CLEAR CREEK GEOMORPHIC MONITORING

Shasta County, California

2009-2011 FINAL REPORT

Prepared for:

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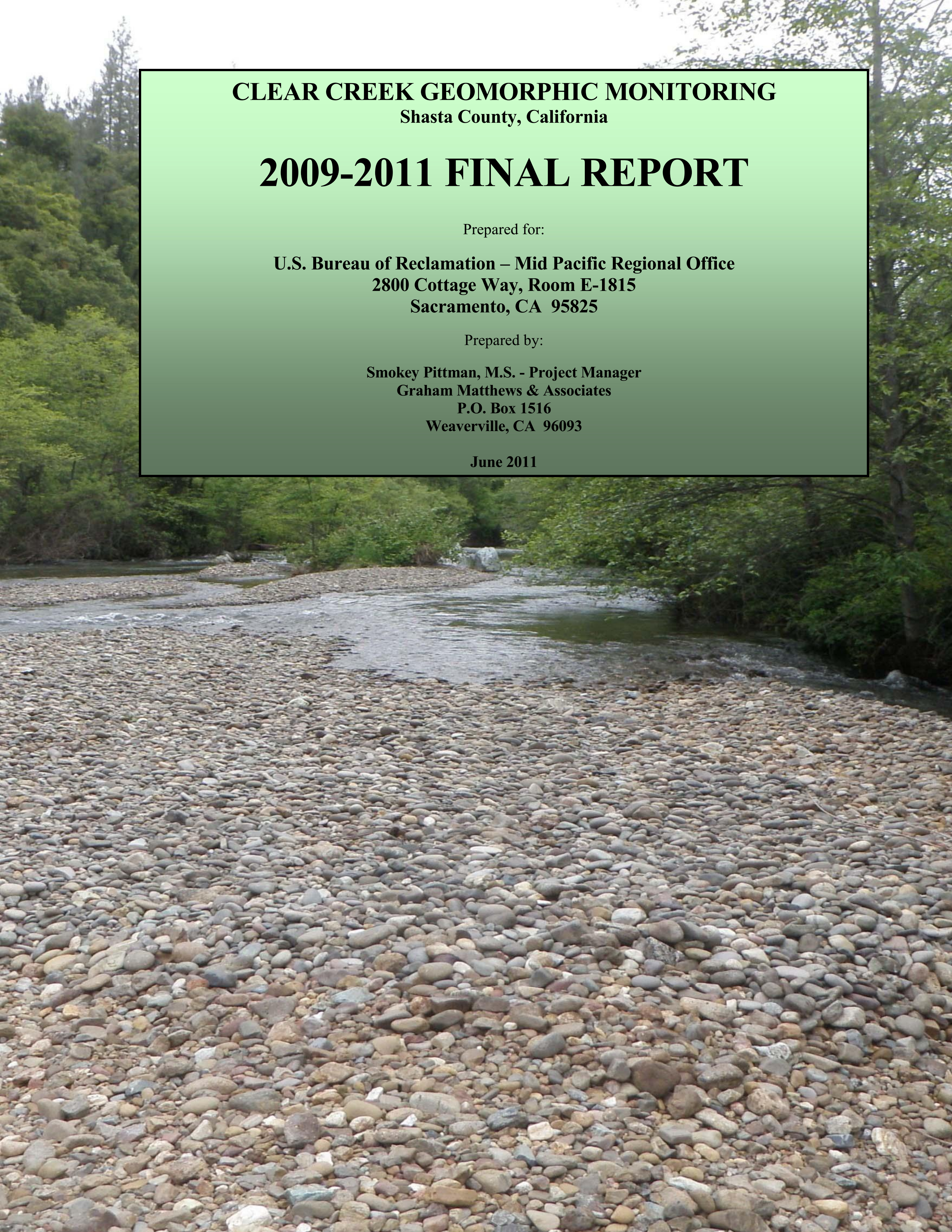

CLEAR CREEK GEOMORPHIC MONITORING 2009-2011

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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)
Natural Resource Conservation Service (NRCS)
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)

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EXECUTIVE SUMMARY

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 130,000 tons of spawning gravel has been added to Clear Creek below Whiskeytown. The goal of this Graham Matthews and Associates (GMA) 2009-2011 US Bureau of Reclamation (USBR) Clear Creek Geomorphic Monitoring Project is to evaluate sediment-related geomorphic issues (e.g. 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."

Orthorectified aerial photographs, topographic and longitudinal profiles surveys were used to evaluate the physical attributes of gravel injections. Spawning surveys and spawning habitat mapping (performed by US Fish and Wildlife Service(USFWS), Red Bluff) were employed to assess the spatial area of habitat created and the degree to which it was utilized for spawning. 2010 habitat mapping (USFWS data) was compared to older inventories (Slater 1956, Coots 1970, McBain and Trush 2001, GMA 2009) to assess the degree of habitat change for various time periods. Spawning habitat created by recent gravel injections was then evaluated in terms of its cost and the degree to which it was used by spawning fish.

Between 2001 (McBain and Trush) and 2009 (Graham Matthews and Associates), the areal extent of spawning gravel increased 533 percent in the two miles below Whiskeytown Dam. The other three assessments used a different method and are only comparable with one another. For the Whiskeytown to Saeltzer reach, spawning habitat measured in 1970 (Coots) was 93 percent less than in 1956 (Slater) levels. From 1970 to 2010 (USFWS) spawning habitat increased over 1,000 percent. 2010 levels may be only 22 percent less than 1956 levels. Flow conditions differed between these surveys and further research is required in order to clearly compare 2010 to results from these earlier time periods.

While all injections were evaluated, this study focused on the reach from Whiskeytown to Saeltzer to facilitate comparisons with the habitat mapping studies. Today, 54 percent of spawning habitat in the Whiskeytown to Saeltzer study reach is composed of injected gravel. Talus cones were found to be most effective at creating spawning habitat with Whiskeytown and Placer contributing 14 percent each to all of the spawning gravel (native and injected). These sites proved the most economical as well at \$0.04 and \$0.05 (per 100 ft^2 of spawning habitat created) respectively. Though it was very costly to build at \$0.89 (per 100 ft^2 of spawning habitat created) the sluicing site above Peltier Bridge turned out to be most economical with regard to utilization (the number of redds built in the created habitat) at 0.28 steelhead redds per \$1,000. The injection below NEED Camp was the most costly both in terms of habitat created at \$0.99/ft^2 and among least effective in terms of steelhead redds per dollar at 0.02. During the study period spring Chinook use of injected gravel in Reach One was virtually zero. Though the indices of habitat creation and of spawning use in the floodway restoration area vary from the rest of the study and a direct comparison is difficult, channel relocation appears to be the most expensive method of creating spawning habitat at approximately \$9 million to date for all phases. Channel relocation is however highly effective at increasing spawning use: USFWS measured an increase in spawned area (in the reach below Saeltzer Gorge) from 2.2 - 7.1 percent pre-Phase 3A construction to 11.4-18.0 percent post-construction.

The apparent high cost of some projects is a function of the criteria for success being used: spawning habitat area. Some projects (e.g. Below NEED Camp) score quite low in terms of the cost of habitat created but simply because the gravel-filled channel below the injection does not fall into the mapping criteria of "habitat" does not mean that it is not filling a very important role. The 1,000 feet of channel below this injection is providing a valuable supply of spawning gravel for downstream reaches which will be redistributed into alluvial features during the next very high flow event. Coarse sediment transport continuity, while not a reasonable short term goal, should remain high on the priority list for restoration. On a reach-level, gravel injections have greatly enhanced coarse sediment transport continuity in Clear Creek. This measure of success is not directly evaluated using habitat mapping and in some cases (e.g. below NEED), using spawning habitat area as an index may imply that injection performance is lower than it is.

The Central Valley Project Improvement Act declared 1956 spawning habitat levels as the target for recovery and the US Bureau of Reclamation requested that this study attempt to answer the question of how far along are we toward this goal. Clear Creek is much smaller than when the 1956 survey was completed and is now much more incised and is highly confined by vegetation. Today, we have concentrated large amounts of spawning gravel into smaller areas in a channel governed by very different hydrologic and hydraulic conditions. While the total spawning area may be approaching 1956 levels (we can't be sure until we calibrate the USFWS 2010 spawning habitat mapping data), spawning fish aren't using the habitat to its potential, which may be tied to geomorphic phenomena (e.g. particle size, embeddedness) or some other unknown variable. Sand delivery in the lower reaches may be a larger threat to recovery than lack of spawning habitat. Different measures of recovery should be evaluated, likely by reach, and these should be used to improve the next phase of gravel injection efforts.

Recommendations include:

- Collect spawning habitat data at different flows to make contemporary results more comparable to historic findings.
- Investigate why salmon are not using injected gravel in reaches one and two.
- Expand geomorphic monitoring of gravel injections to include particle size information and more rigor to volumetric analyses,
- Repeat aerial photos approximately every 3 years.
- The goal of attaining 1956 levels of spawning habitat has proven a powerful tool to drive restoration but it may not be the best measure of recovery. Physical and biological conditions and constraints change. The Clear Creek restoration team should discuss alternative measures of success that will likely vary by reach and will likely include geomorphic and biological criteria.
- Gravel injection recommendations ranked the following sites as the highest priority:
    - Below Dog Gulch
    - Paige Bar
    - Below NEED Camp
    - Placer
    - Clear Creek Road
    - Above 3A
    - Tule backwater

1.0 INTRODUCTION

1.1 Project Description

Funding for the 2009-2011 Clear Creek Geomorphic Monitoring study was provided by the US Bureau of Reclamation (USBR) in response to Solicitation Number 09SQ200075. 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, 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 goal of this project is to evaluate sediment-related geomorphic issues (e.g. distribution and abundance of spawning gravel) which govern key biological and ecological criteria (e.g. quality of salmon spawning habitat) and relate them to specific management objectives such as "achieving complete coarse sediment routing." The objectives delineated in the April 29, 2009 Scope of Work (Table 1) expand upon various investigations initiated in the aforementioned studies and cover Water Years (WY) 2010-2011.

Since many of the tasks include a unique deliverable (such as a photo atlas), this report requires a unique format and numerous references will be made to deliverables which are separate documents. Two of the tasks for this project (Assessing Spawning Habitat Change and Evaluating Gravel Injection Methods) lend themselves to standard reporting format, which is the focus of this document. We suggest having access to the associated three atlases (Table 1) and reviewing the reports listed above to better understand the information provided herein.

The US Fish and Wildlife Service Red Bluff, California office contributed to this study in numerous ways, notably by: collecting the geospatial spawning data used in the Spawning Atlas and evaluating the methods and results of previous studies of spawning habitat in Clear Creek.

Table 1. Objectives defined for 2009-2010 Clear Creek Geomorphic Monitoring.

TASK	OBJECTIVES	DELIVERABLE
Project Management	Attend meetings, provide geomorphic consultation	(see "Methods" section)
	Submit progress reports	
	Meet with USBR; deliver presentations	
Aerial Photographs	Fly and photograph Clear Creek, dam to mouth	Two hard copy atlases (Photo Atlas)
	Orthorectify or rubbersheet and mosaic photos	Seminal data on CD
Conduct a Longitudinal Profile	Survey long profile dam to mouth	Excel and Powerpoint profiles Two hard copy atlases (Survey Atlas) Seminal data on CD
Monitor Topography Below Injection Sites	Conduct 2 instream topographic surveys of all injections	Maps showing change (Survey Atlas) Seminal data on CD
Map Redd Location vs Potential Spawning Habitat	Obtain USFWS GIS data and produce 3 maps on aerials: Redd locations Potential Spawning Habitat (delineate injected gravel) Maps combining redds and habitat	Two hard copy atlases (Spawning Atlas) Seminal data on CD
Assess Potential Spawning Habitat Change	Assess and quantify change below Whiskeytown Dam, using: USFWS-provided Reports/Memos: 1954, 1970, 2001, 2009	Two hard copy reports (this document) Seminal data on CD
Evaluate Gravel Injection Methods	Focusing on Clear Creek, evaluate: Projects, gravel movement, potential habitat created, fish use. Cost/benefits per injection	Two hard copy reports (this document) Seminal data on CD

1.2 Background

1.2.1 Physical Setting

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 9 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).

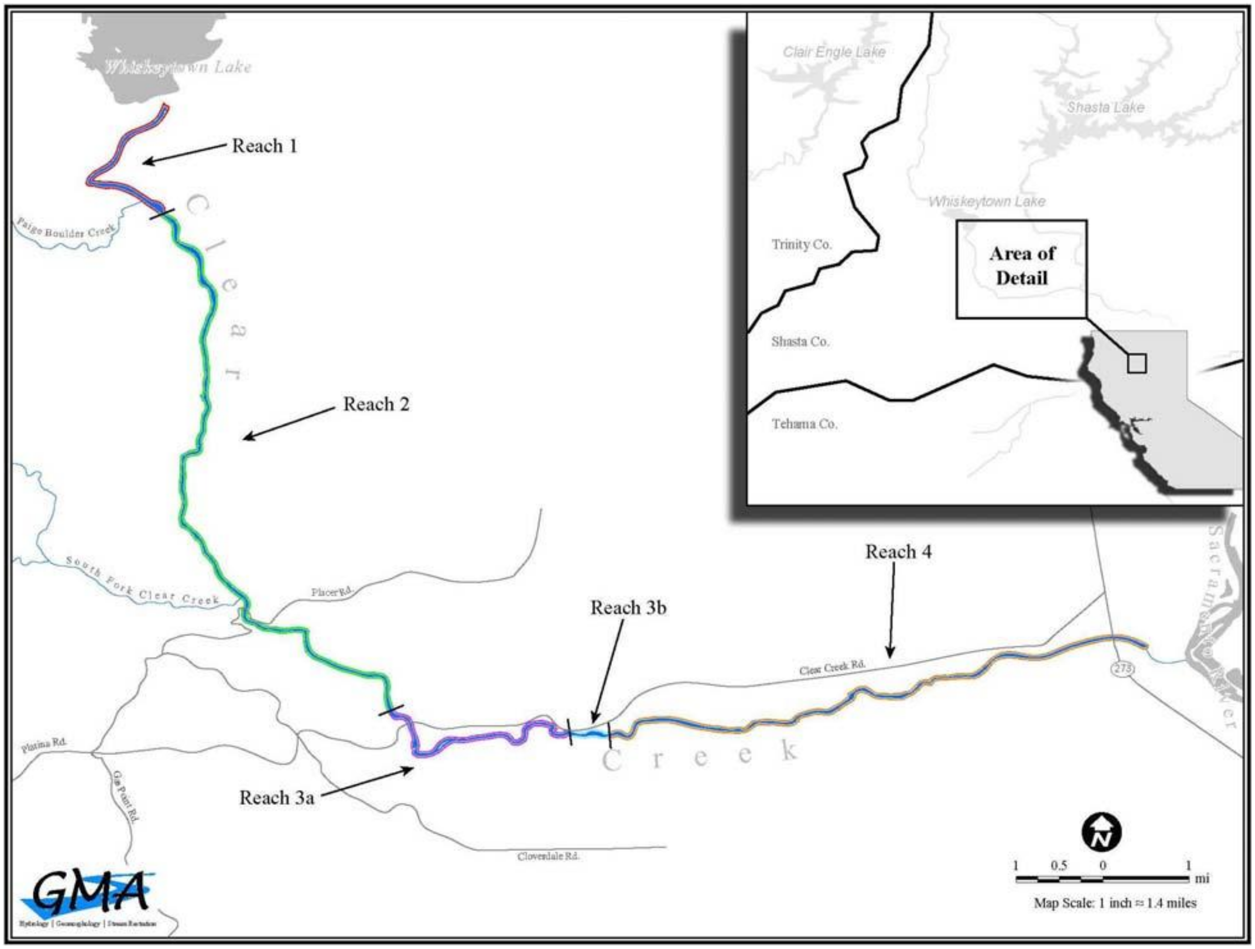

Figure 1: Reach Map for Clear Creek below Whiskeytown Dam.

