USFWS Anadromous Fish Restoration Program
CALFED Bay-Delta Program

LOWER CLEAR CREEK ADAPTIVE MANAGEMENT FORUM REPORT

Prepared by the

Adaptive Management Forum Scientific and Technical Panel

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1. EXECUTIVE SUMMARY

To ensure maximum benefits from the many millions of dollars that they spend on ecological restoration in the Sacramento and San Joaquin river watersheds, the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program (AFRP) and the California-Federal Bay-Delta Program (CALFED) have required that adaptive management be an integral component of the restoration projects they help fund. The Adaptive Management Forum (Forum) was initiated to review current restoration project designs and offer recommendations on how to make adaptive management a more comprehensive and active component of the projects.

For two days in April, 2002 the Forum's Scientific and Technical Panel (Panel) met with the Lower Clear Creek Restoration Team and consultants (Restoration Team) and reviewed the design and implementation of the channel and floodplain habitat restoration projects on Lower Clear Creek below Whiskeytown Dam. This report summarizes the comments and recommendations of the Panel, which are grouped into four topic areas:

- Ecosystem perspective;
- Project design and implementation;
- Monitoring; and
- Opportunities for adaptive management experiments.

The channel and habitat restoration effort along Lower Clear Creek is similar to the projects on the Tuolumne and Merced rivers previously reviewed by the Panel. It is based on the same conceptual model of the idealized gravel-bedded river, which consists of a single thread active channel with a vegetated floodplain at an elevation inundated by approximately the two-year return flow. The model assumes that this channel configuration and dynamic is most suitable to provide spawning and nursery habitat for the principle target species, chinook salmon. The projects are exciting and well thought through experiments in river and species restoration. The Panel compliments the Restoration Team on the success they have achieved in implementing this design so far.

As with the projects on the Tuolumne and Merced rivers, however, there seemed to be a number of design uncertainties that the Restoration Team had not addressed in sufficient detail, that planning and monitoring did not incorporate well an ecosystem approach, and that that the project was not capitalizing on the many opportunities to learn more about the dynamics of the restored system through ongoing experimentation. The nature of the following comments and recommendations for modification to the project should not be taken as reflecting any lack of enthusiasm for the project. Rather they reflect a sincere desire on the part of the Panel to help make an already good project even better.

Ecosystem Perspective

The restoration model for Lower Clear Creek is primarily ecosystem-based but many of the individual projects are specific to the primary target species, chinook salmon. Although an ecosystem perspective is evident in the project designs, it is still not well integrated into project implementation. At the most fundamental level, alternative models of fluvial geomorphology are not examined for Lower Clear Creek. Other models may ultimately be less attractive as a basis for restoration; however, consideration of the geology and geography of the Lower Clear Creek watershed suggests that the single thread, active channel model may also not fit well with local conditions. An examination of alternatives and how they might play out in Lower Clear Creek would help clarify what to expect from the single thread model.

At this stage in the implementation of a suite of projects, there is an opportunity to examine how the individual projects might be integrated within the ecological framework of the chosen restoration model. The restoration design would be greatly strengthened by consideration of how the individual projects nest into one another (at both the tributary and reach scales) and contribute to achieving the overall design and objective of restoring a fully functioning aquatic and riparian ecosystem that would need a minimum of artificial maintenance. Such an evaluation might well lead to reconsideration of the relative importance of the different projects or reveal conflicts and trade-offs that require some changes in design.

The need for better analysis and integration of project design elements was evident from the factors thought to be limiting production of chinook salmon. Five limiting factors are assumed to be important for chinook salmon:

- Flow and temperature;
- Blockage of access to good habitat by dams;
- Lack of gravel recruitment;
- Channel degradation; and
- Input of fine sediments.

A sixth factor, stranding of juveniles, was identified during project design and implementation, and is also thought to be important. The first five limiting factors were derived from analyses done many years ago. However, no evidence was presented to the Panel to substantiate that any of these factors (or any combination) constituted a critical obstacle to salmon recovery. A detailed model of the dynamics of chinook salmon in relation to the limiting factors would help establish priorities. In particular, such a model (coupled with appropriate measurements) would help establish whether stranding should be given such high priority as a mortality factor and also highlight the benefits and costs of filling back channels. The model should also incorporate the differences in ecology associated with spring and fall runs to confirm whether ignoring run timing is an appropriate decision in the restoration design.

The Restoration Team has shown a commitment to using an ecosystem-based approach by their restoration and monitoring of particular communities of organisms. The decisions about which plant species to use in re-vegetating the floodplains and the willingness to use songbird monitoring data to help modify the re-vegetation designs are good examples. However, the Panel believes that the whole project would be strengthened if an ecosystem-based approach were made more explicit. Specific objectives concerning community structure and ecosystem function should underlie decisions about riparian plantings as well as anticipated structural evolution of the channel and flooplain. Sensitive or indicator species could then be used to keep track of community development and evolution.

Project Design and Implementation

As briefly mentioned above, the single thread, active channel model provides an attractive foundation for the restoration project. The physical expectations for this model are developed reasonably well in narrative form. However, when considering the responses of aquatic and riparian communities (including fish) to the channel design, expectations become vague and insubstantial. Specific quantitative objectives and expectations need to be articulated for both the geomorphology of the restored channel and floodplain to future flow dynamics, and the linked biological and ecological attributes of Lower Clear Creek. Without quantitative objectives it will not be possible to evaluate the success of the restoration project or develop appropriate remedial actions to address areas of poor performance. A suite of numerical models ranging from physical to biological is needed to help clarify expected quantitative responses.

Although the Panel felt that the single thread, active channel model for the restoration of Lower Clear Creek was reasonable, it was concerned that the gradient and geology of the creek were not entirely consistent with this model. Historically, it seems more likely that Lower Clear Creek had both single thread and multithread reaches, that the exposed hardpan would have constrained channel migration in many reaches and that avulsive channel relocation may have been as common as incremental channel migration. The Reading Bar event may be an example of such an avulsive response and needs to be carefully analyzed in the context of the expectation of single thread channel behavior.

Future flows are critical to the anticipated geomorphic response of the restored channel. At present, flows are constrained by the design of the release structure at Whiskeytown Dam. A cost-benefit analysis of reconfiguring this release structure to give more flexibility to flow regimes in Lower Clear Creek should be a high priority.

Exactly how the channel will respond to future flow regimes and gravel augmentation are important areas of uncertainty in the model. The Panel was concerned that the ability of future flows to mobilize gravel, the amount and size fractions of gravels that would be mobilized, and their rate of movement through key reaches of Lower Clear Creek may have been misinterpreted. A more thorough analysis of the potential of the creek to redistribute gravel over a specific time frame should be possible with existing geomorphological models. Application of these models might suggest important design modifications. In addition, there is a perceived conflict between the desire for active channel movement and the dense re-vegetation of the floodplain, which will most likely reduce or constrain channel migration. This conflict represents an important unresolved trade-off in the restoration design.

The issue of mercury mobilization was brought up at the Lower Clear Creek Forum. The uncertainties surrounding this critical concern will be very important to resolve. Because gravel augmentation and the use of in-channel sediments for the channel and floodplain restoration are also components of the Tuolumne and Merced River restoration projects, this will likely become a major issue for those rivers as well. There will be more discussion about the mobilization of mercury in the final report for the Adaptive Management Forum.

Monitoring

Monitoring was much better developed for the Lower Clear Creek project than for the projects on either the Tuolumne or Merced rivers. The riparian songbird monitoring particularly impressed the Panel.

Nevertheless, as an integral part of the restoration design, monitoring on Lower Clear Creek still needs to be improved. Monitoring programs should derive from the specific objectives of the restoration and, because these objectives need to be better articulated, the Panel can only emphasize certain areas of monitoring that need to be strengthened. These should be fleshed out as the restoration objectives are clarified and augmented as any adaptive experiments are incorporated into the design.

Project–level monitoring of the physical response of the channel to the restoration seemed to be well thought through and complete. It should be noted, however, that even straightforward measurements of the channel dynamics take a lot of commitment. The Restoration Team will have to pay special attention to designing and obtaining financial support for a well-coordinated and useful set of monitoring measurements.

