increase the rate of alder mortality, again reducing riparian confinement and increasing woody debris loading (Figure 29).

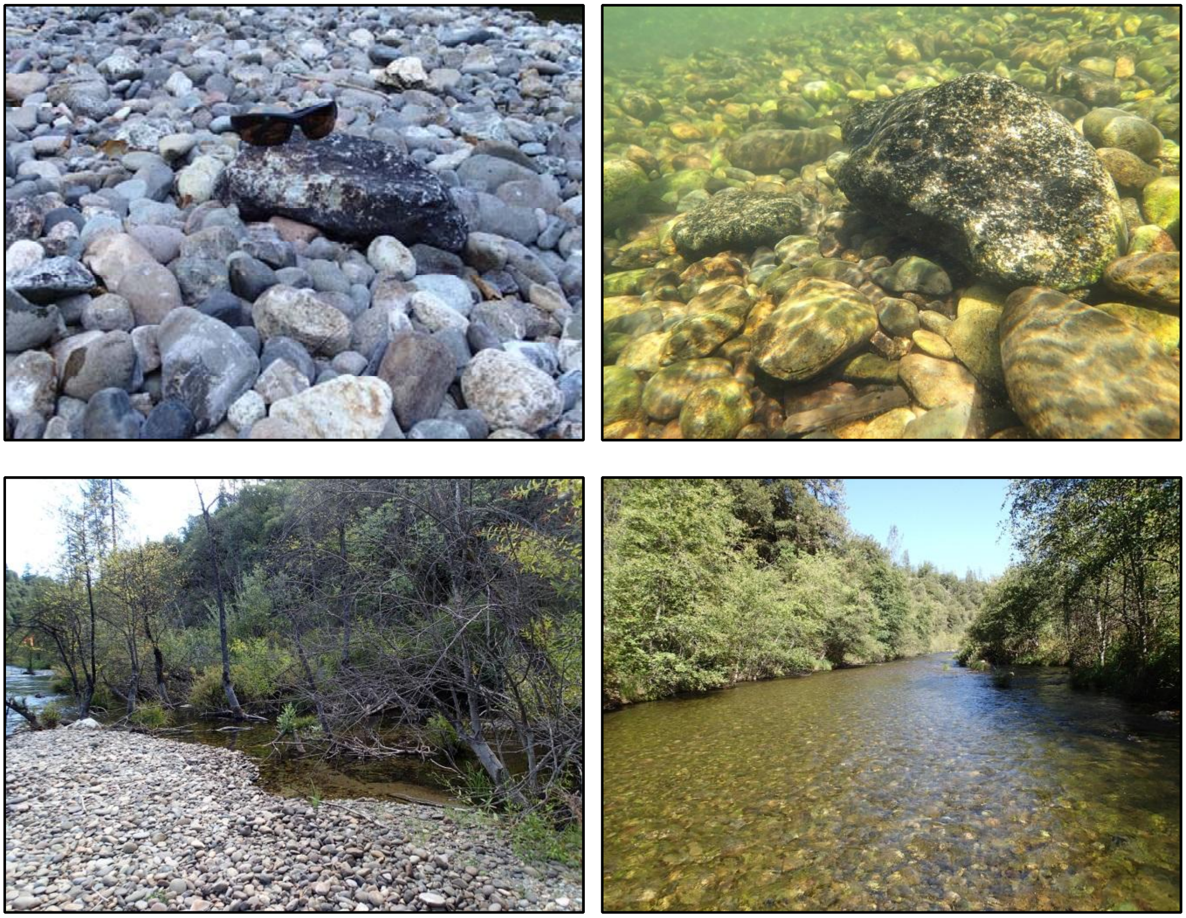


Figure 29. Views of injection-induced changes, from top left: previously immobile boulder "floating on injected riffle gravel; previously immobile boulder perched on active gravel bar; increased floodplain connectivity increases alder mortality; as mid-channel fills with gravel, flow is directed to channel margins, increasing undercutting and bank erosion.

6.3 Recommendations

The focus of this project was to evaluate sediment transport through Reach Two, the section of Clear Creek most limiting to achieving complete coarse sediment routing (GMA 2009, 2011). Gravel injection recommendations are specifically provided for the supply reach (Reach One) and the transport reach (Reach Two). Gravel injection recommendations for all sites downstream of Clear Creek Road (where the channel is more completely recharged within the less confined, more alluvial central valley province and where extensive floodplain and channel restoration has occurred) is regularly discussed by the Clear Creek Technical Team. The team made 2014 recommendations for Clear Creek Road, Phase 3A, Tule Backwater, Phase 3C and Phase 3B during the June 2013 meeting. Additional gravel injection is planned as part of the proposed project at the Cloverview site (Lower Clear Creek Aquatic Habitat and Waste Discharge Improvement Project) just downstream from Reading Bar.