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. The following is summarized from McBain and Trush 2001:

> 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.

McBain & Trush summarized the effects of flow regulation on channel morphology in the lower river, as follows:

- 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:
    a. Low gradient alluvial reach from Clear Creek Road to Saeltzer Dam site (1.6 miles),
    b. 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 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 Spawning Habitat Monitoring

In 1956, Warner and Slater (Slater 1956) conducted a USFWS spawning habitat assessment from Whiskeytown Dam-site to McCormick Saeltzer Dam (river mile 6.5, constructed in 1903 and removed in 2001) to determine the amount of spawning habitat available prior to the building of Whiskeytown Dam. Coots (1970) repeated the assessment eight years after Whiskeytown Dam construction and found that spawning habitat decreased by 93%. Since that time, numerous studies (Villa 1984, Villa 1986, Brown 1996) recognized ongoing physical and ecological degradation of Clear Creek downstream of Whiskeytown Dam that stemmed from historic mining practices, decreased water flows and sediment transport, and fish passage at Saeltzer Dam. These studies documented the resulting decline of salmonid populations and the potential for rehabilitation of Clear Creek. In response, the Clear Creek Restoration Program was developed (McBain and Trush 2001) by multiple agencies, to restore ecological function to the watershed. Subsequent restoration actions included the addition of spawning gravel at numerous locations along Clear Creek. Between 1996 and 2010, over 130,000 tons of gravel was added to the system.

After the initiation of the restoration project, McBain and Trush (2001) re-assessed salmonid spawning gravel in Clear Creek with a focus on the two mile reach below the dam (Reach One). Their technique for identifying spawning habitat was slightly different from that of both previous studies, because they included dry spawning gravel deposits and did not consider hydraulic conditions. Their 2001 results estimated a 45% loss in spawning habitat since the Coots 1970 survey. However, when USFWS compared the 2001 data from Reach One to Coots (1970), they noted a 61% *gain* in the areal extent of spawning habitat (11,743 to 18,955 ft^2). McBain and Trush may have made the comparison from their Reach One survey to the entire Slater/Coots survey (Whiskeytown to Saeltzer, which does in fact reveal an apparent but erroneous 44 percent loss). In 2009, GMA replicated the 2001 survey using the same technique and survey boundaries (Reach One). GMA estimated a 533% increase since 2001 with 170% of this value attributed to the 2009 gravel additions alone (GMA 2009).

Note: McBain and Trush's results may further represent an overestimate compared to the previous studies because they included spawnable size gravel both in and out of water; Warner and Slater's and Coots' reports infer that they used depth, flow, and substrate criteria to subjectively identify suitable spawning habitat. Therefore the estimated decline from 1970 to 2001 (45%) may have been even greater. McBain and Trush estimated that there was no coarse sediment from Need Camp Bridge to Clear Creek Road (Reach Two) but it is unclear if they field verified this. They do not mention surveying from Clear Creek Road Bridge to the Saeltzer Dam site. Therefore, assessing the changes in spawning habitat area from the McBain and Trush study is only relevant in Reach One.

The CVPIA Clear Creek Restoration Program established spawning habitat recovery targets based on spawning area losses due to Whiskeytown Dam. Baseline conditions of potential spawning habitat were based on the Warner and Slater 1956 study (Brown, personal communication 2010). In 2009, the US Bureau of Reclamation requested that the 1956 study be repeated to assess whether gravel supplementation programs are increasing suitable salmonid spawning habitat after the decline shown in the 1970 survey. USFWS surveys are scheduled to be conducted on a yearly basis. This report includes a 2011 review of previous surveys, a description of current methods for assessing spawning habitat, and comparisons to the previous surveys. 2010 is considered a pilot study and included herein are recommendations for improving monitoring techniques and assessment in future years.

1.2.3 Habitat Restoration

Restoration efforts to address habitat degradation include actions ranging from temperature-control flow releases to relic dam destruction to exotic species removal. The focus here 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 NEED Camp 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).

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). Evaluating the performance of these and the other Clear Creek gravel injections against the backdrop of channel condition and habitat quality is the primary purpose of this study.

1.2.4 Hydrologic Setting

The hydrologic setting for Clear Creek below Whiskeytown has been described extensively elsewhere (McBain and Trush 2001, GMA 2007a, 2010) 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 2,900 cfs (Figure 2). Two very different types of peaks exist in the post-dam regime. Pulse flow releases create peaks which travel to the Igo gaging station (generally) unaffected by tributary accretion; whereas peak flows resulting from below-dam runoff (which drive most of the peaks) have very little effect on Reach One. Therefore, the relative effect of pulse and spill flows is greater in Reach One, which rarely encounters flows greater than 200 cfs.

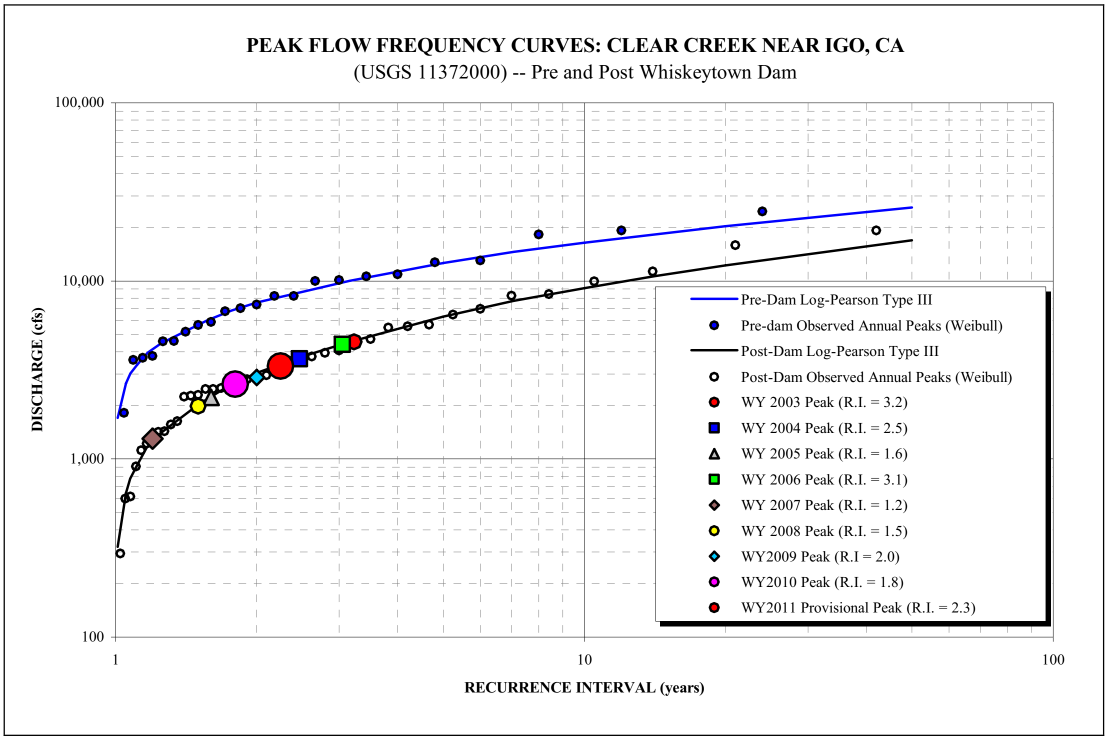

Figure 2. The flood frequency curves (pre and post-dam) for USGS 11372000.

During the study period (WY 2010-2011), Clear Creek encountered flows of each variety: spring pulse flows of 600 to 1,100 cfs, a brief Glory Hole Spill of 1,600 cfs (at Igo) and a storm-driven winter peak of 3,200 cfs which exceeded the design bankfull discharge for the *Floodplain Restoration Project* (Figure 3). Flow data from the GMA gage near NEED Camp (not shown, operated for another project, 2 miles below the dam) indicate that in Reach One, (1) the spring pulse flows were similar in magnitude to those recorded at Igo, (2) the Glory Hole spill (January 22, 2010) was slightly smaller in Reach One (at 1,440 cfs) and (3) the WY2011 peak occurred on a different date than it did at the USGS gage near Igo -- during the spring 2011 pulse flow (1,060 cfs).

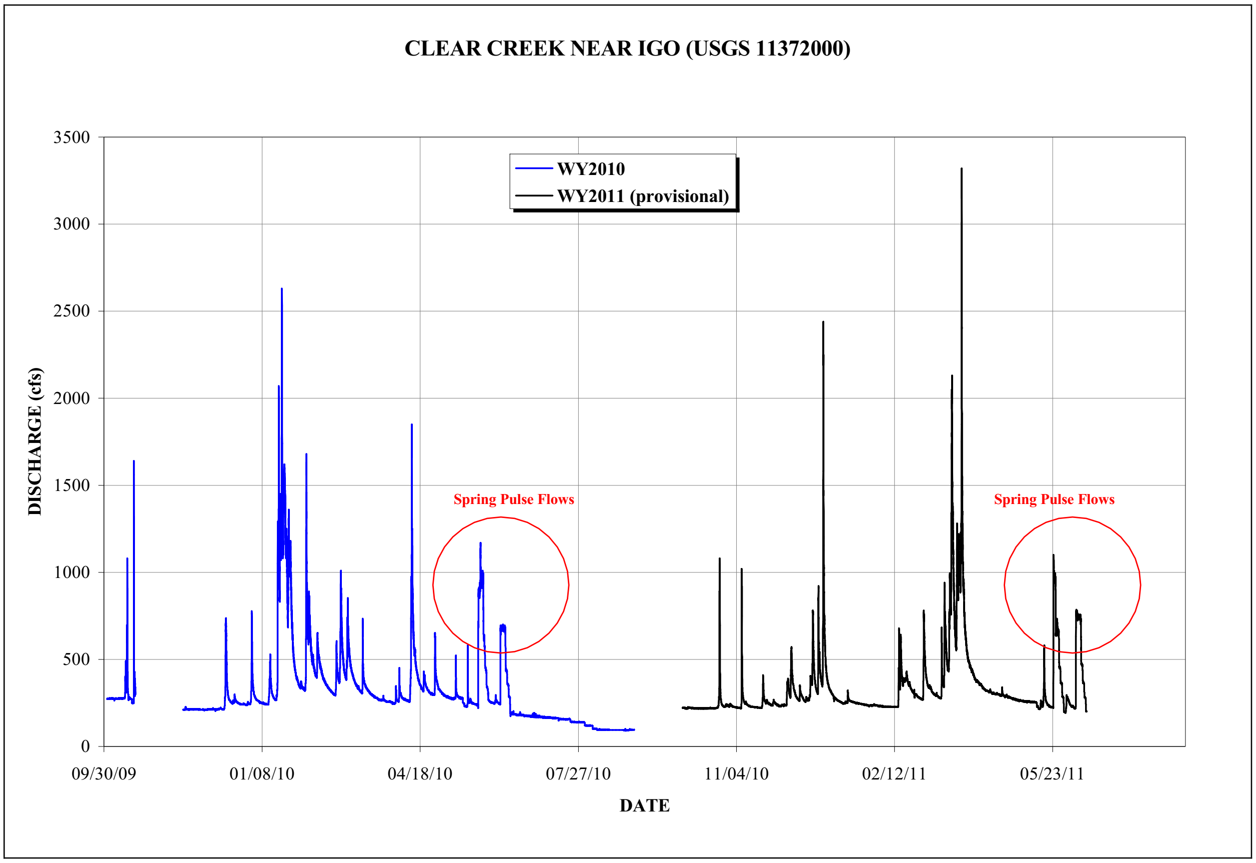

Figure 3. The WY2010-2011 hydrographs for USGS 11372000.

2.0 METHODS

2.1 TASK 1 (Meetings, consultation, project management, presentations)

GMA senior staff attended all Clear Creek Technical Advisory Team (CCTAC) Meetings during the study period and met several times with USBR/CVPIA representatives to discuss project scope and status. Monthly progress reports were delivered as work was completed. In addition to leading numerous field tours, GMA Project Manager Pittman delivered presentations at the following venues during the study period:

- KVIE Channel 6 television interview – Igo, CA, May 2011.
- WSRCD Public Presentation – Anderson, CA, February 2011
- CCTAC Meeting (Pittman) – Redding, CA, January 2011
- CCTAC Meeting (Matthews) – Redding, CA, December 2011
- Bay-Delta Science Conference – Sacramento, CA, October 2010
- Utah State University's Stream Restoration Short Course – Park City, UT, August 2010.