Re-vegetation of the floodplain is an important component of the project. Although the Restoration Team recognizes the importance of physical factors such as groundwater depth to vegetation success, measurement of these variables was not included in the monitoring design. Similarly, there is no monitoring of the shrub and herb layers in the floodplain re-vegetation, yet these communities are most likely to include large numbers of non-native, weedy species. Measuring relevant physical factors and monitoring the herb and shrub layers should be incorporated into the routine monitoring of the floodplain re-vegetation.

Invertebrate production in the riparian vegetation and stream substrate is a critical source of food for fishes and birds. Monitoring the development and dynamics of stream benthos and riparian insect communities would provide important insights into the intermediate linkages between physical restructuring of habitat and the quality of the new habitat for species and communities of concern.

Adaptive Management Experiments

As was the case with the Tuolumne and Merced River restoration projects, adaptive management was not well integrated into the initial restoration design on Lower Clear

Creek. This is understandable because these large-scale river restoration projects were initiated years ago and with funding from agencies and programs not requiring an adaptive management approach. However, as AFRP and CALFED have begun to require the use of an adaptive management approach in the projects they fund, the Panel hopes to provide some guidance for the projects on all three rivers that will address this shortcoming.

The overall restoration design for Lower Clear Creek needs to be augmented in certain ways if it is to become even a passive adaptive experiment. In addition, the project offers many opportunities for small-scale active adaptive experiments that would address important areas of uncertainty in the restoration model. To make the overall Lower Clear Creek restoration project a good passive adaptive experiment, three issues must be addressed. Two have already been mentioned above: 1) articulation of specific objectives for the restoration, and 2) implementation of appropriate monitoring to measure progress toward objectives. The third is an institutional design for incorporating information from the monitoring program into future management decisions. These additions to project design should be implemented as soon as possible.

There are many possibilities for incorporating small-scale active adaptive experiments into the project designs and the Panel has outlined a few in Section 4.4. These include experiments to address uncertainties in fluvial geomorphology, experiments to evaluate response of salmon to changes in flow during critical periods, and experiments to test the importance of physical parameters in riparian re-vegetation. As with the overall project, there needs to be an explicit plan for incorporating monitoring data and information from such experiments into future management decisions for Lower Clear Creek.

Conclusion

The restoration of Lower Clear Creek represents an exciting experiment in ecological restoration. It has been carefully designed and implemented. However, if the project is to achieve its potential as a source of information for improved river restoration project design, some modification is needed. None of these modifications will detract from the substantial progress already made or require any significant change in project objectives. Rather, if incorporated, they should strengthen the project and make it easier for the Restoration Team to understand future evolution of the channel and floodplain.

2. BACKGROUND

The U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program (AFRP) and the California-Federal Bay-Delta Program (CALFED) have contributed millions of dollars to the design and implementation of large-scale river channel and floodplain habitat restoration projects in the Sacramento and San Joaquin River watersheds. Because the field of river restoration is still largely exploratory it is important to learn as much as possible from individual restoration efforts. To increase the information gained from these projects, both the AFRP and CALFED have required that project proponents incorporate adaptive management in project planning, design, implementation, and monitoring (CALFED, 2001). So far this process has produced mixed results.

The CALFED and AFRP anticipate the following benefits from an adaptive management approach:

- Those involved in river restoration will be able to update the models and methods used in river restoration on the basis of sound, scientifically credible information and subsequent projects can then be revised or redesigned to be more effective;

- Success and failure in restoration projects will be ascribed to specific causes, thereby reducing uncertainty in future projects;

- The credibility of multi-million dollar river restoration efforts will increase as will support from project stakeholders and the public; and

- An objective process for incorporating new knowledge (from carefully designed and monitored projects) into future project design and implementation will emerge.

The AFRP, assisted by CALFED's Ecosystem Restoration Program and the Information Center for the Environment (ICE) at U.C. Davis, have initiated the Adaptive Management Forum (Forum) to advise on the incorporation of adaptive management into project design and implementation.

2.1 FORUM GOALS AND OBJECTIVES

The goal of the Forum is to assist the AFRP and CALFED achieve maximum benefits in terms of ecological restoration and improved restoration technology by helping river restoration teams and program staff plan, design, implement, and monitor large-scale river restoration efforts using an adaptive management approach.

The Forum provides assistance to river restoration teams, their consultants, and the AFRP and CALFED restoration program staff by:

- Reviewing conceptual models and habitat restoration plans,
- Helping to integrate multiple restoration projects, and
- Providing input and recommendations on project design, implementation, and monitoring within an adaptive management framework at a watershed scale.

Eventually, the Forum will also compare similar channel and floodplain restoration projects in different watersheds and recommend design, implementation, and monitoring strategies to address key uncertainties associated with these type of large-scale riverine habitat restoration efforts.

2.2 ADAPTIVE MANAGEMENT

Adaptive management is a process resource managers can use to incorporate the problem solving power of the scientific method into ongoing management actions. Adaptive management can be either passive or active (Walters 1986).

2.2.1 Passive Adaptive Management

Passive adaptive management involves the following actions:

- Think of plausible solutions to management problems,
- Subject the solutions to some form of structured analysis to determine which offers the greatest promise of success;
- Specify criteria (e.g., indicators, measures) of success or failure of the most promising option;
- Implement the option (with careful attention to the feasibility of discriminating cause and effect as the system changes) and monitor the system response according to the criteria of success and failure; and
- Adjust the design of the solution from time to time according to the results of monitoring in an attempt to make the approach work better.

2.2.2 Active Adaptive Management

Active adaptive management involves the following actions:

- Think of plausible solutions to management problems;
- Subject these solutions to some form of structured analysis to determine the probable responses of the system and how uncertainty about system response affects the likelihood of success or failure;
- Where uncertainty in system response makes it difficult to choose among solutions, design the management intervention to test among two or more alternatives;
- Use monitoring data to reevaluate the alternatives and improve understanding of system behavior and optimal management.

Both passive and active adaptive management can be integral parts of ecosystem restoration projects funded by the AFRP and CALFED.

2.3 THE STRUCTURE AND PROCESS OF THE FORUM

The Forum provides a structured way for river restoration teams and staff from the AFRP and CALFED to interact with a panel of independent scientists and technical experts that reviews the restoration projects and provides recommendations on the different phases of adaptive management, including conceptual modeling, restoration planning, project design, implementation, and monitoring. The Scientific and Technical Panel (Panel), drawn from academia and the private sector, consists of experts in adaptive management, fish biology, fluvial geomorphology, aquatic invertebrates, aquatic ecology, riparian vegetation ecology, and civil and hydraulic engineering.

Each Forum session is three days long and covers one large-scale riverine restoration effort. The first three rivers being addressed by the Forum in 2001-2003 are the Tuolumne and Merced rivers, and Lower Clear Creek in Shasta County.

The first day of each Forum session is spent touring the rivers and visiting project sites. The second day consists of presentations and discussions among the restoration teams and consultants, the Panel, and staff from the AFRP and CALFED. On day three the Panel discusses the projects, develops preliminary recommendations, and outlines the Forum report.

3. INTRODUCTION

The channel and floodplain restoration on Lower Clear Creek has goals and driving conceptual models similar to those being applied in the restoration projects on the Tuolumne and Merced rivers. The goal of all three projects is to reverse the degradation of aquatic and riparian functions resulting from decades of dredging for gold, gravel mining in the channel and floodplain, and the impoundment and diversion of water.

The design principles for each of the restoration projects are to:

- Create space for the river channel to migrate across the floodplain (usually by creating or reconstructing a floodplain);
- Rescale a single-thread channel to accommodate the two-to-three year flood (approximately);
- Adjust the texture of gravel on the bed so that it will favor Chinook salmon spawning and be mobile at flows near bankfull;
- Create at least a small amount of pool and off-channel habitat for juvenile anadromous fish rearing and other aquatic animals; and
- Re-vegetate the floodplain with native woody species and create enough micro-topography on it to provide a diversity of drainage and other habitat conditions for a variety of preferred aquatic and terrestrial species.