6.3.1 Spawning Gravel Injections

1. Whiskeytown

    a. The primary gravel supply into Reach One. As the upstream-most site, offers the potential to yield the most benefit as gravel deposits slowly migrate downstream.
    b. Volume (tons) – 3,000
    c. Frequency – as frequently as pulses/spills evacuate the cone – approximately every two years
2. Below Dog Gulch
    a. The original design volume has been met here but the gravel has not routed to Peltier. Though Whiskeytown gravel is beginning to arrive at this site, we strongly suggest replenishing Below Dog as a boost to the leading edge of Whiskeytown and to foster the positive geomorphic channel response described in Section 6.2.1.
    b. Volume (tons) – 2,000
    c. Frequency – every 1-2 years
3. Peltier Bridge
    a. Slope and channel distance will facilitate one more placement similar to the 2011 effort. The next placed riffle will likely backwater the next native riffle upstream which might slow the advancement of Below Dog gravels. Thus, this site is a lower priority than Below Dog.
    b. Volume (tons) – 1,000
    c. Frequency – once more, then only if deemed necessary after extremely high flows (e.g. >3,000 cfs)
4. Paige Bar
    a. When gravel from this site connects with the Paige Boulder delta riffle, (assuming full routing has been established upstream) full routing will likely be achieved from Whiskeytown to NEED Camp Bridge (see below). Once-buried bedrock fins within the body of the injection are re-emerging after the second flow season following the last placement, indicating ongoing gradual scour and highlighting the need for ongoing replenishment.
    b. Volume (tons) – 1,000
    c. Frequency – every 2 years
5. Above NEED Camp Bridge
    a. At this time, we do not see a benefit to adding more gravel here as the feature is relatively immobile and by the time Paige gravels arrive, the placed gravels here may be routing through the pool and on into Reach Two.
    b. Volume (tons) - 0
    c. Frequency - 0
6. Guardian Rock
    a. A critical and highly efficient site for achieving complete routing through the system.
    b. Volume (tons) – 2,000-3,000
    c. Frequency – every 1-2 years
7. The Squeeze (“The Narrows”)
    a. This is a new site proposed by GMA in 2011 after several reconnaissance trips through the gorge. It is located 1.55 miles below the leading edge of Guardian rock gravels and

    2.25 miles downstream of Paige Bar Road on Mule town Road (approximate location in Google Earth: 40°33’4.46”N, 122°31’48.95”W)
    b. Volume (tons) – 5,000
    c. Frequency – to be determined
8. Placer Road
    a. Gravel transport has increased dramatically (GMA 2011) since the increase in sand delivery from the South Fork. While habitat quality may be diminished (fines in spawning gravels), the sand has provided an unexpected boost toward achieving coarse sediment continuity by advancing the leading edge from 2,800 to 3,600 feet in one year (GMA 2011). This site was not mapped as part of this 2010-2013 project.
    b. Volume (tons) – 4,000
    c. Frequency – every 2 years
9. Spring Pulse Flows
    a. While the intent of the annual spring pulse flows on Clear Creek have more to do with fish (e.g. attraction flows for spring Chinook), they achieve a high degree of channel maintenance value as well, mobilizing injections and providing the driver for the positive geomorphic response described in Section 6.2.1.
    b. Recommend continuing spring pulse flows (more important in drier years), but increasing magnitude to at least 1,000 cfs (at the dam base) to promote coarse sediment transport past the NEED Camp Gage.

6.3.2 Geomorphic Monitoring

Much of the future geomorphic monitoring for Clear Creek sediment-related phenomena has been proposed under the ongoing efforts to implement *The Environmental Water Program,* an ecological restoration strategy involving high flow spills through Clear Creek. Monitoring suggestions included here may (or may not) be covered by the EWP monitoring plan. We deem them relevant as they arose from the 2011-2013 efforts and relate to Reaches 1 and 2. In order of descending priority:

- Detailed topographic mapping at and below injection sites, after placement and after high flows.
- Integrate surveyed datasets with USFWS spawning habitat mapping data (USFWS 2010) to expand utility (valuation of gravel placements versus fish use) and scope (the USFWS surveys remote, difficult to reach areas) of geomorphic assessments.
- Continued operation of NEED Camp streamgage – provides the only streamflow data for Reach One. Utility would be improved by the operation of a continuous stage recorder above or within Paige Boulder Creek to provide flow information for injections located above Paige Boulder Creek.
- Continued bedload sampling at both locations during very high flow events and pulse flows will improve predictive capability and can provide insight into sediment routing status (e.g. if the percentage of >8mm gravel in bedload samples increases, it may imply that routing has been achieved through the pool above NEED Camp Bridge; the percentage of <2mm size fraction of bedload measured at Igo may indicate decreased sand production within the South Fork Clear Creek.
- Continue qualitative assessments of geomorphic response below gravel injections. Add a quantitative component (e.g. facies mapping, cross section surveys with water surface elevations, tracer gravel mobility studies, sediment transport capacity modeling, habitat mapping) to quantify and thus predict the effect of gravel injections as a passive restoration tool to achieve secondary restoration goals.

6.3.3 Potential Impact of Environmental Water Program Flows

The Clear Creek Environmental Water Program (EWP) could provide more frequent high flows by manipulating Whiskeytown Dam operations to facilitate mid-range peaks with a target magnitude of 3,250 cfs (as the 1 day average at the dam base) at a target frequency of not less than 4 of 10 years and up to 7 of 10 years (Stillwater 2013, *draft*). The last event of similar magnitude and duration was the 2003 Glory Hole spill which initiated numerous positive geomorphic effects in the lower reaches such as: floodplain deposition, channel migration, development of new alluvial features, bed mobilization and gravel transport (GMA 2003). Restored channels and floodplains generally functioned as designed and degraded channel segments were not recaptured (GMA 2003). As of 2003, little restoration work had occurred in the upper reaches (1 and 2), other than gravel injection at the base of Whiskeytown Dam. Since 2003, nearly 60,000 tons of gravel has been added in reaches One and Two (Table 7), leading to a substantial increase in spawning habitat (GMA 2011) and the variety of positive geomorphic changes described in this 2013 report (see Section 6.2.1).

While a thorough assessment of potential positive geomorphic impacts is well beyond the scope of this report, the data collected for this project suggest that some benefits EWP flows could provide might be:

- Increasing coarse sediment transport which might reduce the cost and effort to achieve complete routing.
- Enhance riparian scour both by mechanical disruption by entrained debris and by fluvial cutting at the toes of banks.
- Increased transport of injection gravels may increase the mobility of armored, previously immobile features.
- Spawning gravels distributed by natural flows tend to develop into more complex depositional features which exhibit a wider range of hydraulic conditions than can be achieved by mechanical placement (as in the case of channel evolution Below Dog Gulch).
- For Reach Two in particular, the limiting segment for complete routing of coarse sediment, EWP flows could greatly shorten the time to achieve complete routing.