2.2 TASK 2 (Aerial Photography)

In October 2009, an aerial-photography flight was conducted by HJW Geospatial of Oakland, California covering Whiskeytown Dam along Clear Creek to the confluence with the Sacramento River. The specifications were: 3 inch digital resolution, 60 percent forward overlap and 30 percent side overlap with GPS/IMU data included for exterior orientation.

McBain and Trush of Arcata, California orthorectified and mosaiced the entire dataset, integrating the Graham Matthews and Associates' June 2007 LiDAR data. The products (bound, field-tough 36 page almanacs; and all seminal files) were submitted to USBR Shasta Dam and USFWS Red Bluff in February 2010.

2.3 TASK 3 (Long Profile) and TASK 4 (Monitor Topography)

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 various project sites were developed. Cut-fill analyses, using the grid method, were performed for various purposes. Primary control was established by DWR Red Bluff Office in 2001 using a combination of GPS and conventional techniques. Where possible, GMA surveyed relative to horizontal (NAD83) and vertical (NGVD29) control set by DWR.

Surveying was completed using the Trimble R8 Model 3 RTK (GPS) System. In the field, topography points were surveyed in a rough grid fashion with an average approximate point density 20 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.

Digital terrain models (DTM) were developed for surveyed areas using AutoCAD Land Development Desktop 3 software or Civil 3D 2011. All point data were incorporated into a project file and separated 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: clay pan, control monuments, other control points, project boundary, edge of water, tops, toes, normal ground surface shots, wet shots, gravel deposits, and thalweg. The point groups and their associated breaklines define a triangulated irregular network (TIN) surface that is the basis for contours.

Channel cross sections and longitudinal profiles provide two-dimensional detail for evaluating channel change. Longitudinal profiles down the thalweg (usually the deepest point along a cross section) were surveyed. Surveys were conducted using field and documentation methods described by Harrelson et al. (1994). Profiles were adjusted to a common alignment to facilitate year to year comparisons and comparisons with previous datasets: stationing for long profiles begins with zero at Whiskeytown Dam, and begins again at zero at Clear Creek Road.

The longitudinal profile surveys recorded all pools, riffle crests, and slope changes. The distance between consecutive points typically did not exceed 30 feet was usually much less. A Sonar Mite Echo Sounder was integrated with the RTK system for most reaches and was deployed from a 13 foot cataraft (Figure 4).

Volume differences were calculated by creating composite volume surfaces to establish cut, fill, and net volume values. The composite method triangulates a new surface which represents the mathematical difference between two TIN surfaces. The volume surface is formed using elevation differences at each point from the two surfaces as well as any location where the edges of the triangles between the two surfaces intersect to create prismoidal segments from composite TIN lines.

Figure 4. Cataraft-based survey platform utilizing depth sounder integrated with GPS-RTK system – shown here mapping the leading edge of the Whiskeytown gravel injection in "Pool 3."

2.4 TASK 5 (Map Redds and Spawning Habitat)

2.4.1 Mapping Redds

USFWS redd count surveys were conducted for spring Chinook salmon during September and October and for steelhead from December through April. Individual redds were marked as waypoints using handheld GPS. In the lower reaches of the river (below the Saeltzer dam site) where multiple redds and superimposition make discerning individual redds extremely difficult, actual spawned area was mapped. This technique is called SAM (Spawning Area Mapping) and is used to record locations of fall Chinook salmon redds and to estimate the area of spawning habitat used. SAM was executed using high precision sub-foot GPS (Trimble® GeoExplorer® GeoXH 2008 series handheld) to trace redd areas in the field by creating polylines while walking the perimeter of the redds. The Trimble data is then transferred into GIS and spawning area used is calculated.

2.4.2 Mapping Spawning Habitat

SAM, as described above, is only used in the lower reaches of Clear Creek. The focus of this study is on the Whiskeytown to Saeltzer reach where *potential* spawning habitat (rather than actual spawned area) is mapped (pSAM). USFWS measured potential spawning habitat using the following criteria (1) dominant substrate size range = 1-4 inches, (2) water velocity = 0.5-3.5 feet/second, and (3) water depth = 0.5-4.0 feet. USFWS established criteria using spring run Chinook salmon and steelhead redd measurement data that were collected during spawning surveys since 2003. For velocity and depth criteria, consideration was given to the fact that the flows were lower during surveys than when most spawning (approximately 50 cfs less than when most spawning occurs (150 to 200 cfs)).

Potential spawning habitat was mapped using the GeoXH 2008 GPS unit. Surveys were conducted walking downstream. Each crew member had a snorkel and mask so habitat could be examined underwater if there were difficulties making observations of substrate through the water surface. USFWS made a visual estimate of the dominant substrate and considered potential spawning habitat from 1-4 inches, with no more than 20% sand or larger than 4 inch substrate. They took multiple depth and velocity measurements within potential spawning habitat and along the boundaries until one of the criteria was no longer met. Crews used rulers to train their eyes to substrate size each day and whenever needed throughout the day. Once the boundaries of the habitat unit were established, the crew walked the perimeters of the unit using the Trimble. If there were areas within suitable spawning habitat that did not meet the three criteria (i.e. boulders, sand, logs, etc.) crews used the Trimble to trace and isolate these areas. They were then removed from potential spawning habitat areas in GIS at a later date.

If the Trimble could not get reception or the polylines looked wrong, spawning patches were measured by hand and the general shape was drawn on the printed copies of aerial photos and later digitized into GIS.

2.5 TASK 6 (Assess Spawning Habitat Change)

This task (completed by Red Bluff USFWS) requires a comparison of habitat degradation (loss of spawning gravel/habitat) as measured by five surveys using slightly different methods:

- In 1956, Slater conducted a spawning habitat assessment from Whiskeytown Dam to Saeltzer Dam to determine the amount of spawning habitat available prior to the building of Saeltzer Dam.
- Coots (1970) repeated the assessment 14 years later and found that spawning habitat decreased by 93%.
- McBain and Trush (2001) re-assessed salmonid spawning gravel in Clear Creek. Their technique for identifying spawning habitat was slightly different from Slater (1956) and Coots (1970) because they included spawnable gravel deposits, and did not consider hydraulic conditions (McBain and Trush 2001). Their results estimated that there was 45% loss in spawning habitat since the Coots survey (1971) though they may not have compared the same areas.
- GMA repeated the McBain and Trush survey in 2009
- USFWS (2010) Potential Spawning Habitat Mapping (pSAM). Described in Task 5.

2.6 TASK 7 (Evaluate Spawning Gravel Injection Methods)

Most of the other six tasks contributed to the completion of Task 7, and thus comprise the Methods for Task 7. 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 distributed. Spawning habitat data was used to assess the relative benefit of injections. WSRCD gravel injection cost summaries were developed into unit costs for injections. This analysis of historic WSRCD data was a subjective endeavor and costs generated here should be considered estimates.

3.0 RESULTS

As presented in Table 1 and as described in the "Methods" section, many of the tasks for this project required separate deliverables (e.g. Aerial photos, Spawning Atlas, Survey Atlas). These products inform the results presented herein and numerous references will be made to them. The purpose of this section is to provide the results of Gravel Injection Evaluations and 2010 Spawning Habitat Inventory Comparisons.

3.1 Gravel Injection Evaluations 2011

This section expands upon ongoing evaluations of all known significant Clear Creek gravel injections to date. Small, construction-related augmentations (e.g. pads and stream crossing fill), are not evaluated. The emphasis here is on survey data collected following submission of the *Clear Creek Gravel Injection Monitoring 2007-2009 Report* to USBR (GMA 2009); therefore 2009-2010 injection sites comprise the focus of this section, though observations at and below all injection sites are included herein.

Of particular interest is the degree of gravel recharge in the channel downstream of each injection. The leading edge of injected gravel is subjectively defined as "the dominant, downstream-most lobe of gravel, upstream of which the channel is mostly covered in gravel." This definition does not imply equilibrium or a desired ultimate state of geomorphic function; rather it is a descriptor of how well injections are recharging the system with gravel as implied by the dominant migrating front and its associated spatial distribution of gravel. Some sections of channel (such as a constricted bedrock cascade with very high transport capacity) will not store appreciable amounts of gravel. Others, such as bedrock pools may store gravel until the supply is reduced and high flows occur. Where applicable, we use volumetric analyses from sequential topographic surveys aid in evaluations of gravel injections.

In May of 2009, with the cooperation and support of CVPIA, USBR, USFWS and NPS, the WSRCD implemented the USBR-funded gravel injection project for Reach One. The project included the Below NEED site (at the head of Reach Two) that had been used in previous years, and five new sites:

1. Below Dog Gulch riffle supplement,
2. Above Peltier Bridge riffle supplement,
3. Paige Bar lateral berm,
4. Paige Bar riffle supplement, and
5. Above NEED Camp Bridge constructed riffle.

Budgetary and logistical constraints precluded construction of all injections to the GMA prescribed specifications in the injection designs prepared for USBR and WSRCD between 2006 and 2008. In 2010, the Below Dog Gulch and Below NEED sites were replenished. In the lower reaches, the Clear Creek Road Bridge, Phase 3A, Tule Backwater (new site immediately below Phase 3A), and Phase 2A were also replenished. Injection quantities in tons are provided in Table 2. Since volumetric analyses are often employed to evaluate injection performance, injection quantities are provided in cubic yards (CY) in Table 3. Results for topographic differencing for various time periods, injection volumes and locations, are provided in Table 4. Locations for all gravel injections are indicated in Figure 5.

Table 2. Clear Creek spawning gravel injection totals 1996-2010 (tons).

Year	Whiskey town Dam	Below Dog Gulch	Above Peltier Bridge	Paige Bar	Above Need Camp	Need Camp	Placer Bridge	Clear Creek Rd Bridge	Reading Bar	City of Redding	Phase 3A	Tule Backwater	Phase 2A	LCC Floodway	Phase 2B Exchange	Totals
1996	0	0	0	0	0	0	0	0	0	7,500	0	0	0	0	0	**7,500**
1997	0	0	0	0	0	0	0	0	0	3,500	0	0	0	0	0	**3,500**
1998	4,498	0	0	0	0	0	0	0	0	4,501	0	0	0	0	0	**8,999**
1999	3,500	0	0	0	0	0	0	0	0	4,501	0	0	0	0	0	**8,001**
2000	3,500	0	0	0	0	0	3,001	0	0	4,500	0	0	0	11,721	0	**22,722**
2001	2,500	0	0	0	0	0	3,000	0	0	7,001	0	0	0	0	0	**12,501**
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,404	**1,404**
2003	0	0	0	0	0	0	4,799	1,001	1,000	3,448	0	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	0	**12,258**
2005	2,000	0	0	0	0	1,001	4,003	1,002	0	0	1,729	0	0	0	0	**9,735**
2006	0	0	0	0	0	2,601	0	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	0	0	**10,000**
2008	1,000	0	0	0	0	0	2,997	0	0	0	1,483	0	3,005	0	0	**8,485**
2009	0	1,003	769	1,786	981	1,228	0	0	0	0	0	0	0	0	0	**5,768**
2010	0	1,000	0	0	0	1,000	0	1,450	0	0	3,000	1,200	640	0	0	**8,290**
TONS	**24,257**	**2,003**	**769**	**1,786**	**981**	**5,830**	**27,799**	**4,453**	**1,000**	**36,952**	**8,212**	**1,200**	**3,645**	**11,721**	**1,404**	**132,012**

Table 3. Clear Creek spawning gravel injection totals 1996-2010 (CY).

Year	Whiskey town Dam	Below Dog Gulch	Above Peltier Bridge	Paige Bar	Above Need Camp	Need Camp	Placer Bridge	Clear Creek Rd Bridge	Reading Bar	City of Redding	Phase 3A	Tule Backwater	Phase 2A	LCC Floodway	Phase 2B Exchange	Totals
1996	0	0	0	0	0	0	0	0	0	5,000	0	0	0	0	0	5,000
1997	0	0	0	0	0	0	0	0	0	2,334	0	0	0	0	0	2,334
1998	2,999	0	0	0	0	0	0	0	0	3,000	0	0	0	0	0	5,999
1999	2,333	0	0	0	0	0	0	0	0	3,001	0	0	0	0	0	5,334
2000	2,334	0	0	0	0	0	2,001	0	0	3,000	0	0	0	7,814	0	15,148
2001	1,667	0	0	0	0	0	2,000	0	0	4,668	0	0	0	0	0	8,334
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	936	936
2003	0	0	0	0	0	0	3,199	667	666	2,299	0	0	0	0	0	6,832
2004	2,839	0	0	0	0	0	3,333	667	0	1,334	0	0	0	0	0	8,172
2005	1,334	0	0	0	0	667	2,669	668	0	0	1,153	0	0	0	0	6,490
2006	0	0	0	0	0	1,734	0	0	0	0	0	0	0	0	0	1,734
2007	2,000	0	0	0	0	0	3,333	0	0	0	1,333	0	0	0	0	6,667
2008	667	0	0	0	0	0	1,998	0	0	0	989	0	2,003	0	0	5,657
2009	0	668	513	1,191	654	819	0	0	0	0	0	0	0	0	0	3,845
2010	0	667	0	0	0	667	0	967	0	0	2,000	800	427	0	0	5,527
CY	16,171	1,335	513	1,191	654	3,887	18,533	2,969	666	24,635	5,475	800	2,430	7,814	936	**88,008**