It is intended that after construction the channel-floodplain system will be so close to natural functioning that it will require little engineering intervention to sustain it as productive habitat.

There are some characteristics of the Lower Clear Creek project that should help make it successful in improving ecosystem functioning in the short term. These include:

- A diverse and experienced Restoration Team with a flexible, collegial, problem-solving approach and an intimate knowledge of the river system, gained through years of field studies and day-to-day management;
- An ecosystem that is already quite productive, at least during and immediately after high-flow years;
- The possibility of negotiating more favorable flow releases from the storage and diversion system; and
- Federal ownership of most of the relevant valley-floor land with no structures in the floodway.

This river has more potential than most tributaries in the Central Valley for regaining some aspects of a natural system. There is much to be gained by the agencies working through CALFED to modify the policies of regulators with regard to water releases, large woody debris, flood risk management, water quality standards, and fish stranding.

The Panel was generally optimistic about the eventual outcome of the overall restoration on Lower Clear Creek. Unfortunately, it was difficult to reach many specific conclusions about the success of the current projects because of the limited technical information provided during the presentations. The necessary details about the exact nature of the evidence, the degree to which the conceptual models were backed up with technical information from this river, the significance of other factors not treated in the restoration, the nature and intensity of modeling, the specific expected outcomes of applying the broad conceptual model in this particular river, etc. were not well covered. The presentations on the second day, in particular, were mainly qualitative overviews that seemed designed to promote the project rather than solicit detailed technical discussion. The Panel members often found themselves having to infer why something was being done, or how designs were made. Some critical issues were revealed only in conversations during breaks in the presentations. This was also a feature of the Forum sessions for the Tuolumne and Merced rivers. It is understandable that presentations about these projects, when made in a public, inter-agency meeting, tend to evolve into sales pitches for the project and the proposed approach, rather than being open, pragmatic discussions of technical issues. However, the lack of technical detail on the projects has made it difficult for the Panel to be as helpful as it might otherwise have been. Therefore, some of the comments and recommendations in this report may reflect the lack of detailed technical information presented at the Forum rather than any shortcoming in the project.

A strong and rich coordinating conceptual model that is based on fluvial geomorphology of a single thread, freely migrating, alluvial river supports the restoration projects on Lower Clear Creek. In Lower Clear Creek, however, conditions are pushing the limits of this underlying conceptual model. The project designers used for their restoration model air photos of the valley floor taken in 1952 (post-dredging and during gravel mining), and they realize that they are working at the limits of conditions required for a single-thread channel and that a low-sinuosity, multi-threaded channel may develop, at least episodically. The concept of a freely migrating channel is also being pushed to its limit here because there is a shortage of gravel to provide new sediment for the river, the spectrum of flows is regulated and far from natural, and the river is constrained geomorphically by bluffs and extensive hardpan. The probable effects of these constraints have not been considered in any formal way in the application of the geomorphic conceptual model to the channel design. Nor have expected outcomes been defined. The Restoration Team needs to ask the process level question – "how do you think the river represented by the conceptual model will work in Lower Clear Creek?" The designers need to base their analyses and predictions on a more detailed level of thinking about which processes will work and how they will work on Lower Clear Creek. They need to make the model more detailed given the real constraints on processes such as bank erosion, bar growth, and scour. Some of these predictions will require greater use of mathematical modeling than was presented during the Forum.

The intense focus, at least in the presentations, on the geomorphic basis for restoration, left the Panel to wonder what formal analysis and measurement had been conducted on factors such as flow, water temperatures, food supply, and off-channel habitat, all of which received only passing, and sometimes reluctant mention by the Restoration Team, even under prompting.

The Forum occurred at a time in the evolution of the restoration project on Lower Clear Creek when more formal analysis is just beginning to take place. The Lower Clear Creek Decision Analysis Model (CCDAM), being developed by ESSA Inc., introduces ways of assimilating field measurements into a prediction scheme, ways of predicting the response of riparian and floodplain vegetation to alterations in hydrology, channel cross section, and floodplain micro-topography (all design variables), and ways of incorporating risk analysis even in less-quantifiable realms using a Bayesian Belief Network and a Delphi Process.

Mobilization of mercury was brought up as an issue for the first time at the Lower Clear Creek Forum. This will likely become an issue for the Tuolumne and Merced River restoration projects also because gravel augmentation and use of in-channel sediments for restoration are components of these projects as well. It will be very important to resolve the uncertainties surrounding mercury, especially the critical concern of mobilization. There will be more discussion of this issue in the Adaptive Management Forum Final Report.

There is great potential for significant benefits from the restoration projects on Lower Clear Creek. There is a need for more formal, quantitative analysis of options and expected outcomes, but such efforts are beginning. The Panel also observed a greater commitment to, and experience with, monitoring among the members of the Lower Clear Creek Restoration Team than in other projects reviewed. This bodes well for building an informed adaptive management approach into the restoration program.

4. RECOMMENDATIONS

The channel and habitat restoration effort on Lower Clear Creek provides not only an excellent opportunity to study the effectiveness of this project but also for developing predictions that can be transferred to large-scale restoration projects on other rivers.

The recommendations on the channel and floodplain restoration projects along Lower Clear Creek are grouped into four topics:

4.1 Ecosystem Perspective
4.2 Project Design and Implementation
4.3 Monitoring
4.4 Opportunities for Experiments

Not all of the following recommendations can or should be implemented by the Restoration Team.

4.1 ECOSYSTEM PERSPECTIVE

The channel and habitat restoration projects on Lower Clear Creek are likely to be highly successful in restoring salmon runs because the system has responded favorably to increased flows in recent years. Elements of the project contribute a broader, ecosystem-based approach, namely the restoration of riparian vegetation and the focus on creating songbird habitat.

However, an ecosystem-level conceptual model that addresses the linkages between reach level projects and the response of Lower Clear Creek over its entire length is needed to guide the overall project. This model was not adequately developed, although the basic components were obviously envisioned by the Restoration Team. As a result, tributary-wide objectives were either lacking or vague. Evaluation of the effectiveness of the entire Lower Clear Creek restoration effort will require the articulation of an overarching conceptual model and establishment of tributary-wide objectives to which the individual projects can be clearly related.

Five factors were identified as potentially limiting salmon production in Lower Clear Creek and these factors appear to drive the design of the restoration projects. However, these factors were identified approximately 20 years ago and may need to be re-evaluated. Considering the relatively long time since they were originally identified, it is possible that changes have occurred in the watershed and stream channel. It is also possible that understanding of the linkages between physical processes and ecological functions, or at least their relative priority, may have evolved. In addition, no model of chinook salmon life history dynamics was presented that could be used to evaluate the limiting factors and provide a basis for measuring improvement from the restoration projects.

In addition, as currently designed, the restoration considers only the response of flagship species such as salmon, cottonwood trees, and songbirds. This is understandable at the design and early implementation phases of the project. However, the project has created the opportunity to measure the response of a range of other ecosystem indicators, such as sensitive species (e.g., invertebrates, amphibians, native fish), community types (e.g., floodplain understory vegetation), or functional processes (e.g., aquatic invertebrate production). These kinds of measurements would allow the Restoration Team to learn how broader ecosystem components respond over the near and long term to the restoration projects and to integrate this knowledge into an ecosystem perspective to river restoration.

It is important to note, however, that ecosystem-based management and analysis does not imply just monitoring some more species and some ecosystem-level processes. It really boils down to developing and using a conceptual ecosystem model that properly ties species and processes together and that links the restoration projects into a coherent whole.

4.1.1 Develop conceptual models and restoration objectives that integrate the projects for the entire tributary and also integrate projects within reaches.

Conceptual Models

The project needs a clearly articulated, overarching conceptual model that ties all the individual projects together and illustrates the tributary wide objectives to which the individual projects are expected to contribute. Without an overarching conceptual model and restoration objectives for the entire creek, the interrelationships between various components of the restoration effort will remain unclear and the overall efficacy of the restoration effort cannot be planned and evaluated adequately.