While EWP flows could conceivably evacuate stored gravels from some productive areas (such as spawning riffles), the ecological cost of these impacts would likely be offset by the creation of new habitats. The restoration costs should also be lowered by the reduced effort required to maintain sediment routing once it is achieved: gravel could be placed in fewer locations along a stream that is fully supplied and experiences periodic high flows.

7. References

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Appendix

A1-A3. Rating Table for Clear Creek near NEED Camp: 2013

B1. Isopachs developed from topographic surveys: Below Dog Gulch

B2. 2013 Topography: Below Dog Gulch

B3. Isopachs developed from topographic surveys: Above Peltier Bridge

B4. 2013 Topography: Above Peltier Bridge

B5. Isopachs developed from topographic surveys: Paige Bar

B6. 2013 Topography: Paige Bar

B7. Isopachs developed from topographic surveys and 2013 Topography: Guardian Rock

GMA HYDROLOGY

CLEAR CREEK AT NEED CAMP -- GMA0885500

RATING TABLE NO. 2.0 -- Begin Date 3/26/2011

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	---	---	---	---	---	---	---	---	---	---
0.1	---	---	---	---	---	---	---	---	---	---
0.2	---	---	---	---	*77.7*	*79.5*	*81.3*	*83*	84.8	86.5
0.3	88.1	89.8	91.4	93	94.6	96.2	97.7	99.2	101	102
0.4	104	105	107	108	109	111	112	114	115	116
0.5	118	119	120	122	123	124	125	127	128	129
0.6	130	132	133	134	135	136	138	139	141	143
0.7	145	147	149	151	153	155	157	159	161	163
0.8	165.00	167.00	169.00	171.00	173.00	175.00	177.00	179.00	181.00	183.00
0.9	185.00	187.00	189.00	191.00	193.00	195.00	197.00	199.00	200.00	202.00
1.0	204.00	206.00	208.00	210.00	212.00	214.00	216.00	218.00	220.00	222.00
1.1	224.00	226.00	228.00	230.00	232.00	234.00	236.00	238.00	240.00	242.00
1.2	244.00	246.00	248.00	249.00	251.00	253.00	255.00	257.00	259.00	261.00
1.3	263.00	265.00	267.00	269.00	271.00	273.00	275.00	277.00	279.00	281.00
1.4	283.00	284.00	286.00	288.00	290.00	292.00	294.00	296.00	298.00	300.00
1.5	302.00	305.00	308.00	310.00	313.00	315.00	318.00	320.00	323.00	325.00
1.6	328.00	330.00	333	336	338	341	343	346	349	351
1.7	354.0	356.0	359.0	362.0	364.0	367.0	369.0	372.0	375.0	377.0
1.8	380.0	383.0	385.0	388.0	391.0	393.0	396.0	398.0	401.0	404.0
1.9	406.0	409.0	412.0	415.0	417.0	420.0	423.0	425.0	428.0	431.0
2.0	433.0	436.0	439.0	442.0	444.0	447.0	450.0	452.0	455.0	458.0
2.1	461.0	463.0	466.0	469.0	472.0	474.0	477.0	480.0	483.0	485.0
2.2	488.0	491.0	494.0	497.0	499.0	502.0	505.0	508.0	511.0	513.0
2.3	516.0	519.0	522.0	525.0	527.0	530.0	533.0	536.0	539.0	542.0

NOTES: Values in italics are beyond the validated range

APPENDIX A1

GMA HYDROLOGY

CLEAR CREEK AT NEED CAMP -- GMA0885500

RATING TABLE NO. 2.0 -- Begin Date 3/26/2011

GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
2.4	544.0	547.0	550.0	553.0	556.0	559.0	561.0	564.0	567.0	570.0
2.5	573.0	576.0	579	581	584	587	590	593	596	599
2.6	602	605	607	610	613	616	619	622	625	628
2.7	631	634	637	639	642	645	648	651	654	657
2.8	660	663	666	669	672	675	678	681	684	687
2.9	690	693	696	699	702	705	708	711	714	717
3.0	720	723	726	729	732	735	738	741	744	747
3.1	750	753	756	759	762	765	768	771	774	777
3.2	780	783	786	789	792	795	798	801	804	808
3.3	811	814	817	820	823	826	829	832	835	838
3.4	841	844	848	851	854	857	860	863	866	869
3.5	872	876	879	882	885	888	891	894	897	901
3.6	904	907	910	913	916	919	923	926	929	932
3.7	935	938	942	945	948	951	954	957	961	964
3.8	967	970	973	976	980	*983*	*986*	*989*	*992*	*996*
3.9	*999*	*1000*	*1010*	*1010*	*1010*	*1010*	*1020*	*1020*	*1020*	*1030*
4.0	*1030*	*1030*	*1040*	*1040*	*1040*	*1050*	*1050*	*1050*	*1060*	*1060*
4.1	*1060*	*1070*	*1070*	*1070*	*1080*	*1080*	*1080*	*1090*	*1090*	*1090*
4.2	*1100*	*1100*	*1100*	*1110*	*1110*	*1110*	*1120*	*1120*	*1120*	*1130*
4.3	*1130*	*1130*	*1140*	*1140*	*1140*	*1140*	*1150*	*1150*	*1150*	*1160*
4.4	*1160*	*1160*	*1170*	*1170*	*1170*	*1180*	*1180*	*1180*	*1190*	*1190*
4.5	*1190*	*1200*	*1200*	*1200*	*1210*	*1210*	*1210*	*1220*	*1220*	*1220*
4.6	*1230*	*1230*	*1230*	*1240*	*1240*	*1240*	*1250*	*1250*	*1250*	*1260*
4.7	*1260*	*1260*	*1270*	*1270*	*1270*	*1280*	*1280*	*1280*	*1290*	*1290*

