Environmental Water Program Pilot Flow Augmentation Project:

Concept Proposal for Flow Acquisition on Lower Clear Creek

Environmental Water Program
California Bay-Delta Authority
Ecosystem Restoration Program

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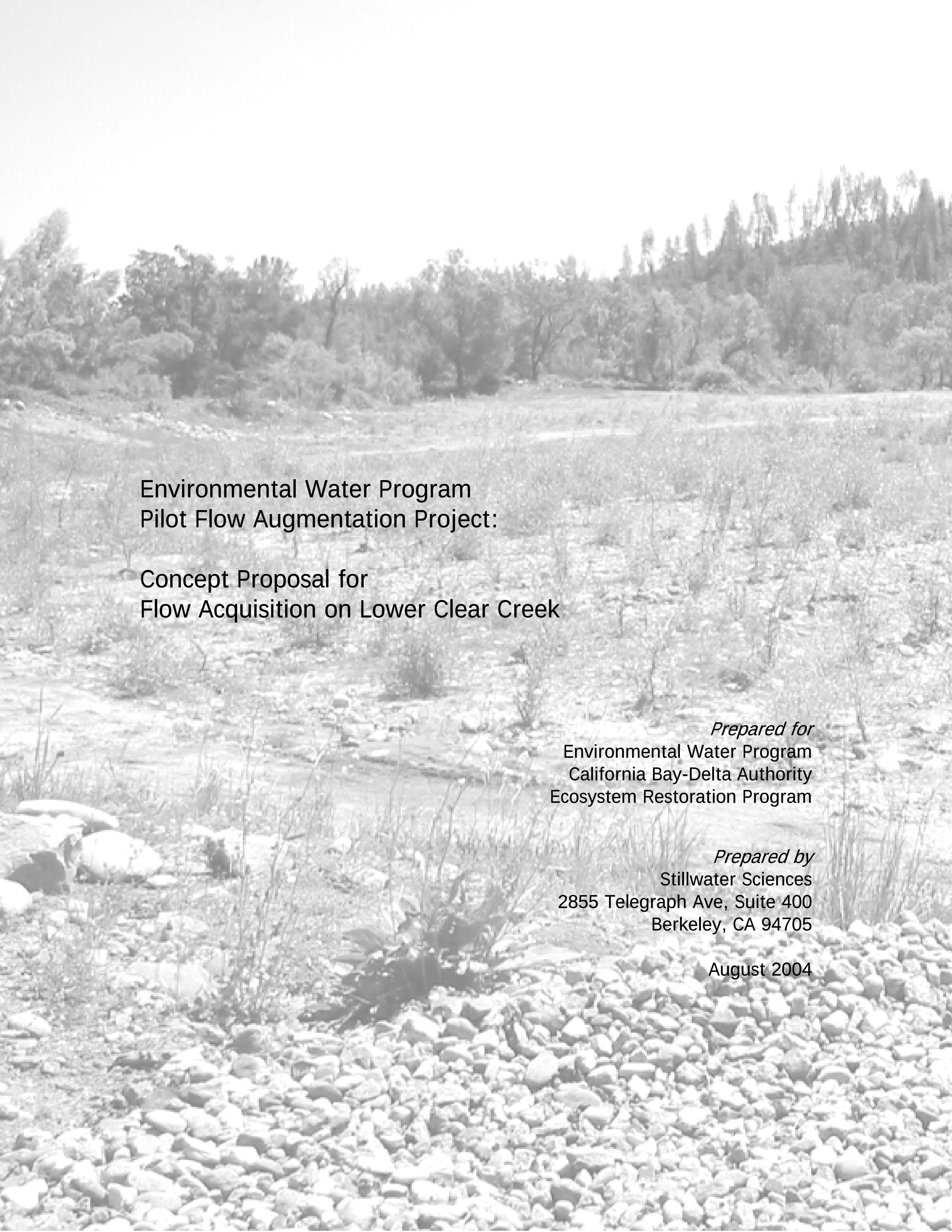

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Prepared for
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Table of Contents

List of Tables

List of Figures

List of Appendices

Abstract

We present a conceptual proposal for designing and evaluating streamflow augmentation to promote recovery of geomorphic process and ecological functions in Clear Creek, a tributary to the Sacramento River. Clear Creek has been cited as an excellent candidate stream for flow augmentation to achieve several of the objectives of the CBDA Ecosystem Restoration Program (CALFED, 2002; Kimmerer et al. 2002, Stillwater Sciences, 2003). Recent multiagency collaborative restoration efforts in Clear Creek require the release of periodic high flows to help achieve maximum benefit to aquatic and riparian habitats, but dam operations have significantly reduced the frequency of mid-range flood flows that are essential for forming and maintaining channel and floodplain morphologies on which habitat and native biota depend. To help optimize the value of these recent activities, and to help advance our understanding of the science underlying channel-forming and channel-maintenance flow events and their interaction with habitat, this proposal outlines in concept a pilot program of flow releases and accompanying data collection and monitoring activities in Clear Creek. The releases and the associated activities are designed to follow and inform an adaptive environmental assessment and management framework consistent with the vision for the CBDA Environmental Water Program. This program is not a general plan for flow management for the creek.

The overall vision of a pilot project of flow augmentation for lower Clear Creek is to release timely discharges of sufficient magnitude, duration and frequency, to reactivate fluvial geomorphic processes. These processes are fundamental to re-create and maintain the diverse template of habitats required in the Clear Creek ecosystem to support and to recover aquatic and riparian species, particularly anadromous salmonids and native floodplain vegetation. Aquatic and riparian habitats in the watershed have been adversely affected by a legacy of human activities that have caused a loss in habitat quality and quantity resulting largely from the reduction or elimination of critical river processes. Examining the linkages between geomorphic process and aquatic habitats focuses primarily on habitat types required to support salmonids and riparian vegetation. These serve as focal indicator species because of the variety of habitat types necessary to support the different life history stages. Bed mobilization and scour are important because they affect the distribution, extent, and quality of spawning habitat by routing and re-distributing gravel; exposing subsurface fines to transport; and transporting sand as bedload, which influences the infiltration of sand in spawning gravels. The scour of fine sediment from pools is important because it affects the depth and volume of pools, which influences the amount and quality of holding habitat for adult spring Chinook salmon and steelhead trout. The deposition of fine sediments on floodplains is important because it may help to reduce the in-channel storage of fine sediments, thus improving aquatic habitat quality while simultaneously benefiting recruitment of native riparian vegetation on otherwise bare mineral surfaces. Gravel and large woody debris (LWD) recruitment are important because these fundamental building blocks of habitat are in short supply. Increasing in-channel gravel storage may improve spawning habitat while LWD will likely increase habitat complexity to support salmonid rearing. The deposition of pockets of gravel in high-gradient reaches is important to expand the amount of spawning habitat for spring Chinook salmon and steelhead trout. These process-habitat linkages are important in other salmon-bearing streams, and the studies implemented in Clear Creek should yield knowledge that is transferable to restoration efforts in other alluvial river systems in the Bay-Delta watershed.

Specifying exactly the magnitude, duration, frequency and timing of the flows required to bring these habitat benefits is challenging. Examination of available hydrologic data suggests that a beneficial and feasible flow augmentation target is the release of flows of between 4,000 to 6,000

cfs with a peak flow duration of two days. The flows should occur three times in an approximate period of 10 years and should be timed for release either in late winter / early spring or late spring. Such flows were typical of sustained channel-forming flows that historically occurred with a recurrence interval of once every 2 – 2.5 years prior to the completion of Whiskeytown Dam, but that now occur with a recurrence interval of approximately ten years. It has been estimated that significant sediment mobility begins at flow magnitudes of 3,000 – 3,500 cfs meaning that a release of ca. 5,000cfs could achieve significant instream geomorphic work. Further, recent rehabilitation activity has included floodplain re-grading to an elevation that is inundated at approximately 3,000 cfs (i.e., to a recurrence interval instantaneous peak flow of 2 years) so that a 5,000 cfs flow release would cause significant inundation of these lowered floodplains. The frequency and timing of flow releases must be flexible in light of the need for the alignment of meteorological, hydrological, operational, and socioeconomic conditions to provide windows of opportunity for the flow releases. The proposed magnitude, duration, frequency, and timing of flow releases is, therefore, provisional, and we expect that the knowledge gained from the initial flow releases will suggest revisions to the parameters of future target discharges.

The approach to evaluating outcomes of flow augmentation in terms of environmental response is based on a program of adaptive environmental monitoring and assessment to maximize learning opportunities using a systematic evaluation of assumptions, objectives and associated hypotheses. The studies focus monitoring activities on the linkages between geomorphic processes, aquatic and riparian habitats, and several limited aspects of biological response. This occurs because, statistically, evaluation of project effectiveness must be limited to those factors that change reliably within the constraints of the experiment. External factors and controls beyond the scope of this experiment discount the prospect of monitoring the status-and-trends in biological populations as a metric of experimental success, although such monitoring as undertaken currently by agencies will provide an important context to the proposed monitoring activities. Instead, the hypotheses tested by the experiment are directed at generating weight-of-evidence conclusions targeted at the dynamic habitat requirements of the focal indicator species. There is an explicit assumption that positive changes for these species will additionally benefit a host of other native species. Beyond learning *about* the environmental performance of high flow releases, evidence will also be gathered that allows learning *from* the project in terms of the adequacy of the monitoring studies and the ability of decision-support and computer simulation models used to generate the operational rules used to obtain the flow releases and to predict the environmental responses, respectively.

The estimated first approximation cost for the proposed flow releases and associated monitoring is in the order of $5.5M. This will depend on the timing of the flow releases, the unit costs for foregone power, the monitoring components, and the frequency and level of detail required for each monitoring survey. This is an order-of-magnitude cost estimate. Costs associated with modeling have not been included as the modeling appropriate to the project can be defined only after further specification of the target flow objectives and hypotheses. Further details of the proposed flow releases and monitoring activities will be defined in the full proposal to be developed pending approval of this conceptual proposal, at which time it will be possible to develop a more specific cost estimate.

Preface

The Environmental Water Program (EWP) is part of the California Bay-Delta Authority's (CBDA) Ecosystem Restoration Program (ERP). The U.S. Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration Fisheries (NOAA-F), and the California Department of Fish and Game (DFG) are designated as the implementing agencies for the Ecosystem Restoration Program (ERP Implementing Agencies) and are working, in coordination with the CBDA, to implement pilot water acquisitions in selected watersheds through the Environmental Water Program. The acquisitions are intended to provide significant biological and ecological benefit, improve the state of scientific knowledge related to the effects of instream flows, and increase knowledge regarding the institutional and social constraints facing environmental water acquisitions.

This draft concept proposal for water acquisition was developed by EWP Staff and the EWP Lead Science Team on behalf of the Clear Creek Local Preparation Proposal Team (Local Team). The EWP Core Team was represented by Campbell Ingram as EWP Program Manager, on behalf of a multi-agency advisory panel including representatives from the ERP Implementing Agencies. The Lead Science Team was represented by Peter Downs as EWP Lead Scientist, and was supported by disciplinary specialist staff from Stillwater Sciences, Berkeley, CA. The Local Proposal Preparation Team consists of a variety of stakeholders who attended participatory meetings during the development and review phases of the proposal development. These meetings encompassed the review and discussion of existing information, the identification of species of concern and biological objectives, and the discussion of potential benefits, concerns, and constraints of the proposed flows on species of concern and the local landscape. Local Team meetings and subgroup meetings of biology specialists occurred on September 14, 2003, October 14, 2003, November 19, 2003, January 27, 2004, February 20, 2004, March 11, 2004, and May 12, 2004. A site visit to lower Clear Creek occurred on April 22, 2004.

The stakeholders include interested citizens, landowners, representatives of non-governmental organizations, local and regional government staff, regional agency staff, and several consultants with prior experience in the watershed. A list of meeting participants can be found in Appendix A. An early draft of this concept proposal (May 5, 2004) benefited from peer review by several of the Local Team members. A second draft of this concept proposal (June 18, 2004) benefited from peer review by several of the ERP Science Board members. Names of the primary developers and reviewers of the concept proposal are also provided in Appendix A. A list of abbreviations is provided in Appendix B.

This concept proposal is part of a two step directed action process for funding pilot water acquisition projects. The function of the concept proposal is to provide sufficient justification for flow acquisition that the Ecosystem Restoration Program Selection Panel will recommend the preparation of a full proposal for the project. If the proposal is approved for advancement, the EWP staff and Local Proposal Preparation Team will draft a full proposal that responds to the recommendations made by the reviewers of the concept proposal, and that expands upon material provided in the concept proposal. A full proposal will include detailed descriptions of the work to be completed, statements of who will be responsible for each element of work, projected costs for each element of work, a science and adaptive management plan, a project management plan, and a water acquisition plan.

1 EWP AND CLEAR CREEK

The goal of the EWP is to acquire water in support of the ERP to enhance instream flows that are biologically and ecologically significant, improve the state of scientific knowledge related to the effects of instream flows, and gain knowledge regarding the institutional and social constraints facing environmental water acquisitions. Pilot water acquisitions will be undertaken to achieve four objectives:

- acquire water on 1–3 priority streams;
- design and apply a science-based adaptive approach to each acquisition to increase our understanding of how the system works;
- improve conditions for target fish species or reinvigorate flow-related ecosystem functions; and
- achieve, where possible, multiple environmental benefits from each acquisition.

The EWP has recognized the value of water and its potential as a source of conflict among competing interests. Consequently, the EWP is guided by a set of principles to ensure that water acquisitions will be:

- made on a willing seller basis;
- developed jointly by local interests and the ERP Implementing Agencies; and
- designed to test hypotheses regarding water management in a manner that
    - facilitates learning through adaptive management,
    - includes appropriate monitoring, and
    - will be peer reviewed by an independent scientific panel prior to approval.

In regard to the objectives of the EWP, Clear Creek is an excellent candidate stream to provide a supply of water to support the on-going, ecosystem-based management approach to restoration. Since 1995, the Clear Creek Coordinated Resource Management Planning group (CRMP) and the Clear Creek Technical Team have been meeting to plan, implement, and monitor restoration projects using a multi-disciplinary restoration approach. These groups include local landowners, agency representatives and other stakeholders. Many of the projects have been implemented by the Western Shasta Resource Conservation District (WSRCD) with technical assistance from more than a dozen federal, state and local agencies (CVPIA 2003). Projects include the removal of Saeltzer Dam, introducing spawning gravels into lower Clear Creek, implementing erosion control programs, reducing fuels within the watershed, and the Lower Clear Creek Floodway Rehabilitation Project. This latter project involves an extensive effort to restore the natural form and function of the Clear Creek channel and floodplain in areas highly affected by channel and floodplain gravel mining. Planning and implementation of the Lower Clear Creek CRMP have been funded primarily through the Central Valley project Improvement Act (CVPIA) and the CBDA ERP. The restoration projects by stakeholders and agencies in the basin are summarized in Section 3.2. In general, these activities will be expected to benefit from the flow acquisitions described in this proposal.

Several planning activities have cited Clear Creek as one of the best opportunities for restoring flows in a manner that will contribute to existing, long-term, multi-agency collaborative restoration efforts. , Simultaneously it provides an excellent opportunity to improve our understanding of how to optimize the ecological benefits of restored flows and how to balance environmental flow needs with human uses of water. These planning activities include the Pilot Water Acquisition Program (PWAP) Stream Selection Recommendations (CALFED 2002), the CALFED-Ecosystem Restoration Program's Independent Science Board memorandum (Kimmerer et al. 2002), and a previous Environmental Water Program report (Stillwater Sciences

2003). The proposed project also directly supports several of the goals of the CBDA's Ecosystem Restoration Program (http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem.shtml, accessed July 2004), notably in regard to rehabilitating natural ecosystem processes, the protection and enhancement of functional habitats, the improvement of water and sediment quality and, overall, to aid the recovery of at-risk native species.

2 PROJECT VISION

The overall vision of a pilot project of flow augmentation for lower Clear Creek is to release discharges of sufficient magnitude, duration and frequency, and at appropriate times, to reactivate fluvial geomorphic processes. These processes are fundamental for creating and maintaining the diverse template of habitats required in the Clear Creek ecosystem to support and to recover aquatic and riparian species, particularly anadromous salmonids and native floodplain vegetation. This vision is founded on documented evidence of adverse changes to aquatic and a riparian habitat caused in Lower Clear Creek in the period since European arrival, and is intended to extend from and maximize the benefit achieved with previous and on-going restoration projects. The project vision is compatible with the objectives of the Environmental Water Program and with several of the goals of the CBDA Ecosystem Restoration Program. Results of the proposed flow augmentation pilot project are intended to inform future processes that decide the feasibility and benefits of an augmented flows program for Lower Clear Creek and the adaptive management of such a program.

Aquatic and riparian habitats in Clear Creek have been adversely affected by land use changes including de-forestation and road construction, hydraulic gold mining, in-stream and floodplain gravel mining, flow diversion, and flow and sediment transport regulation. As such, it is generally understood that these activities have led to a loss in habitat quantity and quality related to the reduction or elimination of critical river processes, and consequently to a reduction in the abundance and diversity of valued native flora and fauna, such as anadromous salmonids species. Surveys conducted in 2000 indicated that a 98% loss has occurred since 1956 in spawning habitat for spring Chinook salmon and steelhead between Whiskeytown Dam and (the former) Saeltzer Dam. Subsequent restoration efforts provide a good example of an ecosystem-based approach to restoration in the Central Valley. Since 1996, local, state, and federal partners (including multi-agency efforts and integration) have augmented the creek's gravel supply, generally using a flow-based strategy, whereby the gravels that are placed on the banks and floodplain are recruited into the channel and distributed by high flow events, rather than being placed directly in the channel. Similarly, there have been efforts to reconstruct 2.2 miles of the channel and floodplain morphology as part of the Lower Clear Creek Floodway Rehabilitation Project (2000–present). The design of these physical modifications assumes the presence of flows to help the channel and floodplain environments evolve over time in order to maintain the value of aquatic and riparian habitat.

Though these physical modifications embody an ecosystem-based approach by relying on natural processes to create and maintain habitats, the current flow regime generally does not include the types of flows necessary for re-establishing the critical ecological processes that were targeted by previous restoration efforts in Clear Creek. Particularly absent are sustained mid-range flood flows (e.g., ~4,000–6,000 cubic feet per second for one day or more) that typically support a number of fundamental riverine processes, such as channel bed mobilization and scour, deposition of fine sediment on floodplains, maintenance of pool depth by scour, and the scouring of riparian vegetation from channel surfaces to prevent encroachment and simplification of the channel and aquatic habitat. Such flow magnitudes are typical of the "channel-forming flows" that used to occur approximately every 2–2.5 years prior to the completion of Whiskeytown Dam in 1963, but that now occur approximately once every ten years. Therefore, increasing the frequency of mid-range floods has both an intrinsic value in re-establishing important ecological functions that should benefit biological populations in the long-term, and value in ensuring that the potential benefits of recent restoration efforts are fully realized.

Consequently, an important step in the restoration of Clear Creek is the provision of periodic experimental flow releases that should help in understanding and restoring the fundamental ecological processes that help to create and maintain aquatic, riparian, and floodplain habitats that can support a variety of fish, avian, and other wildlife species. The potential for acquiring experimental flows is facilitated by the design of Whiskeytown Dam that allows for flow releases using the large capacity spillway structure (familiarly known as the "Glory Hole"). Prospective methods of flow acquisition include a "winter strategy" based around piggybacking releases on large natural reservoir inflows, and a "spring/summer strategy" based on clear weather releases in late spring achieved by lake level modifications. The former method is quite probably cheaper and is closer to natural flood flow timing whereas the latter offers the prospect of greater control on the flow release achieved. For maximum benefit, it is a necessary that the flow releases are accompanied by several supporting management activities including the continuation of gravel augmentation, the mechanical removal of some bank-toe vegetation, and the installation of some boulders and logs to accelerate habitat changes.

Restoring mid-range floods to Clear Creek is expected to help create and maintain several different types of habitat units that are envisioned for the lower Clear Creek corridor between Whiskeytown Dam and the confluence with the Sacramento River. Such habitats include:

- gravels of sufficient quantity and quality to support spawning and incubation of spring Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*) between Whiskeytown Dam and the canyon reach, complemented by overhanging riparian vegetation to provide cover for juvenile rearing of multiple species of salmonids;
- deep, coldwater pools to support salmonid holding in the canyon reach, with scour around large woody debris (LWD) and boulder complexes to provide habitat complexity, cover for juvenile rearing of multiple species of salmonids, and to induce the deposition of pockets of gravel to support spawning by spring Chinook salmon and steelhead trout;
- riffles composed of channel bed sediments that are mobilized and scoured periodically to maintain spawning habitat quality primarily for spring Chinook salmon spawning (and steelhead spawning) between the canyon reach and Clear Creek Road Bridge, flanked by floodplains supporting a diverse riparian vegetation that provides nesting and foraging habitat for neotropical migrant and native resident bird species, and incorporating complex active channel and floodplain habitats to support multiple species of juvenile salmonids and amphibians;
- riffles composed of channel bed sediments that are mobilized and scoured periodically to maintain spawning habitat quality to support fall Chinook salmon spawning between Clear Creek Road Bridge and the confluence with the Sacramento River, also flanked by diverse floodplain-riparian habitats to support nesting and foraging habitat for neotropical migrant and native resident bird species, and multiple species of juvenile salmonids and amphibians.