Quantifiable Objectives

Objectives need to be specified and quantified for the positive effects the Restoration Team expects to achieve from the restoration projects. These objectives should refer to both project specific expectations and tributary wide expectations. Few of the Lower Clear Creek restoration projects were described to the Panel in terms of specific quantitative objectives. Even at the level of an individual project, the expected or desired biological response was often only expressed in a general manner, such as reduce stranding or provide improved spawning habitat. The extent of improvement expected from a specific action was not quantified.

Setting quantitative objectives is generally somewhat subjective, although it can be aided by quantitative modeling of the system. To measure the expected change, the key physical-biological interactions anticipated in the conceptual models need to be identified and monitoring approaches must be designed that enable the quantification of these processes. This procedure for developing objectives is applicable at all spatial scales, providing that the interactions between reach level and tributary-wide responses are appropriately represented in the conceptual models.

Multiple Scales

In articulating the conceptual models and quantitative objectives, the Restoration Team should ensure that they address the multiple spatial scales of the project and incorporate a nested design. This approach enables the system response to projects implemented at the reach scale to be related to the overall objectives for the river and floodplain ecosystems. Similarly, the responses to restoration actions at particular sites within a reach are nested within, and relate to, the objectives for the reach. Such nesting creates an interconnectedness among projects that is critical to the evaluation of overall effectiveness of restoration.

4.1.2 Re-evaluate the original five limiting factors for salmon recovery.

The limiting factors appearing to drive the design of the current restoration projects on Lower Clear Creek were identified approximately 20 years ago. These are:

- Stream flow and water temperature;
- Fish passage at McCormick-Saeltzer Dam;
- Stream channel degradation, including riparian vegetation encroachment;
- Lack of spawning gravel recruitment; and
- Fine sediments from erosion.

No information was provided to the Panel indicating that these limiting factors were reexamined in developing the current projects, except that stranding of juvenile salmon now seems to be an issue for regulators and has been incorporated in project design and monitoring.

It might be necessary to conduct additional studies to confirm that the most important obstacles to salmon production in the creek have been identified. Considering the relatively long time period since the original limiting factors were identified, it is possible that changes in the watershed and stream channel might have brought other factors into play or reduced the importance of some factors. In addition, the general understanding of physical processes and ecological linkages has evolved in ways that might change how these factors could be viewed or prioritized.

For example, aside from the brief presentations about the Strategic Fuels Reduction Plan, little or no information was provided about the magnitude, causes and implications of fine sediment introduction due to watershed erosion, or any actions to deal with the problem, if it exists. The Panel was not shown convincing field evidence or measurements that fine sediment was a significant problem. Yet, if the problem exists there should be concrete, visible, circumstantial evidence of it in the field.

In addition, factors that were not included in the original list may, in fact, be limiting the ecological health of the system. Food resource limitation might impede salmon population recovery, but the Panel was unable to evaluate this possibility because information on this potential limiting factor was not presented in any detail. Assessment of aquatic invertebrate production and food resources requires careful study, and new studies may be needed to increase confidence that food production does not limit salmon recovery. Further, as the restoration proceeds, and salmon numbers presumably increase, the factor(s) limiting salmon production may change. For example, addition of gravel for salmon spawning may not generate commensurate aquatic invertebrate production. Terrestrial inputs of invertebrates (from riparian vegetation) can fuel salmon growth, and this may become relatively more important as restoration proceeds. A monitoring program to estimate annual invertebrate production would be a valuable addition to this project.

4.1.3 Develop a detailed model of salmon life history in Lower Clear Creek and then implement studies that will identify the key mortality factors.

A more thorough understanding of the ecology of the salmon in Lower Clear Creek would provide a much better basis for project prioritization and development of procedures to evaluate project effectiveness. There is relatively complete information on adult chinook salmon abundance and distribution and smolt output. However, there is very little information on other aspects of the freshwater life history of these fish. Currently the only aspect of freshwater rearing being addressed by the restoration projects is the perceived problem with stranding of fry on floodplains. There is apparently no information that indicates the severity of this problem nor is there any monitoring currently ongoing to evaluate the relative significance of this source of mortality as it relates to other possible limiting factors. If stranding is not a significant contributor to mortality during freshwater rearing, addressing this issue by designing floodplain morphology and manipulating flows will have little impact on survival of the fish to smolting (see Section 4.1.4).

Development of a detailed, quantitative life history models for chinook salmon in Lower Clear Creek would help to identify potentially significant factors affecting the performance of the fish. An existing model could be adapted to Lower Clear Creek (models have been developed by Stillwater Sciences, Lou Bottsford, and possibly Wim Kimmerer, etc.). Future monitoring efforts and experiments could be designed to evaluate the relationships and interactions identified in the conceptual models (see sections 4.4.1 and 4.4.2). Information from these investigations would be very valuable in identifying future restoration projects and in designing efficient procedures for evaluating project effectiveness.

4.1.4 Re-evaluate the whole "stranding" issue.

As mentioned above, stranding was the one aspect of freshwater rearing habitat of juvenile chinook salmon being addressed by the restoration projects on Lower Clear Creek. However, no information was presented that demonstrated the significance of this mortality process. Stranding on the floodplain is a very visible source of mortality, but other sources of mortality, such as predation or poor water quality, may be of greater significance. Before extensive and expensive actions are taken to alleviate stranding, some evaluation of its importance in determining productivity of the chinook population should be undertaken. This evaluation should be included as a part of a comprehensive effort to better understand the factors influencing the fish during freshwater rearing.

4.1.5 Re-evaluate the need for separating the salmon runs.

The presence of both spring and fall chinook salmon in Lower Clear Creek complicates the process of evaluating the response of this species to restoration actions. These two populations are segregated both temporally and spatially, therefore, the habitat factors that influence them and their response to restoration efforts may be different and this will need to be taken into account in designing the restoration projects. However, there was no indication that the differential habitat requirements of these two stocks were being considered in the development of the restoration project designs. Some effort should be made to identify the habitats used by the spring and fall runs and to determine their primary factors of mortality. If the habitat requirements and factors contributing to mortality differ for these two stocks, the restoration actions to which they best respond may be different.

4.1.6 Gather information on other sensitive and important aquatic and terrestrial species, and evaluate how the channel and floodplain reconstruction and re-vegetation designs will affect them.

Additional species should be monitored in order to evaluate the ecosystem-level success of the restoration project. In the stream, sensitive aquatic species could include certain benthic insects or native non-salmonid fishes. Terrestrially, plant species indicative of a diverse, native riparian understory should be monitored. The songbird-monitoring program is a real strength because it provides concrete measures of habitat value, biodiversity, and trophic structure. Other sensitive animal species might be worth monitoring as well.

4.2 PROJECT DESIGN AND IMPLEMENTATION

Considering the extent of public ownership and lack of urban and agricultural encroachment into the floodway, the Lower Clear Creek restoration project offers an exceptional opportunity to re-create an ecologically productive and diverse stream corridor that can pass the upstream water and sediment supply with limited impact to public safety. The Restoration Team has also done an excellent job of producing projects that are likely to generate concrete recognizable benefits.

In general, the channel and floodplain restoration designs that have been developed and that are being implemented to achieve these objectives are well thought out in a qualitative way, and the overall objectives of the designs are reasonable. The specific physical objective of restoring a single-thread alluvial channel morphology, which is properly sized to the anticipated future sediment transport and flow release regimes, and which interacts with a functional floodplain, seems very appropriate for the highly disturbed reaches being restored.

There are, however, several specific assumptions related to the geomorphic and ecological objectives of the projects that were used in developing the designs, which do not appear to be supported by the available information. As a result, certain aspects of the design may not achieve the desired objectives. The conceptual model of a free-flowing river that is being used in the design provides a reasonable general framework for the restoration activities, but the actual constraints on Lower Clear Creek, including hardpan underlying portions of the project site, the lack of gravel supply, and limitations on the available flows to create a disturbance regime, limit the potential for achieving many of the alluvial river attributes that are intended in the design.