NOTES: Values in italics are beyond the validated range

APPENDIX A2

GMA HYDROLOGY

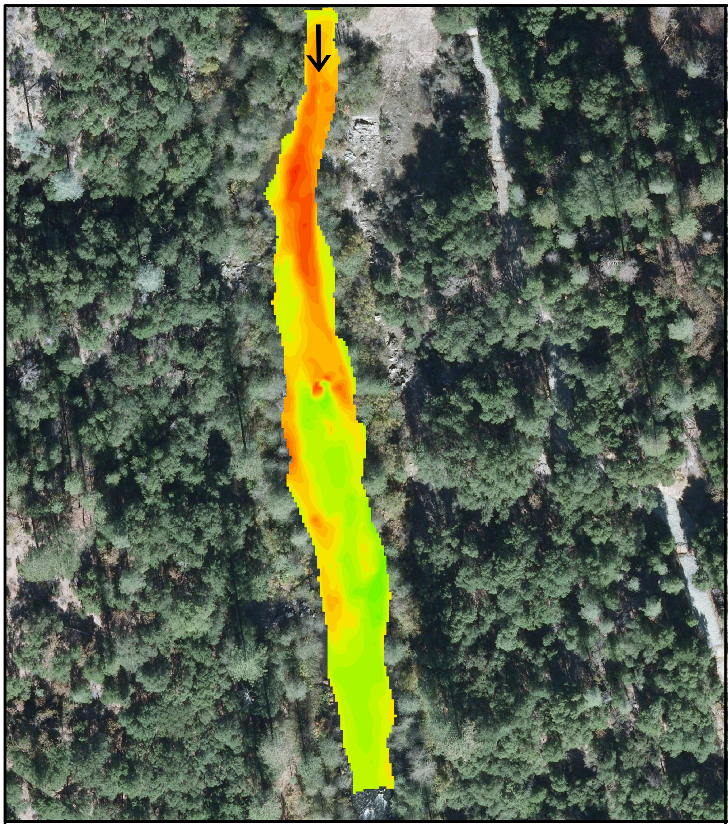
CLEAR CREEK AT NEED CAMP -- GMA0885500

RATING TABLE NO. 2.0 -- Begin Date 3/26/2011

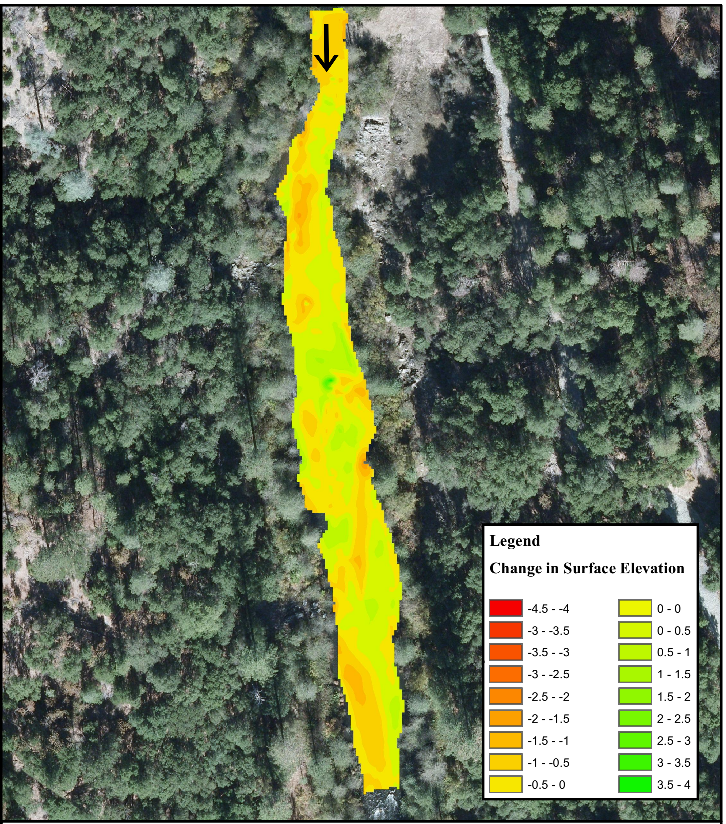
GH	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
4.8	*1290*	*1300*	*1300*	*1310*	*1310*	*1310*	*1320*	*1320*	*1320*	*1330*
4.9	*1330*	*1330*	*1340*	*1340*	*1340*	*1350*	*1350*	*1350*	*1360*	*1360*
5.0	*1360*	*1370*	*1370*	*1370*	*1380*	*1380*	*1380*	*1390*	*1390*	*1390*
5.1	*1400*	*1400*	*1400*	*1410*	*1410*	*1410*	*1420*	*1420*	*1420*	*1430*
5.2	*1430*	*1430*	*1440*	*1440*	*1440*	*1450*	*1450*	*1460*	*1460*	*1460*
5.3	*1470*	*1470*	*1470*	*1480*	*1480*	*1480*	*1490*	*1490*	*1490*	*1500*
5.4	*1500*	*1500*	*1510*	*1510*	*1510*	*1520*	*1520*	*1520*	*1530*	*1530*
5.5	*1540*	*1540*	*1540*	*1550*	*1550*	*1550*	*1560*	*1560*	*1560*	*1570*
5.6	*1570*	*1570*	*1580*	*1580*	*1580*	*1590*	*1590*	*1590*	*1600*	*1600*
5.7	*1610*	*1610*	*1610*	*1620*	*1620*	*1620*	*1630*	*1630*	*1630*	*1640*
5.8	*1640*	*1640*	*1650*	*1650*	*1650*	*1660*	*1660*	*1670*	*1670*	*1670*
5.9	*1680*	*1680*	*1680*	*1690*	*1690*	*1690*	*1700*	*1700*	*1700*	*1710*
6.0	*1710*	*1720*	*1720*	*1720*	*1730*	*1730*	*1730*	*1740*	*1740*	*1740*
6.1	*1750*	*1750*	*1750*	*1760*	*1760*	*1770*	*1770*	*1770*	*1780*	*1780*
6.2	*1780*	*1790*	*1790*	*1790*	*1800*	*1800*	*1800*	*1810*	*1810*	*1820*
6.3	*1820*	*1820*	*1830*	*1830*	*1830*	*1840*	*1840*	*1840*	*1850*	*1850*
6.4	*1860*	*1860*	*1860*	*1870*	*1870*	*1870*	*1880*	*1880*	*1880*	*1890*
6.5	*1890*	*1900*	*1900*	*1900*	*1910*	*1910*	*1910*	*1920*	*1920*	*1920*
6.6	*1930*	*1930*	*1940*	*1940*	*1940*	*1950*	*1950*	*1950*	*1960*	*1960*
6.7	*1960*	*1970*	*1970*	*1980*	*1980*	*1980*	*1990*	*1990*	*1990*	*2000*
6.8	*2000*	*2010*	*2010*	*2010*	*2020*	*2020*	*2020*	*2030*	*2030*	*2030*
6.9	*2040*	*2040*	*2050*	*2050*	*2050*	*2060*	*2060*	*2060*	*2070*	*2070*
7.0	---	---	---	---	---	---	---	---	---	---