Flow augmentation for Clear Creek presents several scientific and management challenges. For example, the relative absence of mid-range floods in the current, regulated flow regime have made it challenging to directly observe, and therefore identify, the specific flow thresholds required to recruit and distribute existing and augmented gravels, to mobilize fine sediment and deposit it on floodplains, to initiate channel migration, and to prevent riparian encroachment. Similarly, it is difficult to define exactly the timing, frequency, and duration of flow releases necessary to optimize certain ecological benefits (e.g., releasing flow to coincide with the seed-release period of key riparian vegetation species) while preventing or reducing conflicts with other ecological objectives (e.g., the release of scouring flows during critical periods of salmonid egg incubation). It is also challenging to integrate flow releases that will balance ecosystem restoration needs with other important uses of water, such as hydropower generation, the delivery of irrigation water and flood control. Conversely, these uncertainties and management challenges also define why such flow releases on Clear Creek are potentially of regional importance in the development of transferable understanding regarding ecosystem restoration, and they underscore the need for implementing the restoration of mid-range floods as part of an experimental program of adaptive environmental assessment and management. As such, proposed flow releases are designed to test clearly-defined hypotheses in conjunction with field data investigations and monitoring activities to evaluate several key categories of project uncertainty including, (1) uncertainty related to the ability to release flows as designed in conjunction with other water uses, (2) uncertainty related to the effectiveness of the flows in re-establishing critical geomorphic processes and, (3) uncertainties related to the creation and biological utilization of habitats altered by the geomorphic processes. Such an evaluation should facilitate specific recommendations regarding the benefits and feasibility of a longer-term flow augmentation program for Lower Clear Creek.

An adaptive management approach to a pilot project of flow augmentation carries with it several fundamental constraints and assumptions that have influenced the development of this proposal. First among these is the constraint that the project is an experiment which will be limited in scope and timeframe by available resources. Therefore, the proposed project does not represent a comprehensive plan for management of instream flows or fish and wildlife resources in Clear Creek. It is focused on evaluating a limited number of mid-range flood flows over a limited time period and, in turn, providing results that maximize the learning experience about flow acquisition within, and beyond, the lower Clear Creek watershed. A necessary and unique aspect of this project is the potential adaptation of the experiment itself to determine the optimum timing, magnitude, duration and frequency of future program flows. Flows are sought which are expected to stimulate fluvial processes and exert influence on habitats for indicator species that can be measured. The data collection and monitoring required to address this goal is complex and intensive because of the potential for both deliberate flow releases and storm-driven events to occur during the duration of the project, and because of the need to clearly identify the direct impacts of experimental flows relative to environmental fluctuations that are controlled by factors outside of experimental control (see below).

A second constraint stems from the fundamental scientific challenge of measuring biological response(s) to credibly establish cause and effect relationships between treatment (mid-range flows) and the chosen response variables. For salmonids, data from multiple generations are needed to establish baseline trends in abundance and variability, followed by years of post-experiment monitoring, for which the effects of natural, stochastic, and management-related external influences must be partitioned. As this requirement cannot be met under a pilot project timeframe, the proposed project must, instead, concern itself primarily with the measurement of factors that are directly the result of flow releases, are amenable to statistical testing, and use a “weight-of-evidence” approach to establish linkages between overall cause-and-effect. As such, data collection is focused primarily on (1) the physical response of the Clear Creek channel and floodplain to mid-range flood flows, as the physical effects of experimental flows can be established more robustly under shorter time frames, (2) on the quantity, quality and distribution of habitat for aquatic and riparian species that can be measured in response to flow events, and (3) on short-term variations in biological factors that can be reliably established within the pilot project timeframe. Longer-term measures of ecosystem improvement (biological responses such as life-stage-specific survival of salmon, growth and succession of riparian vegetation, and the abundance and distribution of amphibians) are best addressed through continued and/or expanded long-term monitoring by resource agencies and stakeholders. On-going and planned future biological monitoring efforts (e.g. spring Chinook adult monitoring in Clear Creek by the

USFWS (Newton and Brown 2004) are considered complementary to data collection in this flow augmentation experiment.

A related assumption in the proposed project is that an approach to flow acquisition targeted primarily at habitat improvement for salmonid species and native riparian vegetation will be of overall benefit for other native species. Such an approach is based on the premise that indicator species such as anadromous salmonids are highly dependent on ecosystem conditions similar to those prior to intensive human impact in the watershed. As such, the approach requires the rehabilitation of natural ecosystem processes that are likely also to have been instrumental in supporting other native species. Proposed monitoring is, therefore, focused on performance measures and the creation of habitats that are generally understood to be limited or to have been significantly altered through historic human activities and continued management. Under such circumstances, a process for identifying and ranking limiting factors is often undertaken. However, for Clear Creek, there has been no formal limiting factors analysis. Consequently, as part of this conceptual proposal, data have been assembled that provide evidence of contemporary ecosystem condition relative to reference conditions (Section 3.1), and these data are interpreted using expert judgment to identify an appropriate range of ecosystem attributes to be achieved with flow augmentation.

3 PROJECT SETTING

Clear Creek is a 238-mi^2 watershed draining into the northwestern portion of the upper Sacramento River Basin. Clear Creek originates near 6,000-ft elevation in the Trinity Mountains, and flows south between the Trinity River basin to the west and the Sacramento River basin to the east, and into Whiskeytown Reservoir (elevation 1,210 ft) at Oak Bottom, 11 miles west of Redding (Figure 1). This proposal focuses on lower Clear Creek which extends for approximately 17.5 miles from Whiskeytown Dam to the confluence with the Sacramento River five miles south of Redding (elevation 440 ft). Downstream of Whiskeytown Dam, Clear Creek flows south for about 9 miles before changing direction and flowing east approximately 8.5 miles upstream of the Sacramento River confluence. The unregulated drainage area between Whiskeytown Dam and the confluence with the Sacramento River is 49 mi^2.

Clear Creek flows through two distinct geologic provinces: the Klamath Mountains province (encompassing reaches 1 and 2) and the Great Valley province (reaches 3 and 4) (Blake et al. 1999). The Klamath Mountains province is composed primarily of Paleozoic to Mesozoic igneous, metasedimentary, and metamorphic lithologies that are largely resistant to erosion. The Great Valley province is composed of Mesozoic to Recent sedimentary lithologies, which are much less resistant to erosion that the Klamath Mountain rocks. The different erosion properties between the two provinces both influence the composition of the alluvium and cause significant differences in channel morphology among the reaches of lower Clear Creek (McBain and Trush 2001).

Streamflow hydrology in lower Clear Creek is typical of streams draining the west side of the Sacramento Valley. The maximum watershed elevation is approximately 6,000 ft, but a majority of the watershed area is below the 4,000-ft snow line, so natural high flow hydrology is driven by rainfall and rain-on-snow events, which typically occur during the winter months. The unimpaired snowmelt hydrograph is small in magnitude; the snowmelt peak is typically less than 1,500 cfs. Average annual precipitation measured at Whiskeytown Reservoir is approximately 63 inches, with most rain falling in the winter and spring months (Tetra Tech 1998). Average annual precipitation measured in Redding is approximately 22 inches per year. Unimpaired summer/fall baseflows were low because the imperviousness of the Klamath Mountains terrain minimizes shallow and deeper groundwater storage to the point where no significant springs exist to maintain high baseflows (TAT 1999). This imperviousness, combined with periodic high intensity rainstorms, results in extremely flashy streamflow response to rainfall events. Current hydrology is outlined in Section 3.1.1.

Clear Creek Reach Delineation

The four reaches of lower Clear Creek referred to in this conceptual proposal (Figure 2 and Table 1) are those delineated by McBain and Trush (2001). They are based primarily on geomorphic characteristics (e.g., channel slope and confinement, alluvial vs. bedrock channel, extent of floodplains and riparian vegetation, etc.), and secondarily on land use impacts resulting from dredge mining for gold, aggregate mining, streamflow regulation, and coarse sediment blockage from Whiskeytown Dam and the former Saeltzer Dam. This reach delineation is useful in describing the specific geomorphic conditions of each reach, and providing a context for identification of specific ecological stressors (CALFED 1999) and different anadromous salmonid issues, and for developing restoration actions and strategies that target specific features of the different reaches. However, other studies have defined reaches of Clear Creek differently and examples are provided in Table 1 for comparison purposes.

Table 1. Reach descriptions used by various studies on Clear Creek.

Reach	Description	River Mile
McBain and Trush (2001)		
1	The upstream, confined, alluvial reach directly below Whiskeytown Dam	17.5–15.4
2	The canyon reach from Paige-Bar to Clear Creek Bridge	15.4–8.4
3	The alluvial reach upstream and downstream of the site of the former Saeltzer Dam, comprising: Reach 3A: Clear Creek Bridge to Saeltzer Dam gorge Reach 3B: Saeltzer Dam gorge	3A: 8.4–6.8 3B: 6.8–6.5
4	The alluvial reach downstream of Saeltzer Dam gorge	6.5–0.0
USFWS snorkel surveys (Newton and Brown 2004)		
1	Whiskeytown Dam to NEED Camp Bridge	18.1–16.0
2	NEED Camp Bridge to Kanaka Creek	16.0–13.0
3	Kanaka Creek to Igo Gage	13.0–10.9
4	Igo Gage to Clear Creek Rd. Bridge	10.9–8.5
5	Clear Creek Rd. Bridge to Saeltzer Dam Site	8.5–6.5
6	Saeltzer Dam Site to Rotary Screw Trap	6.5–1.7[a]
CCDAM channel submodel (Alexander et al. 2003)		
1	Whiskeytown to the confluence with Paige Boulder Creek	17.5–16.3
2	Paige Boulder Creek to the confluence with South Fork Clear Creek (slightly upstream of USGS Gauging station)	16.3–10.9
3	South Fork Clear Creek to the Clear Creek road bridge	10.9–8.5
4	Clear Creek road bridge to former Saeltzer Dam site	8.5–6.5
5	Former Saeltzer Dam site to the confluence with the Sacramento River	6.5–0.0

[a] In 1999, the downstream boundary for reach 6 was RM 2.2.

3.1 Watershed Historical Context and Baseline Conditions

Analyzing the historical context to changing environmental conditions in a watershed provides the basis for understanding why river system functioning and baseline biological conditions have changed from an assumed reference condition. For most watersheds, this analysis equates to a cause-and-effect examination of the role of increasing human intervention in altering natural hydrologic and geomorphic system functions. The analysis is valuable in: (1) identifying the underlying causes of problems or issues leading to the need for restoration; (2) documenting historical conditions to assist in determining ecological potential; and (3) setting realistic and appropriate goals for restoration (Kondolf and Larson 1995, Kondolf and Downs 1996). Implicit in a cause-and-effect analysis of watershed biological baseline conditions is a hierarchy of governing processes, as outlined in Figure 3. These processes help explain the dependency of biota on habitats, of habitats on channel and floodplain form, and of channel and floodplain form on fluvial geomorphic processes driven by hydrology and sediment transport Several reports have traced the degradation of aquatic and floodplain habitats in Clear Creek as a function of various human activities over time (McBain and Trush 2001,; Williams and Kondolf 1999; Coots 1971, as cited in McBain and Trush 2001). Several of these reports have also tried to correlate the loss of habitat quantity and quality with the reduction or elimination of critical river processes, such as the elimination of mid-range floods (i.e., bankfull flow events) by Whiskeytown Dam operations (McBain and Trush 2001) and the increased intervals between flows capable of mobilizing and scouring gravel, which has permitted fine sediments to infiltrate framework spawning gravels (Williams and Kondolf 1999). In addition to the numerous reports summarizing historical conditions and the loss of habitat, there have been several recent physical and biological monitoring studies that assist in providing the empirical basis for the proposed flow acquisition

(Table 2). A summary of salient details from these reports is provided in this section. Acknowledging the lack of a formal limiting factors analysis for salmonids or other species, these details are used as surrogate evidence from which target ecosystem attributes can be developed.

Table 2. Recent physical and biological monitoring activities by reach in lower Clear Creek.

	Reach 1	Reach 2	Reach 3	Reach 4
Physical Monitoring				
Geomorphology, hydrology (GMA 2003)				X
Geomorphology (McBain and Trush 2001)	X	X	X	X
Geomorphology (Stillwater Sciences 2001)			X	X
Geomorphology (Miller and Vizcaino 2004)				X
Groundwater (in rehabilitation sites)			X	X
Mercury (Ashley et al 2002)	X	X	X	X
Trace metals (Moore 2002)	X	X	X	X
Biological Monitoring				
Fish (Villa 1984)	?	X	X	X
Fish (CDFG pers. comm. Colleen Harvey, as cited in WSRCD 1996)			X	X
Fish (Newton and Brown 2004)	X	X	X	X
Spawning habitat (Coots 1971, as cited in McBain and Trush 2001	X	X		
Riparian vegetation surveys (Bair 1999)	X	X	X	X
Riparian vegetation (Bair et al. 2003, Souza Environmental Solutions et al. 2004)			X	X
Riparian songbirds (Burnett and Harley 2003)	X	X	X	X

3.1.1 Hydrology and Land Use Changes

The hydrology and channel morphology of lower Clear Creek have been altered by flow diversion, sediment interception, and sediment removal. The Trinity River Division of the Central Valley Project has significantly altered the hydrology of lower Clear Creek since the completion of Whiskeytown Dam in May 1963. The inter-basin transfer of Trinity River water, via the J.F. Carr tunnel, represents the overwhelming majority of inflow to the reservoir, comprising 74% of total volume of inflow to the reservoir since the inter-basin transfers began. Most of the water stored in the reservoir is eventually routed through the Spring Creek tunnel (94% of annual flow releases), which transports the water to Keswick Dam on the Sacramento River, generating hydropower during transit. Other impacts to the river and floodplain include a combination of hydraulic mining for gold (beginning in 1848), in-stream gravel mining (1950–1978), floodplain gravel mining (1950–present), operation of Saeltzer Diversion Dam (1903–2000) and other land uses in tributary drainages (e.g., road construction, timber harvest). Cumulative effects of historic disturbances can be assumed to have affected the entire lower Clear Creek watershed.

Changes in Lower Clear Creek streamflow as a result of flow regulation by Whiskeytown Dam have been dramatic, and have had significant impacts to fluvial processes, riparian dynamics, and salmonid populations. McBain and Trush (2001) analyzed the hydrologic record at the USGS Clear Creek at Igo gauge (#11372000) to assess the impact of Whiskeytown Dam on flow in Clear Creek (Figure 4). They found that Whiskeytown Dam has significantly reduced the magnitude and frequency of mid-range high flows, defined here as flood flows of 3,000–10,000 cfs (Table 3). Further, average flood flow magnitude and variance has decreased (Williams and Kondolf 1999, p. 21). Smaller high flow events of short duration (2,000–3,000 cfs) can still occur due to tributary inflows below Whiskeytown Dam, and larger flow events (>10,000 cfs) still occur during large storms that exceed the storage capacity of Whiskeytown Reservoir. While the Whiskeytown Glory Hole spillway can provide uncontrolled releases up to 28,000 cfs, the Outlet Works can only release a controlled maximum flow of 1,200 cfs, which is incapable of initiating any significant fluvial processes (USBR 1999, p. 14). As such, flows greater than 3,000 cfs generally result from Glory Hole spillway releases. The frequency of moderate, channel-forming flows typical of a bankfull event prior to dam construction have been severely reduced (McBain and Trush 2001, p. 80); the 1.5 year instantaneous flood magnitude has decreased from 5,700 cfs before Whiskeytown Dam was built to 2,100 cfs post-dam construction. The end result is a reduced frequency of events that cause bedload sediment transport, deposit fine sediment on floodplains, and scour riparian vegetation from the channel edge.

Table 3. Changes to Clear Creek near Igo gauging station (USGS #11372000) flood magnitudes for 1.5 to 10 year floods (McBain and Trush 2001).

Recurrence Interval (years)	Pre-Dam (1941–1963)	Post-Dam (1964–2000)	Percent Reduction
Annual instantaneous flood series			
1.5	5,640	2,067	63
2.5	8,900	3,750	58
5	12,750	6,550	49
10	18,700	9,530	49
1-day daily average maximum flood series			
1.5	3,690	926	75
2.5	6,185	1,817	71
5	9,048	3,355	63
10	14,300	5,958	58
3-day daily average maximum flood series			
1.5	2,950	648	78
2.5	4,891	1,253	74
5	6,398	2,336	63
10	10,550	4,380	58

Additional hydrograph components have also been altered. The small snowmelt hydrograph has been completely eliminated. Summer baseflows, typically between 60 cfs in wetter years to less than 30 cfs in drier years pre-dam (McBain and Trush 2001), have been increased to minimum summer baseflows ranging between 70 and 95 cfs to provide adequate water temperatures (cooling flows) for steelhead and spring Chinook salmon. Prior to 1999, baseflows were less than 50 cfs after the construction of Whiskeytown Dam. Flows were maintained at 150 cfs throughout the summer in 1999 to maintain temperatures for spring run Chinook and steelhead below Saeltzer Dam. In 2000, flows were maintained at 50 cfs due to the deconstruction of Saeltzer Dam, and temperature targets were not met. From 2001 to the present, flows have been adjusted throughout the summer to meet the temperature target of 60° F at Igo gauging station for holding spring run Chinook. Since 2001, flows have been maintained between 70 and 100 cfs throughout the summer and 200 cfs after September or October to meet holding and spawning temperature requirements (Giovannetti, S. 2004. *Personal communication*. USFWS, Red Bluff, CA. 26 May). These increased baseflows may have caused substantial changes in the composition and distribution of riparian vegetation species (especially promoting encroachment by riparian vegetation), yet these flows must be maintained to achieve the temperature targets for spring run Chinook.

Gold and aggregate mining at Reading Bar and aggregate mining in reaches 3A and 4 drastically altered the channel and floodplain morphology (McBain and Trush 2001, p. 7), and consequently, the sediment transport processes and aquatic and riparian species composition in lower Clear Creek. Floodplains were geomorphically isolated from the main channel (McBain and Trush 2001, p. 33). In some areas, aggregate mining removed the floodplain surface altogether, creating shallow depressions which became wetland complexes (McBain and Trush 2001, p. 33). The complexes were typically connected to the low flow channel, which often led them to function as sediment sinks, potential stranding areas for juvenile and adult salmonids, and potential habitat for non-native, piscivorous fishes. Channel incision has also been documented on lower Clear Creek, which Williams and Kondolf (1999, p. 4, 5) attribute to some combination of reduced sediment supply downstream of Whiskeytown Dam, downcutting through aggradation resulting from hydraulic mining for gold, in-stream and floodplain gravel mining, and the reduced base level of the Sacramento River at the Clear Creek confluence.

3.1.2 Biological Communities

The Fish species addressed in this proposal include anadromous salmonid and resident fish species. The construction of Whiskeytown and Saeltzer dams reduced stream flows, and the introduction or expansion of non-native fish species have altered the distribution and composition of the fish community within the Clear Creek drainage from historical conditions. For example, Clear Creek may have supported various life stages of salmonids and other fishes up to the vicinity of French Gulch (approximately 3 miles north of Highway 299) where Hanson et al.(1940, p. 87) considered the stream “too small to attract migrating salmon”. Anadromous salmonids in Clear Creek listed under the federal Endangered Species Act (ESA) include Central Valley spring Chinook (*O. tshawytscha*, Federal and State status-threatened) and Central Valley steelhead (*O. mykiss*, Federal status-threatened). Fish species of interest that are not listed under the ESA include anadromous Central Valley fall and late-fall Chinook (*O.tshawytscha*) and Pacific lamprey (*Lampetra tridentata*), and native resident rainbow trout (*O. mykiss)*, Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento sucker (*Catostomus occidentalis*), hardhead (*Mylopharodon conocephalus*), California roach (*Hesperoleucus symmetricus*), and hitch (*Lavinia exilicauda*), as well as non-native largemouth bass (*Micropterus salmoides*) and smallmouth bass (*M. dolomieu*). Anadromous salmonids are emphasized due to their ESA and California Endangered Species Act (CESA) status and their recreational and commercial importance. The timing of spawning for spring, fall, and late fall Chinook salmon and steelhead in lower Clear Creek are summarized in Figure 5.

The community of woody riparian species varies from the confined upper reaches of Clear Creek to the broad alluviated valley bottom in the lower reaches. Similarly, near-riparian conifer-dominated vegetation vary in mosaic patterns and potential influence on the aquatic species such as Douglas fir (*Pseudostuga menziesii*), ponderosa pine (*Pinus ponderosa*), and bigleaf maple (*Acer macrophyllum*) in the upper reaches to valley toe. Lower elevation terraces are dominated by stands and isolated individuals of gray (Digger) pines (*Pinus sabiana*). Riparian vegetation is limited to a narrow band along the channel margins in the confined canyon reaches of Clear Creek between Whiskeytown Dam and Clear Creek Bridge where the alluvial section of the creek begins. Vegetation occurs in bedrock cracks, and along small tributary deltas and lee deposits; arroyo and narrowleaf willows (*Salix lasiolepis* and *S. exigua*) thrive wherever local site conditions can sustain them. However, there are some areas near Paige Bar, close to the Whiskeytown Dam site, where white alder (*Alnus rhombifolia*) and Pacific willow (*S. lucida* ssp. *lasiandra*) have colonized along the low water channel. Downstream of Clear Creek Bridge where the valley widens, the channel becomes predominately alluvial, and floodplains and terraces allow riparian vegetation to be more extensive. Prior to construction of Whiskeytown

Dam, climate and seasonal streamflow variation created hot and dry conditions during much of the growing season (Bair et al. 2003). Bair et al. (2003) propose that woody riparian vegetation could only establish infrequently (during or immediately after wet years) and in isolated stands with little connectivity. In the alluvial reaches of Clear Creek, riparian vegetation historically existed in patches near abandoned primary channels or high flow scour channels where the water table was closer to the rooting surface (McBain and Trush 2001). For example, recent monitoring of the Lower Clear Creek Floodway Rehabilitation Project indicates that natural recruitment has been occurring in the recreated scour channels and in some other locations in the floodplain (Bair et al. 2003, Souza et al. 2004).