The Restoration Team did not present comprehensive hydraulic and sediment transport models (or at least a means of quantifying the sediment budget) as a component of the background studies on which the engineering design was based. The lack of reference to such models for the reach between Whiskeytown Dam and the restoration sites brings into question the validity of many of the assumptions regarding the sediment supply to the restoration sites and the hydraulic capacity of the restored channel. Based on the documents and material that were provided in advance to the Panel, and the presentations at the Forum, there also appears to be a fundamental lack of connection between the physical models and the expected biological responses. For example, no information was provided that clearly established a specific linkage between the physical manipulation of the channel, several of the limiting factors, and the expected changes in fish production (aside from the qualitative assumption that reconstructing the channel and floodplain according to the plan will create the desired habitat).

4.2.1 Consider other conceptual models for the channel and floodplain reconstruction designs.

One of the geomorphic objectives is to restore the channel to a "historical meandering/semi-braided morphology" (McBain and Trush, 2001). Based on information presented, this model for the channel morphology appears to be based, at least in part, on conditions that are evident in aerial photographs taken in the 1950's. Considering that the channel was highly disturbed by placer and dredge mining during the late 1800's and early 1900's, the channel morphology seen in the 1950's photography is unlikely to be an appropriate model for the restored channel under future hydrologic and sediment supply conditions.

Based on the characteristics of the watershed and valley, it is likely that, prior to mining, Lower Clear Creek was a low sinuosity gravel bed stream that had an irregular pattern of instability consisting of a series of moderately braided reaches separated by more stable single thread reaches similar to the wandering gravel bed rivers described by Desloges and Church (1989). In contrast to meandering channels where there is a systematic change in planform through time that results in a diminishing radius of curvature of individual bends that eventually leads to bend cutoff (Fisk, 1947; Harvey, 1988), planform changes in wandering channels tends to be irregular and controlled by episodic flood flows. During periods between the large, sustained channel-altering flows, a small amount of sinuosity develops as a result of localized bank erosion.

Whether or not these morphologic characteristics are appropriate for the regulated hydrology and reduced sediment supply to Lower Clear Creek has not been clearly established. Even with an ambitious gravel re-introduction program, it may not be possible to deliver sufficient quantities of gravel to the restored reaches to maintain the "semi-braided" morphology that is desired, and the very ambitious re-vegetation program will probably result in a floodplain surface that is very stable. As a result, with the regulated flow regime that is likely to continue into the future, the restored channel may become locked in place with little ability to migrate across the floodplain.

A detailed hydraulic analysis to quantify the expected performance of the proposed channel design and gravel re-introduction is justified. This analysis should be conducted utilizing the expected post-dam hydrologic flow regime coupled with appropriate sediment transport computations. The hydraulic design coupled with proper interpretation of the most geomorphically appropriate channel form will lead to the selection of the most appropriate channel to achieve project objectives.

4.2.2 Consider using high-resolution topographic surveys to develop the project designs.

One of the largest costs in constructing river restoration projects is the on-site earthwork, including regarding of the existing materials, and the purchase, transport and placement of very large volumes of gravel and finer-grained overbank material. Even small errors in estimating the original volume of the source and fill material in the design phase can lead to large differences in actual construction cost. As a result, accurate topographic surveys in the design phase are critical to insure that the construction cost estimate and bids are reasonable. Information presented at the Forum and in some of the review materials included recommendations that earthwork volume calculations be performed based on high quality ground surveys, and that mapping based on photogrammetric and bathymetric techniques not be used. Justification for this recommendation includes the observation that bathymetric soundings typically pick up the top of the muck layer in ponded areas, and not the functional bottom of the ponds, and that vegetation can cause inaccuracy in the topographic mapping of subaerial portions of the site. Both reasons are well founded, and particularly with respect to the problem of identifying the thickness of the muck layer, remote-sensing techniques can certainly lead to inaccuracy.

On the other hand, bathymetric and photogrammetric mapping are standard techniques that are widely used for this purpose, and when performed to appropriate standards of accuracy (e.g., National Map Accuracy Standards, National Standards for Spatial Data Accuracy) during times of the year when vegetation does not obscure the ground, these methods have consistently yielded accurate maps and terrain models. The National Map Accuracy Standards, for example, require that a suite of well-defined points be tested for both vertical and horizontal accuracy. The standard requires that at least 90 percent of the tested points be within allowable tolerances that are specified based on the horizontal scale and contour interval of the maps. Considering the added cost of mapping the site using only high quality ground surveys, it is questionable whether adoption of the design team's recommendation is justified and cost-effective.

The decision to utilize ground surveys in-lieu of photogrammetric surveys will always be based on the relative cost of the surveys versus the necessary accuracy for the intended method of construction. It must also consider the intended method of pay that will be spelled out in the construction documents. Earthwork that is based on a bid must be accurate enough that bid quantities will be within allowable contract tolerances (typically 15 to 25%) to prevent construction cost adjustments. In the case of bid construction, ground surveys may be justified or the method of pay adjusted to reflect the inaccuracies associated with the surveys. The initial ground survey method must be in agreement with the measure and pay section of the contract since post construction surveys may be used to determine the specific pay amount. However, projects that are extensive, and where survey accuracy can be verified by ground truthing and where vegetation will not significantly affect topographic mapping, may be more cost effectively surveyed by aerial photographic techniques. The method of pay must be explicitly described so that the appropriate survey can be determined. In the case of tailings piles, it is very difficult to survey them by any method. Much more important is their volume change from their present condition to their final placed condition. A percentage of the discrepancy in cut and fill volume can likely be attributed to borrow shrink or swell during placement.

The design team is encouraged to re-examine the mapping standards that were used to insure that they are sufficiently accurate for the intended purpose. The team is also encouraged to consider supplementing the remotely sensed data using additional, but less intensive, ground surveys in local areas where inaccuracy is likely in the remotely-sensed data on future design efforts, rather than relying only on relatively expensive, complete ground surveys of the sites.

4.2.3 Clarify the assumptions about gravel storage and movement in Lower Clear Creek.

The lack of gravel supply to the restoration sites is attributed to two primary factors: 1) direct gravel extraction at the Lower Clear Creek site, and 2) cutoff of the upstream sediment supply by Whiskeytown Dam. The removal of "several hundred thousand cubic yards" (McBain and Trush, et al, 2000) of material by instream mining undoubtedly had a significant effect on the morphology of the channel, including channel incision, exposure of the clay hardpan, and removal of portions of the floodplain. A conceptual model was presented at the Forum indicating that the steep, confined bedrock reaches upstream from Lower Clear Creek Road bridge stored significant quantities of sediment prior to construction of Whiskey Town Dam in 1963. The model further indicated that construction of the dam eliminated the upstream bedload supply and the remaining stored gravel within this reach has since been transported downstream, creating a significant deficit in the gravel supply to the Lower Clear Creek site.

Given the hydraulic characteristics of the steep, bedrock confined channel, the relatively short time-frame since construction of the dam (less than 40 years), the reduced magnitude and duration of flood flows, and the relatively slow rate at which gravels typically move through a river system, it seems very unlikely that trapping of sediment behind Whiskeytown Dam has yet had a measurable effect on the gravel supply to the restoration sites. As mentioned in Section 4.2.1 above, a sediment budget for the reach between the dam and the restoration sites that is supported by a hydraulic model would provide a means of quantifying the sediment supply to the restoration sites and would assist in designing the gravel augmentation program to deliver an appropriate quantity and size-range of material. In addition, more detailed hydraulic models of the restoration sites would significantly improve the confidence that the design will function as intended.

At the Reading Bar site, for example, the channel was intended to have a bankfull capacity of 3,000 cfs, but significant overbank flows occurred soon after the reach was constructed at a discharge of about 1,000 cfs. A properly formulated hydraulic model of the site would have identified the limited capacity at the overflow area, which would have provided an opportunity to identify this apparent hydraulic limitation before construction of the project.