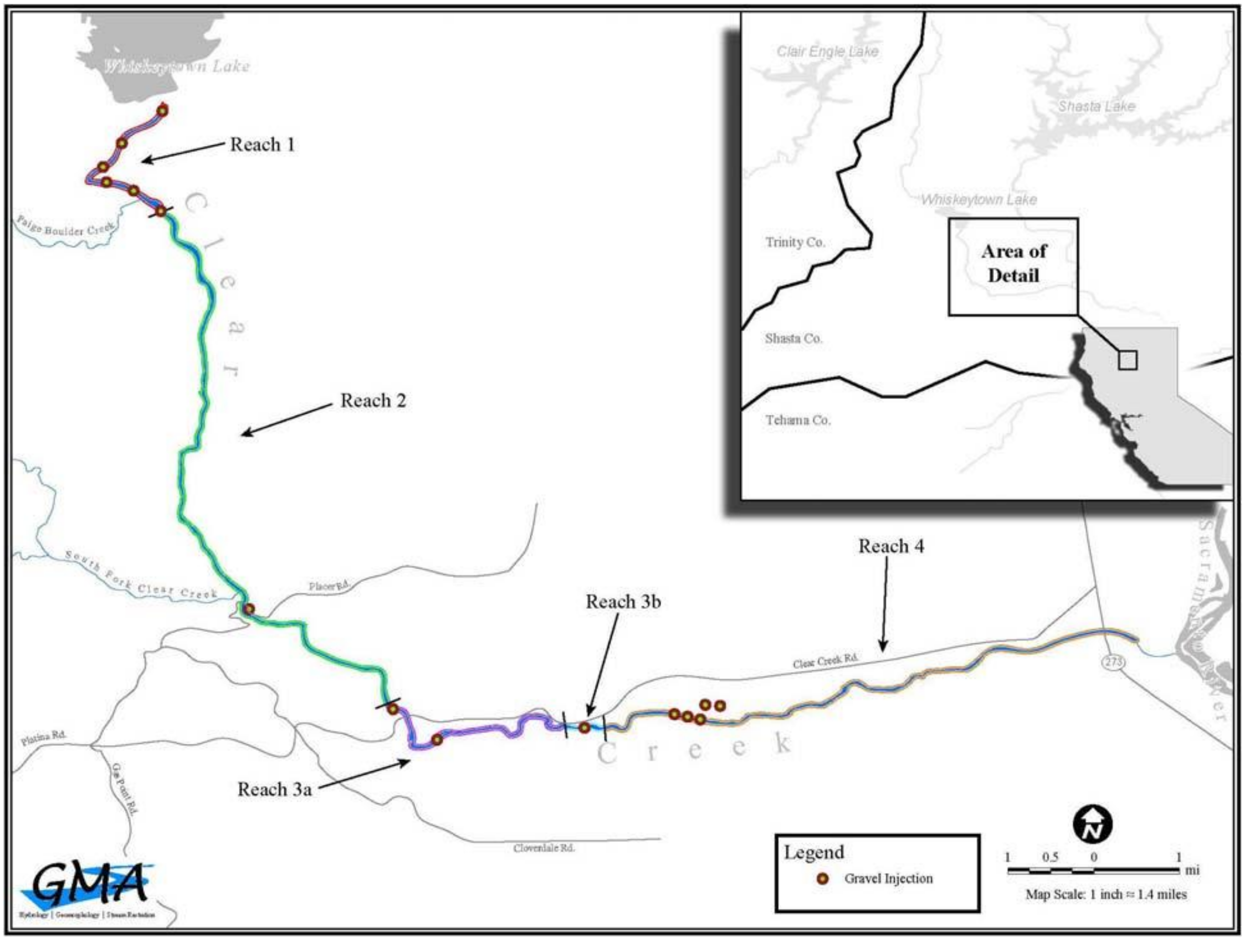

Figure 5. Clear Creek reach map showing locations of gravel injections. Locations correspond sequentially to site names in Table 1.

3.1.1 Whiskeytown

Type: Talus Cone
Year Initiated: 1998
Last Replenished: 2008
Tons Injected at Site: 24,257
Volume (CY) Injected at Site: 16,171

Over 24,000 tons of gravel has been added at the Whiskeytown Dam site since 1998 (Table 2). Though the injection has not been charged since 2008, enough gravel was stored in the reach near Dog Gulch to facilitate gravel routing through Pool 3 (Survey Atlas) as the result of two flow events: the 2010 spill (Figure 6) and the 2011 pulse flow. The spill provided over 30 hours of flow exceeding 700 cfs (as measured near NEED Camp) and the spring pulse flow 2011 provided over 3 days of flow greater than 700 cfs (as measured at Igo). The 2010 event caused only moderate change (net fill 13 CY) in the pool, while the 2011 pulse flow resulting in 99 CY of fill in the pool (Table 4). Any evidence of gravel routing through the pool and depositing in the reach below would be masked by the Below Dog injection. But since the profile remains essentially unchanged (Survey Atlas) and 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.

Table 4. Volumes derived from topographic surveys and surface differencing for WY2010-2011 injection sites (Survey Atlas).

Sheet	Site	Period	Cut (CY)	Fill (CY)	Net (CY)	Cut/Fill	Event
1	Pool 3	9/09-6/10	114	127	13	FILL	Jan 2010 Spill & Spring 2010 Pulse
	Pool 3	6/10-6/11	81	180	99	FILL	Spring 2011 Pulse
2	Below Dog Upstream	9/09-6/10	216	6	210	CUT	2009 As-built + Jan 2010 Spill & Spring 2010 Pulse
	Below Dog Downstream	2008-11/10	66	589	523	FILL	Pre-Project + WY2010 & WY2011 Injections and flows
	Below Dog Upstream	6/10-11/10	6	365	359	FILL	2010 injection
	Below Dog All	11/10-6/11	263	275	12	FILL	2010 inj + Spring 2011 Pulse
4	Peltier Upstream	9/09-6/10	108	66	42	CUT	2009 inj + Jan 2010 Spill & Spring 2010 Pulse
	Pletier Downstream	2008-6/10	-	-	150	FILL	Pre-Project + WY2010 & WY2011
	Peltier All	6/10-6/11	97	27	70	CUT	Spring 2011 Pulse
	Peltier All	2008-6/11	64	500	436	FILL	Pre-Project + WY2010 & WY2011
6	Paige Bar	9/09-11/10	442	45	397	CUT	2009 As-built + Jan 2010 Spill & Spring 2010 Pulse
	Paige Bar	11/10-6/11	241	115	126	CUT	Spring 2011 Pulse
	Paige Bar	2008-6/11	84	785	701	FILL	Pre-Project + WY2010 injection & WY2010-2011 flows
8	Above NEED	9/09-11/10	80	22	58	CUT	2009 Inj As-built + WY2010 peak flows*
	Above NEED	11/10-6/11	16	65	49	FILL	Spring 2011 Pulse
	Above NEED	2008-6/11	47	372	325	FILL	Pre-Project + WY2010 injection & WY2010-2011 flows
10	Below NEED	9/09-6/10	-	-	762	CUT	2009 Inj As-built + WY2010 peak flows*
	Below NEED	6/10-8/10	-	-	565	FILL	2010 Injection As-built
	Below NEED	8/10-6/11	482	16	466	CUT	2010 Injection As-built +WY2011 peak flows*
11	Guardian Rock Pool	9/09-8/10	27	814	787	FILL	WY2010 peak flows advance leading edge*
13	Reading Bar Upstream	8/10-6/11	1216	800	416	CUT	CC Rd Injection As-built + WY2011 peak flows
	Reading Bar Downstream	8/10-6/12	126	112	14	CUT	Old Reading Injection stable through WY2011
15	Phase 3A -3B	8/10-6/11	2632	4942	2310	FILL	2010 floodway Injections redistributed in WY2011
							*includes peak flows from Paige Boulder Creek

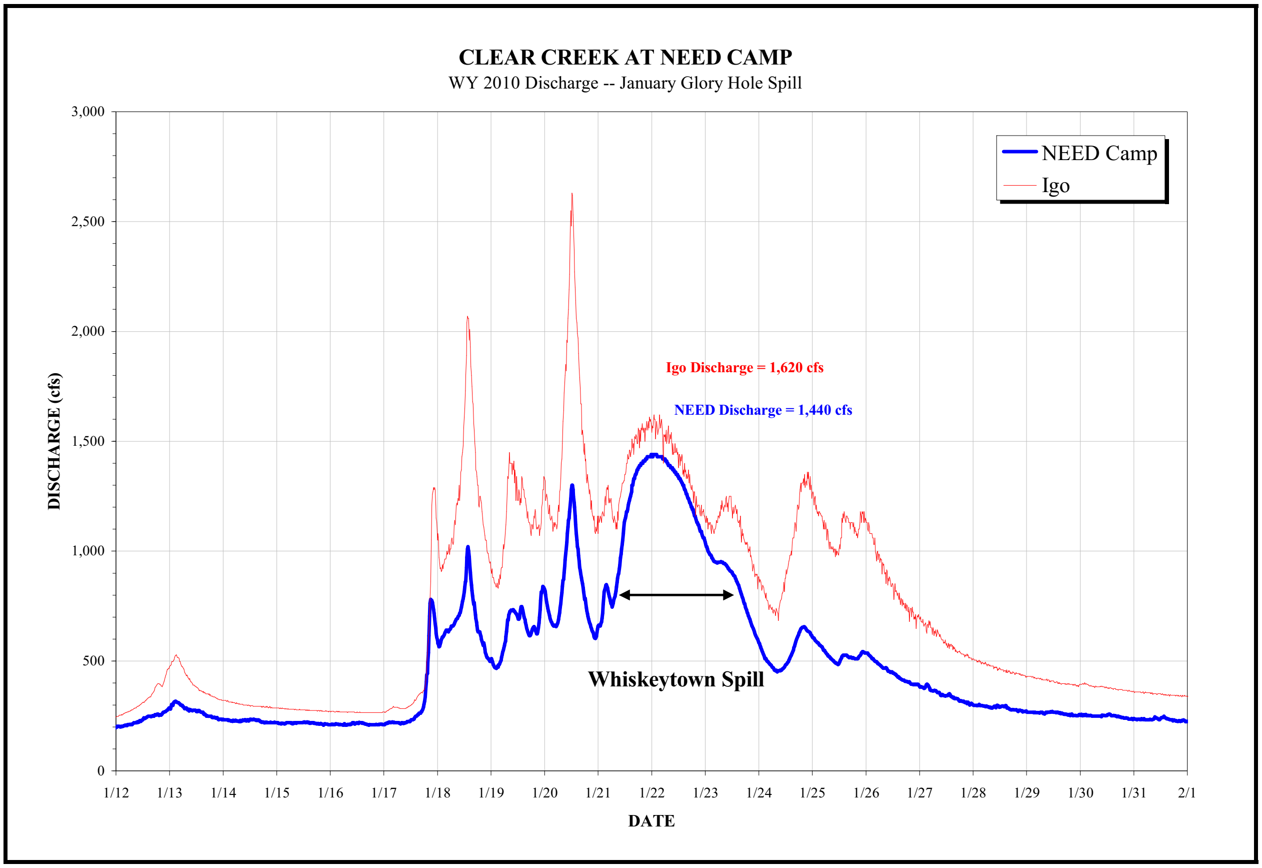

Figure 6. The WY2010 Glory Hole spill: USGS near Igo vs GMA NEED Camp hydrographs.

3.1.2 Below Dog Gulch

Type: Riffle Supplement
Year Initiated: 2009
Last Replenished: 2010
Tons Injected at Site: 2,003
Volume (CY) Injected at Site: 1,335

This project was intended to boost the leading edge of the Whiskeytown gravel injection by adding gravel just below a deep bedrock pool (Pool 3, roughly 3,000 ft downstream of the Whiskeytown injection) which was inhibiting routing of gravel. The site is at the upstream end of a long, coarse run 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. As designed, the project would have nearly connected with injection projects (sluicing) designed for the site 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 in 2009. The injection was completely mobilized by the 2010 Glory Hole spill and was recharged in the exact same manner in 2010 (Figure 7). The gated access road and the working relationship with NPS greatly facilitated efficient reoccupation of this site. Though the injection takes on the appearance of a placed riffle, it functions more like a berm: it is primarily a lateral feature that is easily mobilized through the placement riffle and the next short, constricted bedrock pool downstream. Most of the injected gravel is re-deposited into a complex bar sequence beginning 100 feet downstream where incipient bar forms are emerging (Figure 8). While numerous isolated deposits exist downstream of these bar forms, where the channel bed is aggrading in places and riffle crests are prograding downstream in some cases, the practical downstream extent (dominant leading edge) is as described in the topographic surveys, roughly 500 feet below the upstream boundary of the injection site(Survey Atlas).

The volumes estimated from topographic differencing appear anomalous at this site: the cut/fill values in Table 4 from 2009 show roughly 200 CY of cut/fill when the actual value should have been over 600 CY (assuming the entire amount was placed). Some of this apparent error can be explained by the quality of the pre-project topography which was acquired from a rough conceptual design which was not intended for surface differencing levels of resolution.
For the entire period, spanning two 667 CY placements, the net change below the site is 523 CY. Again, the pre-topography was rough and some of the gravel clearly moved downstream farther than the computational unit.

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) – two views of the now empty placement site.

Figure 7. Below Dog Gulch gravel injection site showing site conditions relative to peak flow and gravel recharge events.

Pre-2009 channel condition vs. June 2011 – downstream view.

Upstream view and leading bar edge, June 2011.

Figure 8. Below Dog Gulch: incipient bar forms emerge with increased gravel supply. 2010 gravel migrating over 2009 bars, indicated by gray gravels atop brown gravels.

3.1.3 Above Peltier Bridge

Type: Riffle Supplement
Year Initiated: 2009
Last Replenished: 2009
Tons Injected at Site: 769
Volume (CY) Injected at Site: 513

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, along the downstream-most of the riffle crest inflections identified in the 2007 design report.

This site was not replenished during the study period but has evolved somewhat from the same peak flows described previously. This site is located 2,000 feet downstream of the Below Dog leading edge. Using the 1.5 (tons/CY) conversion yields 513 CY originally injected. The volume-differencing sediment budget does not balance for the first season, perhaps due to survey error (rough 2007 topography) or aggradation from upstream gravel sources (not likely). The isopach of WY2010 change (Survey Atlas) shows most of the erosion (42 CY) occurred at the upstream end of the riffle and the leading edge prograded ~50 feet downstream (150 CY). The WY2011 change implies that some of the injected gravel travelled downstream during the spring pulse flow (70 CY cut). This is corroborated by the overall change from pre-existing ground to post-2011. The ispoach shows 436 of the original 513 CY of gravel remaining on site. As shown in Figure 9 and in the long profile data (Survey Atlas), the riffle supplement has prograded downstream 50 feet since 2009.

Figure 9. Looking upstream from Peltier Bridge at gravel sluicing implementation 2009 and geomorphic monitoring bathymetric survey 2010.