The lower Clear Creek watershed provides habitat for many wildlife species including various mammals, herpetofauna, and avifauna. Based on geographic and vegetative characteristics, the lower Clear Creek watershed is transitional between valley floor, foothill, and montane wildlife habitats (McBain and Trush 2001). This transition is reflected by the wildlife species composition of the area, as a mixture of both resident and migratory valley and foothill/montane species occur (McBain and Trush 2001). Wildlife inventories were conducted in lower Clear Creek in 1998 and 1999 (McBain and Trush 2001). Riparian songbird populations have been monitored along lower Clear Creek since 1999 by Point Reyes Bird Observatory (PRBO), in order to assess the impacts of the Lower Clear Creek Floodway Rehabilitation Project and provide adaptive feedback to improve its effectiveness (Burnett and Harley 2003). No benthic macroinvertebrate studies are known to have been conducted in lower Clear Creek. Special-status species and other species of particular interest which may be present in lower Clear Creek are listed in Table 4. These entries are based on wildlife inventories conducted in 1998 and 1999 (McBain and Trush 2001), PRBO riparian songbird monitoring (Burnett and Harley 2003) and species occurrences found in the Rarefind database, from the records of the Shasta Trinity National Forest, the National Park Service Whiskeytown Unit, and DFG (WSRCD 1996).

Table 4. Special-status wildlife species and wildlife species which may be present in lower Clear Creek.

Common Name	Latin Name	Status*
Valley Elderberry Longhorn Beetle	*Desmocerus californicus dimorphus*	FT
Bald Eagle	*Haliaeetus leucocephalus*	FT, SE
Bank Swallow	*Riparia riparia*	ST
Little Willow Flycatcher	*Empidonax traillii brewsteri*	
Willow Flycatcher	*Empidonax traillii*	FE, SE
Yellow-Breasted Chat	*Icteria virens*	SSC
Yellow Warbler	*Dendroica petechia*	SSC
Spotted Towhee	*Pipilo maculates*	
Song Sparrow	*Melospiza melodia*	
Black- headed Grosbeak	*Pheucticus melanocephalus*	
Osprey	*Pandion haliaetus*	SSC
Peregrine Falcon	*Falco peregrinus*	SE
Long-eared owl	*Asio otus*	SSC
Northern spotted owl	*Strix occidentalis*	FT
Pale big-eared bat	*Plecotus townsendii*	SSC
Pacific fisher	*Martes pennanti pacifica*	SSC
Northwestern Pond Turtle	*Clemmys marmorata marmorata*	SSC
Foothill Yellow-Legged Frog	*Rana boyleii*	
California Red-Legged Frog	*Rana aurora dratonii*	FT

* FE = Federally Endangered SE = State Endangered SSC = California Species of Special Concern
FT = Federally Threatened ST = State Threatened

3.1.3 Habitat Changes

Spawning habitat for spring Chinook salmon and steelhead historically existed in reaches 1 and 2 and farther upstream before Whiskeytown Dam was built (McBain and Trush 2001, p. 8). A 1971 CDFG memo (Coots 1971, as cited in McBain and Trush 2001, p. 35,) reported (with no description of methods or process) that 347,288 ft^2 of spawning habitat (from Whiskeytown Dam to [former] Saeltzer Dam) were estimated to exist in 1956, while only 29,121 ft^2 of this habitat were found in 1971 (91 percent reduction). In 2000, the same reaches were revisited and 98 percent of the gravels that were present in 1956 were gone. The 1956 survey did follow a series of wet years (1951-1954) that may have "maximized" the amount of available spawning gravel but, nonetheless, the reduction is startling. Further, previously classified spawning habitat was replaced by stretches of unproductive coarse sand deposits due, in part, to the reduced sediment carrying capacity of the stream relative to the sediment delivery from the undammed tributaries (i.e., Paige Boulder Creek and South Fork Clear Creek). Over the same period, such coarse sand deposits may have increased due to erosion in the upper watershed. Sediment supply from Paige Boulder Creek is primarily coarse sand derived from decomposed granite. "Fine" sediment (<12.8 mm) composition in the spawning gravels, based on three bulk sediment samples, was reported as 30 percent on average in 1971 (Coots 1971, as cited in McBain and Trush 2001, p. 35). USFWS found that 50 percent and 48 percent of spawning gravels were composed of sediment <13 mm in 1997 and 1998, respectively (McBain and Trush 2001, p. 35), suggesting that the percentage of fine sediment is relatively high and increasing over time.

Salmonid juvenile rearing occurs primarily in the alluvial reaches 3 and 4, which are also the location for fall and late fall Chinook salmon (and possible steelhead) spawning (Alexander et al. 2003). It is not apparent how much of this historical pattern of rearing was influenced by the migration barrier provided by Saeltzer Dam. Currently, reach 4 provides the highest quality salmonid spawning habitat in lower Clear Creek, and it is heavily utilized by fall Chinook salmon (McBain and Trush 2001, p. 43). However, rearing habitat in these reaches is now simplified due to flow regulation, sediment supply reduction, and gold and aggregate mining (see above). The channel in this area consists mainly of long pool reaches, in part due to lack of higher flows to mobilize and sort sediment, riparian encroachment, and reduced input of large woody debris (LWD) from channel migration, and upslope source areas.

Floodplain habitats have become largely disconnected from the channel due to a combination of channel and floodplain modifications, and channel incision. Whiskeytown Dam altered the flow regime nearly eliminating the recruitment flows required for Fremont cottonwood regeneration and enabling alders and willows to encroach on the margins of the low flow channel (Bair et al. 2003). Gravel mining in the 1970s and 1980s removed the vegetation and altered natural surfaces for establishment of riparian vegetation, and resulted in a wide channel marked with numerous pits (Bair et al. 2003) and large areas of dredge tailings. Seasonal and perennial wetlands created by the pits were colonized by cattail and surrounded by white alder and narrowleaf willow thickets (Bair et al. 2003).

3.1.4 Biotic Response

Fish Populations

Spring Chinook salmon and steelhead populations in lower Clear Creek have been limited by habitat loss, water regulation and high in-stream summer water temperatures (McBain and Trush 2001, p. 8), although increases in baseflow to benefit native fish since 1999 have now reduced the prospect of elevated stream temperature as a limiting factor. Increases in baseflow have also reduced predation on salmonids to the extent that, by general consensus among local experts, predation is probably not a significant limiting factor, either. Still, the abundance of spring Chinook salmon is relatively low. From 1999 to 2002, annual abundance estimate of spring Chinook salmon in Clear Creek have ranged from 0 to 66 fish. Access for both spring Chinook salmon and steelhead to spawning and rearing habitat in the upper reaches above (the former) Saeltzer Dam had been limited prior to dam removal in 2000 (McBain and Trush 2001, p. 8). Historically, these runs accessed upper mainstem and tributary habitats during the spring high flow runoff, holding over until fall or winter, when spawning would take place (McBain and Trush 2001, p. 8). Clear Creek may have supported various life stages of salmonids and other fishes up to the vicinity of French Gulch (approximately 3 miles north of Highway 299) where Hanson et al.(1940, p. 87) considered the stream "too small to attract migrating salmon". The construction of Whiskeytown Dam blocked approximately 12 miles of stream suitable for spawning (WSRCD 1996, citing Hanson et al. 1940). An unknown area of rearing habitat for salmon and steelhead was likely lost as well.

A spring Chinook salmon population may be re-establishing in Clear Creek. Surveys by the USFWS in Clear Creek from 1999–2002 provide an index of annual adult spring abundance (i.e., total number of live Chinook observed during August snorkel surveys) that was 9 in 2000, 0 in 2001, and 66 in 2002 (Newton and Brown 2004). Spatial or temporal separation between spring and fall races of Chinook in Clear Creek appeared to be partial in 2001 and 2002. (Newton and Brown 2004

Fall Chinook salmon population estimates have fluctuated from 10,000 fish in 1963 to 60 fish in 1978, yet this run was still considered to be the most abundant run in Clear Creek (CALFED 1998, as cited in McBain and Trush 2001). In recent years (up to 1999), the estimated fall Chinook salmon escapement was frequently greater than the 7,100 adult escapement target set by the Anadromous Fish Restoration Program (USFWS 1995). More recent estimates of fall Chinook escapement by the USFWS are: 2000 - 6,687; 2001 - 10,865; 2002 - 16,071; and 2003 - 9,475 (J. Newton, *pers. comm.*, July 2004). Escapement records are not available for late-fall Chinook salmon or steelhead, due to the difficulty in sampling during the winter. Steelhead runs have been described as being small prior to removal of (former) Saeltzer Dam (WSRCD 1996, p. 2–19).

It is likely that native species such as river lamprey, brook lamprey, and Sacramento splittail were also abundant in Clear Creek prior to European influence (WSRCD 1996, p. 2–19). WSRCD (1996, p. 2–20) speculated that the loss of low velocity spawning and rearing habitats is the main cause of splittail decline within the upper Sacramento River. Recent surveys have confirmed that riffle sculpin are still common in Clear Creek (USFWS, pers. comm., 2004). Habitat for these other native species are not addressed explicitly in this proposal, although it is anticipated that they will benefit from measures designed to improve salmonid habitat.

Riparian Vegetation

Direct impacts to riparian vegetation in the alluvial reach downstream of Clear Creek Bridge occurred as a result of gravel mining, which often involved the physical removal of large tracts of riparian vegetation growing on floodplains and terraces (TAT 1999, p. 10), and the replacement of floodplain soils with mine tailings poorly connected to groundwater. These conditions continue to suppress the contemporary regenerative ability of native riparian vegetation to the benefit of non-native species adapted to growth in highly disturbed conditions. Indirect impacts began following the completion of Whiskeytown Dam, as the reduction in the magnitude and duration of high flows caused the virtual cessation of channel migration and avulsion. This caused a reduction in the areal extent of riparian patches of oak, cottonwoods and willow thought to have been associated naturally with abandoned channels and high flow scour channels on the floodplains, and the reduction of organic input to the channel as channel migration virtually ceased. Instead, alterations to hydrology and channel morphology created an environment that selected for plants that seed in the summer (during low water), or for plants that could develop a short-term seed bank (such as white alder) (TAT 1999, p. 10), while the attenuation of winter storm peaks reduced the annual mortality of seedlings that established the prior summer. This has allowed narrowleaf willow and white alder to encroach along the low flow channel edge where they occupy most of the potential seed beds and “fossilize” (i.e., immobilize) the low flow channel with a simplified age-class diversity and stand structure (McBain and Trush 2001, p. 33-34). Natural riparian regeneration is virtually non-existent, while the remnant floodplain vegetation that predated Whiskeytown Dam is now maturing and becoming senescent (e.g. Fremont cottonwoods >50 years old occur in dredger tailing hollows). Wetland emergent vegetation has established within the in-stream and off channel ponds, with narrowleaf willow thickets and bands of white alder surrounding the ponds (TAT 1999, p. 10). Wetland vegetation is also beginning to establish in the scour channels created as part of the Lower Clear Creek Floodway Rehabilitation Project.

Wildlife

Changes in channel and floodplain morphology and sediment transport processes and subsequent changes in riparian vegetation species composition have altered habitat conditions for a variety of wildlife species in lower Clear Creek. For instance, gravel mining pits provide habitat for northwestern pond turtles, (*Clemmys marmorata marmorata*) yet also pose a risk to foothill yellow-legged frogs (*Rana boylii*) by providing habitat for predatory bullfrogs (*R. catesbeiana*). Many bird populations in lower Clear Creek are limited by nesting success, which is correlated with plant species and vegetation structure. Monitoring results from Burnett and Harley (2003) indicate that nest height and substrate choice varied substantially among species, suggesting the need to create diversity in vegetation structure and age of riparian habitat to promote the diversity and reproductive success of the riparian bird community.

3.2 Restoration Projects

In recognition of the adverse changes caused to aquatic and riparian habitats in Lower Clear Creek, beginning in 1996, a suite of restoration programs have been implemented (Table 5). Many of the projects have been implemented by the WSRCD with technical assistance and funding from federal, state and local agencies and entities, including CALFED Bay-Delta Program (CALFED), USFWS, DFG, California Dept. of Forestry and Fire Protection (CDF), USDA Forest Service (USFS), National Park Service (NPS), US Bureau of Land Management (USBLM), California Department of Water Resources (DWR), US Bureau of Reclamation (USBR), and the Cantara Trustee Council. These projects include:

- gravel augmentation periodically since 1996 to replenish spawning gravels lost following the disconnection of the upper and lower watershed by Whiskeytown Dam;
- increases in baseflow to benefit native fish. Since 2001, flows have been maintained between 70 and 100 cfs throughout the summer and 200 cfs after Sept or Oct to meet holding and spawning temperature requirements (S. Giovannetti, *pers. comm..,* 2004. USFWS, Red Bluff, CA) from 5 and 20 cfs, respectively, set initially after the onset of Whiskeytown Dam operations;
- morphological reconstruction and promotion of riparian re-vegetation (including planting of cuttings of cottonwood, willow, etc and floodplain reconfiguration to encourage

natural recruitment) along 2.2 miles of channel and floodplain morphology as part of the *Lower Clear Creek Floodway Rehabilitation Project* (2000–present);
- removal of the 15 ft-high (former) Saeltzer Diversion Dam to provide fish access to an additional 10 miles of habitat in the watershed;
- and reduction of upslope fine sediment supply from tributaries through best management practices and land acquisition.

Table 5. Recent restoration projects by reach in lower Clear Creek.

Restoration Projects	**Reach**				**Sources (project planning, implementation, and monitoring results)**
	1	**2**	**3**	**4**	
Increased baseflows	X	X	X	X	CVPIA 2003 USFWS 2001
Gravel augmentation	X	X		X	McBain and Trush 2001 WSRCD 2003
Floodway rehabilitation project				X	Bair et al. 2003 Burnett and Harley 2003 GMA 2003 Lower Clear Creek Technical Work Group 1999 Souza Environmental Solutions et al. 2004 WSRCD 2003
Saeltzer Dam removal			X		CDFG 2000 Miller and Vizcaino 2004 Miller et al. 2003 Stillwater Sciences 2001
Upslope restoration and land acquisition	X				USBLM 1999 WSRCD 2003

The purpose of many of these measures was encapsulated in the objectives for the Lower Creek Floodway Restoration Project (Lower Clear Creek Technical Work Group 1999):
- reverse channel damage caused by historic gravel extraction at the Project site by reconstructing a properly sized bankfull channel and floodplain ;
- restore the ability of the channel to route coarse sediment downstream and deposit fine sediment on floodplain surfaces;
- restore native riparian vegetation on floodplain surfaces by focusing on species that provide a diverse canopy structure and removing competing exotic plant species;
- reduce salmonids stranding and mortality in floodplain gravel mining pits;
- provide improved habitat conditions for native fish and wildlife including priority salmonids species of central concern to CALFED and CVPIA restoration programs;
- create diverse off channel wetland habitats in marginal upland habitats that are currently degraded by dredger tailings and in other upland locations as opportunities arise.

Environmental conditions in lower Clear Creek are already improving as a result of the various restoration efforts (and recently increased base flows) directed at these objectives. However, none of the projects to date have been targeted at the provision of an increased frequency of moderate flood flows to provide the essential hydrological driver for many of the processes required by the restoration objectives (see Figure 3). This is a critical aspect of environmental restoration and it has long been argued (e.g. NRC 1992) that restoring such "upper level" factors as flow processes is a highly appropriate means of achieving sustained ecosystem improvement. The rationale is that in improving the flow regime, beneficial changes to channel and floodplain morphology will result that create a greater diversity of aquatic and riparian habitats to support a greater abundance and diversity of native flora and fauna. Conversely, restoration efforts that start lower down the process-form-habitat-biota chain are more likely to be adversely affected by the deficiencies that remain in the upper level factors such as flow processes. As such, the project proposed herein should both act to assist the previous projects in building and sustaining the ecosystem processes which create desirable habitat conditions for salmon and other species, while at the same time providing an important and specific experimental learning opportunity that benefits ERP goals and restoration science in general.

4 NEED FOR FLOW AUGMENTATION

4.1 Impairments to Aquatic and Riparian Habitat

To assist in developing detailed targets for a flow augmentation strategy in Lower Clear Creek, it is beneficial to organize our historical (unimpaired) and contemporary (impaired) understanding of fluvial system functioning into ordered sets of cause-and-effect statements detailing interactions in the unimpaired and impaired systems. As such, a series of summary conceptual models were developed based on the investigations reviewed in Section 3 and organized according to the process hierarchy outlined in Figure 3. "Reference" condition conceptual models of the confined upper reaches (1 and 2) and alluvial reaches (3 and 4) were developed (Figures 6a and 6b) to represent the unimpaired functioning of processes in Lower Clear Creek prior to the onset of flow regulation, gold mining, and channel and floodplain gravel mining. In contrast, the impaired condition conceptual models presented in Figures 7a through 7d were developed to represent conditions in lower Clear Creek circa 1996 (following major watershed disturbances, and prior to the onset of restoration actions). Differences between the models are indicative of the impact legacy of human activities in altering (usually impairing) ecosystem function. Comparison between the models is the basis for determining the major ecosystem restoration requirements. The arrows in each model imply the direction of causal linkages from the flow and sediment inputs through to biotic response via a series of processes, forms and resultant habitat structures. The habitat structure and biotic response components of the conceptual models primarily reflect salmonids as the chosen aquatic indicator species and native floodplain trees (e.g. cottonwoods) as the riparian indicator species. Salmonids are chosen because of their special status under both the ESA and CESA, their cultural, commercial, and recreational value, and because their habitat requirements are sufficiently demanding as to make them worthy indicators of general ecosystem health. Consequently, it is presumed that restoring the aquatic habitat units and conditions that satisfy the requirements of the different life history stages of salmon will simultaneously benefit several other aquatic species. Similarly, achieving the habitat requirements of native riparian tree species is inferred to be beneficial for other native floodplain flora and fauna, especially neotropical migrant and native bird species that require diverse floodplain habitats.

Comparing the conceptual models suggests that the primary purpose of flow acquisition is to restore those flow and sediment transport processes that are far less frequent under the current flow regime and which are critical to functional ecosystem relationships. Of particular interest is the impact of flow regulation in reducing the frequency of "channel bed maintaining" and "channel morphology maintaining" flows (Stillwater Sciences 2003) characteristic of unimpaired alluvial channels. Acquiring water to promote very large flow events (ten- to twenty-year recurrence interval) to reset riparian stands to early-successional stages, scour floodplains, and form and maintain side channels and off-channel wetlands is less necessary due to the periodic Glory Hole spills from Whiskeytown Dam when natural inflows exceed storage capacity. Ideally, flows of an appropriate frequency, magnitude, duration and timing should be acquired to re-establish geomorphic processes that will result in progressive, beneficial, changes to river ecosystem structure and functioning and so reduce the difference in the extent, distribution, and quality of current habitat conditions in Clear Creek as compared with historical conditions. However, there are practicable limits to the improvement s that can be achieved. For instance, although Clear Creek was historically a multi-threaded channel in its alluvial reaches, the overall reduction in flows and interception of sediment load by Whiskeytown dam reduces downstream sediment delivery and precludes the prospect of restoring a multi-threaded channel, as high sediment loads are necessary to maintain multiple channels. As a result, the prospect for restoration in the alluvial reaches is likely served best by ecosystem attributes typical of a single-thread, meandering, channel, which can be more feasibly attained in light of the continual need to augment the coarse sediment supply of lower Clear Creek. Ideally, such a system would include a dynamic pool-riffle morphology, frequent bed mobilization, a balanced sediment budget, channel migration and fairly frequent floodplain inundation (Trush et al. 2000). In the long-term, an increase in the frequency of high flows, channel migration, and the input of fallen trees, in conjunction with the creation of high flow channels on floodplains as part of the Lower Clear Creek Floodway Rehabilitation Project may combine to promote channel avulsion and the formation of multi-thread channels in limited locations.

4.2 Benefits and Key Uncertainties

4.2.1 Prospect for Biological Benefit

This section addresses the expected responses of aquatic and riparian habitats and target aquatic species to experimental flow releases. Potential benefits to salmonid habitat include improved quantity and quality of spawning habitat in all reaches, as well as improved rearing habitat primarily in reaches 1, 3, and 4. These habitat benefits are expected to materialize relatively soon after implementation of each flow release. However, the precise timing of the biological responses to the habitat improvements is uncertain because several factors outside of the Clear Creek basin will influence the population dynamics of several species, especially where migratory fauna are involved, such as anadromous salmonids and neotropical bird species.