NOTES: Values in italics are beyond the validated range

APPENDIX A3



Volume Difference from May 2012 to September 2012
Cut 651 CY, Fill 368 CY, Net Fill 283 CY



Volume Difference from September 2012 to September 2013
Cut 265 CY, Fill 140 CY, Net Cut 125 CY

Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

Below Dog Gulch
Clear Creek Geomorphic Monitoring
2011-2013

Appendix

B1

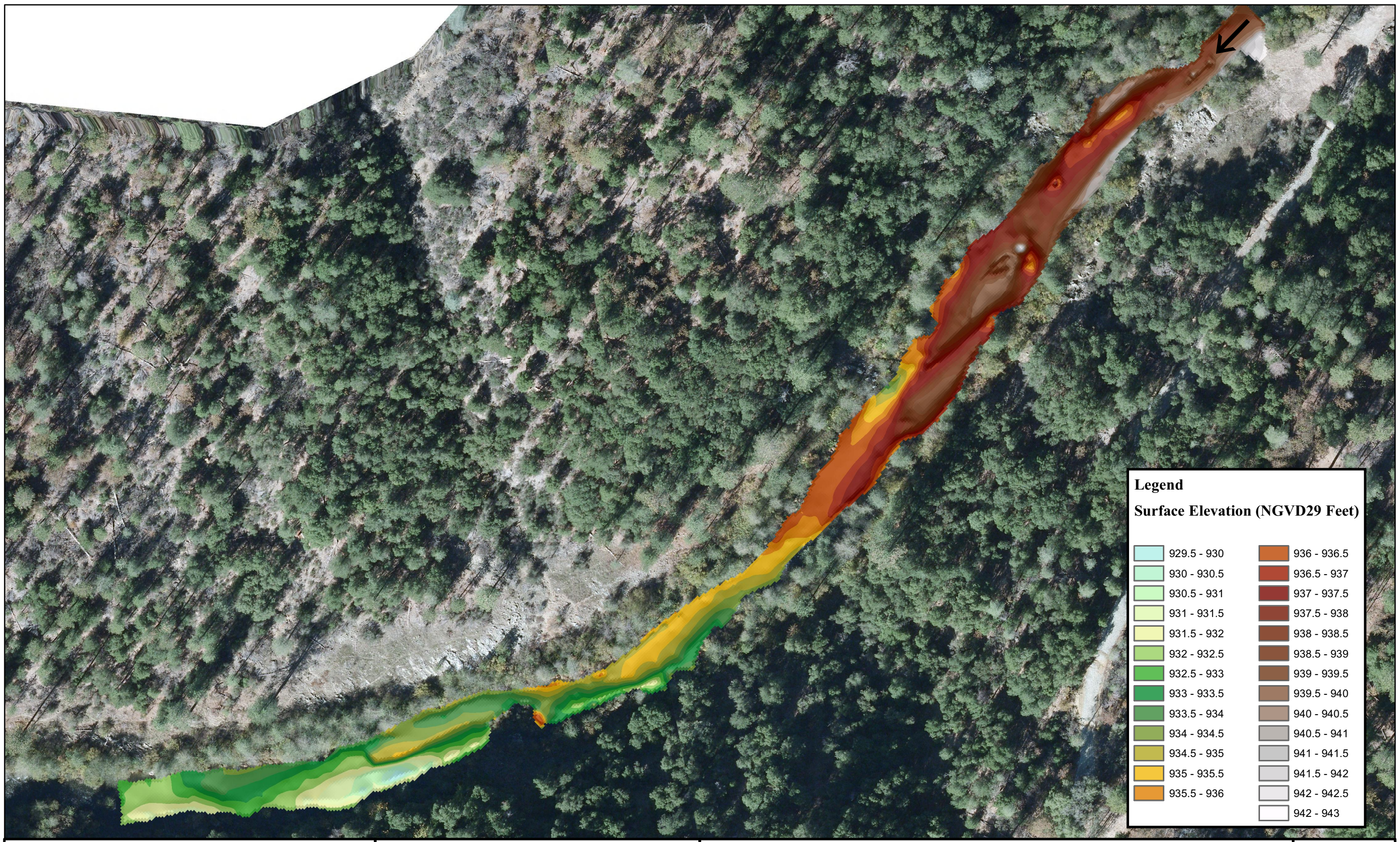
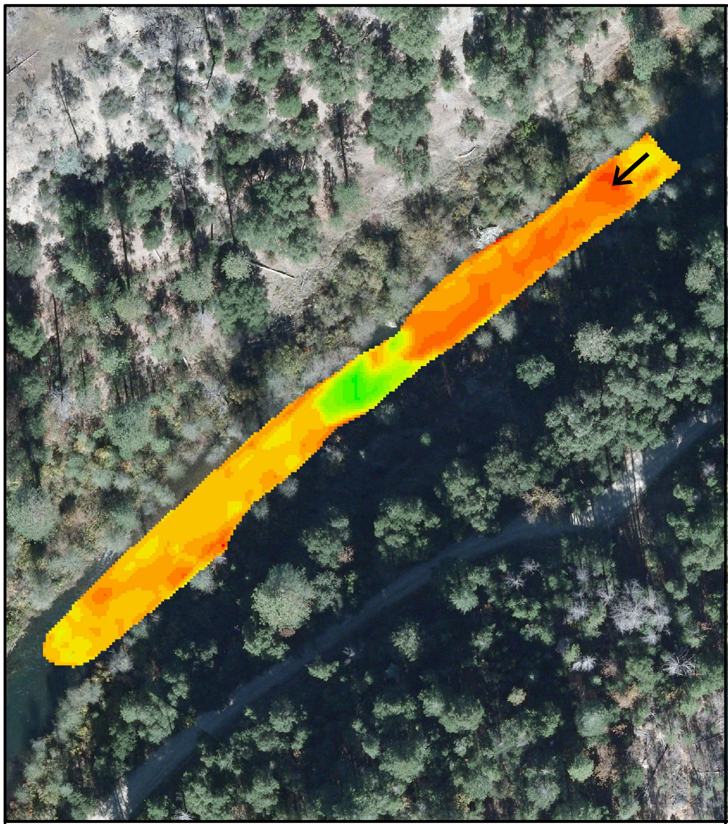


Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

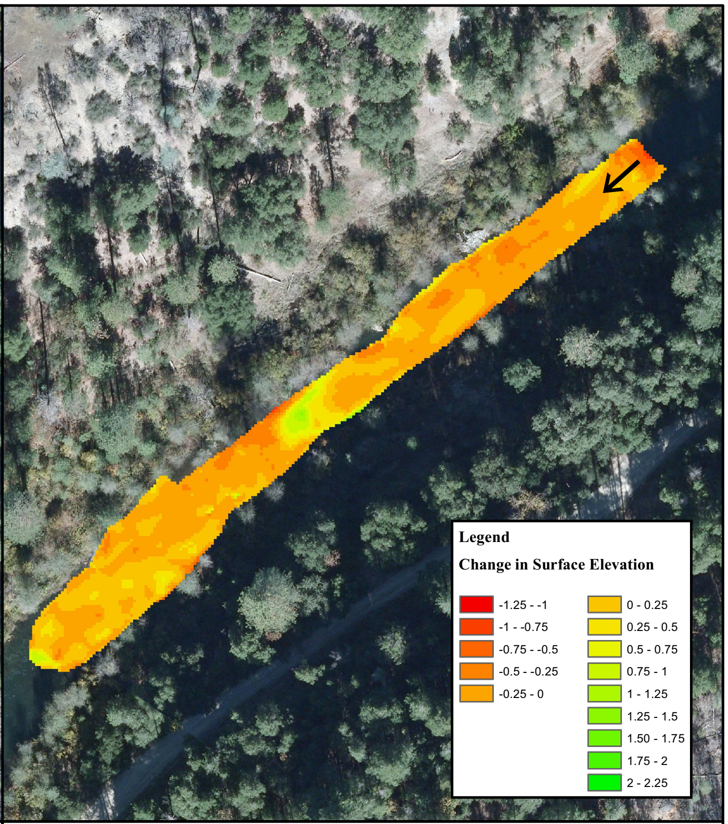
Below Dog Gulch - September 2013
Clear Creek Geomorphic Monitoring
2011-2013

Appendix

B2



Volume Difference from May 2012 to September 2012
Cut 101 CY, Fill 139 CY, Net Fill 38 CY



Volume Difference from September 2012 to September 2013
Cut 73 CY, Fill 64 CY, Net Cut 9 CY