4.2.4 Re-analyze what happened as a result of the overbank flow at Reading Bar.

The erosion event at the Reading Bar project site highlighted an important conflict in the proposed design concept. A naturally functioning channel was the target of the design, yet when unexpectedly low discharge overflowed onto the floodplain and a new channel eroded into the overbank, it was viewed negatively and the bank was adjusted to prevent this from happening again. This event should be carefully evaluated to determine if remedial action really was required and what should be done differently in response to future erosion events. Was more hydraulic analysis necessary? What form would the new channel have created and why did it avulse at the particular cross section? Did the new channel that began to develop before the flow was re-directed back to the designed channel result in recruitment of riparian vegetation? Without immediate repair, would this new channel have resulted in a situation that was beneficial or harmful to the project objectives? In adaptive management, these kinds of situations should be viewed as opportunities to evaluate the actual performance of the design and to learn more about the response of the modified system. The Restoration Team should be supported to mount opportunistic studies of such events and their ecological consequences. Designers, agencies, and funding agents need to be able to view these newly constructed fluvial systems as highly variable with a large number of unknowns. The design provides a visual representation of the designers' best hydraulic and biologic portrayal of what the riverine system, driven by a complex array of variables, should be. In light of the complexity of each system, unpredicted events like that at Reading Bar provide a valuable opportunity for learning and should not be an occasion for assigning blame.

4.2.5 Improve the linkages between ecosystem science, engineering design, and project construction.

None of the projects that the Panel has reviewed has proceeded on the basis of a clear definition of the linkage between the scientific studies, project engineering and design, and project construction. The most important linkage is that between the restoration design and the predicted ecological result. The Panel was uncertain about the range of expected results from the remedial construction. In some instances, such as the removal of Saeltzer Dam, the expected result was salmon passage and colonization of spawning areas upstream. The linkage was not so clear, however, in the case of adding spawning gravels to the channel. Adding spawning gravels at a few select locations and expecting the sediment to move through the system and deposit in opportune areas to create new spawning habitat is likely to meet with some success near the addition points. How the gravels will migrate downstream from these sites to create spawning habitat elsewhere is not so clear. Hydraulic models/analyses that would show where and when deposition is likely to take place downstream and confirming that bars and riffles will form as suspected were not presented. Nor was there a quantitative analysis of the effect of increased spawning habitat on salmon populations.

The designers project that gravel infusion will create new bar and riffle forms downstream because they assume that the river is sediment starved. It also appears that the present channel is oversized with respect to its sediment and hydraulic carrying capacity and is being made narrower by vegetative encroachment into the channel. If we assume, simply for illustration, that a 3-foot deep channel would eventually decrease from 60-feet wide to 45-feet wide, a fill volume of approximately 9000 cubic yards of material would be required per mile. How long would it take under present hydraulic conditions to move an amount of gravel necessary to form spawning areas in a one-mile reach of the stream? Is it better to let the river create the bar forms or is it more cost effective and productive to construct actual bar and riffle forms to accelerate spawning opportunities? How much new spawning gravel is needed over what time frame and what is the expected consequence of the new spawning area on salmon abundance? Questions or uncertainties regarding the science are usually never entirely completed prior to commencement of design, however all of the design considerations must be completed before construction unless a phased construction approach is taken.

The example above can be, and probably has been, applied to other project area concerns. It may be that these science-design-construction linkages have been made and the Panel's limited knowledge of the projects did not allow a detailed analysis of the abundant background data that is probably available. And it is not the place of the Panel to dictate the design of the projects. However, there must be linkages with accurate assessment of the problem(s), determinations of the best methods of rectifying these problems, and conclusions concerning the most appropriate method(s) and time frame(s) for implementing the remedies. In addition, the most cost effective solution may not be the implementation plan that provides the best opportunities for salmon recovery.

4.2.6 Address the conflict between the dynamic channel concept/design and the re-vegetation design and implementation.

Flows are no longer of sufficient magnitude or frequency on Lower Clear Creek to mobilize the streambed and thus prevent woody vegetation from encroaching on the channel. The encroachment of alder and other woody riparian species onto portions of the formerly active channel is a clear indication of comparatively stable flow and channel conditions. Vegetation encroachment and the active establishment of riparian trees on newly created floodplain surfaces will, under the current flow regime, promote increased channel stasis by increasing frictional resistance and soil-binding by living roots. Thus, the current flow regime and active re-vegetation of the flood plain are at cross purposes with the concept of a dynamic channel and the hypothesized diverse ecological benefits that derive from fluvial geomorphic processes such as bed scour, bank erosion, and point bar deposition.

The concept of a geomorphically dynamic channel is critical to self-sustaining aquatic and riparian ecosystems, and it is clear that such a vision is critically dependent on restoring geomorphically effective floods (Costa and O'Connor 1995). Modifying the glory hole outlet on Whiskeytown Reservoir offers the future possibility of prescribing and implementing geomorphically effective floods (see Section 4.2.9). In the absence of such floods, the patch heterogeneity that supports high biological diversity in less regulated systems, will be comparatively limited along Lower Clear Creek, or would need to be sustained by long-term, and likely costly human intervention.

4.2.7 Develop a plan to control weedy exotic species in the re-vegetation plots on the reconstructed floodplain.

Riparian corridors are generally more prone to invasion by exotic species than are upland environments and typically host relatively high percentages of non-native species ranging from 25-30% (Planty-Tabacchi et al. 1996). Additionally, in riparian environments, young communities, communities that are disturbed, and patches that have high edge to area ratios are especially sensitive to invasion by exotic plants. Given the extensive surface disturbance associated with restoration of riparian floodplain along Lower Clear Creek, it would be important and instructive to monitor the establishment and spread of weedy exotic plants, and perhaps to have in place a plan to control an invasion in its early stages.
Once established, non-native herbs can persist on sites by maintaining non-native seed banks and creating soil and litter conditions that discourage native species. The successful establishment of a deciduous, woody over-story at the restoration site may not be insurance against invasion by exotics. For example, in the Pacific Northwest, alder flats along the Hoh River are heavily invaded by exotics, presumably because of favorable light conditions that exist for understory species following leaf-fall.

4.2.8 Conduct a cost-benefit analysis of reconfiguring the outlet structure of the dam and compare that with implementing the re-vegetation designs.

Encroachment of riparian vegetation onto portions of the active channel suggests that achieving the objective of restoring a dynamic channel throughout much of the restoration reach of Lower Clear Creek is contingent upon the ability to produce geomorphically effective flows below Whiskeytown Dam. Evaluating the economic feasibility of modifying the outlet structure at Whiskeytown Dam, to provide prescribed flood-flows downstream, should be a high priority for this restoration effort. Such a feasibility study would need to balance the long-term costs of forgone services, such as power generation, against the long-term benefits derived from restoring a number of self-sustaining ecological processes. The economic values of restoring these processes could be roughly approximated by the initial costs of the restoration effort, in addition to the long-term costs of artificially maintaining ecological integrity in the absence of geomorphically effective flows.

4.2.9 Evaluate the benefits and risks are of filling the back channels and eliminating that habitat.

Although there is a perceived risk of retaining these habitats, the rationale for filling in existing back channels in the channel restoration is not strong. Because previous studies show that fish use them, eliminating them clearly destroys habitat. A clearer demonstration of the benefit to salmon of filling these existing channel features is needed. Further, it is likely that such low-energy habitats also support other species, perhaps locally-rare ones, such as amphibians or native non-salmonid fish. The risk to the broader biotic community of filling in these habitats needs to be thoroughly evaluated.

4.3 MONITORING

Despite some of the problems noted earlier in this report, there are numerous aspects of the monitoring design and implementation on Lower Clear Creek that are superior to monitoring on the Tuolumne and Merced rivers, which were also reviewed by the Panel. Assessment of riparian re-vegetation and physical response of the channel to floodplain and channel reconfiguration at the project level are more complete. The smolt sampling and spawner survey programs on Lower Clear Creek also provide the foundation for a more comprehensive biological sampling program that would provide important information for evaluating projects and prioritizing future restoration projects.

As currently designed, however, the monitoring program will not allow the project team to distinguish the effect of individual projects on the overall tributary response. In addition, data are not being collected that will allow evaluation of the response of aquatic biota other than salmon to changes in the channel form or floodplain conditions. A very positive aspect of the monitoring program, however, is the fact that the link between habitat changes caused by restoration and the response of the riparian bird community is being evaluated. In fact, the songbird monitoring on Lower Clear Creek is the best example of an attempt to link restoration actions with a biological response of the target organisms that the Panel has seen during the Adaptive Management Forum. Unfortunately, there is no comparable monitoring plan for chinook salmon or other fishes or aquatic biota.