Increasing the quantity of available spawning habitat in the upper reaches may be particularly critical for establishing a larger population of spring Chinook salmon and steelhead trout in Clear Creek. It is reasonable to expect that injected gravels and recruitment and mobilization of stored gravels will increase the available gravel supply and create new spawning habitats. In turn, these habitats are expected to be readily utilized by spawning salmon and steelhead. As noted in Section 3.1.3 there has been a 98 percent reduction in spawning gravels since 1956. Of course, the potential benefit (primarily to spring Chinook salmon and steelhead in the upper reaches) can only be realized when sufficient numbers of spawning salmonids return to Clear Creek.

Interaction of flow with augmented gravels is readily apparent in Clear Creek and can be expected to continue. For instance, in the lower part of reach 1, a significant slug of augmented gravels was deposited as a mid-channel island as a result of recent high flows, inducing hydraulic complexity in the form of a backwater eddy, riffles, and velocity shear zones (potential feeding stations for rearing salmon). In reach 2, it is expected that high flow events will transport augmented gravels from reach 1 into reach 2, where they would be available for deposition behind bedrock and in short stretches of lower channel slope. Although the benefit may not be seen in overwhelming increases in available spawning habitat, it is expected that these pocket spawning gravels may provide valuable spawning habitat for spring Chinook salmon and steelhead. If gravels are added at Peltier Bridge and the NEED Camp Bridge near the downstream end of reach 1, proposed flows may transport and deposit these gravels into pocket areas available for spawning in reach 2.

The quality of spawning gravels is expected to increase through scouring of in-channel fines, which will help increase salmonid survival from egg to emergent fry. Delivery of dissolved oxygen to the egg pocket is the major factor affecting survival-to-emergence, which is impacted by the infiltration of fines into the spawning substrate. Several studies have correlated reduced dissolved oxygen levels with mortality, impaired or abnormal development, delayed hatching and emergence, and reduced fry size at emergence in anadromous salmonids (Wickett 1954, Alderdice et al. 1958, Coble 1961, Silver et al. 1963, McNeil 1964, Cooper 1965, Shumway et al. 1964, Koski 1981). Fine sediments in the gravel interstices can also physically impair the fry's ability to emerge through the gravel layer, trapping (or entombing) them within the gravel (Phillips et al. 1975, Hausle and Coble 1976). As described in the Statement of the Problem (Section 1.5), the fraction of fines in incubation habitats appears to pose such a problem. Therefore, the proposed flows are expected to improve fry production by improving survival-to-emergence.

Improvement in the quantity and quality of rearing habitat through creation of point bars, off-channel habitats, and low-velocity margin habitat is expected to result from flow releases and gravel augmentation, providing increased rearing opportunity for juveniles. Even with a limited number of spawners, improving the quality of spawning habitat is expected to benefit the production of fry, while improving rearing habitat is expected to benefit the production of juveniles through increased survival from the fry to smolt stages, particularly for spring Chinook and steelhead.

In reach 1 another possible benefit could be the scouring of riparian vegetation and the formation of point bars. Although reach 1 is bedrock-controlled and not wide enough to allow for channel migration, more frequent sediment and woody debris transport will result in a greater potential for deposition on the inside of bends and channel margins to create complex point bar habitats and to benefit rearing habitat for juvenile salmonids . It is expected that increasing channel roughness via boulder recruitment in certain areas, in combination with experimental flow releases may further help promote deposition of augmented gravels, and thus increase channel complexity.

Improved spawning habitat in lower reaches is expected to benefit all races of salmon, but particularly fall Chinook salmon. It is more likely that spring Chinook salmon and steelhead will use upper reaches for spawning. Based on surveys from 1999–2002, USFWS found that spring Chinook salmon had a passage rate of ≥70 percent above Saeltzer gorge, as compared to only 2.0 percent for fall Chinook salmon (Newton and Brown 2004). Another long-term benefit in lower reaches is the prospect of increased sediment storage capacity, resulting in available gravels for spawning and a continuation of channel migration and floodplain processes which may lead to LWD recruitment and greater potential rearing habitat in the form of alluvial point bars, LWD-formed backwaters, and greater amounts of edge habitat. As well, continued growth and succession of nearby upslope forest will contribute LWD. In addition, expected benefits will accrue to avian species that can utilize the greater riparian structure and diversity as well as amphibians such as yellow-legged frogs, which appear to utilize cobble habitat provided by point bars.

Within lower reaches, particularly in floodplain rehabilitation areas (RM 2.2 to 3.8), it is expected that the flow release will continue to help create low velocity channel margin and backwater habitat, as it has in completed Phase 2 and 3 rehabilitation areas (sites described in GMA 2004). Flows have re-worked augmented gravels as the channel has migrated, providing available spawning gravel as compared to the previous channel, which had incised down to the clay hardpan. Assuming that continued gravel augmentation will help maintain coarse sediment storage in the lower reaches, the effects of high flow releases will also benefit salmon rearing habitat by creating more backwater and low velocity channel margin habitat through channel migration.

Floodplain development and channel migration processes are expected to be encouraged within the lower reaches (3, 4). At completed lower Clear Creek rehabilitation sites, initiation of these processes has resulted in fine sediment deposition on the floodplain and recruitment of willows and cottonwoods. It is expected that a winter flow release timed to coincide with tributary flows (Section 6.3.1) would help reduce in-channel fine sediment, as most of the fines would be moving in suspension rather than as bedload. The benefit would be improved spawning habitat quality, and increased deposition of sediment onto floodplains, with long-term benefits being improved avian habitat and potentially off-channel floodplain rearing habitat for salmonids. The benefit to salmonids would, however, be contingent on a flow regime that allows for frequent and extended floodplain inundation.

It is expected that, as a long-term benefit, upper canopy species such as cottonwood will continue to grow on the floodplain, and that these trees will eventually be recruited as LWD, through bank erosion associated with channel migration processes. This will require a continued commitment to a flow regime with moderate events (4,000–6,000 cfs). In addition, channel migration processes are expected to reduce bank armoring by riparian vegetation and mine tailings by gradually eroding and undercutting these banks. As an example, the phase 3A rehabilitation site has already witnessed unexpected erosion of riparian berms from 2003's high flow events. The result has been greater hydraulic complexity, and increased low-velocity edge habitat. As natural recruitment of riparian plants continues to occur over time, there will be greater topographic complexity, further increasing fine sediment deposition and storage on the floodplain. This positive feedback loop will continue to enhance the structural diversity in riparian communities. Flow timing should be used to benefit particular species such as cottonwood by dispersing seeds onto the floodplain in early spring.

Related Benefits to Non-target Species

In addition to the anticipated direct benefits of the high flow releases to target geomorphic, salmonid, and riparian objectives, it is reasonable to expect that other biological resources in the Clear Creek ecosystem will also respond, and potentially benefit, from improvements in ecosystem functioning. This subsection describes native aquatic and terrestrial species that might also benefit indirectly from the proposed flow releases, but that are not the focal indicator species for this experiment. As discussed for target species and habitats (above), assessment of biological responses for these other native species are not presently being considered. These native species will be noted in elements of surveys of habitat and habitat utilization for targeted species (e.g. riparian surveys).

Related benefits can be reasonably expected for the following biological resources:

- **Native frog populations:** The tadpoles of introduced bullfrogs must overwinter, and cannot tolerate high-flow events during this period; consequently, the proposed flows are likely to suppress the spread of bullfrogs in the Clear Creek basin. Introduced bullfrogs are regarded as an important factor in the decline of the California red-legged frog, a federally listed Threatened species. Across their range, foothill yellow-legged frogs appear to be greatly impacted by predation by introduced bullfrogs where they co-occur. Foothill yellow-legged frogs are strongly associated with the stream features that the proposed flows are intended to create: breeding occurs in shallow, flowing water, with at least some gravel and cobble substrate; adults appear to prefer gravel/cobble river bars along riffles and pools with at least some shading. Effects of flushing flow events on these species need to be considered in the design of experimental flows.

- **Native bird species:** Enhancing backwater marsh habitat in old river channels (as was created as part of the Phase 3A Restoration) using high flow releases will increase the amount of creek side habitat favored by many species at Clear Creek, including Yellow

Warbler and Song Sparrow (Burnett and Harley 2003, p. 31). Song Sparrows have colonized the mouth of scour channels where natural recruitment of herbaceous cover has occurred (Burnett and Harley 2003, p. 31). Many of the riparian focal species at lower Clear Creek, such as Spotted Towhee, Song Sparrow, and Yellow-breasted Chat, nest in low-lying vegetation. Understory species such as mugwort are positively correlated with nest success in several riparian songbird focal species. More diverse and structurally complex floodplain and riparian vegetation is anticipated to promote a more diverse bird community.

- **Native mammals**: WSRCD (1996) provides an extensive list of terrestrial animal species, including mammals that may have or have had suitable habitat in Clear Creek. A variety of seasonal and yearlong mammal species along the Clear Creek stream corridor can be expected to benefit from changes in floodplain and riparian habitats attributable to short and longer term effects of experimental flows.

- **Native fish species:** Resident rainbow trout should also benefit from the prescribed flows and gravel enhancement. If variable size fractions are used in the introduced gravel mixtures, then resident fish will be more likely to benefit. The substrate composition selected by rainbow trout for spawning tends to be smaller in size than for spring Chinook salmon. The particle size of gravels selected by spawning salmonids are influenced by factors other than fish size (e.g., water depth and velocity, cover, upwelling or downwelling currents) (see Kondolf and Wolman 1993, p. 2283–2284). Timing of in-gravel egg incubation of rainbow trout will be considered in the design of the flow experiment.

  The Lower Clear Creek Watershed Analysis identified at least 13 native fish species (Villa 1984, as cited in WSRCD 1996). The fish community, as described in section 1.4, is diverse and distributed in habitats through reaches 1-4. A variety of changes in the productivity, distribution, and interaction of these species is complex, but can generally be expected with changes in habitat. Habitat utilization surveys for target fish species will note changes in the distribution and/or habitat utilization by other fish species, but is not intended to substitute for a specific assessment of changes in the fish community, which would require a more focused study design and level of sampling effort.

- **Reduction in exotic plant species:** The expectation that flow releases will cause changes in channel and floodplain habitat structure somewhat towards pre-disturbance conditions provides the indirect prospect that many of the non-native plant species that have thrived under disturbed conditions may be less well suited to the “improved” conditions or, at least, they will be less able to compete with native species in the altered areas. It is also reasonable to expect that scour of floodplain surfaces will affect the germination and establishment of exotic species.

4.2.2 Uncertainty in Flow Augmentation

Worldwide, there have been very few rigorously planned and implemented high flow augmentation programs from which understanding can be transferred (Stillwater Sciences 2003). Assessment is probably best documented for the 1996 Grand Canyon Controlled Flood (*i.e.*, Webb et al. 1999) but the flow release objectives and morphodynamic type of river involved (*i.e.*, sand-bedded, in a bedrock canyon) are somewhat dissimilar to the Clear Creek case. In biological terms, deliberate flow augmentation serves to partially restore the ‘flood pulse advantage’

(Bayley 1991) to channel ecosystems. The challenge for flow augmentation assessment in Clear Creek lies partly with the fact that some high flows still occur in the lower watershed, so that the effect of these flows needs to be isolated from the effect of any deliberate flow releases. Flow augmentation should also be based on clearly stated management objectives (see Section 5.1). However, as the operation represents only a partial return of the pre-regulation hydrograph (and deals only with sediment transport, not sediment supply), various conflicts can arise between management objectives. These may include (based on Kondolf and Wilcock 1996):

- Gravel mobility versus gravel loss, concerned with potential conflicts in rates of sediment transport and supply;
- Scouring marginal vegetation versus gravel loss, concerned with potential conflicts in flow rates and sediment supply;
- Floodplain building versus in-channel diversity, concerned with potential conflicts in flow magnitude between moderate and extreme scour events;
- High flows versus hazards and water resources management, concerned with potential conflicts between flow magnitude, flood control, erosion and water availability;
- Habitat management for target species versus comprehensive management for the fish community, concerned with potential conflicts between habitat provision for indicator species and those required for other native flora and fauna.

Partly, these concerns can be offset by supporting management actions but it should be recalled both that (1) setting experimental discharges is an exercise in creating a flow regime that interacts with a highly modified sediment budget to mimic the natural disturbances that maintain aquatic and riparian habitats, but it has few naturally-formed counterparts, and (2) there are currently insufficient examples of carefully planned and targeted high flow releases to categorically prove their claimed utility (Downs and Gregory 2004). As such, the uncertainties surrounding such experimental management actions are high and require a strategically applied and carefully monitored approach to ensure the greatest possible project benefit. Approaches will differ according to the ecosystem objectives of the project and the type and schedule of high flows applied (see Stillwater Sciences 2003). Conversely, the prospect of a well-monitored and evaluated approach providing numerous learning opportunities is also high.

There are several primary categories of uncertainty in flow augmentation for Clear Creek. They include:

1. uncertainty related to the ability to release flows as designed and in conjunction with other water uses,
2. uncertainty related to the effectiveness of the flows in re-establishing critical geomorphic processes and,
3. uncertainties related to the creation and biological utilization of habitats altered by the geomorphic processes.

The first category of uncertainty relates to the ability to predict, and successfully release the required flow magnitude, duration, frequency and timing, in a manner that is compatible with other flow requirements. In this regard, augmentation in Clear Creek is being planned around a component of the Clear Creek Decision Analysis and Adaptive Management Model (CCDAM, see Appendix C). The DOHPLR (Dam Operations, Hydrology, Power and Lake Recreation) component of this model is designed to evaluate flow outcomes based upon various inflow strategies to Whiskeytown Lake. Preliminary assessments of the likely mechanics of flow acquisition using this model are detailed in Section 6.3. The second category of uncertainty relates primarily to the ability to predict the dynamics of sediment transport and morphological change related to the designed flow releases. At present, this understanding is based primarily on the results of prior field experiments and monitoring undertaken during and subsequent to various high flows over the last several years (section 5.2). One prospect is to develop and test sediment transport models as part of the experiment. The third category on uncertainty focuses on the habitats created through flow augmentation and the enhancement of geomorphic processes, and biological utilization of the habitats. As such, the category has implicit uncertainties related to the former categories, and additional sources of uncertainty related to habitat formation and biological population response. Further, as explained in Section 2, because biological population responses are (1) dependent on a hierarchy of response to flow augmentation, (2) include factors outside of experimental control, and (3) can only be statistically validated over timeframes exceeding a pilot project, monitoring will require an approach focused on weight-of-evidence hypotheses and on targeted experiments rather than solely on ‘status and trends’ in the key success criteria (*e.g.*, total salmon smolt output). This approach is developed in Section 6.

In additional to generic uncertainties related to flow augmentation, review of the literature regarding Clear Creek and field reconnaissance identified a series of uncertainties particular to geography and ecosystem of the Clear Creek watershed. A variety of these uncertainties are outlined below. Knowledge of these uncertainties has influenced the provisional experimental design detailed in Section 6, and should be considered further in any future development of this proposal. Uncertainties include:

Reaches 1 and 2

- **There is limited information on tributary flows** and their relationship to rainfall patterns, which should be improved with future stream gauging efforts. Greater knowledge of tributary flows should improve understanding of the potential effect of accretion on mobilization of augmented gravel and cleaning of subsurface fines in reach 1.
- **The volume of tributary gravel and fine sediment input is unknown**. Studies should target monitoring both fine sediment and gravel input from tributaries, particularly sand from Paige-Boulder Creek at the lower end of reach 1.
- **Input from mass wasting events is poorly understood**. Studies investigating sediment sources and input mechanism would be beneficial in the long-term understanding of the creek.
- **The extent of subsurface fines in the mainstem channel is currently unknown**, but an infiltration bag experiment can help assess the extent of fine sediment infiltration during flood flow events.
- **It is uncertain whether spawning habitat is actually limiting** spring Chinook and steelhead production, although it is likely to be a factor given that so much spawning habitat has been eliminated since the construction of Whiskeytown Dam. Currently there is no clear evidence supporting or disputing that spawning habitat is limiting. It was estimated that current spawning habitat may support spawning for approximately 88 pairs of Chinook salmon based on the estimated area of spawning habitat and habitat area requirements (McBain and Trush 2001b, p. 9).
- **There is uncertainty related to partial sediment transport.** It is yet to be proven empirically whether it is feasible to remove fine sediment from the channel bed without significant mobilization of coarse sediments.
- **There is uncertainty related to gravel augmentation size ranges.** Introducing different size compositions of gravels in augmentation projects will help define a relationship between flow and annual sediment transport rates, to further refine the choice of substrate composition of future gravel introductions. Varying the size composition may also provide spawning habitat for more species to utilize.

Reaches 3 and 4

- **It is probable that moderate flood flows cannot remove significant amounts of encroaching vegetation**. An adaptive approach will be needed to develop a high flow schedule to improve rearing habitat conditions by decreasing conditions suitable for vegetative encroachment. It is possible that the negotiated low flow schedule may not create drought stress in the encroached vegetation. Further, it is unlikely that the moderate flood flows will be capable of removing vegetation by scour except, perhaps, at the outside of meander bends. Therefore, mechanical removal is assumed to be necessary.
- **The no conclusive understanding of the role of large woody debris in Clear Creek.** Williams and Kondolf (1999, p. 5, 6) speculated that logging which accompanied early mining efforts may have depleted the sources of large wood available for recruitment. The uncertainty is whether, in the long-term, improved riparian conditions and routine and episodic recruitment of LWD to the channel will increase in-channel loading sufficiently to act a geomorphic agent. The role of LWD in fluvial processes of island formation, channel avulsion, etc. is widely understood, as is utilization of LWD associated habitats by all life stages of salmon.
- **If pool habitats are improved for holding adults, what is the trade-off for rearing and emigrating fry and juvenile salmonids?** It has been assumed that current shallow pool habitat is not satisfactory in terms of depth, velocity and complexity as holding habitat for adult salmonids (Biologist Subteam meeting notes, February 20, 2004). These same habitats may now be utilized by fry and juvenile salmon at various time of the year. The opportunity and uncertainty is to identify a proportion of various habitats that benefit all life stages.
- **Use of the current habitat by non-native predators is poorly understood** at this point. Introduced non-native predators may also be affected by actions intended to improve rearing habitat for juvenile salmonids. Restoring more natural alluvial conditions may decrease habitat for predators, since native species are adapted to the dynamic conditions of an alluvial river system.
- **Is rearing habitat limiting survival**? One of the most substantial uncertainties is whether juvenile Chinook and steelhead rearing habitat is limiting survival in Clear Creek, particularly since rearing in the cooler mainstem Sacramento River may be occurring. It is thought unlikely, but is possible that water temperatures may not be cold enough in Clear Creek to support summer rearing, and therefore improving rearing habitat may not result in increased rearing success for juvenile salmonids.
- **Uncertainties related to bird populations and habitat.** Monitoring results (Burnett and Harley 2003, p. 30) illustrate that it is not sufficient to solely monitor the abundance and diversity of bird populations in order to determine if a site is providing high quality breeding habitat. Habitat sinks (sites where birds do not have sufficient reproductive output to sustain the population, so populations only persist due to an influx of birds from more productive sites) may have the same abundance or density of birds as more productive sites. Monitoring both bird abundance and distribution, productivity, and survival are all critical components of determining the quality, or value of habitat to a bird community (Burnett and Harley 2003, p. 30).

5 PROJECT DESCRIPTION

5.1 Target Ecosystem Attributes Following Flow Augmentation

Physical and biological benefits of releasing moderate flood flows are summarized below in terms of three primary project goals. Each goal is broken into a series of objectives that indicate the target ecosystem attributes resulting from achieving the goal. Reach-specific details related to each of these desirable attributes are provided below. The objectives are the precursors to developing a series of hypotheses that can be used to test the attainment of objectives and that form the basis for monitoring experiments that will judge the effectiveness of the flow releases (Section 6). The goals and objectives have been designed to be complementary to those developed previously as part of the Lower Clear Creek Floodway Restoration Plan (Lower Clear Creek Technical Work Group 1999) but, in accordance with the caveats outlined in Section 2, are specific to the aspects of the ecosystem that can be tackled explicitly using experimental flow acquisitions over a limited timeframe.

Goal #1: Increase the quantity and quality of habitat that support salmonids.
Objectives include:

a. Increase the recruitment of augmented gravels into the channel, and increase the rates of transport and deposition of both augmented and existing gravel stored in the channel in general and, in particular:
    i. Increase the area and depth of spawning gravels (reaches 1, 3, 4);
    ii. Increase the area of pocket gravel storage in hydraulic backwaters and behind roughness elements (boulder / LWD) (reach 2);
b. Increase the area of low-velocity channel-margin habitat for rearing Chinook and steelhead fry (reaches 1, 3, 4);
c. Increase the frequency and availability of seasonally connected backwater channels to provide rearing habitat and refuge (reaches 3, 4);
d. Increase instream habitat complexity and cover by recruiting LWD to provide juvenile rearing habitat (reaches 1, 3, 4);
e. Reduce interstitial fine sediment accumulation in framework spawning gravels to benefit spawning and promote benthic macroinvertebrate production and diversity (reaches 1, 3, 4);
f. Increase and maintain pool depth to provide habitat for migrating and holding adult spring Chinook salmon and steelhead trout (reaches 2, 3, 4).