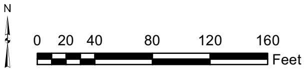


Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

Above Peltier Bridge
Clear Creek Geomorphic Monitoring
2011-2013

Appendix

B3

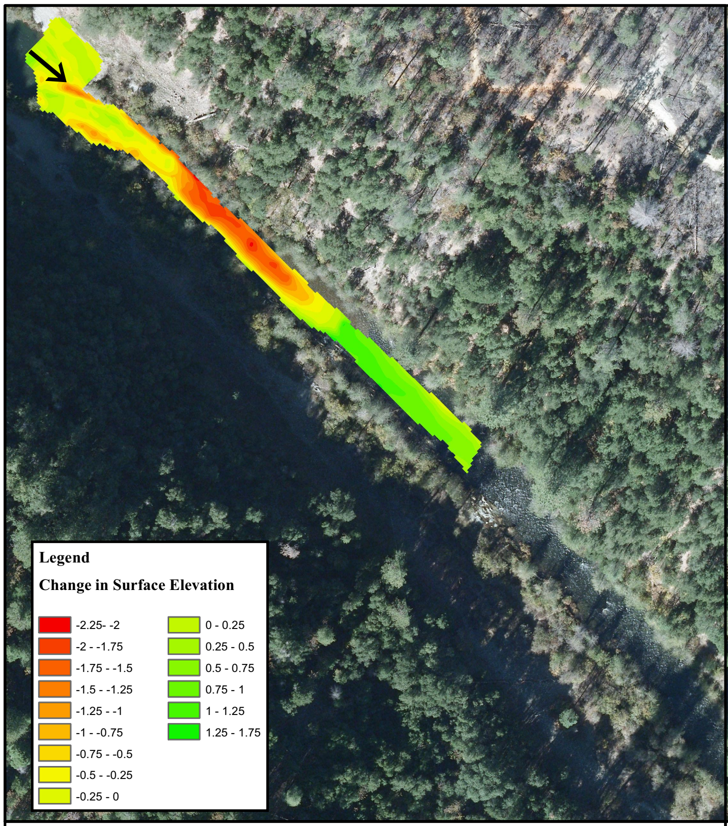
N

0 15 30 60 90 120 Feet

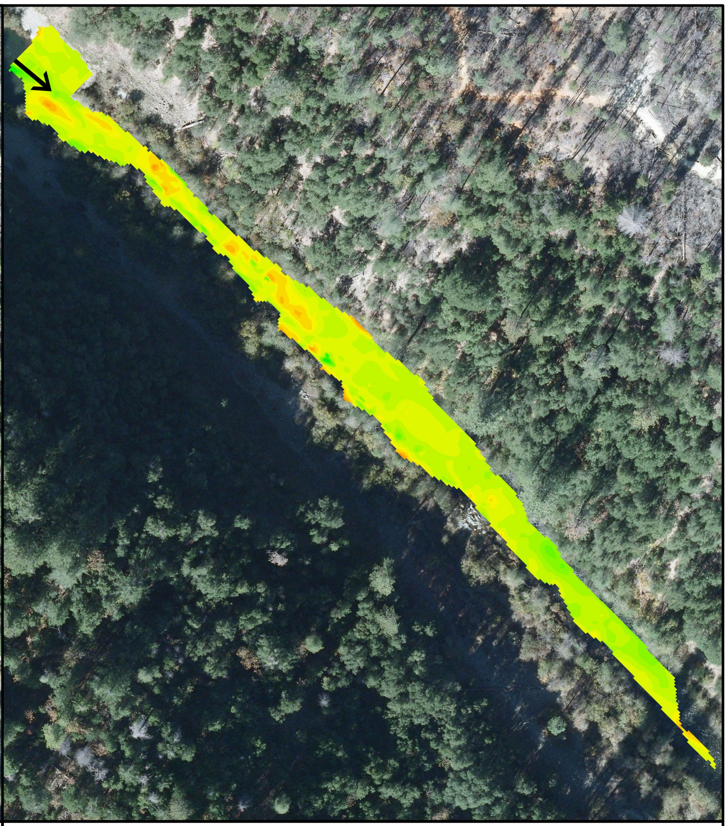
Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

Above Peltier Bridge - September 2013
Clear Creek Geomorphic Monitoring
2011-2013

Appendix
B4



Volume Difference from May 2012 to September 2012
Cut 225 CY, Fill 124 CY, Net Cut 101 CY



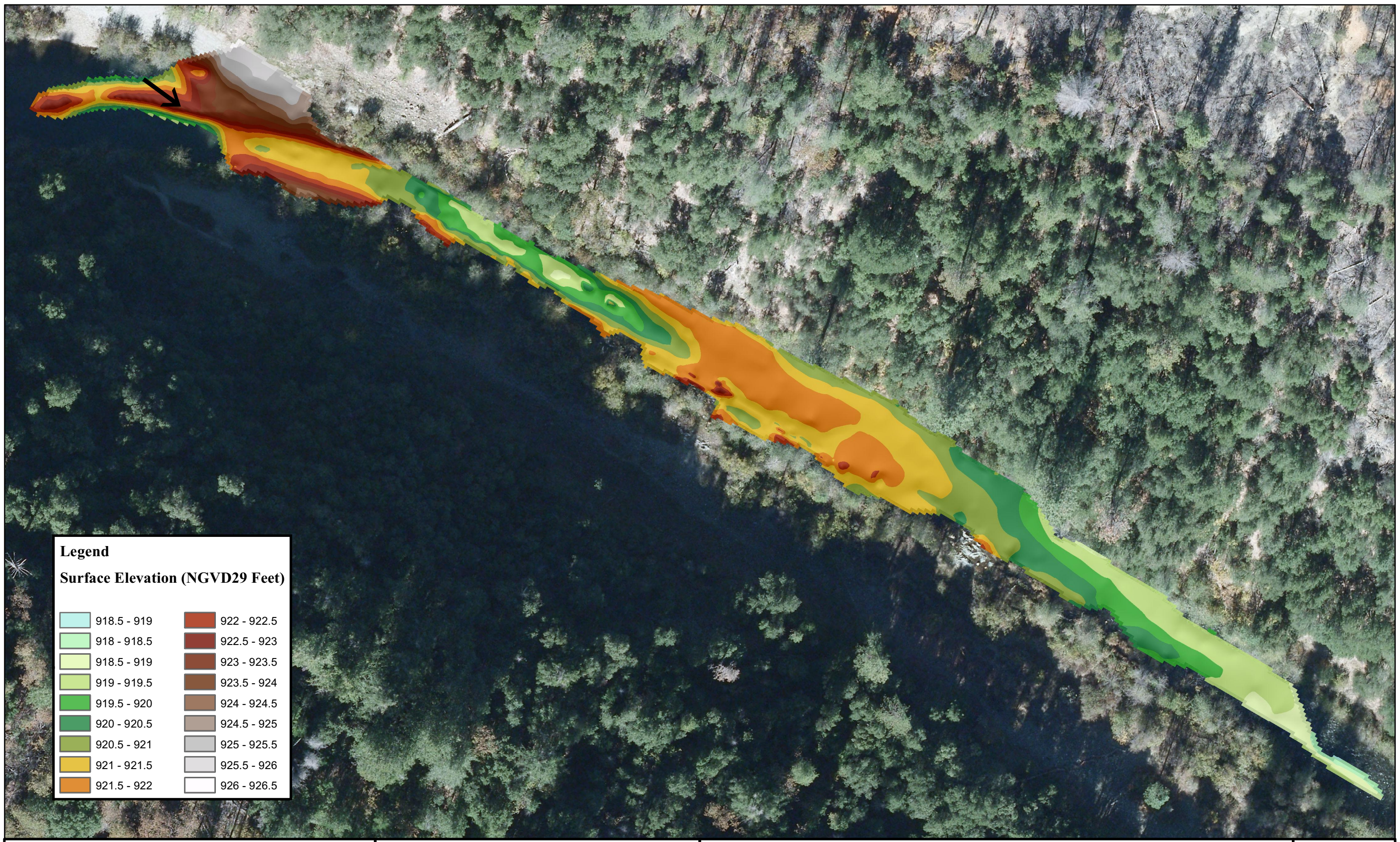
Volume Difference from September 2012 to September 2013
Cut 109 CY, Fill 90 CY, Net Cut 19 CY