4.3.1 Measure the key physical factors that drive biotic response in the re-vegetation plantings.

Depth to groundwater, surface water elevation, and soil moisture exert strong control on the survival and growth of re-vegetation plantings, as well as plants that establish naturally. Measurement of these variables should be integrated with the ongoing monitoring of actively or naturally established vegetation and some scheme for analyzing the results to make them transferable to other sites should be developed.

An efficient design for gathering such data is to locate transects or plots for monitoring vegetation in close proximity to stream hydraulic cross-sections, groundwater wells, and access tubes for soil moisture probes, all surveyed to a common benchmark so that hydraulic calculations could be made for purposes of generalization and transfer to other sites. To maximize the opportunity for adaptive learning, monitoring plots or transects should be designed as experiments to test explicit hypotheses about the relationship between vegetation response and the physical variables. For example, by monitoring depth to groundwater together with survival/growth of riparian tree plantings over a range of floodplain elevations from channel edge to upland boundary, one could explore specific questions concerning depth to ground water and riparian trees, such as:

- **Is ground water limiting establishment, survival, and growth of riparian trees?** Before implementing restoration plantings or passive establishment experiments, monitor ground water depth. If needed, excavate flood plain surfaces such that water tables are near plant rooting zones. Monitor depth to groundwater (monthly measurements, at a minimum) across the lateral gradient from the channel to the floodplain/upland boundary; vegetation response variables, such as cover, density, and/or height of riparian trees.

- **What pattern of flood timing and draw down rate are needed for establishment of riparian pioneer trees and shrubs, notably cottonwoods and willows?** During wet years when large spring flood pulses are to be released, release the floods at an appropriate time relative to seed dispersal and impose a recession rate within the limit of daily root growth of cottonwoods and willows. Monitor post-flood recession rate of stream flow and ground water. Monitor abundance (density) and size (height) of riparian tree seedlings in recruitment zones.

4.3.2 Monitor the shrub and herbaceous layers in the re-vegetation plots.

Development of a species rich, structurally diverse shrub and herb layer is critical to the restoration and maintenance of a biologically diverse riparian ecosystem. For example, patch-specific bird diversity is directly related to the structural and compositional diversity of the herb and shrub layer. Thus, quantifying the development of these layers, even if they are not part of the active re-vegetation effort, should be an important element of a post-restoration, vegetation-monitoring plan. Monitoring of these layers could be done in conjunction with the sampling of the woody trees and could be as simple as recording species presence/absence for herbs in plots and cover, by species, for shrubs along established transects. Likewise, monitoring could be designed to answer specific questions experimentally (see Section 4.4.6).

4.3.3 Consider monitoring invertebrate production.

It would be useful to measure or monitor the response of invertebrates to the habitat restoration projects. Invertebrates are important sources of food for salmon, and they can be expected to respond in a predictable way to the habitat enhancements. Development of the insect community in the riparian vegetation is also important for the bird community.

Measures of annual secondary production would be ideal; however, this is probably not feasible given the effort required to gain such information. Alternatively, standing stock biomass could be collected at critical times of the year to assess production in a more static fashion. This could be done in a stratified random manner for different types of habitat (e.g., riffles, backwaters, etc.) This information would contribute to long-term understanding of the response of an important trophic level to geomorphic habitat restoration.

The value of the invertebrate data could be enhanced by coupling them with an evaluation of the diet of the juvenile salmon. As with the invertebrate data, the fish diet should be characterized for different habitat types (e.g., main channel, floodplain habitats, etc.). The effect of various restoration efforts on food availability for the fish will depend on the productivity (or biomass) response of those taxa that are most important in the diet of the young salmon. As the dietary preferences of the fish will change as they grow, the invertebrate response should be evaluated over the entire period during which the fish are rearing in the river.

4.4 OPPORTUNITIES FOR ADAPTIVE MANAGEMENT EXPERIMENTS

As was the case with the Tuolumne and Merced River restoration projects, experimentation to resolve uncertainties in restoration design were not yet a visible component of the Lower Clear Creek project. The Panel felt that a huge opportunity to improve the technology of river restoration would be missed if some of the uncertainties surrounding these large-scale channel and floodplain habitat restoration projects are not investigated. The Panel felt that there were many opportunities for experimentation within the context of the current and proposed projects on Lower Clear Creek and that the Restoration Team could capitalize on the many small and medium scale experiments that could still be done to explore uncertainties in their restoration design.

The opportunities run the gamut from geomorphology (gravel augmentation, use of woody debris, floodplain topography, etc.) to fish (species, habitat use, food production, predation, growth, survival, etc.) to vegetation (community structure, restoration methods, regeneration, non-natives, etc.) to mercury mobility, to invertebrates and other species, etc. Examples of experiments that the Panel felt could be incorporated into the restoration design without compromising any of the broad objectives of the program are described below. It should be noted, however, that these examples are presented for illustration and constitute only a sample of some of the opportunities that were most obvious to the Panel.

4.4.1 Investigate the relationship between increased flows and how the fish respond, especially the increase in spawning.

During the Lower Clear Creek field tour it was noted that a large increase in the number of chinook salmon occurred during a year when flows were unusually high. The cause of this increase was assumed to be attraction of the fish from the Sacramento River to Lower Clear Creek by the higher discharge. However, no attempt was made to explore alternative explanations for this phenomenon. The fact that high flow caused such a dramatic increase in adult spawners may indicate something very fundamental about the way in which chinook salmon utilize Lower Clear Creek. Understanding why salmon moved into Lower Clear Creek at high flow may aid in the design of restoration projects. If additional water is absolutely necessary to attract fish to the system, many of the current efforts to improve habitat may not be effective. However, if some factor associated with the increase in discharge was the key in triggering migration into Lower Clear Creek, e.g., decreased water temperature, elevated turbidity, access to otherwise dry spawning areas, etc., these factors might be incorporated into the design of future restoration projects.

The high spawner density also may have provided an opportunity to evaluate spawning and rearing habitat capacity in Lower Clear Creek. If habitat is truly limiting production in this system, smolt output would be expected to be similar to that observed in other years with lower numbers of spawning fish. However if smolt numbers produced by this cohort were substantially elevated over that seen in years of lower spawner density, this fact would suggest that the primary factor limiting smolt production is not habitat quantity or quality in the tributary but the number of adults spawning in the system. If this later situation is the case, restoration efforts focused on increasing spawning or rearing habitat may be ineffective unless coupled with actions that attract spawning fish to the system. Understanding what it is about elevated discharge that makes Lower Clear Creek more attractive to chinook salmon may be critical to devising a restoration strategy that will increase the abundance of these fish.

Although some information can be gained from studying natural variations in flow, these are always accompanied by variation in a range of other conditions so that isolating the effect of flow can be problematic. Although the Restoration Team should take advantage of natural variations in flow to investigate fish response, more conclusive evidence could be gained by deliberately manipulating flow in Lower Clear Creek (see section 4.4.3). The Panel is aware that undertaking such flow manipulations can be difficult but recommends that the Restoration Team explore opportunities to do so. Often useful manipulations can be accomplished without increasing total discharge from the system.

4.4.2 Conduct studies that will identify the key mortality factors for the salmon.

The identification and quantification of the primary factors influencing salmon survival in Lower Clear Creek would aid greatly in identifying those projects with the greatest potential to increase population levels and in the design of an efficient monitoring program (see section 4.1.2). Attributes that might be included in such an evaluation would include an assessment of egg to fry survival, extensive sampling of the distribution of rearing fry, and data on the growth, condition factor or other attributes that relate to survival. Data on smolt production and adult abundance and distribution are already collected. This information can be used to form the foundation for more detailed investigations of the performance of the salmon during freshwater rearing and the factors most responsible for mortality. Given sufficient time, the spawner and smolt data alone may provide an indication of the cumulative effectiveness of all the restoration projects. If restoration efforts are successful, some improvement in the number of smolts per spawning female, accounting for density-dependent effects on survival, may be apparent after a sufficient amount of data is accumulated.