Goal #2: Promote floodplain development and channel migration processes.
Objectives include:

a. Decrease the volume of fine sediments stored in the channel by routing them downstream and depositing them on floodplains through overbank flooding (reaches 3, 4);
b. Increase the topographic diversity of floodplain surfaces by increasing fine sediment and organic matter storage on floodplains and the formation of scour channels (reaches 3, 4);
c. Reduce armoring of banks by riparian vegetation and mine tailings using flow scour in combination with supporting management measures (e.g., mechanical removal of vegetation) (reaches 3, 4);
d. Increase the rate and frequency of outer bend migration to increase gravel and LWD recruitment and to increase channel habitat complexity (reaches 3, 4);
e. Increase the in-channel deposition and storage of bed gravel, especially in clay hardpan areas, to reduce thalweg amplitude (reaches 3, 4);

f. Decrease the lineal extent of riffle-runs in straightened reaches using structural roughness elements (installed logs, boulders) to diversify habitat (reaches 3, 4).

Goal #3: Promote appropriate riparian vegetation recruitment and growth.
Objectives include:

a. Increase floodplain inundation to encourage the recruitment of desirable plant species on floodplains and banks in general, but especially to result in:
    i. changes to the composition and structure of riparian vegetation towards a mixed conifer/hardwood community (reach 1);
    ii. an increase in the early seral stage component of cottonwood riparian forest (reaches 1, 3, 4);
    iii. improvement in the age and structural diversity of riparian vegetation communities to support bird nesting and foraging (reaches 1, 3, 4);
b. Encourage flow scour of emergent woody riparian vegetation from active channel surfaces (reaches 1, 3, 4).

5.2 Experimental Flow Recommendation

The goal of flow augmentation for Clear Creek is to release discharges of sufficient magnitude, duration and frequency, and at appropriate times, to stimulate the reactivation of geomorphic processes that support the diverse array of habitats required to support and recover native aquatic and riparian species. Such flows were one of a range of possible flow acquisition types discussed for the Sacramento-San Joaquin valleys in general at the CALFED Independent Science Board's Adaptive Management workshop in 2002 (Kimmerer et al. 2002). In total, this group considered *flow increases for attraction or passage*, *elevated base flows* and *flow releases sufficient to reactivate geomorphic processes*. The first two would be considered as "depth maintaining flows" under the high flow classification of Stillwater Sciences (2003) whereas the latter would be considered as a "channel bed maintaining" and "channel morphology maintaining" flow. In general, the latter flow type was the most highly recommended by the workshop, for its potential of having the greatest impact in a multi-faceted, adaptive management approach to river management, such as that which underpins the goals of the CBDA Ecosystem Restoration Program. It was also recognized that geomorphic flows present the greatest complexity for planning purposes. *Flow releases sufficient to reactivate geomorphic processes* were also specifically recommended by the group for Clear Creek and form part of the justification for the flow augmentation approach adopted in this concept proposal:

> "The idea would be to establish a hydrograph that provides either a flow regime close to natural during some seasons, or a "miniaturized natural flow regime", which would provide some of the natural processes but at a reduced flow and in a smaller physical space. This would require continued augmentation of inputs of gravel and possibly woody debris below the dams, since the geomorphic processes would continually move gravel downstream. This manipulation was described as an "acute" effect, lasting a relatively short time, although effects could last much longer." (Kimmerer et al. 2002).

It should be recognized that the limited acquisition of flows proposed herein as a pilot project for flow augmentation does not qualify the project either as a "flow regime close to natural in some seasons" or as a "miniaturized natural flow regime". These would, potentially, be goals of a more overarching change in flow regime that might be proposed as a result of understanding gained during this experiment. The flow recommendation justified below is instead intended to re-instate periodic mid-range flood flows as single events to reactivate natural processes in a physical space that is dictated by individual reach type. For instance, in the bedrock canyon reach (#2) mid-range flow flows will cause limited or no overbank flow, replicating their past impact. However, in the rehabilitated stretches of reach 3 that have had their floodplain lowered to an elevation that corresponds to the flow depth of the prevailing (i.e. post-dam) bankfull discharge, augmented mid-range flows will provide an inundation depth and extent that is potentially greater than achieved by the same flow prior to floodplain gravel mining.

The primary focus of *flow releases sufficient to reactivate geomorphic processes* for Clear Creek is to contribute to the aquatic habitat, geomorphic, and riparian goals outlined in the previous section, and thus complement and support recent restoration efforts in Clear Creek. A key factor for determining the magnitude of a mid-range flood flow is exceeding the minimum threshold required for coarse bed sediment entrainment. In previous investigations on Clear Creek using the Shields equation (McBain and Trush 2001, p. 79, 80), the threshold for transport of the 84th percentile diameter sediment (D_{84} – 200 mm) was predicted to occur at around 3,400 cfs at the USGS Igo Gauging Station (RM 10.1, reach 2). Monitoring during a high flow of 3,200 cfs indicated that medium-sized gravels were in transport at this flow, but not the D_{84}, providing some corroboratory evidence for this threshold prediction. The implication of this result is that, under the current flow regime (Table 3), coarse sediment entrainment occurs about once every 2 – 2.5 years (i.e., Q2 – Q2.5 *instantaneous* flood peak) whereas more sustained sediment transport (such as that necessary to re-shape channel bedforms) occurs approximately once every ten (i.e., Q10 *daily average* maximum flow) under current post-dam flow releases. Prior to dam completion (Table 3, and assuming that channel bed sediment sizes are similar to today's channel), the initiation of coarse sediment entrainment would likely occur several times per year, and sustained bed mobility could be expected about every year. The reasons for this include:

1) Whiskeytown Dam has reduced flood flows and coarse sediment supply, coarsening the channel bed and reducing the frequency of bed mobilization.
2) The channel bed response to reduced coarse sediment supply is winnowing (whereby smaller gravels are transported out of the reach at a greater rate than coarser particles) and a progressive coarsening of the bed surface (Dietrich 1987, as cited in McBain and Trush 2001, p. 80).
3) Loss of coarse sediment supply prevents the stream from being able to adjust its channel geometry to the smaller flow regime.
4) Transport of coarse sediment is hindered in some locations by the combination of a larger channel with less flow and coarser particle size within the bed surface.

It is probable that recent gravel augmentation (see Section 3.2) has, at least locally, offset some of these impacts.

5.2.1 Flow Magnitude

Following from above, the magnitude of the experimental flow releases will need to be in excess of 3,200 cfs to allow at least for partial bed mobility. To achieve full bed mobility and notable coarse sediment transport, flow releases will need to be even greater. Sediment transport on Clear Creek has been examined using sediment transport modeling and field-based monitoring. Sediment transport thresholds were investigated using the Shields equation at five sites (Table 6) by McBain and Trush. They placed tracer rocks at 14 cross sections between 1998 and 2000 to verify the sediment transport modeling results (Table 7). In addition GMA (2003) monitored marked rocks at the floodplain rehabilitation site (Phase 3A) and at Reading Bar. Sediment transport modeling using the Shields equation found that, in general, critical discharge was approximately 3,000–3,500 cfs, although thresholds were much lower in Renshaw Riffle at the upper end of reach 4 (Table 6). Bedload transport measurements at the Igo gauge site indicated that 3,200 cfs, the highest monitored discharge, was very close to the transport threshold for bedload. Based on these measurements, McBain and Trush (2001) estimated that the majority of the bed was in motion at this site at about 4,000 cfs. Critical discharge was much less for Renshaw Riffle (RM 5–5.3); likely because of the smaller grain size and narrow channel width at those sites. Bedload transport modeling using the Parker equation at the Peltier Valley Bridge site (in reach 1) indicate that transport begins at about 3,700 cfs and significant transport (transport greater than about 1 ton/day) begins at about 5,500 cfs. These thresholds would decrease if there is a large gravel infusion in reach 1. In their conclusion McBain and Trush (2001) recommended release of a somewhat higher high flow magnitude (>5,000 cfs) partly to mobilize a greater size range of particles and initiate alluvial processes such as periodic scour of alternate bars, channel migration, and floodplain inundation (McBain and Trush 2001, p. 96), and partly in an attempt to offset riparian vegetation encroachment that leads to deeper, simplified habitat (Williams and Kondolf 1999, p. 6).

Table 6. Predicted critical discharge for D_{84} using Shields equation at various locations in Clear Creek downstream of Whiskeytown Dam (McBain and Trush 2001).

Study Site	Reach	River mile	Predicted Critical Discharge (cfs)
Peltier Valley Bridge	1	16.2	5,500*
Igo gauging station	2	10.1	3,400
Reading Bar	3a	7.6–8.0	3,500
Lower Renshaw Riffle	4	5.0	1,700
Upper Renshaw Riffle	4	5.2	1,100
Floodway Rehabilitation Project	4	2.2–3.8	3,100

*Prediction based on bedload transport rates exceeding 1 ton/day using the Parker equation.

Table 7. Tracer rock experiments conducted by McBain and Trush (2001) between 1998 and 2000.

Study Site	Cross Section	Peak Discharge	D_{50} (mm)	% D_{50} rock sets moved	D_{84} (mm)	% D_{84} rock sets moved
Peltier Valley Bridge	879+00	250 cfs	50	0%	117	0%
	883+50	250 cfs	87	0%	143	0%
	885+00	250 cfs	76	0%	135	0%
	885+00	250 cfs	70	0%	113	0%
	886+20	250 cfs	110	0%	176	0%
Reading Bar	410+26	2,134 cfs	57	0%	115	0%
	411+66	1,926 cfs	65	28%	132	7%
	411+66	2,710 cfs	65	59%	132	31%
	411+66	2,134 cfs	65	48%	132	14%
	426+33	750 cfs	44	0%	76	0%
	426+33	2,134 cfs	44	100%	76	63%
Renshaw Riffle	273+65	2,134 cfs	36	78%	92	40%
	277+55	2,134 cfs	27	75%	75	44%
	283+20	2,134 cfs	32	92%	56	100%

Marked rock studies at Renshaw Riffle (Table 7) found that the majority of the marked rocks moved following a tributary-based flow of approximately 2,100 cfs, a somewhat higher flow than thresholds predicted by the modeling, but still much lower than for other sites. GMA (2003) found that models based on Parker's surface bed material equation, which calculates the sediment transport capacity, under-predicted sediment transport rate at Renshaw Riffle for flows greater than about 3,000 cfs and over-predicted measurements for flows less than 3,000 cfs. Sediment transport did not occur at Peltier Valley Bridge, which is approximately 1 mile downstream of the dam as above the tributary inputs, as discharge did not exceed 250 cfs. This was corroborated by scour cores which showed no sediment transport.

Recently, GMA (2003 p. 3-13) monitored four winter storm events (December–January 2003) exceeding 3,000 cfs. These included an annual maximum peak discharge of 5,600 cfs, one spring high flow, and a long duration Glory Hole Spill (peak discharge 4,770 cfs). A combination of the high flows and the recent morphological restoration of channels in the lower watershed (see Section 3.2) resulted in substantial channel migration and bed mobilization in the restored reach, with more complex habitat as a result (GMA 2003, p. 3-13). Bed mobility modeling using Shields equation predicted mobility of D_{84} at the floodplain restoration sites at 3,100 cfs, and approximately 50 percent of D_{84} particles were mobilized at 3,200 cfs. Inundation occurred at the 2002 floodplain restoration site, with bank overtopping occurring at 3,000–3,400 cfs. Monitoring has also shown that a flow in excess of 3,000 cfs is necessary to recruit augmented gravels from floodplain staging sites, particularly the augmented gravels input directly below Whiskeytown Dam.

The overall implication of these experiments is that the required flow magnitude should be in the range 4,000–6,000 cfs to achieve sediment transport sufficient to re-arrange channel habitats. As noted above (section 5.2), this flow should also cause significant inundation of floodplain areas of reach 3 that have been constructed to an elevation related to the discharge associated with the current Q1.5 - 2 instantaneous peak discharge. As such, the transfer of fine sediment and organic matter from channel to riparian habitats should be achieved.

5.2.2 Flow Duration

Because sediment supply is limited and is achieved largely by periodic gravel augmentation in many reaches, the duration of such flows should be short enough that the total sediment transport does not result in a net loss of storage in each reach. McBain and Trush (2001, p. 91) previously recommended a high magnitude, short duration flow event for its "water efficiency" in performing the geomorphic work required to transport sediment. For example, a 4,000-cfs flow lasting 1 day will move as much sediment as a 2,200-cfs flow lasting 10 days based on conditions at Peltier Bridge (McBain and Trush 2001, p. 91). Over five times as much water (43,000 compared to 7,900 acre-ft) is projected to be required for the lower magnitude flow release to accomplish the same amount of geomorphic change as the shorter high magnitude flow release, although different sizes of bedload are likely to be moved by the two different flow releases. In such situations, the prospect of enhanced gravel transport out of reaches 1 and 2 (and a potential loss of spawning habitat *quantity*) needs to be balanced against the need to mobilize the gravels to maintain spawning habitat *quality* and the requirement for coarse sediment transport from the upper reaches to feed the lower reaches, where the geomorphic objectives include raising bed levels to decrease bedrock exposure within the channel (GMA 2003, p. 1-5). Therefore, continued and possibly accelerated gravel augmentation would be required in the upper reaches.

Based on this information related to gravel mobilization (and, by implication, to habitat change), and being conscious of the costs of obtaining large volumes of water over extended time periods, a provisional recommendation is that the flow duration should peak over a 2-day period. Refinement of this estimate under a Full Proposal development should consider also the potential impact of the flows on targeted species.

5.2.3 Flow Timing

Several prospective flow timings exist, centered on late winter / early spring flows or late spring flows. The potential benefit of late spring flows is the minimization of redd scour. If flow timing avoids or significantly minimizes scouring of redds, then higher flows can be implemented with limited consequences to salmonids. In addition, the increased habitat area and access to more complex edge and floodplain habitats available to fry during the flow event will serve as refuge and offer a partially compensating effect. Alternatively, a high flow release in late winter (e.g., in January or February) has greater potential for scouring steelhead redds in the upper reaches and, to a lesser extent, scouring fall Chinook and late fall Chinook salmon redds throughout both upper and lower reaches. This assumes that the threat of redd scour is real, that gravels will be mobilized to a depth of 1 ft or more so that egg pockets are disturbed, or that sub-optimal spawning habitat results in eggs being buried to less than 1 ft. in depth and so are scoured more readily. The likelihood of scouring spring Chinook salmon redds is low because the spawning period is from September to October. There is also some potential for a winter high-flow event to suddenly provide spawnable habitats for steelhead that are subsequently dewatered with passing of the event. However, the duration of flow is sufficiently limited that few spawning steelhead and none of the earlier or later spawners would be affected. Both spring Chinook and steelhead fry from the upper reaches may be displaced. Salmonid spawning behavior is less likely to be disrupted with a winter high flow than with a spring flow. A positive biological consequence of a higher winter flow event would be the greater likelihood of promoting floodplain connectivity and seasonal channel rearing opportunities when compared to a spring high-flow event; this is due to the likely higher magnitude flow and tributary accretion during a winter flow release. Planned flow releases should also be timed to minimize impacts to other aquatic species and to nesting bird species. The peak of bird breeding activity at Clear Creek occurs between late April and late June (Burnett and Harley 2003).

Reference to pre-dam hydrographs suggests that the dominant hydrologic (and, therefore, geomorphic) events in Clear Creek generally occurred in January and February during rain-on-snow events (McBain and Trush 2001, p.18). Lesser flow peaks associated with snowmelt occurred generally in March to May but, unlike larger streams draining the Trinity and Sierra Nevada mountains, these flows may have been less important for performing geomorphic work. As such, biological processes under pre-dam hydrology were likely adjusted to accommodate and respond to high flows occurring mainly in late winter and this should be the target of flow acquisitions. For maximum benefit to floodplain vegetation, there is probably a need, ideally, for high winter discharges and additional moderate discharges in the spring. Therefore, subject to further review of biological processes occurring under the current flow regime, and to the realities involved in acquiring flow from Whiskeytown Dam, flow timing is proposed to provide the greatest potential benefit to ecosystem processes in the watershed if timed to occur in late winter.

5.2.4 Flow Frequency

The required flow augmentation frequency is probably the least well-understood component of artificial hydrographs. There are significant uncertainties in judging the geomorphic effectiveness of multiple flow events that arise because flow events of the same magnitude rarely have the same geomorphic effect in terms of sediment transport or morphological changes in river systems. This precludes an obvious analytical approach for dealing with the effectiveness of multiple events. In addition, there is the matter of high flow events that will continue to occur anyway when Whiskeytown Dam spills, and the need to balance flow augmentation requirements with those of competing flow management interests. Further, the prospect of achieving a desired flow event frequency is ultimately dependent on weather events, and also the need to experiment with lake level management to increase the probability of achieving the scheduled flow release (see Section 6.3). As such, flow frequency is best based on objectives derived from knowledge of the pre-dam flow frequency in comparison with post-dam frequencies (i.e., Table 3). Improving understanding about the effects of different flow frequencies is an integral part of the learning experience offered by the project.

At present, at the Igo Gauging Station, the 1-day average maximum flood flows are approximately 1,800 cfs for the 2.5 year flood, and 3,400 cfs for the 5-year flood (Table 3). Pre-dam values were approximately 6,200 cfs and 9,000 cfs respectively. Relative to the provisional recommendations for flow magnitude and duration of 4,000 to 6,000 cfs for two days, it is suggested that a flow of around or in excess of 5,000 cfs be obtained no less than once in every three years. Interpolating from Table 4, this would, be comparable to the pre-dam 2–2.5 year event for a two-day duration flow and represents a dicscharge that happens with a frequency of approximately once every ten years under the current flow regime. As such, the proposed flow represents a fairly significant shift in the frequency of two-day duration flows. It will have a smaller impact on the instantaneous flood data series at the Igo gauge, but this series includes short-lived flood peaks generated by tributary streams including the South Fork Clear Creek that enters Clear Creek towards the downstream limit of reach 2. As such, the proposed flow will also result in a significant increase in the frequency of instantaneous flood peaks in reaches 1 and 2.

5.3 Requirements for Supporting Management Actions

The proposed pilot project in flow augmentation is designed, in part, to encourage maximum environmental benefit from the existing restoration measures (Section 3.2). This potential exists because flow augmentation improves one of the fundamental drivers of river ecosystems, namely the flow hydrograph, and the others measures are expected to respond positively from this stimulus. However, flow augmentation in itself does not improve all ecosystem processes, especially in an impoverished ecosystem such as Clear Creek, and supporting management are required to be integrated with the released flow to increase the chance of beneficial ecosystem response. Three categories of supporting action are required:

- It will be necessary to continue and possibly accelerate the program of gravel augmentation to maximize the habitat benefits accruing from enhanced rates and distances of gravel transport promoted by the flow releases. Gravel augmentation practices in Clear Creek are currently under investigation by WSRCD and a pilot program of flow augmentation could be integrated with the outcomes of this investigation;
- It will probably be necessary to mechanically remove vegetation that has encroached into channel margin locations. This is because the magnitude of the proposed flows is imagined to be insufficient to scour encroaching vegetation except at outer bend locations. There is an experimental expectation that the high flow releases will assist in reducing the rate of re-colonization of sites that have been mechanically cleared of vegetation (Section 6).
- In straight reaches of the lower creek (reaches 3 and 4) where riffle-run morphologies have formed, it is expected that logs and boulders may need to be installed in order to accelerate the development of habitats that are diverse in terms of flow and sediment.

5.4 Prospective Aquatic and Riparian Habitat Conditions

Stemming from the current impairments in ecosystem conditions identified in Section 3 and summarized in Section 4.1, this section has identified a series of target ecosystem objectives that might be achieved by flow augmentation (Section 5.1) and provisionally recommended a pilot project of flow releases that are expected to benefit ecosystem functioning in Clear Creek (section 5.2), especially when undertaken in conjunction with supporting management actions (section 5.3). A summary of a prospective aquatic and riparian habitat conditions following flow augmentation is indicated in Figures 8a – 8d. These figures, conceptual models that follow the format of Figures 6 and 7, represent expected conditions in lower Clear Creek following the implementation of flow releases and supporting management actions. They incorporate expected outcomes of the restoration actions already undertaken, including gravel augmentation, channel and floodplain reconstruction and the removal of Saeltzer Dam. The differences between impaired condition/pre-restoration conceptual models and post-flow augmentation/post-restoration actions conceptual models are indicative of the effects of managed flows and other restoration actions in altering and improving ecosystem function. It is these expected responses that form the basis for setting the experimental hypotheses and data collection recommendations described in Section 6.

6 EXPERIMENTAL APPROACH

6.1 Adaptive Environmental Assessment and Management

The experimental approach for this pilot project is based on an adaptive management framework of "learning by doing" (Walters 1986), dealing with project uncertainties in a practical manner and leading to a progressive improvement in scientific and management understanding regarding river restoration. The role and potential of adaptive management is perhaps most eloquently described by Halbert and Lee (1991, p138) as:

> "…an innovative technique that treats management programs as experiments. Rather than assuming that we understand the system that we are attempting to manage, adaptive management allows management to proceed in the face of uncertainty. Adaptive management uses each step of a management program as an information-gathering exercise whose results are then used to modify or design the next stage in the management program. In adaptive management, there is a direct feedback between science and management such that policy decisions can make use of the best available scientific information in all stages in its development".

Obtaining practical value from an experimental approach to restoration requires the careful structuring of the project to ensure the maximum benefit following project monitoring and evaluation. The structure for this proposal for pilot flow augmentation in lower Clear Creek has followed several previous generic adaptive management frameworks including the "Healey ladder" (SRAC 2000) and an approach specific to adaptive management for high flow augmentation (Stillwater Sciences 2003, derived from a proposal for high flow prescription developed for the Trinity River; USFWS and Hoopa Valley Tribe, 1999). Superimposing the two frameworks, the current project is shown graphically in Figure 9.