N
0 25 50 100 150 200
Feet

Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

Paige Bar
Clear Creek Geomorphic Monitoring
2011-2013

Appendix
B5



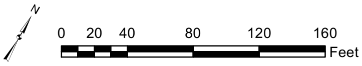
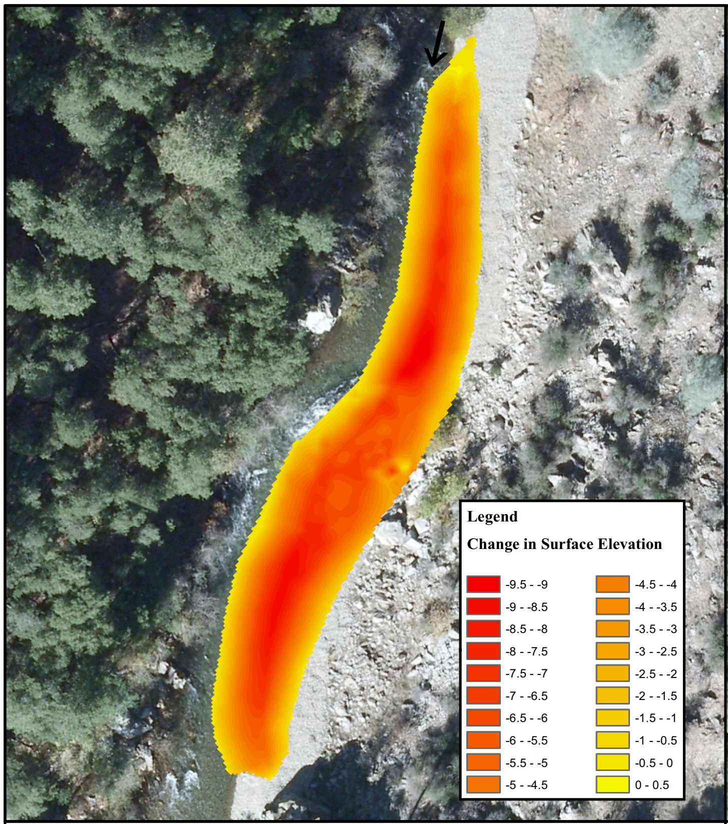


Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

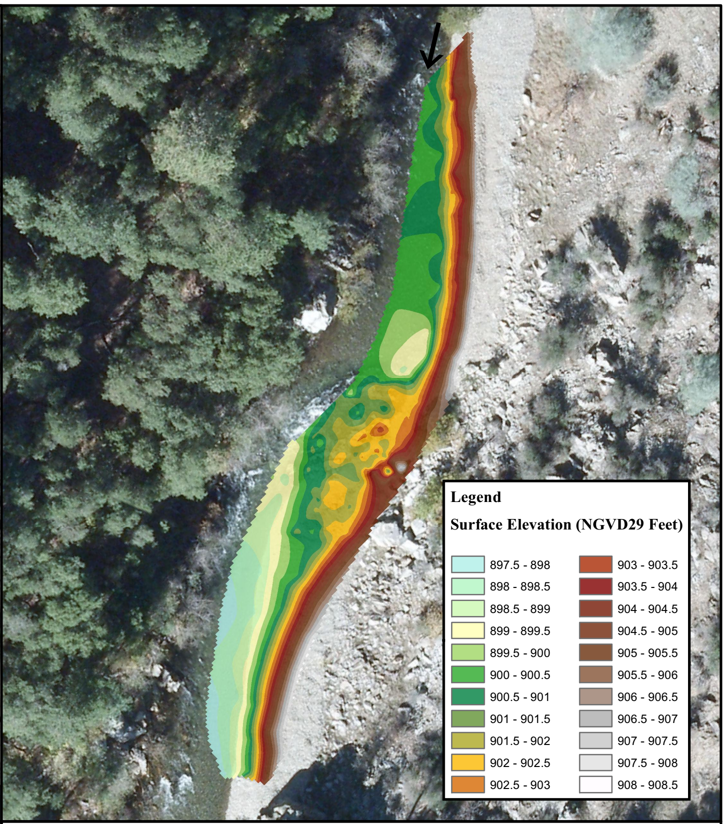
Paige Bar - September 2013
Clear Creek Geomorphic Monitoring
2011-2013

Appendix

B6



Volume Difference from September 2012 to September 2013
Cut 1,271 CY, Fill 0 CY, Net Cut 1,271 CY



September 2013 Topographic Map

N
0 10 20 40 60 80
Feet

Photo Date 10/30/2009
Flow 213 cfs @ USGS 11372000

Guardian Rock Pool (Below NEED Camp)
Clear Creek Geomorphic Monitoring
2011-2013

Appendix

B7