Augmenting the smolt and spawner data with information on the distribution, abundance, and survival of juvenile salmon from emergence from the gravel through smolt outmigration may provide a more rapid indication of project success. Juvenile outmigration takes place at many stages from emergent fry to yearling smolts. It is likely that different migratory behaviors vary in contribution to adult returns from year class to year class and the variation in behavior is a hedge against uncertain environments in tributaries and main stem. Therefore, it is generally very difficult to determine which segment of the population contributes most to adult returns.

However, improved data on the distribution, abundance, and survival of those juvenile salmon that reside in Lower Clear Creek for an extended period of time prior to emigration may enhance the assessment of project success. Changes in the distribution and relative abundance of juvenile salmon at treated and untreated stream reaches would provide an indication of the suitability of habitat created by the projects. A reduced mortality rate of rearing juvenile salmon was an objective of several of the projects, so a measure of survival would be a very useful measure of the effectiveness of these efforts. In some cases it may be possible to differentially mark fish rearing in treated and untreated stream reaches. Subsequent capture of tagged fish at the smolt trap would provide an indication of relative rate of survival of fish rearing at different sites and provide some direct evidence of project effectiveness.

A better understanding of the key factors influencing the survival growth and behavior of juvenile chinook salmon in Lower Clear Creek can aid in selecting future projects based on their capacity to contribute to the attainment of the tributary scale restoration objectives. As noted above, there is a need to improve on the objectives that currently exist. However, even with improved objectives, assessment of the contribution future projects will make towards the objective is currently hampered by a lack of data.

4.4.3 Conduct a set of experimental constant-flow releases from the dam and measure the response of water temperature, scour, inundation, backwater habitat created, etc. Construct a predictive mathematical model from the results.

There seems to be few or no quantitative relationships that can be used to predict how habitat for various species will respond to alterations of channel geometry and flow (the two variables being discussed for alteration) in Lower Clear Creek. A set of field experiments could be designed, in which (for example) scour depth, water temperature, area of backwater habitat, fish utilization etc. could be measured during flow events designed (especially low to medium flow releases from dams) or anticipated (floods). These quantitative results could be utilized to make predictions of the amount and nature of habitat for various planning scenarios. The mathematical model would allow results to be transferred to times when the creek is not being measured and to other creeks in the region.

4.4.4 Conduct gravel augmentation experiments that integrate fish measures.

The restoration of Lower Clear Creek offers an excellent opportunity for experiments to determine whether it is feasible to introduce a size-range of gravels that would be mobilized under the expected future flow regime and that would also enhance spawning habitat. Considering the scaling issues associated with incipient motion under a reduced flow regime, the experiments may show that the gravel sizes that would have the desired mobility would be smaller than those that are important to spawning habitat. The current program of monitoring particle transport through radio-tracking is important, and could be augmented by collaborating with other radio-tracking programs in other rivers to share and generalize about particle mobility and to develop ways of assimilating the sparse data into predictive methods. A set of properly designed experiments could be conducted to define the gravel sizes, quantities and methods of introduction that would optimize benefit to spawning habitat. The seasonal risk of bed scour, relevant to spawning success and the cleansing of gravel substrates that facilitates alevin escapement, could be monitored, related to flow, and utilized in life history models of fish production.

4.4.5 Develop in-channel structural diversity/complexity experiments.

A dynamic channel and the diverse ecological benefits that derive from fluvial geomorphic processes such as bed scour, bank erosion, and point bar deposition are central to the restoration of self-sustaining aquatic and riparian ecosystems along Lower Clear Creek. Thus, it is important to monitor the evolution of fluvial geomorphic features, such as point bars, under the current flow regime, or in response to any experimental flows, or channel manipulations designed to initiate or enhance the creation of in-channel complexity. Questions regarding the competence of the current flow regime to create and maintain channel complexity, or the role of channel manipulations in jump-starting the development of such complexity, can be addressed as a series of questions that can be addressed experimentally. For example:

- **Is the current flow regime competent to move and sort bed materials and thus create structural complexity in the channel?** Create permanent topographic cross-sections in a variety of channel settings such as straight reaches and at channel bends. Establish a baseline survey and then resurvey the cross-sections after significant flow events. Monitor changes in bed elevation and particle size distribution along transects, and abundance (density) and size (height) of riparian tree seedlings in recruitment zones.

4.4.6 Conduct herb and shrub layer experiments and track their biological response.

Examples of questions to explore experimentally are:

- **Does topographic diversity at a re-vegetation site influence plant species diversity?** Some studies show that riparian plant biodiversity increases with the diversity of physical site conditions, such as diversity of floodplain surface elevations, microtopography, and soil characteristics. At highly degraded sites where channel or floodplain reshaping is warranted, design half of the area for increased topographic diversity (e.g., create a range of floodplain elevations and thus of inundation frequencies) and the other half for less topographic diversity. In some areas, increase microtopographic diversity by adding small depressions. A related treatment could be the excavation of cut-off meander bends or overflow channels. Monitor herbaceous plant cover and species richness (quadrats); shrub cover (line intercepts); tree density and dbh (quadrats).

- **Is the absence of fine sediments limiting survivorship of particular plant species, overall vegetation cover, or flood plain species diversity?** Some riparian plant species tolerate coarse-textured sediments but others require fine sediments (silts, clays) that retain moisture and nutrients. At some riparian sites, herbaceous plant diversity and cover increase with decreasing particle size. Add fine-textured soils (e.g., silts) and/or organic matter to restoration sites; leave some areas as non-augmented control sites. The soil amendments could be added to areas targeted for riparian planting and seeding, as well as 'no-plant areas' targeted for study of natural regeneration. In the treatment areas, simulate the natural flood plain soil texture gradient, which presumably ranges from coarser soils near the channel to finer soils on older flood plains. Monitor herbaceous plant cover and species richness, woody plant vegetation volume, canopy cover, height, and species richness.

- **Is seed addition a viable alternative to planting mature plants, in terms of cost, effort, rate of plant community development, and habitat quality?**

Riparian areas typically have high floristic diversity. Direct plantings generally increase the abundance of only a few species, due to high costs of plant growing. Less expensive techniques for increasing biodiversity include direct seeding or transfer of seed-rich donor soils. In addition to having areas planted with mature plants, designate others as seed-only areas. Treatments could include broadcast seeding, raking of seeds into the soil or litter layer, or transfer of seed-rich donor soils. Include 'no-plant' areas as controls. For woody plants such as cottonwoods and willows, fruit-bearing stems can be clipped and placed into the ground during spring to provide a seed source. Monitor herbaceous plant cover and species richness (quadrats); shrub cover (line intercepts); tree density, dbh, and woody species richness (quadrats).

- **In the areas targeted for irrigated plantings, can adding native seed mixes minimize the abundance of exotic weed species? W**hen plants are irrigated, 'volunteers' (including less desirable weeds) become abundant in the wetted soil zone. Saturation of the site with a native seed mix may preclude this problem. When planting and irrigating trees or shrubs, seed the area immediately around the re-vegetation site with a diverse mix of native riparian seeds. Experimental treatments could include the application of a range of seed densities (including a no-seed control). Another treatment could be addition of a seed-rich soil plug (donor soil) that was collected either from a high quality riparian site or perhaps from a nearby field site or nursery planted as a riparian seed-farm. Monitor plant cover (by species), vegetation volume (by species), and species richness.

- **Do plant survivorship and habitat value vary depending on initial planting density?** Some habitat restorationists have suggested there may be benefits to 'over-planting' cottonwoods and willows, i.e., planting at very high densities, similar to those that can occur on natural recruitment sites. Although there will be considerable stand thinning (density-dependent mortality) in the high density stands, there are possible benefits to the understory plant population from increased flood resistance and increased humidity, and benefits to wildlife from high cover values and dead 'snags'. When planting cottonwoods or other plant species, plant over a range of densities then monitor vegetation volume (including volume of live and dead stems), vegetation height, canopy cover, and plant stem density.

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