One of the primary requirements of an adaptive management approach is the development of a series of experimental hypotheses, organized by project goal and specific to single or multiple reaches. These hypotheses are central in testing our overarching questions (and primary sources of project uncertainty, Section 4.2.2) regarding (1) our ability to effectively manage flow releases, (2) the extent to which such releases can provide benefits to the geomorphic processes in Clear Creek, and (3) the extent to which new habitats are created and biologically utilized. As such, an effective data collection and monitoring program is critical to project success. The importance of developing a carefully crafted monitoring program for studying experimental flows has been emphasized by Luna Leopold (1991) with regard to the Glen Canyon Environmental Studies:

> "The use of experimental flows to observe what happens under semi-controlled conditions is one of the scientific methods most likely to add new and useful information to our store of present knowledge. But the full use of these experiments will be greatly compromised if an adequate observation program is not in place at the time that they are operative."

Within the context of this experiment, there are three fundamental constraints to the scope of the project (as outlined Section 2) that influence the potential monitoring design:

1. this is an experimental flow release that is limited both in time and resources and does not constitute a general plan for flow management in the watershed, although it may ultimately become the foundation for such a plan;
2. evaluation of project effectiveness should be limited to experimental monitoring of those factors that might reasonably be expected to change reliably within the

constraints of the experiment, and this focuses attention of physical and habitat factors (i.e., testing hypotheses about process-form-habitat linkages);

3. hypotheses are targeted at the dynamic habitat requirements of several indicator or focal species (e.g., Chinook salmon, steelhead, Fremont cottonwood, and various willow species) with an assumption that positive changes for these species will additionally benefit a host of other native species.

The proposed monitoring program would provide the core data for completing an adaptive management experiment in which there is both specific learning *about* the project in terms of the environmental performance of the high flow releases in causing predicted geomorphic, habitat and biological improvements) and generic learning *from* the project regarding the effectiveness of the monitoring program and associated activities such as the use of decision-support software as the basis for setting the flows) (Downs and Kondolf 2002). Appraisal requires evaluation in addition to monitoring in order to conclude the experiment and restate the post-experiment conceptual model and also to provide input to the adaptive processes in which knowledge regarding future high flow prescriptions is adjusted and disseminated (Stillwater Sciences 2003, and see Figure 9). The prospect of further action is then assessed by one of several processes, including (1) re-formulating hypotheses that can clearly be rejected, or, where hypotheses were accepted, either by (2) refining the hypotheses based on re-stated conceptual models if significant change was achieved by the experiments or, (3) where the previous experiment did not achieve significant ecosystem changes, a complete revision of ecosystem goals (USFWS and Hoopa Valley Tribe 1999). A fourth prospect is to reassess the problem in its entirety, and to question the potential of individual flow events to cause ecosystem changes even under favorable conditions. These issues are developed in Section 6.4

In terms of learning *from* the project, this experiment also provides the prospect of testing a formal decision analysis model (Clear Creek Decision Analysis and Adaptive Management Model (CCDAM); Alexander et al. 2003; and see Appendix C) used to formulate the operational actions required to set the flow releases (Section 6.3). The prospect is that CCDAM can bring an explicit and integrated approach to uncertainty reduction that can lead to improved decision-making in the long-term (Von Winterfeldt and Edwards 1986, Peterman and Anderson 1999, Peters and Marmorek 2001). Formal decision analysis is now being applied to many resource management questions and it has been extended to evaluate alternative flow management experiments (Alexander et al. in review). The approach maximizes information value to decision-makers by incorporating and weighting alternative hypotheses and linking hypotheses across sub-systems, often through use of empirical simulation models. The decision analysis approach to evaluating alternative actions with formal accounting of uncertainties is typically summarized using a decision tree (e.g., see example in Figure 10). In the example of Figure 11, new monitoring results provide critically valuable information in the form of revised probabilities for the alternative hypotheses for one or more particular elements of the decision problem.

6.1.1 Data Collection Design Considerations

The proper design of experiments is a critical step in adaptive management programs. In this project, we propose to assess the planned experimental flow releases using a combination of experimental data collection and focused monitoring activities to test physical and habitat indicators of success. It is not possible statistically within the parameters of the flow experiment to rely solely on biological 'status-and-trends' monitoring (*e.g.*, of a salmon population indicator such as smolt production) as the key success criterion. Instead, specific, linked physical, habitat and biological hypotheses will be pursued in order to evaluate the ERP goal of ecosystem functioning as the core component of project success. A weight-of-evidence analysis is proposed for rigorously testing hypotheses in a fashion that helps identify, address and reduce uncertainties in the fundamental issues surrounding the effects of environmental water releases on geomorphic process, habitat creation and aquatic and riparian habitat utilization by indicator species. Weight-of-evidence analyses were developed, initially for ecotoxicology risk applications, to assist in dealing with environmental problems that are subject to a wide range of influences acting at varying scales, and that make it difficult to draw regional-scale conclusions (Lowell et al. 2000, Leuven and Poudevigne 2002). Such analysis uses field data and experimental hypothesis testing for its predictions.

The requirement for a weight-of-evidence approach in flow augmentation arises because the regional environmental benefits of the proposed flows, especially for biota, are unlikely to materialize immediately. As such, considerable time would be required to disentangle any effects of the environmental flow releases on salmon populations from, for example, the effects of changes in ocean harvest regulations, El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) cycles, and so on. Weight-of-evidence approaches therefore provide a structured, “stepwise” way of reducing the uncertainty that these practical considerations bring to the experiment by understanding how each component in the process-form-habitat-biota hierarchy is, in turn, affected by the flow releases. Under this approach, fundamental questions for the experiment become:

- Have the operational changes made to lake-level management in Whiskeytown Lake resulted in the predicted changes in hydrology (e.g., the magnitude, duration, frequency and timing of deliberate flow releases?)
- Have the changes to hydrology had the expected effects on geomorphic processes (e.g., are we really moving gravel as often and as far as we wanted?)
- Have the changes to geomorphic processes had the expected effects on stream structure (e.g., have we really increased gravel recruitment, increased floodplain fine sediment deposition, increased pool depth?)
- Have the changes in stream structure had the expected effects on stream habitat (e.g., have we really increased spawning habitat quality, the extent of low velocity marginal habitat, etc.?)
- Have the changes to habitat had the expected ecological effects (e.g., have we really increased freshwater productivity of anadromous salmonids and contributed to increased smolt output or spawner abundance?)

It is apparent that, further down the bulleted list, the questions become harder to resolve by monitoring, for two reasons. First, the time-horizons become longer, so that it would take longer to determine success even with perfect information. Second, both the accuracy with which things can be measured and the degree to which factors outside project control can be accounted for deteriorate. Therefore, increasingly long periods of time are required to provide results that can be interpreted with a high degree of confidence. Therefore, experimentally, the focus of monitoring is necessarily on short-term effects which may indicate longer-term trends in habitat productivity of target species.

Within this context, long-term status-and-trend monitoring that is already carried out annually by agency personnel (e.g., USFWS) is necessary to complement the proposed monitoring in this experiment and contribute to establishing the overall benefit of the project. Elements of the proposed monitoring should also complement the long-term biological monitoring efforts conducted by other entities by examining process-based, cause-and-effect mechanisms that can assist in explaining the observed trends. For example, mapping of changes in habitat quality and distribution that result from the flow releases (1) will provide direct evidence of the effectiveness of the releases in causing desirable habitat responses, and (2) will contribute to any interpretation of changes in abundance and distribution of target species that might be monitored outside of this experiment as indications of restoration effectiveness, without substituting for long-term biological monitoring.

6.2 Performance Metrics and Data Collection Program

The goals and objectives for augmentation developed previously in section 5.1 are linked to a series of provisional hypotheses, *models*, performance measures and monitoring methods in Table 8. Further development of these various components should occur in the development of the Full Proposal for flow augmentation. The guiding criterion is that, for an experiment to be regarded as "scientific", it should be possible, in principle, to *refute* the hypotheses which are being tested. Monitoring associated with the experiment should consider not only what constitutes evidence of project success, but also what would constitute evidence of failure. For adaptive management purposes, this may include an expert assignment of degrees of belief (subjective probabilities) on alternative hypotheses, taken within a structured decision-making framework potentially to advise short-term changes in the flow augmentation regime (i.e., within the timeframe of the pilot project) that will improve the prospect of maximizing ecological benefits.

Comprehensive, quantitative assessment of biological responses is an intuitive and desirable measure of the effectiveness of the proposed flow augmentation project but is considered beyond the scope and timeframe of the proposed experiment. Certainly, the body of knowledge of the habitat requirements of target species (particularly for salmonids) is extensive and provides a sound basis for generally assessing responses to changes in habitats (i.e., increases in the quality and/or quality of life-stage specific habitats). Assessing response of fishes to experimental flow will primarily be focused on utilization of newly created and existing habitats. Without doubt, the ideal measure of project effects and overall benefits throughout the project area would be to monitor changes in the production of early life stages of target salmonid species (Chinook salmon and steelhead). Theoretically, increases in the quality and quantity of incubation, fry, and juvenile habitats should be manifest as increased survival rates of downstream emigrants to the mainstem Sacramento River, and beyond. Practically, however, definitive establishment of such increases is a rigorous, lengthy effort that must account for many factors not directly associated with proposed adaptive management of flows. Potential changes in fish populations (e.g. increased abundance of downstream migrant salmonids) that might be directly associated with newly created habitats are, for example, easily masked by inter-annual variability in spawner escapement and fecundity, particularly for the small Clear Creek population of spring Chinook seen in recent years. On-going fish monitoring by the USFWS and CDFG (downstream migrant trapping, weirs, redd/spawner counts, etc.) will be complemented by specific data collection in the framework of flow experiments but is not proposed as an explicit, separate task

A set of biological responses will be assessed through surveys of habitats and habitat utilization for target species (emphasis on salmonids) that can be directly associated in time with experimental flows. Physical habitat and biological surveys are described in outline in Table 8 (below) and include utilization and distribution of salmon and steelhead spawning habitats, utilization and distribution or rearing habitat for salmonid fry and juveniles, stranding of salmonids and other aquatic species, macroinvertebrate communities, and riparian vegetation. Description of the general emphasis of data collection and monitoring efforts is outlined by stream reach below.

In the upper reaches (1 and 2), the primary data collection and monitoring goal is to document changes in both the areal distribution of spawning gravels and the quality of spawning gravels in terms of the rate of sediment transport and the depth of scour. The monitoring of geomorphic and riparian vegetation change is essential to assess if the proposed flows and supplementary management actions are (1) accomplishing the physical changes intended, such as mobilizing gravels, and (2) to a more limited extent, restoring alluvial processes in reach 1, a bedrock-controlled alluvial reach.

The primary monitoring goal for reaches 3 and 4 is to determine whether or not the proposed flows, in combination with necessary supplemental management actions, help to improve the quantity and/or quality of spawning and rearing habitat available for salmonids. Habitat available for the establishment of riparian vegetation will also be assessed. Fish monitoring will be focused on evaluating salmon habitat use and evaluating stranding. Habitat utilization by potential predatory fish will also be assessed. Monitoring should also be conducted to document the development of alternating bar sequences, floodplain inundation and the creation of topographic diversity, and establishment of diverse riparian vegetation structure.

In addition, studies for lower flow events (less than 1,200 cfs) will also be considered, including an infiltration bag experiment, study of juvenile salmonid response to spring pulse flows less than 1,200 cfs, monitoring the abundance, distribution and/or behavior of native resident species, testing of the potential to scour riparian vegetation at the lower flow, and testing of the effectiveness of placed large woody debris and boulders in both upper and lower reaches. These studies would be intended to complement the studies targeting habitat improvements caused by moderate flood flow events.

Table 8. Hypotheses, representative performance measures and monitoring method examples to evaluate the effect of flow releases for the Clear Creek flow augmentation experiment.

Goal	Objective (Section 5.1)	Potential Hypotheses	Performance Measure(s)	Data Collection and Monitoring Methods	Reaches
Provision of mid-range flood flows	n/a	Achievement of target magnitude, duration, frequency, and timing of flows	Flow magnitude, duration, frequency, and timing	Gauging of mainstem and tributary flows	1, 3, 4
Salmonid habitat quantity & quality	a	Flows will increase frequency & volume of gravel recruitment from gravel augmentation (bankside input) locations	Volume of gravel recruited per unit time	Measurement of residual gravel quantity at input locations	1, 2, 3
	a	Flows will increase rates of transport of augmented gravels	Bedload transport rate, gravel scour depth and/or largest grain size moved	Bedload monitoring, tracer analysis, scour cores/chain	1, 2, 3
	a	Flows will increase the area and depth of available spawning gravel	Area of spawning habitat, gravel depth in spawning areas	Gravel area & depth surveys	1, 3, 4
	a	Flows will increase the area of pocket gravel storage	Coarse sediment storage, area of spawning habitat;	Expert habitat mapping, gravel area & depth surveys	2
	a	Flows will increase the frequency of sediment transport, improving spawning habitat quality by reducing the average angularity of augmented gravels	Roundness of particles	Measurement of particle roundness following flood events	1
	b	Flows will increase the area of low velocity channel margin habitat	Existence of low velocity, shallow habitat at base flow, evidence of habitat utilization	Channel bed topography / water depth surveys, direct observation	1, 3, 4
	c	Flows will increase the frequency and availability of seasonally connected backwater channels	Existence and area of backwater channels, evidence of habitat utilization	Survey of backwater habitat extent, hydraulic model, direct observation, stranding surveys	1, 3, 4
	d	Flows will increase instream habitat complexity	Relative variability of channel bed elevation and channel asymmetry	Channel bed surveys following floods	1, 3, 4
	e	Flows will decrease interstitial fine sediment accumulation in potential spawning habitat	Gravel permeability (and/or grain size distribution), fine sediment transport rates	Permeability tests, infiltration bags, bedload and suspended load monitoring	1-4
	e	Flows will alter standing biomass and diversity of benthic macroinvertebrate communities	Biomass and diversity of macroinvertebrates.	Macroinvertebrate sampling	1-4
	f	Flows will increase pool depth for migrating and holding habitat	Pool depth, area and volume, evidence of habitat utilization	Residual pool depth, direct observation	2, 3, 4

Goal	Objective (Section 5.1)	Potential Hypotheses	Performance Measure(s)	Data Collection and Monitoring Methods	Reaches
Floodplain development & channel migration	a	Flows will decrease the area of surficial in-channel fine sediments	Surface area of channel bed with significant component of <2mm material	Facies mapping	3, 4
	a	Flows will increase the overbank deposition of fine sediments	Surface area of floodplain composed of <2mm material	Sediment trapping	3,4
	b	Flows will increase the topographic diversity of floodplains	Comparative diversity of floodplain elevations in sample locations	Surface mapping survey	3, 4
	c	Flows will reduce armoring of banks and increase frequency of scour of early seral stage riparian vegetation in the active channel	Low flow channel width, area of exposed bar in summer	Repeat cross-section surveys, vegetation mapping and surveys	3, 4
	d	Flows will increase the rate and frequency of outer bend migration	Channel sinuosity and asymmetry, length of eroded bank	Repeat cross-section surveys, aerial photographs, thalweg surveys	3, 4
	d	Flows will increase LWD recruitment following outer bend migration	Volume and number of LWD pieces	LWD surveys	3, 4
	e	Flows will increase in-channel deposition and storage of bed gravel	Area & depth of coarse sediment storage, reduction of channel slope in sample reaches	Gravel area and depth surveys, thalweg surveys	3, 4
	f	Flows will decrease the extent of riffle-runs in straightened reaches	Variability of channel bed elevations, pool frequency mapping	Thalweg surveys, expert habitat mapping	3, 4
	f	Flows will increase deposition of gravels associated with roughness elements	Bed elevation behind roughness elements, substrate size behind roughness elements	Survey, pebble counts	3, 4
Riparian vegetation recruitment & growth	a	Flows will increase the frequency and extent of floodplain inundation	Frequency of flooding and water surface elevation	Monitoring water surface / groundwater elevations on floodplains	3, 4
	a	Flows will result in an increased ratio of hardwood to coniferous species	Ratio of hardwood to coniferous species	Riparian vegetation surveys	1
	a	Timing and stage of proposed flows will promote natural recruitment of cottonwood seedlings	Number of cottonwood recruits	Vegetation plots	1, 3, 4
	a	Proposed flows will shift the age structure of woody riparian vegetation towards younger age-classes	Age structure of woody riparian vegetation	Vegetation mapping and surveys of tree and shrub age/size class structure	1, 3, 4
	b	Instream and floodplain loading of LWD will increase	Volume and number of LWD pieces	LWD surveys	3, 4

Prospective on the Use and Benefits of Modeling Predictive Outcomes

It is inherent to adaptive environmental assessment and management that the potential for learning is maximized by developing models of potentially-affected components of the ecosystem. The models can assist in generating the experimental objectives, details of hypotheses for testing, and assumptions inherent to the experiments. Without the use of such models, our learning opportunities from this experiment are substantially limited. Linking model predictions with strategic monitoring outcomes helps to challenge prevailing assumptions, explain experimental outcomes and reveals inherent but sometimes overlooked relationships. Monitoring also provides important information regarding the accuracy and precision achieved by the model predictions, thus helping in model refinement. In this specific application, it is primarily the physical aspects of this project that are amenable to modeling because the indeterminacy of morphological response to high flow events largely precludes explicit predictions of habitat or biotic gain. Prospects for modeling may include:

- The hydrological parameters of the flow augmentation, including the magnitude, duration, frequency and timing of the releases. Provisional work in this regard has already been undertaken using CCDAM (Clear Creek Decision Analysis and Adaptive Management model), and is detailed in Section 6.3;
- The hydraulic parameters associated with the proposed flow releases, including the discharge respective flow depths achieved in individual reaches, and the extent of flood inundation expected in reaches with significant floodplain (reaches 3 and 4). Reliable hydraulic model predictions are unlikely to be possible in reach 2. To reliably estimate the hydraulics of floodplain reaches will require a dynamic two-dimensional model and high resolution topography topographic data;
- The bedload sediment transport parameters of the flow releases, including additional resolution on sediment entrainment thresholds (see Section 5.2), bed scour potential and the flow dependent evolution of the “pulse” of bed material resulting from flow augmentation, including the transport distances, depth and grain size characteristics of the deposits in reaches 1, 3 and 4. Evaluating model predictions with empirical field data will increase future accuracy in describing post-flow release habitat benefits. A further prospect is to model potential fine sediment dispersion onto the floodplains using models of advective and diffusive processes; this would also require high resolution topographic data and extensive calibration of suspended sediment concentrations in individual flood events;
- Predictions of habitat change and biological response. Opportunities for such predictions are limited. Prospects include predicting habitat extent using a channel classification system based on physical parameters to predict the distribution of habitat types following flow events; predictions of the extent of spawnable area from assumed gravel re-distribution; predictions of riparian recruitment based on recruitment box concepts in relation to the timing and recession limb of the flood hydrograph; and predictions of juvenile salmonid production based on flow, temperature, bed scour and fine sediment estimates. Modeling predictions would be checked largely using expert habitat mapping.

The potential for, and details of, such modeling will be developed further under a full proposal following work to resolve any potential flow conflicts and the generation of a best compromise flow release strategy for flow augmentation

Time Frame for Data Collection

It is proposed that the data collection and monitoring occur for a period of ten years such that such surveys are undertaken ahead of the first managed flow release to establish baseline conditions, and are extended through a period of three such releases. This time frame is based on the flow releases occurring on approximately a three-year interval. Measurement should include the effectiveness monitoring of supporting management measures that are complementary to the flow releases (e.g., large woody debris recruitment, vegetation management, see Section 5.3), and should include contingencies to allow monitoring following unplanned flow releases. In the context of this experiment, implementation monitoring will refer largely to achieving the target flow frequency, magnitude, duration and timing.

Data collection components can be classified as including hydrology, sediment transport, morphological change, habitat evolution and local biological utilization and were briefly outlined by method in Table 8. Hydrological monitoring will require the establishment of a distributed set of gauging stations that would operate, at a minimum, during the winter / spring flow seasons and allow the monitoring team to understand the dynamic between mainstem and tributary inflows during flow releases and at other high flow periods. Sediment transport monitoring will be based on real-time assessment of bedload and suspended sediment load during high flow events, preferably to include both planned and unplanned high flow releases. Data collection to document morphological change and habitat evolution will require baseline surveys during baseflow conditions prior to, and following planned flow releases, and may be required annually or following other unplanned flow releases that are deemed to have a geomorphic impact (i.e., flows which result in significant sediment transport and/or channel bed re-organization). Floodplain surveys will be required following each inundation event and may, in part, be achieved by interpretation of aerial photography taken annually, which is also the basis for monitoring planform changes. Biological surveys will require baseline monitoring, timed annual surveys and post-flood surveys as suited to the lifecycle of the target species.

6.3 Mechanics of Flow Acquisition

Whiskeytown Dam and Reservoir function primarily as a re-regulation facility in support of hydropower production. The inter-basin transfer of Trinity River water, via the J.F. Carr tunnel, represents the overwhelming majority of inflow to the reservoir, comprising 74% of total volume of inflow to the reservoir since the inter-basin transfers began. Most of the water stored in the reservoir is eventually routed through the Spring Creek tunnel (94% of annual flow releases), which transports the water to Keswick Dam on the Sacramento River, generating hydropower during transit.