3.1.4 Paige Bar

Type: Riffle Supplement
Year Initiated: 2009
Last Replenished: 2009
Tons Injected at Site: 1,786
Volume (CY) Injected at Site: 1,191

The 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 10) at the upstream end of the project area. Hydraulic conditions prevented berm development for the upper site, so the site was modified into a deep riffle supplement. At the downstream location, where an active spawning area along the right bank was avoided (Figure 10), the riffle supplement extended downstream two hundred feet. In all, 1,786 tons (1,191 CY) of gravel was injected at the two sites.

In the first winter following injection, 397 CY or 33 percent of the injected gravel moved from where it was placed (Survey Atlas – isopach) and the "recharged" section extended another 500 feet downstream, filling interstitial voids in the coarse riffle below (Survey Atlas – profile). The next year's pulse flow (WY2011) removed another 126 CY from the reach which was corroborated by GMA field crew observations of discontinuous lateral deposits below the leading edge. A large lobe of gravel remains in the pool above the riffle supplement (remnants of the lateral berm attempt) which apparently requires more than 1,000 cfs to move it into the riffle.

Figure 10. Looking downstream at the riffle supplement component of the Paige Bar injection. The extent of the gravel can be discerned as the pale line crossing the river near top of photo.

3.1.5 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 11). 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 two years, prograding to a small degree downstream into the pool (Survey Atlas).

Figure 11. 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.

3.1.6 Below NEED Camp Bridge

Type: Lateral Berm
Year Initiated: 2005
Last Replenished: 2010
Tons Injected at Site: 5,830
Volume (CY) Injected at Site: 3,887

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 12). 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. 900 feet downstream lies Guardian Rock pool where gravel was arrested until Spring of 2010 when the lobe of gravel reached the end of the pool and routed downstream (Figure 13). From April 2009 to August 2010, the pool aggraded 787 CY (Survey Atlas), the equivalent of an entire annual injection volume.

Fully charged September 2009 Following October 2009 storm ~1,000 cfs

Fully charged July 2010 June 2011

Figure 12. Looking upstream at the below NEED Camp Bridge injection: four views WY2010-2011

August 2006 January 2007

October 2009 March 2010

Figure 13. Photographs of the leading edge of the Below NEED injection at Guardian Rock Pool showing the evolution from pool filling to complete routing.

3.1.7 Placer Bridge

Type: Talus Cone
Year Initiated: 2000
Last Replenished: 27,799
Tons Injected at Site: 2008
Volume (CY) Injected at Site: 18,533

Nearly 28,000 tons have been added to the talus cone below Placer Road since 2000 (Figure 14). Much like the Below NEED injection, the leading edge of Placer had been held up in a long, bedrock pool for several years. Channel condition in the 2,800 feet between the injection site and the leading edge showed alternate bar sequences and low gradient riffles and was often used for spawning (USFWS personal comm.). Coincident with the recent increase in sand production from the South Fork of Clear Creek just upstream (GMA 2011), the leading edge suddenly migrated through the pool and into the bedrock gorge below. Long, sandy, lateral gravel deposits punctuate the steep step pool cascade below the dominant leading edge. The preponderance of sand makes it difficult to discern where the dominant gravel lobe ends approximately 3,573 feet below the injection site.

Figure 14. The Placer Road gravel injection: actively eroding during a March 2009 storm, and depleted in March 2010.

3.1.8 Clear Creek Road

Type: Lateral Berm
Year Initiated: 2003
Last Replenished: 2010
Tons Injected at Site: 4,453
Volume (CY) Injected at Site: 2,969

The Clear Creek Road gravel injection site is located at the upstream end of the Reading Bar floodplain lowering project footprint (Figure 15). Ten cross sections have been monitored at various times within the Reading Bar project footprint as part of geomorphic monitoring efforts associated with floodplain rehabilitation efforts (GMA 2003-2007, 2011). Sections closest to the Clear Creek Road gravel injection tend to be the most dynamic, as large bedforms of injected gravel migrate through the reach during high flows (Figure 16), typically in the form of transverse bars.

The leading edge is not discernable beyond approximately mid-reach (Cross Section 433+50 in Figure 17). While the noise in the upper half of the thalweg profile is typical of reaches immediately below injections, where high sediment loads create a dynamic setting (Figure 18, Survey Atlas), in the lower half of the reach outside the project footprint, every pool has scoured and every riffle has eroded, indicating a headcut migrating into the reach. At this downstream boundary, a substantial amount of erosion has occurred along the downstream-most cross section (419+00), a feature that had remained relatively stable through most of the period following construction.

In 2010, the net change at Reading Bar, presumably mostly due to gravel injection, was fill – 1,898 CY between 2007 and 2010 (GMA 2011). 2,002 CY were injected between 2003 and 2005 (Table 3). The injected volume and the fill volume are nearly identical, implying that most of the volume change can be explained by gravel injection. Knowledge of volume change during intervening years and knowledge of sediment transport in an out of the reach would reduce the uncertainty surrounding the assertion that the volume changes can be explained by injections. However, since (1) coarse sediment transport into the reach is negligible (GMA 2007a), and (2) since the reach downstream of the project continues to incise (implying the transport capacity below the reach is higher than the supply delivered), it seems highly likely that injected gravel created most of the volume change at Reading Bar for the 2007-2010 period.

The Clear Creek Road injection was replenished with 1,450 tons (969 CY) in August 2010. Topography of the injection site and channel downstream was surveyed following injection and again in June 2011. Volume differencing of the two surfaces indicates 1,216 CY of cut, 800 CY fill for a net cut of 416 CY (Survey Atlas) for the first 1,000 feet below the injection.

Figure 15. Downstream view of the Clear Creek Road gravel injection, June 2011.

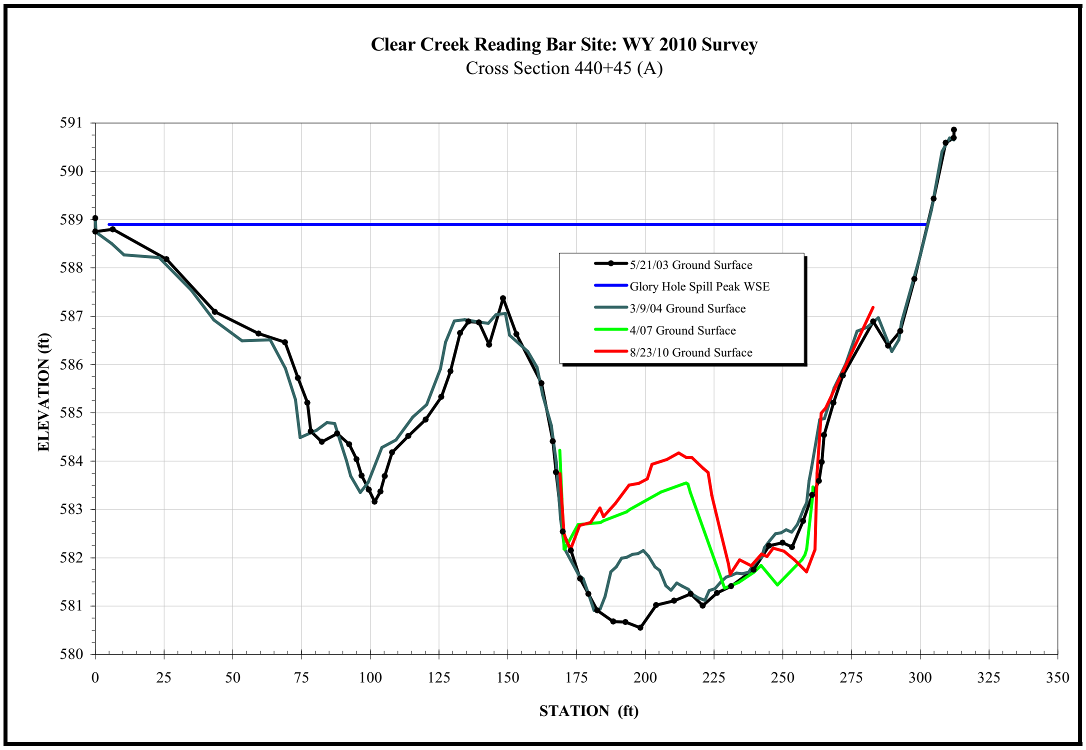

Figure 16. Channel change below Clear Creek Road due to gravel injection.

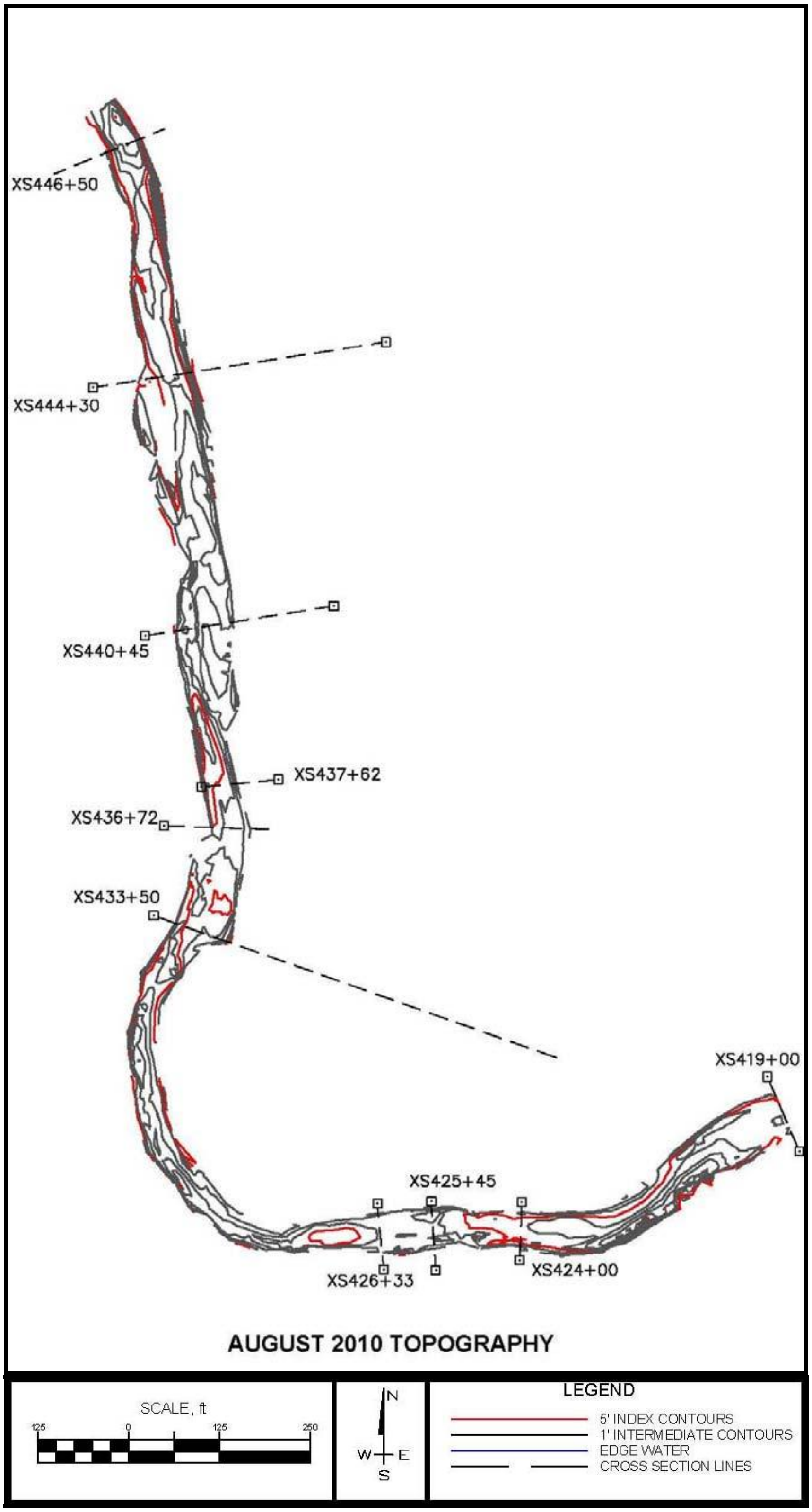

Figure 17. 2010 topography of the Reading Bar project site.

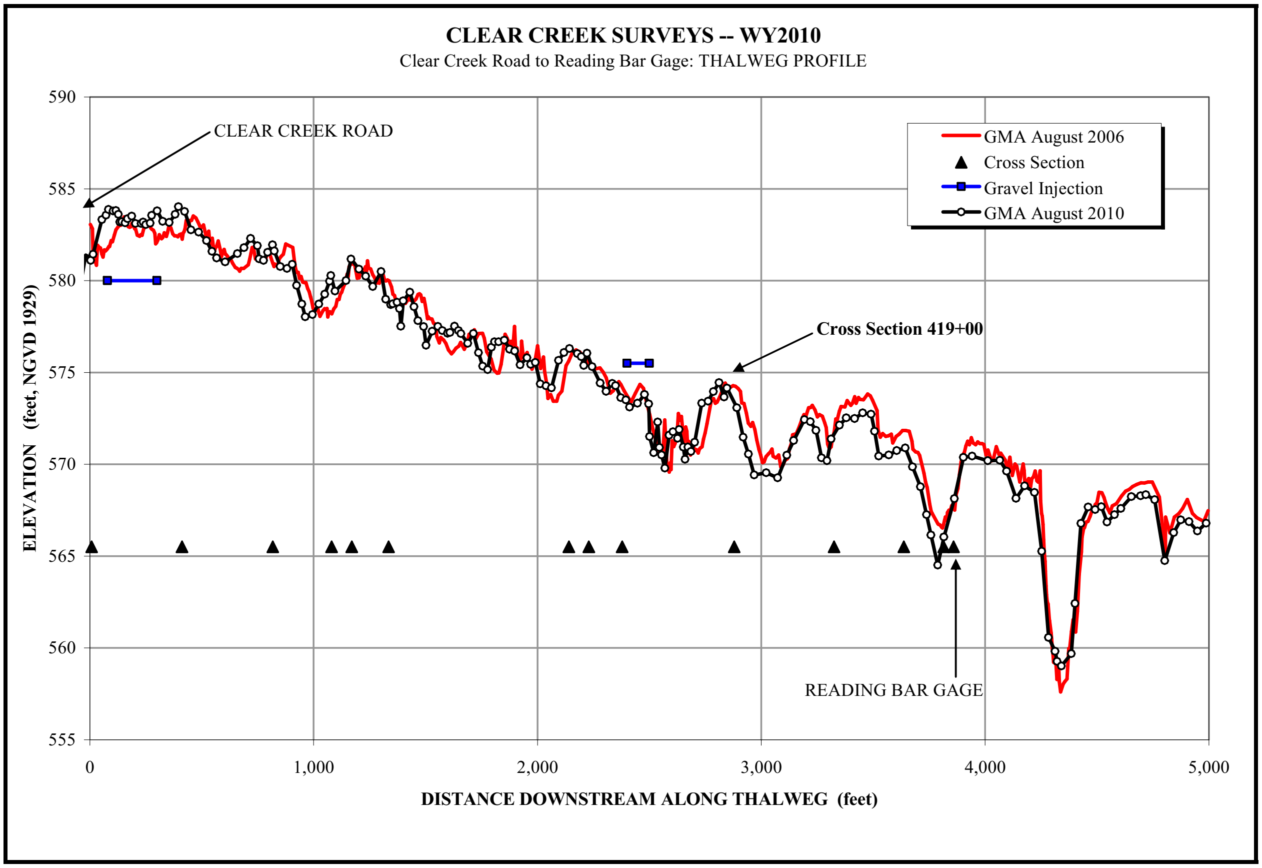

Figure 18. 2010 thalweg profile at Reading Bar showing downcutting in the lower half of the reach.