Whiskeytown Dam is equipped with two structural facilities for releasing water into the Clear Creek channel: the Clear Creek outlet and the Glory Hole flood bypass structure (see Figure 12). Most of the flow in the Clear Creek channel is released from the dam's outlet, which has a relatively small capacity of 1,200 cfs. In contrast, the Glory Hole flood bypass can route up to 28,000 cfs. Though the managed release capacity of 1,200 cfs is sufficient for supporting many fishery objectives (e.g., providing passage, supporting spawning, and maintaining suitable water temperatures), this limited routing capacity is not sufficient to achieve the higher channel-forming and channel-maintenance flows. As described in Section 5.1, the flow augmentation program described by this proposal calls for flow releases between 4,000 to 6,000 cfs in the Clear Creek channel to re-invigorate basic channel forming processes that help to create and maintain aquatic and riparian habitats. Though there are tributaries downstream of Whiskeytown Dam that contribute flow to lower reaches (e.g., Paige Boulder Creek, South Fork Clear Creek), the incremental contribution of flows from these tributaries, combined with the 1,200 cfs managed release capacity of the dam, are insufficient in most water year types to achieve the target discharges for the Clear Creek channel (Figure 13). There has been a recent analysis of options for increasing the managed release capacity of Whiskeytown Dam (USBR 1999); however, no structural changes to the dam are imminent, and any such change would require years to design, permit and build. In the near term, achieving the targeted discharges in Clear Creek will generally require operating Whiskeytown reservoir in order to route flows through the Glory Hole structure. Current operation of Whiskeytown reservoir occasionally results in spills through the Glory Hole; however, most of the winter and spring releases through the Glory Hole have had a magnitude less than the targeted discharge of 4,000 to 6,000 cfs (Figure 14).

The inlet of the Glory Hole bypass structure has an elevation of 1,210 ft, so the elevation of Whiskeytown Lake must exceed this elevation in order to spill into Clear Creek (Figure 15). The current operation plan for Whiskeytown Reservoir generally targets a lake elevation of 1,198 ft. during winter months (typically November 15th through March 31st), which provides approximately 37,000 acre-feet of flood storage space during the period of peak runoff in the basin. Beginning in April, the reservoir is allowed to fill, approaching a maximum pool elevation of 1,209 ft. around May 1st. Throughout the summer and fall recreation season, the elevation of Whiskeytown Lake is maintained just below the 1,210 ft crest of the Glory Hole structure.

To route the target discharges of 4,000 to 6,000 cfs through the Glory Hole structure into the Clear Creek channel, two basic operational scenarios for Whiskeytown Reservoir are being explored. The “winter strategy” involves increasing the target elevation of the lake during winter months (December through March/April) above the current winter target of 1,198 ft. Maintaining a higher lake elevation during the winter runoff period would allow natural inflows associated with storm events to fill the reservoir more quickly and pass through the Glory Hole. The “spring/summer strategy” builds on the current operation of Whiskeytown reservoir during the spring and summer months (April to September), when the reservoir is typically filled to maximum pool. The spring/summer strategy relies principally on temporarily ceasing diversions from the reservoir through the Spring Creek tunnel, so that Trinity River water routed through the J.F. Carr tunnel, along with natural inflows, would be allowed to gradually fill the reservoir until the lake elevation exceeded the crest of the Glory Hole structure, thereby spilling into the Clear Creek channel.

Each of these strategies has advantages and disadvantages, and both of these strategies could be used over the multiple years of the proposed adaptive management and monitoring program. The following subsections briefly sketches the elements of the winter and the spring/summer operational scenarios. It is important to note that the following subsections do not attempt to capture the operational complexity of routing water to satisfy the numerous flood management, hydropower, water supply, water quality, and fishery mandates associated with the Central Valley Project. Rather, this discussion attempts to simplify water routing in Northern California in order to explore and illustrate the possibility of achieving targeted flows in Clear Creek via Glory Hole releases, without minimizing the difficulty of coordinating the operations of multiple facilities and balancing competing needs.

6.3.1 Winter Strategy

The primary period of runoff in the Clear Creek basin occurs between December and April (Figure 16). Increasing the lake elevation from the current winter target of 1,198 ft during this period would allow natural inflow from winter storms to fill Whiskeytown reservoir more quickly, so that flows spill through the Glory Hole structure more frequently than occurs currently. The targeted lake elevation for a winter release period could be tied to medium-range inflow and meteorological forecasts, such that lake elevations would be 1,200 to 1,202 ft for anticipated wet periods, 1,204 to 1,206 ft for forecasted normal conditions, and 1,207 to 1,209 ft for expected dry periods. Once the targeted discharges were achieved in the Clear Creek channel, Whiskeytown reservoir could be operated to return lake elevations to the usual winter target of 1,198 ft.

In addition to natural inflow events associated with winter storms, a winter strategy would likely also include management of inflows of Trinity River water via the J.F. Carr tunnel (Figure 17) and diversions from the reservoir into the Spring Creek tunnel (Figure 18) to manage reservoir elevations and the subsequent amount of water spilling through the Glory Hole structure. We suspect some additional 'winter environmental water release protocols' would be required to ease the ramping rate and magnitude of releases exiting the Glory Hole. For example, such protocols could involve reducing J.F. Carr inflows and increasing Spring Creek tunnel outflow during some of the larger winter precipitation events.

One advantage of the winter strategy is the relatively lower cost of electricity during winter months, which would likely reduce the cost of foregone power production as compared to spring and summer months when the demand for electricity is typically higher. Another potential advantage of the winter strategy is timing the release of "clear water" from the dam with periods of high flow and increased turbidity on tributaries downstream of Whiskeytown Dam. "Piggybacking" dam releases with turbid tributary flows could help to route fine sediment downstream and possibly deposit fine sediment on floodplain surfaces along the Clear Creek channel, thereby enhancing both aquatic and floodplain habitat conditions. A winter release would also have comparatively less impact on recreational activities in Whiskeytown Lake and the Clear Creek channel, as compared to spring and summer months. The winter strategy also provides comparatively greater flexibility in varying the design discharge released into the Clear Creek channel, within the targeted 4,000 to 6,000 cfs range. Preliminary simulations using the CCDAM model show that the likelihood of achieving a Glory Hole release in any given year is high (depending on the reservoir elevation chosen). However, the peak discharge magnitude realized using this strategy is less certain due to limitations in forecasting inflows and the inherent lags in building and releasing incoming water at Whiskeytown Reservoir.

As suggested above, a disadvantage of the winter strategy is the loss of flood reservation space in Whiskeytown reservoir during the rainy season. Though Whiskeytown Dam does not have a mandated flood management purpose, it nevertheless provides the USBR with operational flexibility for managing flow events in the Sacramento River basin. Indeed, in extremely large flood years (e.g., 1983, 1998), Whiskeytown Dam's standard operation itself does not presently afford general control over large flood events in Lower Clear Creek (USBR 1999). Another potential disadvantage of the winter strategy is the potential conflict with some fishery objectives. For example, high flows released into the channel during December and January have the potential to scour salmonid redds, thereby increasing the potential for egg mortality. Similarly, high flows released from the dam in February and March could pulse juvenile salmonids downstream prematurely. However, viewed beyond the current cohort, this same disadvantage may turn out to be a net benefit should these flows improve the amount and quality of spawning habitat and associated incubation survival rates in the years that follow. It may also be difficult to rely on Trinity River inflows to help manage Whiskeytown reservoir elevations during winter months, because diversions through the J.F. Carr tunnel are typically reduced in winter to allow Trinity Dam to refill.

6.3.2 Spring/Summer Strategy

Current operation of Whiskeytown Reservoir targets a lake elevation of 1,209 ft (just below the 1,210 ft elevation of the Glory Hole inlet) beginning around May 1st and lasting through the summer and fall months. Consequently, releasing the target discharge of 4,000 to 6,000 cfs through the Glory Hole during the spring or summer months requires a smaller change in the target reservoir elevation for that time of year relative to the winter strategy. However, to achieve the necessary lake elevation to permit the target flows to spill through the Glory Hole, it would be necessary to temporarily cease diversions from the reservoir through the Spring Creek tunnel, while simultaneously maximizing the inflow of Trinity River water through the J.F. Carr tunnel. To increase the rate at which the reservoir elevation builds, the Clear Creek outlet discharge could also be reduced to some safe minimum discharge, though this is likely to have a minimal effect. The J.F. Carr tunnel has a routing capacity of 3,600 cfs (J. DeStaso, *pers. comm*, 2004), so maximizing this inflow would gradually increase the lake elevation until, ostensibly, a flow of approximately 3,600 cfs spilled through the Glory Hole.

Spring/summer releases would likely permit greater control over the magnitude of discharges in the Clear Creek channel, because natural inflow to the reservoir and flow in the downstream tributaries is generally more predictable than in winter when storms can cause rapid flow fluctuations.

One disadvantage of the spring/summer strategy is that it may be difficult to achieve the targeted Glory Hole flows of 4,000 and especially 6,000 cfs. The routing capacity of the J.F. Carr tunnel (3,600 cfs) constrains the volume of managed inflow to the reservoir below the target discharge. Though it may be possible to time the Glory Hole flow releases with spring/summer storm events that may temporarily increase natural inflow to the reservoir, such storms are rare (Figure 16) and the required operational changes at J.F. Carr and Spring Creek tunnel may be difficult to achieve in light of the interconnectedness of Whiskeytown operations with Trinity River flow mandates and flow management in the Sacramento River basin. Another disadvantage of spring/summer flow releases is the comparatively higher cost of electricity during spring and summer months when demand is greater, which would add to the expense of purchasing foregone hydropower as compared with a winter flow release. A spring/summer release would also have a comparatively greater impact on recreation both in Whiskeytown Lake and the Clear Creek channel, as compared to a winter release. Table 9 summarizes some of the key trade-offs and uncertainties associated with the winter and the spring/summer strategies.

6.3.3 Operational Triggers

The requisite inflow and trans-basin supply conditions will not exist in every year to achieve the desired Glory Hole releases, nor would these releases be sought every year. It will be necessary to define criteria that will trigger a change in reservoir operations when conditions are ripe for the release of a mid-range flow event in the Clear Creek channel. These criteria would need to address operating rules for determining the appropriate reservoir elevation and fill timing as well as attendant rules for managing J.F. Carr inflows and Spring Creek Power Plant outflows. Triggers for an environmental flow release event would likely be related to:

(a) 1 to 3 month snow-pack/precipitation forecasts for the Trinity, Clear Creek and Shasta basins;
(b) the total allowable flow available for diversion from the Trinity River to Whiskeytown Reservoir (i.e., ROD water year class and flow allowances set by/through collaborations with the Trinity River Restoration Program);
(c) short-run flood risks in lower Clear Creek and upper Sacramento Rivers; and
(d) short-run electrical power demand and supply, and foregone power generation costs.

Table 9. Qualitative summary of trade-offs and key uncertainties/considerations associated with winter and spring/summer alternatives for generating environmental water releases in Clear Creek.

Strategy of water release		Approx. range of water released (acre-feet)	Ramping requirements	Water acquisition volume	Expected return interval (probability of achievement)	Lower Clear Creek flood potential	Trinity River water diversion requirements	Foregone power generation (Spring Creek PP)
Winter strategy involving piggybacking (December to April)	*Short-term*	20,000 to 41,000	Minimal - Low	**Lower**	Perhaps better than 1 in 5 years – *but unknown?*	Higher	Lower	Lower
	Longer-term							
	Key variables/ uncertainties	Magnitude and timing of storm inflow			Weather and operational tactic dependent	Downstream tributary inflows	ROD, TRRP, Water Year	Cost formula, value of power
Spring/ summer approach leveraging Trinity River flows (April to September)	*Short-term*	15,000 to 24,000	Higher	**Higher**	More control, more frequent	Lower	Higher	(Likely) Higher
	Longer-term							
	Key variables/ uncertainties	Time required to build necessary head over Glory Hole crest			Operational tactics	n/a	ROD, TRRP, Water Year	Cost formula, value of power

6.4 Ecosystem Outcomes and Feedback to Inform Future Flow Augmentation

The structure of the experiment proposed here is designed to facilitate an efficient feedback and learning process regarding the value of the pilot project. Feedback policy to decrease environmental uncertainty is a critical part of adaptive management and forms a large part of Walters' (1986) benchmark treatise on the subject. However, due either to the complexities of ecosystem processes over and above the salmon harvesting processes illustrated by Walters, or perhaps because case studies in adaptive management have been designed and undertaken relatively poorly (Walters 1997), examples of explicit guidance provided by such feedback is rare. The potential for learning is restricted largely by the timeframe of post-project study and the level of commitment to pre-project planning, documentation and baseline studies (Downs and Kondolf 2002, Ralph and Poole 2003). As such, the data collection and monitoring methods proposed in outline in this concept proposal have included a significant commitment to pre-project data collection, including hypotheses generated by model simulations, and the targeting of specific hypotheses related to each of the process-form-habitat-biota components of the proposed pilot augmentation. These items will be developed in the full proposal to ensure that the knowledge gain is as specific as possible.

As indicated in Figure 9, there are four elements to the feedback process following the data collection and monitoring exercises. In outline (Stillwater Sciences 2003; step number in parenthesis), these include:

1. Analysis and Evaluation (step 11), including:
   a. Assessment relative to expectations stemming from baseline / pre-project field data and simulation modeling;
   b. Evaluation relative to the experimental hypotheses and proposed conceptual models of post-augmentation ecosystem functioning;
2. Restatement of Conceptual Model (step 12) – as a summary of pilot project evaluation
3. Learning from and adjustment of system understanding (step 13), including:
   a. Learning about overall system behavior and the efficacy of the pilot project in terms of the apparent strength of coupling between the flows released and the process-form-habitat-biota responses;
   b. Learning about the efficacy of procedures for assessment and evaluation, data collection and monitoring;
   c. Learning about the importance and relevance of the assumptions and simplifications in simulation models used to generate experimental predictions;
4. Decisions regarding future prospects for flow augmentation in the watershed and the extent of transferable understanding achieved (step 14).

Details regarding item four in the list above are illustrated in Figure 9 as the prospect of a variety of actions subsequent to the completion of the pilot experiment (following SRAC 2000). Options at this stage include:

- Reassessment of the problem – if the evaluation suggested that individual flow events released as part of the pilot project were insufficient to achieve significant improvement to ecosystem functioning (or that they achieved deleterious effects). Under this scenario, the improvement of ecosystem functioning may require, instead, the application of multiple flow events either to replicate complete seasonal flow components or to create a miniaturized flow regime;
- Revision of goals and objectives – if the evaluation suggested that only minor ecosystem improvement has resulted; the project goals and objectives may need to be re-cast. The structured analysis proposed for this project should be valuable in indicating where the chain of improvements broke down. For instance, if the target flows are achieved but the expected sediment transport does not occur, leaving the habitats largely unchanged, there may be little biological benefit. Under this scenario, the flows proposed for any future experiments would be altered accordingly;
- Redefined conceptual models – if the evaluation suggested a moderate ecosystem response to augmented flows, then it might be concluded that the project goals and objectives are adequate, but that the ecosystem function was rather different to that imagined at the project outset. In this case, redefined concept models can be the basis for altering the experimental hypotheses sufficiently that a revised program of flows would result in significant ecosystem improvement.
- Continue with restoration – in the case that evaluation concludes that significant, anticipated, ecosystem improvements occurred, it may be possible simply to re-set the project hypotheses to accommodate a new round of flow augmentation largely similar to the pilot project, or involving a larger program of flow augmentation with the expectation that additional benefit would result.

7 COST

Provisional estimates have been derived for the water and monitoring costs associated with this experiment. They should be considered as 'order-of-magnitude' estimates for planning purposes.

Cost estimates for water are based on several scenarios in the price of foregone power (Table 10) and are subject to change with fluctuations in power costs and exact definition of the flow magnitude, duration, frequency and timing. Using the assumptions in Table 10, mid-range water costs are expected to total approximately $2.55M, assuming 3 releases of 5000 cfs for two days duration under the 'expensive' water purchase category, but the range conceivably varies from $1.5M to $4.2M depending on unit cost, flow magnitude and duration.

Costs of monitoring are provisional and based upon initial concepts of a suitable monitoring experiment (Table 11). They will change as the monitoring approach is refined, according to the importance accorded to individual elements of the plan. Refinement will require consensus decisions regarding the focal elements and detail required in each element. The current estimate assumes:

- one thorough baseline data collection event covering all the suggested monitoring requirements;
- event-based monitoring for some elements, encompassing 5 events, that is, 3 planned water releases over the 10 years, and 2 unplanned events that will require monitoring to re-establish experimental control;
- annual monitoring for the remaining tasks;
- person-day estimates have encompassed planning, mobilization, field, analysis and reporting commitments. Other potential commitments could include stakeholder, and technical meetings. Overview report writing and analysis is already encompassed by the scope of work for the EWP Lead Scientist and is not included here.
- rough estimates of costs for equipment, lodging, meals, vehicle and miscellaneous expenses have been incorporated.

The total monitoring cost is estimated at $2.86M over ten years at current prices, or $286,000 per year. Such an estimate seems in-keeping with the exacting data demands placed on river projects by adaptive management approaches, and is likely to yield an exemplary data set as the basis for future investigations that might require less intense data collection. It is conceivable that the cost could vary considerably according to the level of details agreed as appropriate to the experimental hypotheses. Eventually, the costs will need to accommodate the rising cost of labor over the experiment period.

On the basis of these simple calculations, a ten-year program of high flow releases and associated monitoring on Clear Creek may total in the region of $5.5M. More thorough cost estimates will be derived as part of a full proposal preparation, should the concept proposal be selected for further development. Beyond 10 years, it is anticipated that the results of this project, in conjunction with other lower Clear Creek restoration activities, would provide the foundation for a new phase, such as the development of a general flow management plan.

Table 10. Water and power cost estimates *per event* for a range of 2- and 3-day flow events at two different values for hydropower, assuming Spring Creek Power Plant efficiency of 0.6 MWhr/acre-foot.

Target flow (cfs)	Duration (days)	Acre-feet	Acre feet for ramping requirements (assume 50% of first days value)	Total acre-feet required (or used)	Estimated Foregone Power Cost	
					Assuming Average Power Value ($44.25 per MWhr)	Assuming Average Power Value ($57.25 per MWhr)
4000	2	15,868	3,967	19,835	$ 526,612	$ 681,322
4000	3	23,802	3,967	27,769	$ 737,256	$ 953,851
5000	2	19,835	4,959	24,793	$ 658,264	$ 851,653
5000	3	29,752	4,959	34,711	$ 921,570	$ 1,192,314
6000	2	23,802	5,950	29,752	$ 789,917	$ 1,021,983
6000	3	35,702	5,950	41,653	$ 1,105,884	$ 1,430,777

Table 11. First approximation of monitoring costs required over 10 years to support monitoring plan for the Clear Creek flow releases (2004 labor rates and expenses).

Monitoring component	Frequency	Baseline survey required?	Total frequency	Approximate cost per event ($ k)	Total cost ($ k)
Hydrology gauging	Permanent, periodic checks	No	10	34.3	343
Flood monitoring of flows, suspended and bedload transport;	Following flow releases & other flows >3000 cfs if possible	No	5	33.6	168
Tracer and scour chain/core deployment and recovery	Following flow releases and all other flows >3000 cfs (assume 5 total)	No	5	50.2	251
Morphological surveys: cross-section and thalweg, floodplain total station;	Following flow releases and all other flows >3000 cfs (assume 5 total)	Yes	6	27.8	167
Sediment-related surveys: depth, area, permeability, facies mapping, pebble counts, particle roundness, floodplain sediment traps;	Following flow releases and all other flows >3000 cfs (assume 5 total)	Yes	6	37.2	223
Expert habitat mapping	Following flow releases and all other flows >3000 cfs (assume 5 total)	Yes	6	63.5	381
Infiltration bags deployment and recovery	Annually	No	10	15.8	158
LWD surveys (volume and mapping)	Annually	Yes	10	19.3	193
Observational surveys for utilization & potential stranding	During and following flow releases and all other flows >3000 cfs (assume 5 total)	Yes	6	46.5	279
Spawning surveys	During and following flow releases and all other flows >3000 cfs (assume 5 total)	No	5	37	185
Invertebrate sampling	Annually	Yes	10	25.9	259
Vegetation surveys/mapping	Annually	Yes	10	25.9	259
				Total	**$2.87M**

8 REFERENCES

Alderdice, D. F., W. P Wickett, and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. Journal of the Fisheries Research Board of Canada 15(2): 229–250.

Alexander, C.A.D., P.S. Higgins, D.R. Marmorek, and C.N. Peters. In review. *A* decision analysis of adaptive management experiments for Columbia River mountain whitefish (*Prosopium williamsoni*) management: Is it worth varying flows to reduce key uncertainties? Canadian Journal of Fisheries and Aquatic Sciences.

Ashley, R. P., J. J. Rytuba, R. Rogers, B. B. Kotlyar, and D. Lawler. 2002. Preliminary Report on Mercury Geochemistry of Placer Gold Dredge Tailings, Sediments, Bedrock, and Waters in the Clear Creek Restoration Area, Shasta County, California. USGS Open-File Report 02–401.

Bair, J. 1999. Clear Creek rehabilitation project and borrow sites special status plant survey results. Prepared by McBain & Trush, Arcata, California for North State Resources, Redding, California. July 30, 1999.