3.1.9 Reading Bar

Type: Riffle Supplement
Year Initiated: 2003
Last Replenished: 2003
Tons Injected at Site: 1,000
Volume (CY) Injected at Site: 666

At this site, near the downstream end of the Reading Bar project, a single experimental riffle placement was implemented in 2003 with a volume of 1,000 tons. In February of 2008, three 64mm tracer gravels which had been placed on the lower injection were found on the riffle below the deep pool downstream, nearly 400 feet. The implication here is that though much of the constructed riffle material remains in place, gravel is clearly routing through the next pool. Below this pool, however, is where the downcutting begins in the long profile (Figure 18).

3.1.10 City of Redding

Type: Talus Cone
Year Initiated: 1996
Last Replenished: 2004
Tons Injected at Site: 36,952
Volume (CY) Injected at Site: 24,635

Located a short distance below the former Saeltzer Dam site, the City of Redding location proved ideal for gravel injection: the steep side slopes and high degree of confinement create a setting with high transport capacity and high entrainment potential. The injection, coupled with coarse sediments liberated by the removal of Saeltzer Dam in 2001 and mobilized by the very high flows of WY2003 and WY2006, created a highly dynamic alternate bar sequence through the gorge below. This combining of gravels however makes the leading edge difficult to discern. 2,400 feet below the injection site, a substantial sediment sink stores much of the injected gravel in the form of a cut off meander bend (Gorge Spawning Curve, GMA 2007a). Below here, bars become more vegetated and the bar flanks show active gravel erosion.

Figure 19. Downstream views of the City of Redding injection site in January 2005 and November 2006.

3.1.11 Phase 3A

Type: Lateral Berm
Year Initiated: 2005
Last Replenished: 2010
Tons Injected at Site: 8,212
Volume (CY) Injected at Site: 5,475

Topographic change was assessed for the following periods: 2009-2010 and 2010-2011.

The 2009-2010 isopach (included in the final annual *Geomorphic Monitoring Report*, GMA 2011) shows the remaining gravel injection material (last replenished in 2008) was excavated in WY2010, though the dominant trend is toward aggradation, with fill indicated in all but one unit.

The fill occurs primarily in mid channel areas and along the inside of bends. The net fill for the period was 1,568 CY indicating the reach is storing gravel.

For the second period, 2,000 CY was injected at the upper end of the reach as a lateral berm split between two locations (Figures 19 and 20). The net fill in the reach was 2,310 CY (Survey Atlas) indicating again that the reach is storing, not losing gravel. Since the thalweg profile (Survey Atlas) shows little change, most of the gravel is stored in the form of lateral features.

Figure 19. Downstream views of the 2010 injection efforts above Phase 3A pre and post-winter high flows. Note the exposed claypan in the post-winter photo.

Figure 20. Downstream views of the lower lateral berm above Phase 3A during and following construction in July 2010.

3.1.12 Tule Backwater

Type: Lateral Berm
Year Initiated: 2010
Last Replenished: 2010
Tons Injected at Site: 1,200
Volume (CY) Injected at Site: 800

This site is located at the downstream boundary of the Phase 3A project footprint, on the left bank along the outside of a bend. This high energy bend has shown considerable scour and a claypan reef has begun to show just downstream in the P2 Reach (GMA 2003-2007, 2011). The claypan was temporarily covered by injected gravel but has reappeared as of June 2011 (Figure 21). The thalweg profile shows some minor aggradation as the injected gravel moved into voids in the claypan substrate below (Survey Atlas).

Figure 21. The Tule Backwater lateral berm located below Phase 3A: May 2010 (pre-injection) and January 2010.

3.1.13 Phase 2A

Type: Riffle Supplement
Year Initiated: 2008
Last Replenished: 2010
Tons Injected at Site: 3,645
Volume (CY) Injected at Site: 2,430

In 2008 this site was implemented as a modified riffle supplement (2,003 CY) – that is, it did not reach all the way across the channel. Hence, there was little change to the thalweg profile initially. The intent behind this site is to supply Phase 3B with gravel in the short term, until complete dam to mouth coarse sediment routing is established. In 2010, another 427 CY was added in much the same manner but over a smaller area. Most of the change is observed above the Phase 3B rootwad bend where the riffle has aggraded a foot (Survey Atlas – Long Profile Reach 4). The entire section from the 3A downstream boundary (just above Tule Backwater), to the first cross section in Phase 3B shows 2,212 CY of fill between 2010 and 2011.

3.1.14 LCC Floodway and Phase 2B Exchange

These injections were associated with the floodplain restoration effort in 2000 and 2002 respectively. They contributed 11,721 and 1,404 tons to channel rehabilitation primarily as designed riffles. The signature of these injections is impossible to discern against the backdrop of a decade ambient bedload transport and more recent injections. These injections do however contribute to the channel condition observed in 2010 as described in the *Clear Creek Geomorphic Monitoring Reports (2003-2007, 2011).* Actual restoration costs are much greater than that implied by the injection volumes, as the entire cost of all phases Floodplain Restoration Project (~$9 million) must be considered.

3.2 Spawning Habitat Inventories

3.2.1 USFWS pSAM 2010

The USFWS 2010 survey took eight days to complete with a three to four person crew on each survey. Results of spawning surveys and habitat mapping for the entire creek are graphically detailed in the Spawning Atlas. Streamflow during the survey was 150 cfs. The results for the portion of the 2010 survey common to the 1956 and 1970 surveys (Whiskeytown to Saeltzer), showing the percentage of injected gravel in each of the spawning habitat sections, are provided in Table 5. To more easily relate habitat inventory results to injection locations, the same data are provided by reach in Table 6. USFWS uses a different but very similar reach system (detailed in the Table 6) than the McBain and Trush 2001 system.

Table 5. Percent injected gravel in surveyed habitat units for 2010 USFWS potential spawning habitat mapping (pSAM).

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Location	Station (mi)	Section Length (mi)	2010 Injected Gravel (ft^2)	2010 Native Gravel (ft^2)	2010 Total Gravel (ft^2)	Percent Injected Gravel
Whiskeytown Dam Top*	18.60	0.25	7,064	0	7,064	100%
	18.35	0.10	12,553	0	12,553	100%
	18.25	0.25	15,777	912	16,688	95%
	18.00	0.75	18,255	12,190	30,445	60%
	17.25	0.25	15,318	1,485	16,804	91%
Need Camp Bridge	17.00	0.55	7,328	14,453	21,781	34%
	16.45	0.25	3,471	115	3,587	97%
	16.20	0.3	1,629	0	1,629	100%
	15.90	0.5	0	73	73	0%
	15.40	6.4	38,538	6,486	45,024	86%
Lower Reading Bar	9.00	1.25	27,667	26,875	54,542	51%
	7.75	0.8	0	62,138	62,138	0%
1956 survey end	6.95	**				
		11.65	147,600	124,728	272,329	54%

*Base of Dam is at 18.55 (where 2010 surveys started)

** Another 0.17 mi was mapped in 2010, yielding 3,037 ft^2 -- not included here

Table 6. Percent injected gravel by USFWS survey reach (versus geomorphic reaches) as per 2010 USFWS potential spawning habitat mapping (pSAM).

USFWS Reach #	Description	Injected Gravel (ft^2)	Native Gravel (ft^2)	Total	%Injected
1	Whiskeytown to Need Camp Bridge	76,295	29,156	105,451	72%
2	Need Camp Bridge to Kanaka Creek	5,100	2,016	7,116	72%
3	Kanaka Creek to Igo	0	3,463	3,463	0%
4	Igo to Clear Creek Road Bridge	38,538	1,572	40,110	96%
5	Clear Creek Road Bridge to Saeltzer Dam Site	27,667	88,521	116,188	24%
	Total	**147,600**	**124,728**	**272,328**	**54%**

Table 6 reveals that 72 percent of the habitat in Reach One comes from the Whiskeytown talus cone and the four in-channel placements below the leading edge of the Whiskeytown gravels. 72 percent of the habitat in the upper gorge reach is keyed to the Below Need gravel injection. No injection gravels have made it to Kanaka Creek. Habitat in the reach below Igo is nearly all (96 percent) composed of Placer Road injected gravel. The Reach 5 data shows 24 percent of the habitat to be the combined expression of the Clear Creek Road and Reading Bar injections. Clear Creek crosses into the Central Valley Province at Clear Creek Road and enters a lower gradient, less confined setting that is controlled less by bedrock than by alluvial processes. Significant sources of alluvium in the form of tailings, tributary deltas and in channel sources (such as Saeltzer Dam delta remnants) contribute to the higher percentage of native gravels in this reach.

The lowermost reach (USFWS number 6, Saeltzer to the lower screw trap) is not discussed here, as the previous surveys did not include this section and the USFWS uses a different mapping system in Reach 6). Further, gravels in this lower reach are nearly impossible to identify as to their origin: the massive gravel injection volume in the Saeltzer Gorge (nearly 37,000 tons from 1996 to 2004, Table 2) coupled with the liberation of sediments from Saeltzer Dam removal in 2001 and the very high flows in water years 2003 and 2006, contribute to a highly dynamic geomorphic setting. Virtually all gravels in this reach are called "mixed" after just one year of mobilizing and mixing injected and native gravels during high flow events.

3.2.2 Review: Slater 1956, Coots 1970

The USFWS in Sacramento conducted the first spawning habitat survey in 1956, prior to the construction of Whiskeytown Dam (Slater 1956). They surveyed from the estimated location of Whiskeytown Dam site to very near Saeltzer Dam. Their methods consisted of delineating sections divided by stationing-breaks (based on river mile), measuring depths and velocities and visually estimating a percentage of "usable spawning gravel" (USG). They do not mention the criteria they used for determining usable spawning gravel.

Rather than measuring and summing the areas of USG units, Slater first calculated total area by multiplying the average width of spawning gravel units by the linear distance of creek in that particular section. Then they estimated a visual percentage of "usable spawning gravel" relative to the total area (at that flow). Total area was then multiplied by usable percent to get usable area. The number of estimated salmon redds was calculated by dividing the usable area by 40 sq. ft. Number of salmon was estimated by multiplying redds by 2.5.

On June 25 and 26, 1956 they "intensively" surveyed (presumably they walked) from the Whiskeytown Dam site to approximately river mile 15.4 and from river mile 9.0 to 6.95. McCormick Saeltzer dam was located at river mile 6.75 on the profile map. Spot checks and interpretation from the USGS plan and profile map 1938 were performed from river mile 14.7-9.0 to estimate habitat through most of the gorge. They estimated that there was 347,308 ft^2 usable area at approximately 110 cfs (Slater's paper contains a minor arithmetic error in its 347,288 ft^2 total).

The interpretation of flow magnitude at which the surveys were performed is somewhat unclear. Slater took discharge measurements at Whiskeytown and Igo using a pygmy meter, which were calculated to be 116 and 107 cfs respectively. However, USGS historical gaging data shows that flows were 89 cfs on June 25 and 69 cfs on June 26.

On September 6, another survey, (presumably also by Slater -- we do not have the cover page to the document) was conducted. We believe they went back to do a survey to determine the usable area at lower flows. They took discharge measurements at Whiskeytown and Igo again and flows were calculated to be 24 cfs and 21 cfs, respectively. *Coots, in the 1971 paper, simply states that the 1956 study encountered flows of 21 to 89 cfs.*

Coots repeated the Slater survey 14 years later, from July 28 to July 31, 1970. He states that, "Techniques employed ... were generally similar and included mapping of spawning habitat, visual estimates of the size composition of bottom materials, measurements of flow velocities, and depths of water over potential spawning habitat." Flows during the study were 47-50 cfs, though Coots established correction factors for depth and velocity to estimate habitat at 100 cfs. He did this in order to relate the results to a Whiskeytown dam release "during the king salmon spawning period." Coots concluded that 29,121 ft^2 of spawing habitat remained in 1970. His arithmetic is off however and the actual total from his data is 24,121 ft^2.

3.2.3 Comparing 2010 to 1956 and 1970 Surveys

To compare our results to previous studies, we had first to establish where the boundaries existed in the 1956 study. Warner and Slater (1956) provided river miles and distances between stations based on *A Plan and Profile of Sacramento River, California, Red Bluff to Mile 65, Clear Creek to French Gulch Dam Sites, Sheet E, United States Department of the Interior Geological Survey.* Although survey boundaries were assigned river miles, the only hard point that we could use to reconstruct the stationing was Saeltzer Dam. From this point, we could measure upstream in GIS using a route to find the section breaks.

Slater (1956) stated their survey ended at river mile 6.95, which they noted was the location of Saeltzer Dam. However, the USGS map mentioned above labels Saeltzer Dam as river mile 6.78. We assumed their survey boundary likely ended before the dam pool, which would be in line with river mile 6.95. So, to match their stationing, we assigned Saeltzer Dam to site at 6.78 and measured upstream 0.17 miles to mark the survey end boundary at 6.95.

To accurately measure stationing distances for our comparison, we used a shape file polyline route, which we created by tracing the center of the creek using the 2007 NAIPS imagery data in GIS. We first created this route in 2007 and currently use it for assigning river miles and features marked on our adult salmonid monitoring surveys. For this survey, we altered our 2007 route to represent the creek alignment in 1956. We used the USGS 7.5’ topographical maps from the 1970s to determine if the creek changed in the more alluvial sections. Since most of the canyon (Reach 2) is confined by bedrock, the creek would not migrate so we left this section as is. We did redraw the section between Clear Creek Road Bridge and Saeltzer Dam. The 2007 creek alignment from Whiskeytown to Need Camp Bridge (Reach 1) was close to the USGS alignment.

This new route was used to measure the distances between stations reported in Warner and Slater 1956. Starting at the 6.95 point and working upstream, we used the route measuring tools to find distances and mark breaks. Using this method, the survey start-point ended at the top of Whiskeytown Dam (on the road, 265 ft upstream of the base of the dam). This seems within the error of our measuring (difference between how they got distances and how we did in GIS, deviations in the creek line, etc) and seems very likely that the starting point of the survey would not be directly at the base of the dam, as they would not know exactly where the dam was going to be built. All of the contemporary potential spawning habitat (pSAM) could then be allocated to sections based on the stationing breaks and compared to 1956 and 1970 (Figure 22).

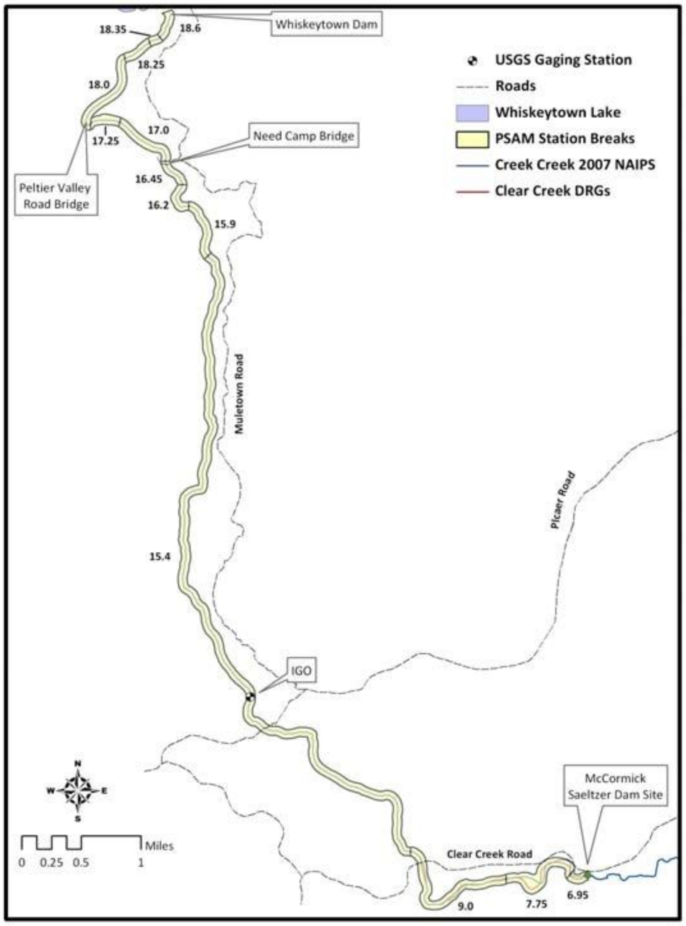

Figure 22. USFWS pSAM stationing-breaks relating spawning habitat survey boundaries used in the1956, 1970 and 2010 inventories.

3.2.4 McBain and Trush 2001, GMA 2009

In September 2009, GMA repeated the 2001 spawning gravel inventory conducted by McBain and Trush which measured the areal extent of spawning gravels (not spawning habitat, as dry lobes of gravel are included). In areas where we completed topographic surveys, we used survey data to provide areal values. Otherwise, we repeated the 2001 protocol of mapping on aerial photos, digitizing and computing areas. Apparent anomalies arose in the first cut at data analysis, as some areas appeared vastly different than in 2001. We repeated the surveys in October 2009, using a handheld rangefinder and a tape to physically measure spawning gravel deposits, thus confirming the accuracy of the first survey.

Results of the 2009 vs 2001 survey through Reach One show spawning gravel area increased from approximately 19,000 ft^2 to nearly 120,000 ft^2, a net change of over 500% (GMA 2009). Subtracting the 2009 placed-gravel areas (Below Dog, Paige Bar etc.) from the total area reveals an increase of roughly 69,000 ft^2 through Reach One, primarily due to the Whiskeytown injection, which has charged the channel down to the Below Dog Gulch injection site. Some areas apparently winnowed since the 2001 survey, namely downstream of the leading edge of the Whiskeytown injection.

3.2.5 Comparing the Five Inventories

The results from all five surveys compared to one another should be interpreted carefully as they are not all directly comparable (Table 7). Slater, Coots and USFWS each used a similar method though the studies encountered different flow conditions. McBain and Trush and GMA used the same method which was not influenced by flow conditions. The data in Table 7 reasonably depicts change over four periods for the Whiskeytown to Saeltzer reach:
(1) the well known 93 percent reduction in spawning habitat from 1956 to 1970,
(2) the rebound from 1970 to 2010 with an increase of over 1,000 percent in spawning habitat,
(3) a comparison of 1956 to 2010 shows contemporary extent of spawning habitat to be only 22 percent less than the pre-Whiskeytown 1956 condition, and
(4) changes in Reach One due to gravel injection for the 2001-2009 period with a 533 percent increase in the spatial extent of spawning gravels.

Table 7. A comparison of five inventories: Slater 1956, Coots 1970, McBain and Trush 2001, GMA 2009, USFWS 2010.

Location	Station (mi)	Section Length (mi)	Slater[2] 1956 (ft^2)	Coots[2] 1970 (ft^2)	McBain[3] 2001 (ft^2)	GMA[3] 2009 (ft^2)	USFWS 2010[2] PSAM (ft^2)
			21-89 cfs	47-50 cfs			100 cfs
Whiskeytown Dam Top[1]	18.60	0.25	2,640	260	0	12,420	7,064
	18.35	0.10	528	1,200	80	31,770	12,553
	18.25	0.25	2,640	973	470	20,655	16,688
	18.00	0.75	74,250	1,405	12,835	30,339	30,445
	17.25	0.25	9,900	3,950	310	8,370	16,804
Need Camp Bridge (end of Reach One)	17.00	0.55	69,720	3,955	5,260	16,405	21,781
	16.45	0.25	10,560	0	NA	NA	3,587
	16.20	0.3	6,340	0	NA	NA	1,629
	15.90	0.5	5,280	160	NA	NA	73
	15.40	6.4	33,800	3,430	NA	NA	45,024
Lower Reading Bar	9.00	1.25	57,750	3,000	NA	NA	54,542
	7.75	0.80	73,900	5,788	NA	NA	62,138
1956 survey end -- near Saeltzer	6.95						
Total		12	347,308	24,121	18,955	119,959	272,329

Reach One (Whiskeytown to Need Camp Bridge) -- all five surveys

Totals		2.15	159,678	11,743	18,955	119,959	105,336
Change 1956-1970	-147,935	-93%		Change 1970-2010		93,593	388%
Change 1956-2010	-54,342	-16%		Change 2001-2009		101,004	533%

Whiskeytown to Saeltzer -- Slater, Coots, USFWS

Totals		11.65	347,308	24,121			272,329
Change 1956-1970	-323,187	-93%					
Change 1970-2010	248,208	1029%					
Change 1956-2010	-74,979	-22%					

[1] Base of Dam is at 18.55 (where 1970, 2010 surveys started), 0.05 mi is subtracted from reach length

[2] Mapped Spawning Habitat

[3] Mapped Aereal Extent of Spawning Gravel (including dry gravel and eddy deposits)

4.0 DISCUSSION

4.1 Conclusions

The goal of comparing the spawning habitat inventories is to assess the relative decline or recovery of spawning habitat for the following time periods and influences:

1. 1956-1970: Saeltzer to Whiskeytown, pre-Whiskeytown Dam, post-Saeltzer Dam (Slater, Coots)
2. 1970-2001: Reach One, 5 years of gravel injections at Whiskeytown (Coots, McBain and Trush)
3. 2001-2009: Reach One, 5 new gravel injection sites plus Whiskeytown (McBain and Trush, GMA)
4. 1956-2010: most of Clear Creek, numerous injection sites (Slater,USFWS).

Because methods (spawning habitat mapping versus gravel mapping) and conditions (streamflow depth and velocity) varied between surveys, the results from the five surveys are not directly comparable with one another. The 1956, 1970 and 2010 studies mapped actual habitat and are flow dependent:

1. 1956: 89 cfs (USGS), 107 (Slater)
2. 1970: 50 cfs (presumably extrapolated to approximate conditions at 100 cfs)
3. 2010: 150 cfs

With a higher flow, the 2010 study probably overestimates habitat compared to 1956 and 1970. The implied rebound from 1970 to 2010 (to levels only 22 percent less than 1956) is also an overestimate.

The 2001 and 2009 studies are directly comparable and show a dramatic increase (533 percent) in the areal extent of spawning gravel. This method, which includes dry bar surfaces and gravel deposits in slack water, is more an index of geomorphic condition than of spawning habitat: it tracks the dynamic redistribution of gravels in the channel below talus cones. Spawning habitat mapping omits features such as exposed transverse bars and numerous lateral deposits that can serve as indicators of geomorphic condition related to the establishment of complete sediment routing. Better methods exist (topographic surveys, detailed facies mapping, geomorphic mapping) but simply mapping the areal extent of spawning gravels is an inexpensive and efficient means of tracking the distribution of injected gravel through the system.

However, CVPIA dictated specifically that spawning habitat is the target for recovery (Brown, personal communication 2010). Habitat area, compared to gravel placement method, quantity, and cost, provides a useful assessment of injections: how much habitat do we get from each injection site? Are certain types of injections better than others?

Today, 54 percent of spawning habitat in the Whiskeytown to Saeltzer study reach is composed of injected gravel (Table 6). Whiskeytown and Placer contribute much more than the others at 14 percent each (Table 8). As a percentage of gravel injected into Clear Creek however (within the study reach), Whiskeytown and Placer compose 75 percent of all gravel placed. They are both talus cones and require high flows to mobilize gravel and redistribute it into habitat, so 75 percent of the gravel yields 28 percent of the (injected) habitat (Table 7). More beneficial (in terms of near term benefit) is direct placement into riffles: the four riffle supplements in Reach One represent 8 percent of gravel injected (in the study reach) yet they contribute 26 percent of the habitat. Gravels placed directly into riffles naturally show a higher ratio of habitat to injected volume than those requiring fluvial redistribution of a very large sediment wave. Even when mobilized by high flows, riffle placements (e.g. Below Dog and Paige Bar) contribute less gravel to storage elements (such as exposed bars and lateral voids, which are not included in habitat mapping) than do the talus cones which over time charge the channel with an abundance of material that can be later redistributed (GMA 2007).

Table 8. Relative contributions of gravel injections to instream spawning habitat area in the USFWS 2010 pSAM inventory (study reach -- Whiskeytown to Saeltzer).

Injection Site	Gravel Injection Quantities		Spawning Habitat Mapping Quantities		
	Tons of Gravel Injected through 2010	**Percent of Gravel Placed through 2010**	**Potential Spawning Area (ft^2) Composed of Injected Gravels**	**Percent of Total Injected Gravel Area**	**Percent of All** Spawning Gravel**
Whiskeytown	24,257	35%	38,153	26%	14%
Below Dog	2,003	3%	6,165	4%	2%
Above Peltier	769	1%	9,330	6%	3%
Paige Bar	1,786	3%	15,609	11%	6%
Above NEED	981	1%	7,038	5%	3%
NEED Bridge*			2,868	2%	1%
Below NEED	5,830	8%	2,232	2%	1%
Placer	27,799	40%	38,538	26%	14%
Clear Creek Road	4,453	6%	16,121	11%	6%
Reading Bar	1,000	1%	11,546	8%	4%
Total Injected Gravel	**68,879**	**100%**	**147,600**	**100%**	**54%**

Sum Native Gravel (ft^2)	127,765
Sum All Spawn** Gravel (ft^2)	275,365
% Injected Gravel	54%

*Small amount of gravel was injected as part of bridge construction

** Injected and naturally occurring spawning gravel in mapped habitat units

Placed riffles come at a very high dollar price, as many require complex logistics (multiple staging locations for materials), advanced methodologies (Peltier gravel sluicing) and site preparation (gates and road improvements into Below Dog). When it comes to actual dollar cost, Whiskeytown and Placer excel at $0.04 and $0.05 per 100 ft^2 of habitat created (Table 9), due in part to the extremely low placement cost of talus cones. As expected, Above Peltier, with its sluicing and complex staging of materials, is the most expensive at $0.89 per 100 ft^2 of habitat created. The cost for Below Dog Gulch, which includes a very high site development cost, should go down as the site is reoccupied. The extremely high cost for habitat created by the Below NEED injection can be explained by the fact that though it is charged with gravel, little of the reach immediately below the injection qualifies as habitat in pSAM (Spawning Atlas, USFWS 2010). Further, Guardian Rock Pool stores the equivalent of an entire year's injection volume (Survey Atlas, Table 4).

Table 9. Unit costs of habitat created by gravel injections (WSRCD 2010 gravel injection data).

Injection Site	**Tons**	**Total Cost***	**Computed Unit Cost (per ton)**	**Habitat Created by Injection (ft^2)**	**Computed Unit Cost (per 100 ft^2)**
Whiskeytown	24,257	$ 361,290	$ 14.89	38,153.1	$ 0.04
Below Dog	2,003	$ 63,670	$ 31.79	6,165.4	$ 0.52
Above Peltier	769	$ 64,102	$ 83.34	9,330.4	$ 0.89
Paige Bar	1,786	$ 53,062	$ 29.70	15,608.5	$ 0.19
Above NEED	981	$ 31,327	$ 31.92	7,037.7	$ 0.45
Below NEED	5,830	$ 128,440	$ 22.03	2,231.7	$ 0.99
Placer	27,799	$ 515,613	$ 18.55	38,538.2	$ 0.05
Clear Creek Road	4,453	$ 69,953	$ 15.71	16,121.1	$ 0.10
Reading Bar	1,000	$ 12,000	$ 12.00	11,546.0	$ 0.10
Total	**68,879**	**$ 1,299,457**			

*This table was generated from WSRCD historic gravel injection data.
Analysis of this data is highly subjective and these figures should be considered approximate.
Some projects were grouped into a single contract making it difficult to determine exact cost.
Included are change orders, shared costs and overhead allocated as assumed appropriate.
Some projects have a very high initial cost which will go down as the site is reoccupied.