Bair, J., J. Souza, and T. Griggs. 2003. New design approaches for floodplain restoration and riparian revegetation on Clear Creek, California. Pages 290-301 in Faber, P.M., Editor. California Riparian Systems: Processes and Floodplain Management, Ecology, and Restoration , 2001 Riparian Habitat and Floodplain Conference Proceedings, Riparian Habitat Joint Venture, Sacramento, CA.

Bayley, P.B. 1991. The flood-pulse advantage and restoration of river-floodplain systems. Regulated Rivers*:* research and management 6: 75-86.

Blake, M.C., D.S. Harwood, E.J. Helley, W.P. Irwin, A.S. Jayko, D.L. Jones. 1999. Geologic Map of the Red Bluff 30'x 60' Quadrangle, USGS Map No. I-2542.

Burnett, R.D. and J. Harley. 2003. Songbird Monitoring of the Lower Clear Creek Floodway Rehabilitation Project. 1999–2003 Comprehensive Report. PRBO Conservation Science. Stinson Beach, CA. Contribution # 1174.

CALFED Bay-Delta Program. 1998. Strategic plan for the Ecosystem Restoration Program. Prepared for CALFED by Strategic Plan Core Team (M. Healey, W. Kimmerer, G. M. Kondolf, R. Meade, P. B. Moyle, and B. Twiss), with technical assistance from D. Daniel, T. Mills, and P. Kiel, CALFED Bay-Delta Program, and Jones & Stokes Associates, Inc., Sacramento.

CALFED Bay-Delta Program. 1999. Ecosystem restoration program. Volume 1: Ecological attributes of the San Francisco Bay-Delta watershed, Sacramento, California. CALFED Bay-Delta Program, Sacramento, California.

CALFED. 2002. Executive summary of the Pilot Watershed Acquisition Program's stream selection recommendations. CALFED, Sacramento, California.

CBDA's Ecosystem Restoration Program (http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem.shtml, accessed July 2004)

CDFG (California Department of Fish and Game). 2000. Final Environmental Assessment/Initial Study for the Saeltzer Dam Fish Passage and Flow Preservation Project. Available online: http://www.usbr.gov/mp/cvpia/3406b12/f_final_documents.html

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

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevin. International Pacific Salmon Fisheries Commission, New Westminster, British Columbia, Canada. Bulletin 18.

Coots, Millard. 1971. Unpublished California Department of Fish and Game data, Redding, CA.

CVPIA (Central Valley Project Improvement Act). 2003. Work Plan for Fiscal Year 2004: CVPIA § 3406 (b)(12), Clear Creek Restoration. Program Managers: Jim De Staso (USBR) and Matt Brown (USFWS). October 16, 2003. 8 pages. Available online: http://www.usbr.gov/mp/cvpia/awp/2004/2004-3406(B)(12)ClearCreek.pdf

Dietrich, W. E. 1987. Mechanics of flow and sediment transport in river bends. Pages 179-227 in K. S. Richards, editor. River channels: environment and process. Institute of British Geographers Special Publication # 18. Basil Blackwell Scientific Publications, p. 179-227.

Downs, P.W. and G.M. Kondolf. 2002. Post-project appraisals in adaptive management of river channel restoration, Environmental Management 29: 477-496.

Downs, P. W., and K. Gregory. 2004. River channel management: towards sustainable catchment hydrosystems. Arnold, London.

GMA (Graham Matthews & Associates). 2003. Clear Creek Floodplain Rehabilitation Project, Shasta County, California: WY 2003 Geomorphic Monitoring Report. Prepared for Western Shasta Resource Conservation District, Anderson CA by Graham Matthews & Associates, Weaverville, CA. July 2003.

Halbert, C.L. and K.N. Lee. 1991: Implementing adaptive management. The Northwest Environmental Journal 7: 136-150.

Hanson, H.A., O.R. Smith, and P.R. Needham. 1940. An investigation of fish salvage problems in relation to Shasta Dam. U.S. Bureau of Sport Fisheries, Special Scientific Report 10.

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

Kimmerer, W., B. Cavallo, F. Ligon, S. McBain, C. Stevens, J. Williams, and S. Birk. 2002. CALFED Adaptive Management Workshop March 19–20, 2002, Topic area summary report: Flow manipulation.

Kondolf, G. M. and P. W. Downs. 1996. Catchment approach to planning channel restoration. River channel restoration: guiding principles for sustainable projects. A. Brookes and F. D. Shields, John Wiley and Sons, Chichester**:** 130–148.

Kondolf, G. M., and M. Larson. 1995. Historical channel analysis and its application to riparian and aquatic habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 5: 109-126.

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

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

Koski, K. V. 1981. The survival and quality of two stocks of chum salmon (Oncorhynchus keta) from egg deposition to emergence. Rapports et Proces-Verbaux des Reunions, Conseil International pour L'Exploration de la Mer 178: 330–333.

Leopold, L. B. 1991. Closing remarks. Pages 254-257 *in* G. R. Marzolf, editor. Proceedings of the symposium: Colorado River ecology and dam management. National Academy Press, Washington, D. C.

Leuven, R.S.E.W. and I. Poudevigne. 2002: Riverine landscape dynamics and ecological risk assessment. Freshwater Biology 47: 845-865.

Lowell, R.B., J.M. Culp, and M.G. Dube. 2000. A weight-of-evidence approach for Northern River risk assessment: integrating the effects of multiple stressors. Environmental Toxicology and Chemistry 19: 1182-1190.

Lower Clear Creek Technical Work Group. 1999. Conceptual Plan for Restoration of the Lower Clear Creek Floodway. November.

McBain and Trush. 2001. Geomorphic Evaluation of Lower Clear Creek downstream of Whiskeytown Reservoir. Final Report. Submitted to the Clear Creek Restoration Team.

McBain and Trush. 2001b. Geomorphic Evaluation of Lower Clear Creek downstream of Whiskeytown Reservoir. Appendix D: Lower Clear Creek Gravel Management Plan. Final Report. Submitted to the Clear Creek Restoration Team.

McNeil, W.J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report Fisheries 469.

Miller, P. and P. Vizcaino. 2004. Channel Response to Dam Removal, Clear Creek, California. Water Resources Center Archives Restoration of Rivers and Streams. January 9, 2004.

Miller, P., G.M. Kondolf, and M. Ferry. 2003. Channel response to dam removal, Clear Creek, California. Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract H42E-1119, 2003.

Moore, J.N. 2002. Trace Metals in Sediments from Mine-impacted Rivers: Clear Creek, California Project. Final Report for Award No. 02WRAG001. University of Montana. Missoula, MT. December 30.

NRC (National Research Council). 1992. Restoration of Aquatic Ecosystems: Science, Technology and Public Policy. National Academy Press, Washington, D.C.

Newton, J. M., and M. R. Brown. 2004. Adult spring Chinook salmon monitoring in Clear Creek, California,1999-2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Peterman, R.M. and J.L. Anderson. 1999. Decision analysis: a method for taking uncertainties into account in risk based decision making. Human and Ecological Risk Assessment 5(2): 231–244.

Peters, C.N. and D.R. Marmorek. 2001. Application of decision analysis to evaluate recovery actions for threatened Snake River spring and summer chinook salmon (Oncorhynchus tshawytscha). Can. J. Fish. Aquat. Sci. 58: 2431–2446.

Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104 (3): 461–466.

Sacramento River Advisory Council, 2000. Sacramento River Conservation Area Handbook, California Department of Water Resources, Sacramento, CA.

Shumway, D. L., C. E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Transactions of the American Fisheries Society 93: 342–356.

Silver, S. J., C. E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different velocities. Transactions of the American Fisheries Society 92 (4): 327–343.

Souza Environmental Solutions, Terrestrial Connections, F.T. Griggs, and N.C. Schwertman. 2004. 2003 Riparian Revegetation Monitoring Report, Lower Clear Creek Floodway Rehabilitation Project. Prepared for Western Shasta Resource Conservation District, Anderson, California and Lower Clear Creek Restoration Team. Prepared by Souza Environmental Solutions, Los Molinos, California, Terrestrial Connections, Forest Ranch, California, F. Thomas Griggs, River Partners, Chico, California, and Neil C. Schwertman, California State University, Chico, California. March.

Stillwater Sciences. 2003. Environmental Water Program: Restoring Ecosystem Processes Through Geomorphic High Flow Prescriptions. Final Report. Prepared for CALFED Bay-Delta Program and Jones and Stokes. March 2003.

Stillwater Sciences. 2001. Comparison of predicted and observed geomorphic changes following the removal of Saeltzer Dam: Task 6 Deliverable Report. Prepared by Stillwater Sciences, Berkeley, CA for UC Davis, Davis, CA. June 2001.

TAT (Tributary Assessment Team). 1999. CALFED Stage 1 Actions Central Valley Tributary Assessments: Clear Creek North Sacramento Valley Ecological Management Zone. Prepared by: ERP Staff, North State Resources, Dr. G. Mathias Kondolf, McBain & Trush, and Stillwater Sciences. September 1999.

Tetra Tech. 1998. Upper Clear Creek Watershed Analysis. Prepared for Western Shasta RCD. Available online: http://www.shastalink.k12.ca.us/clearcreek/WA%20Final.htm. Viewed March 2004.

Trush, W. J., S. M. McBain, and L. B. Leopold. 2000. Attributes of an alluvial river and their relation to water policy and management. Proceedings of the National Academy of Sciences 97 (22): 11858–11863.

USBLM (U.S. Bureau of Land Management). 1999. Sacramento Valley – BLM CA Annual Report 1999. Available online: http://www.ca.blm.gov/news/reports_docs/annualreport_1999/sacramento_valley.html. Viewed March 2004.

USBR (U. S. Bureau of Reclamation). 1999. Lower Clear Creek hydraulic analysis at Whiskeytown Dam. Conducted for USBR Mid-Pacific Region by USBR, Technical Service Center, Denver, Colorado. Presentation report May 7, 1999; final report Oct 22, 1999.

USFWS (U.S. Fish and Wildlife Service). 1995. Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Volumes 1–3. Anadromous Fish Restoration Program Core Group. Stockton, CA.

USFWS. 2001. Identification of the Instream Flow Requirements for Aquatic Ecosystems in Clear Creek. CALFED PSP Proposal.

USFWS (U.S. Fish and Wildlife Service) and Hoopa Valley Tribe. 1999. Trinity River Flow Evaluation: final report. Prepared for the U.S. Department of the Interior, Arcata, USFWS.

Villa, N.A. 1984. The potential for rehabilitation salmon habitat in Clear Creek, Shasta County. California Department of Fish and Game.

Von Winterfeldt, D., and W. Edwards. 1986. Decision analysis and behavioral research. Cambridge, UK, Cambridge University Press.
Walters, C.J. 1986. Adaptive Management of Renewable Resources. Macmillan, New York.

Walters, C.J. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1(2): 1. http://www.consecol.org/vol1/iss2/art1 [Accessed August 6, 2004].

Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez. 1999. The Controlled Flood in the Grand Canyon. Geophysical Monograph 110, Washington, American Geophysical Union.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada 11(6): 933-953.

Williams, J.G., and G.M. Kondolf. 1999. Rehabilitation Concepts for Lower Clear Creek. Submitted to Matt Brown, USFWS, Red Bluff, CA.

WSRCD (Western Shasta Resource Conservation District). 1996. Lower Clear Creek Watershed Analysis, prepared for the United States Bureau of Land Management (USBLM), Redding, CA.

WSRCD. 2003. Western Shasta RCD 2002-2003 Annual Report. Available online: http://www.westernshastarcd.org/docs/2002_2003_annual_report.pdf

EWP Conceptual Proposal for Clear Creek Figures

EWP Conceptual Proposal for Clear Creek Appendices

Appendix A: Abbreviations

Appendix B: Local Proposal Preparation Team

Appendix C: Flow Release Design Tool—Clear Creek Decision Analysis and Adaptive Management Model

Appendix A: Abbreviations

CALFED	CALFED Bay-Delta Program
CBDA	California Bay-Delta Authority
CCDAM	Clear Creek Decision Analysis and Adaptive Management Model
CDF	California Dept. of Forestry and Fire Protection
CDFG	California Dept. of Fish and Game
CESA	California Endangered Species Act
CRMP	Clear Creek Coordinated Resource Management Planning group
CVPIA	Central Valley Project Improvement Act
DFG	Department of Fish and Game
DOHPLR	Dam Operations, Hydrology, Power and Lake Recreation
DWR	Division of Water Resources
ENSO	El Niño/Southern Oscillation
ERP	Ecosystem Restoration Program
ESA	Endangered Species Act
EWP	Environmental Water Program
FE	Federally Endangered
FT	Federally Threatened
GMA	Graham Matthews & Associates
LWD	Large Woody Debris
NOAA-F	National Oceanic and Atmospheric Administration Fisheries
NPS	National Park Service
NRC	National Research Council
PDO	Pacific Decadal Oscillation
PRBO	Point Reyes Bird Observatory
PWAP	Pilot Water Acquisition Program
RM	River Mile
SE	State Endangered
SSC	California Species of Special Concern
ST	State Threatened
TAT	Tributary Assessment Team
USBLM	U.S. Bureau of Land Management
USBR	U.S. Bureau of Reclamation
USFS	USDA Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WSRCD	Western Shasta Resource Conservation District

Appendix B: Local Proposal Preparation Team

The Local Proposal Preparation Team consists of a variety of stakeholders, listed below, who attended participatory meetings during the development phase of the proposal. These meetings encompassed the review and discussion of existing information, the identification of species of concern and biological objectives, and the discussion of potential benefits, concerns and constraints of the proposed flows on species of concern. Local Team and subgroup meetings of biology specialists occurred on September 14, 2003, October 14, 2003, November 19, 2003, January 27, 2004, February 20, 2004, March 11, 2004, and May 12, 2004. Also included in this list are individuals who participated in a site visit to lower Clear Creek on April 22, 2004.

Bob Anderson, Landowner
David Baitlov, French Gulch Landowner
Mike Berry, California Department of Fish & Game
Serge Birk, Central Valley Project Water Association
Richard Blackford, Redding Rancheria
Tricia Bratcher, California Department of Fish & Game
Stefanie Brearley, Environmental Water Program Staff, Jones & Stokes
Howard Brown, NOAA Fisheries
Matt Brown, U.S. Fish & Wildlife Service, Red Bluff
Al Carter, Landowner
Steve Chainey, Facilitator, Jones & Stokes
Alton & Betty Chatham, Cattle Owners
Jim De Staso, U.S. Bureau of Reclamation
Peter Downs, Environmental Water Program Lead Scientist, Stillwater Sciences
Irvin Fernandez, U.S. Bureau of Land Management, Redding
Charley Ferrell, HCCP
Phil Garbutt, Western Shasta Resource Conservation District
Sarah Giovannetti, U.S. Fish & Wildlife Service, Red Bluff
Ruth Griffin, Landowner
Gillian Harris, National Fish and Wildlife Foundation
Michael Harris, Western Shasta Resource Conservation District
Brenda Haynes, Assemblyman Doug La Malfa's Office
Travis Hemmen, Jones & Stokes
Buford Holt, U.S. Bureau of Reclamation
Campbell Ingram, Environmental Water Program, Program Manager
Wayne King, Landowner
Rick Lauderdale, Landowner
Kit Lauderdale, Landowners
Stan Leach, French Gulch/Upper Clear Creek Landowner
Malin Lowe, Landowner
David Marmorek, ESSA Technologies Ltd.
Bob Nash, Shasta County Farm Bureau
Don Neptune, Clear Creek Preserve
Ingrid Norgaard, Environmental Water Program Staff
Randy Smith, Redding Rotary Club
Jeff Swanson, Attorney
Michael Viscaino, Landowner
Eric Wedemeyer, Shasta County Water Agency
Frank Womack, Landowner

Primary Proposal Developers

- Campbell Ingram, EWP Program Manager, U.S. Fish and Wildlife Service;
- Peter Downs, EWP Lead Scientist and Senior Fluvial Geomorphologist, Stillwater Sciences;
- Mike Parton, Senior Fisheries Biologist, Stillwater Sciences;
- Michael Fainter, Environmental Planner, Stillwater Sciences;
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- Clint Alexander, Senior Systems Analyst / Technical Architect, ESSA Technologies Ltd.

Draft Concept Proposal Peer Reviewers:

- Patricia Bratcher (California Department of Fish and Game, Region 1, Redding, CA) ;
- Mike Berry (California Department of Fish and Game, Region 1, Redding, CA);
- Matt Brown (US Fish and Wildlife Service, Red Bluff Fish and Wildlife Service);
- Sarah Giovannetti (US Fish and Wildlife Service, Red Bluff Fish and Wildlife Service);
- Gillian Harris (Bay-Delta Contract Administration Program, National Fish and Wildlife Foundation);
- Alice Low (California Department of Fish and Game, EWP Core Team);
- Wim Kimmerer (Ecosystem Restoration Program Science Board);
- Duncan Patten (Ecosystem Restoration Program Science Board).

Appendix C: Flow Release Design Tool—Clear Creek Decision Analysis and Adaptive Management Model

As a pilot demonstration of the use of decision analysis for evaluating alternative flow management experiments, ESSA Technologies Ltd. in partnership with local stakeholders and disciplinary experts developed a prototype computer simulation model to evaluate alternative flow management experiments for Clear Creek. The overall objective of the project is to provide a quantitatively rigorous design of a management experiment for a problem of immediate concern, to serve as a useful example of the application of decision analysis, modeling and adaptive management.

The Clear Creek Decision Analysis and Adaptive Management (CCDAM) model focuses on the design and simulation of flow releases from Whiskeytown Reservoir to Clear Creek, and evaluation of trade-offs inherent in different Whiskeytown operation policies for all interests (e.g., fish, wildlife, riparian, power generation, temperature control, and recreation). Development of this model required the support and participation of local experts in biology, geomorphology, hydrology, and economics that are familiar with the issues specific to flow management on Clear Creek. Part of ESSA's task in developing the model, therefore, was to work closely with these experts to ensure that the model adequately captured all relevant issues. To this end, ESSA was also responsible for facilitating technical meetings and formal workshops to engage local experts and solicit their inputs to the model. Key agencies involved include the U.S. Fish and Wildlife Service, the Bureau of Reclamation, California Department of Fish and Game, the Western Area Power Administration, and the Western Shasta Resource Conservation District.

In Clear Creek, the CCDAM model can be used to systematically compare the trade-offs between economic, biological, and learning objectives for alternative flow experiments. The model is built on a formal decision analysis framework to enable a more rigorous accounting of uncertainties. CCDAM is not intended to provide precise predictive results but to present the anticipated outcomes associated with different operational alternatives and other model assumptions, thereby allowing these alternatives to be ranked relative to one another. The basis for and details of the CCDAM model are detailed in the model design document (Alexander et al. 2003).

At present, the prototype CCDAM model generates relevant output for a wide variety of performance measures. The model developers (ESSA Technologies) have noted that more work is required to thoroughly analyze the behavior of the channel, fish and riparian submodels under a variety of management actions and scientific hypotheses, and compare model output to recent observations and expert judgment. These sensitivity analyses will help to determine which functional relationships nested within the model most significantly affect the outcomes of flow management decisions for various objectives (i.e. flood risk management, channel maintenance, riparian recruitment, fish production, power production).

CCDAM's Dam Operations, Hydrology, Power and Lake Recreation Submodel (or DOHPLR submodel) is able to evaluate the outcomes associated with large managed releases from Whiskeytown Reservoir for maintenance of fluvial processes and smaller releases from Whiskeytown at low flows for maintenance of fish habitat, especially temperature; and changes to interbasin inflows and outflows from Whiskeytown (Judge Francis Carr Power Plant (or J.F. Carr PP) inflow, Spring Ck. PP tunnel outflow). Daily data on inflows to and outflows from Whiskeytown reservoir, together with stream gage measurements at Igo below the canyon reach of Clear Creek, are the key *inputs* to the hydrology submodel; such measurements are available for over 30 water years. The hydrology portion of the submodel consists of fairly simple “volume-balance” manipulations of these historical data to approximate outcomes of future flow management scenarios. Thus the historical water years drive the behavior of the submodel, and it implicitly assumes that future climate will follow past patterns.

The key *outputs* from DOHPLR are daily average flows at Clear Creek outlet, Glory Hole, the Igo gage, and daily tributary inflows between Whiskeytown and Igo, and daily temperatures. The *performance measures* were all discussed at the January 2000 workshop, but due to time limitations quantitative approaches were only developed for foregone power revenues. Some of these performance measures are reasonably straightforward to estimate based on other studies (i.e., capital, Operation and Maintenance (O&M) costs). The flood risk for Clear Creek can be roughly assessed by examining the frequency that projected flows exceed levels considered to be damaging, under different dam operations. The changes in flood risk to the Sacramento River, and temperature implications for Shasta and Trinity Reservoirs, need to be assessed using a model at a larger spatial scale. Effects on the total suspended solids and number of visitors to Whiskeytown may be approximated by looking at the projected frequency, timing and magnitude of Whiskeytown reservoir drawdown events.

Participants at a November 2003 CCDAM training workshop agreed that the DOHPLR submodel provided a sufficiently credible link between reservoir operation actions and daily average flows to be useful in the design and evaluation of moderate flushing flow releases of interest by the EWP. This recognizes that CCDAM’s DOHPLR submodel is not intended to provide a predictive or fine time step hydraulic simulation to give detailed “event based” information. The ESSA CCDAM development team notes that other empirical approaches are more suitable for looking at specific issues such as the hourly rate of development head over the Whiskeytown Reservoir’s Glory Hole spillway as a function of different variables.