How beneficial are the injections if the fish aren't using the habitat? The 2009-2011 USFWS redd count data shows 48 percent (three year average) of all steelhead redds (in USFWS Reaches 1-5) occur in injected gravel. By contrast, 33 percent of all spring Chinook redds occurred in injected gravel. The spring Chinook are the run which, due to the separation weir near Reading Bar, has access to most of the reach covered by this study. However 19 of those 24 redds occurred in the Clear Creek Road and Placer injected gravels. Three of the remaining four occurred at the NEED Camp Bridge site which is a construction-related enhancement not connected with the other injections. The fourth was in the Guardian Rock Pool segement which is created by the Below NEED injection and is in Reach 2. So in the period 2009-2011, of the entire assemblage of spawning habitat created in Reach One, Chinook did not use any of it (though in the 2003-2008 period they did use Whiskeytown gravels).

Though beyond the scope of this project (due to the numerous confounding factors and variability in fisheries assessments), perhaps more useful would be a measure of redds per dollar. On very simple analysis is to examine 2009-2011 steelhead redd data for the study reach (Table 10). Suddenly, Above Peltier, the costliest to implement, becomes the most beneficial with 0.28 redds per thousand dollars spent. Whiskeytown comes in second with half as many, and the rest come in much lower.

Table 10. Redds per $1,000 of injection investment: USFWS 2009-2011 steelhead redds in the habitat inventory study reach (Whiskeytown to Saeltzer).

Injection Site	Tons	Total Cost*	Computed Unit Cost (per ton)	Habitat Created by Injection (ft^2)	Computed Unit Cost (per 100 ft^2)	Steelhead Redds 2009-2011**	Redds per Thousand Dollars	Dollars per redd
Whiskeytown	24,257	$ 361,290	$ 14.89	38,153.1	$ 0.04	49	0.14	$ 7,373
Below Dog	2,003	$ 63,670	$ 31.79	6,165.4	$ 0.52	4	0.06	$ 15,918
Above Peltier	769	$ 64,102	$ 83.34	9,330.4	$ 0.89	18	0.28	$ 3,561
Paige Bar	1,786	$ 53,062	$ 29.70	15,608.5	$ 0.19	4	0.08	$ 13,266
Above NEED	981	$ 31,327	$ 31.92	7,037.7	$ 0.45	2	0.06	$ 15,664
Below NEED	5,830	$ 128,440	$ 22.03	2,231.7	$ 0.99	2	0.02	$ 64,220
Placer	27,799	$ 515,613	$ 18.55	38,538.2	$ 0.05	0	0.00	NA
Clear Creek Road	4,453	$ 69,953	$ 15.71	16,121.1	$ 0.10	14	0.20	$ 4,997
Reading Bar	1,000	$ 12,000	$ 12.00	11,546.0	$ 0.10	0	0.00	NA
Total	**68,879**	**$ 1,299,457**				**93**		

*This table was generated from WSRCD historic gravel injection data.
Analysis of this data is highly subjective and these figures should be considered approximate.
Some projects were grouped into a single contract making it difficult to determine exact cost.
Included are change orders, shared costs and overhead allocated as assumed appropriate.
Some projects have a very high initial cost which will go down as the site is reoccupied.

** NEED Bridge (3) was omitted
and Dino Pool was lumped
with Paige Bar

This study focused on injections and inventories conducted in the Whiskeytown to Saeltzer reach but the largest effort of all is the Lower Clear Creek Floodplain Restoration Project which has cost roughly $9 million to date. Redd areas for fall Chinook as measured by SAM were not yet finalized and redd counts are not conducted for fall Chinook in this reach. For the post-Phase 3A (but pre-Phase 3B era 2003-2007), data are available relating percent contribution of various sub-reaches to total spawning habitat use in USFWS Reach 6 (USFWS 2008). These data show that the relocated Phase 3A design channel contributes 11.4 to 18.0 percent of actual spawned area. Prior to construction, the 3A channel contributed 2.2 and 7.1 percent (2000 and 2001). So while an exact comparison cannot be made with the other injection types, it is clear that channel relocation is extremely expensive. But given the relative increases in spawning use, it is also very effective at creating spawning habitat.

Many factors influence whether a fish will choose to spawn a given area and we are clearly not able to quantify and predict all of those criteria. The full range of particle size distributions, interstitial flow characteristics and embeddedness all may play a role. These and other factors may need to be investigated to improve the predictive ability of field mapping methods.

This study however was tasked in investigate how far along Clear Creek is on the path to recovering lost spawning habitat and how effective are the various means for recovering spawning habitat. While we can clearly see improvement (increases in areal extent and apparent increases in habitat area), we cannot quantify the answer to this question until we can relate contemporary findings to historical data.

The apparent high cost of some projects is a function of the criteria for success being used: spawning habitat area. Some projects (e.g. Below NEED Camp) score quite low in terms of the cost of habitat created but simply because the gravel-filled channel below the injection does not fall into the mapping criteria of "habitat" does not mean that it is not filling a very important role. The 1,000 feet of channel below this injection is providing a valuable supply of spawning fall into the mapping criteria of "habitat" does not mean that it is not filling a very important role. The 1,000 feet of channel below this injection is providing a valuable supply of spawning gravel for downstream reaches which will be redistributed into alluvial features during the next very high flow event. Coarse sediment transport continuity, while not a reasonable short term goal, should remain high on the priority list for restoration. On a reach-level, gravel injections have greatly enhanced coarse sediment transport continuity in Clear Creek. This measure of success is not directly evaluated using habitat mapping and in some cases (e.g. below NEED), using spawning habitat area as an index may imply that injection performance is lower than it is.

The Central Valley Project Improvement Act declared 1956 spawning habitat levels as the target for recovery and the US Bureau of Reclamation requested that this study attempt to answer the question of how far along are we toward this goal. Clear Creek is much smaller than when the 1956 survey was completed and is now much more incised and is highly confined by vegetation. Today, we have concentrated large amounts of spawning gravel into smaller areas in a channel governed by very different hydrologic and hydraulic conditions. While the total spawning area may be approaching 1956 levels (we can't be sure until we calibrate the USFWS 2010 spawning habitat mapping data), spawning fish aren't using the habitat to its potential, which may be tied to geomorphic phenomena (e.g. particle size, embeddedness) or some other unknown variable. Sand delivery in the lower reaches may be a larger threat to recovery than lack of spawning habitat. Different measures of recovery should be evaluated, likely by reach, and these should be used to improve the next phase of gravel injection efforts.

We should continue to examine biological, geomorphic and financial data to seek correlations that may guide restoration efforts and serve as a better index to recovery than 1956 spawning habitat levels. Clear Creek endures long periods of stasis punctuated by stochastic intervals which produce profound changes to the system (e.g. 1997 Paige Boulder debris flow, 2001 Saeltzer Dam removal, 2008 fires and commensurate 2009 increase in South Fork sand production). Historic levels of spawning habitat may not be a suitable target given today's constraints (the dam will not be removed, the channel is severely encroached and high flows are much less frequent) and the fact that limiting factors do not remain the same (spawning habitat no longer appears limiting but overall numbers, utilization and perhaps juvenile production appear to be down). Perhaps a more functional target, defined within the context of existing constraints, such as an index of habitat utilization or state of geomorphic function, should be used instead. It would likely be better to employ more than one functional target, as physical conditions and limiting factors are likely to continue to change.

4.2 Recommendations

4.2.1 Spawning Habitat Mapping

- Even if salmon do not fully utilize the habitat mapped by pSAM, it is highly comparable to the historic studies and should be continued. The areal extent of spawning gravel distribution could be mapped (as per 2001 and 2009) simultaneously which would allow comparisons with those studies and could inform geomorphic monitoring efforts.

- Further research is required to more accurately relate the 2010 studies to 1956 and 1970 findings. While not likely possible, mapping should always be conducted at 90-100 cfs. In lieu of this, a series of pSAM area comparisons at 100 and 150 cfs should be stratified by habitat type or geomorphic criteria (e.g. channel type or reach) and examined for a correlation. If one exists, the relationship could be used to transform 2010 data to be comparable with the previous studies. If no such relation exists, explore predictive hydraulic models.

- Below the Saeltzer Dam site (Reach 6 in the USFWS survey), USFWS maps spawning habitat and use down to the lower rotary screw trap below the floodpain restoration area. Redd superimposition and sheer numbers preclude individual redd mapping and "spawning area" is mapped (SAM). Thus, pSAM transitions to SAM in the lower reaches and since SAM only includes utilized habitat, it may produce different numbers than would pSAM. If habitat mapping is to be the index of recovery for management targets, then pSAM should be performed in Reach 6 as well.

- Salmon are not using the Reach One injected gravel. The full range of particle size distributions, interstitial flow characteristics and embeddedness all may play a role. These and other factors should be investigated to improve the predictive ability of field mapping methods and to guide management efforts: if the critical variable is controllable (such as a missing component of the gravel size distribution) then it can be addressed with future injections.

4.2.2 Geomorphic Monitoring

- Numerous researchers and resource managers identify the need for monitoring gravel injection projects (Harvey et al. 2005, Kondolf and Minear 2004). If full coarse sediment routing (continuity) remains a goal (e.g. for the Clear Creek Restoration Team), then some level of topographic surveying and geomorphic mapping should be continued. Injection sites and the reach of channel directly downstream are particularly important to monitor as this describes channel evolution and provides quantitative feedback relating gravel injection volumes and changes with high flow events. Studies of channel condition before and after injection (pebble counts, tracer gravel studies, bulk sampling, photo monitoring) can show clearly the geomorphic impact not only of reintroducing gravel but also the impact (or lack thereof) of any high flows encountered following implementation.

- Another simple metric to examine might be "the area of stream channel covered with gravel" (as in McBain and Trush 2001) below injections. More expensive though often more informative, are topographic and volumetric analyses as employed for this 2009-2011 project. While sometimes prone to larger errors, volumetrics should be used in addition to simple area mapping to provide information on storage attributes and potential for supplying downstream reaches. *Geomorphic Change Detection Software* (Wheaton 2010) can reduce uncertainty in morphologic sediment budgeting.

- The 2009 orthorectified aerial photo dataset and atlas has proven highly valuable for many agencies and other researchers on Clear Creek. Recommend completing such flight every 3 years or following extreme flow events.

4.2.3 Indices of Recovery

- As physical conditions and limiting factors change, the Clear Creek Restoration Team should periodically revisit the restoration targets used as indices of recovery. The goal of attaining 1956 levels of spawning habitat has proven a powerful tool to drive restoration but it may not be the best measure of recovery. Channel incision, riparian encroachment, riparian colonization of once mobile features, sand delivery and channel armoring are some conditions that persist despite the creation of new habitat. Restoration targets should be developed by reach that consider attainable desired conditions (e.g. liberating the stored sediments in vegetated bars is not very practical). Once defined, new criteria can be established as measures of success.

4.2.4 Gravel Injection Recommendations

- Whiskeytown – Medium Priority
    - Recommend keeping it full, especially in light of potential forthcoming high flow spills and releases such as that proposed by the Environmental Water Program. Lack of spawning use in this reach should be investigated (e.g. particle sizes of utilized versus mapped but not used areas) and future injected size gradations should take these results into account. The supply stored in this reach is a valuable "bank" of coarse sediment ready to be supplied to downstream reaches during the next very high flow event.
- Below Dog Gulch – High Priority
    - Relatively modest flows move 100 percent of this placed riffle, so it really responds and evolves more like a berm placement. However, in the absence of high flows, the site provides riffle spawning habitat. Transport characteristics may change over time as the downstream features continue to aggrade, reducing water surface slope and transport capacity and the injection site may become less easily mobilized. Recommend filling if and after high flows deplete the site. Maximum volume (as per 2011 GMA observations) appears to be 2,000 tons.
- Above Peltier Bridge – Medium priority
    - Arguably the most successful site with regard to attracting spawning steelhead. Continue developing site with additional injections as per the original design. Build riffles at the specified inflections using sluicing methodology. This is not a high priority as it should soon receive gravel from Below Dog.
- Paige Bar – High Priority
    - Same as Below Dog – inject as frequently as flows allow.
    - Avoid placing gravel in the pool above the riffle.
    - Continue to explore the possibility of implementing the original floodplain lowering project.
- Above NEED Camp Bridge
    - Currently a low priority for additional gravel as it is not highly mobile and it lies in a low gradient reach – further expansion would likely further backwater the next riffle upstream, degrading existing habitat.

- Below NEED Camp Bridge – High Priority
    - While it does not balance well in the unit cost analysis, this site is critical for achieving complete sediment routing through the gorge.
    - Keep this full by adding gravel at least once per year.
    - 3,000 tons fits here easily.
- Placer Bridge – High Priority
    - Capitalize on the South Fork sand infusion (which has likely increased gravel transport rates resulting in the dramatic advancement of the leading edge) by filling this injection with up to at least 5,000 tons.
- Clear Creek Road – High Priority
    - Recharge at least every other year to offset the headcut migrating into the reach.
- Reading Bar
    - Low priority for additional gravel.
- City of Redding
    - Low priority for additional gravel.
- Phase 3A -- High Priority
    - Very effective at reducing claypan exposure -- Replenish at every opportunity.
- Tule Backwater – Medium Priority
    - Located above a claypan exposure -- Replenish at every opportunity.
    - Medium instead of High because Phase 3A is protected from incision in this area by the grade control just above the injection site.
    - Future channel conditions downstream should inform the relative priority of this site from year to year.
- Phase 2B – Medium Priority
    - Replenish at every opportunity.
    - Lower priority than Phase 3A and Tule backwater.
    - Future channel conditions downstream should inform the relative priority of this site from year to year.

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