USFWS Anadromous Fish Restoration Program
CALFED Bay-Delta Program

LOWER TUOLUMNE RIVER ADAPTIVE MANAGEMENT FORUM REPORT

Prepared by the

Adaptive Management Forum Scientific and Technical Panel

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1. SUMMARY

Although it was not possible for the Panel to absorb every nuance and detail of the complex Habitat Restoration Plan for the lower Tuolumne River Corridor (Restoration Plan) in the time available for the Forum, the Panel is very positive about the design and the dedication of the restoration group. Overall, the Panel feels that the Restoration Plan represents an excellent opportunity to improve conditions for chinook salmon and other species. But it is important to note that the Restoration Plan is based on a relatively novel concept of river restoration and its complete success is uncertain. The Panel feels that the Restoration Plan would be strengthened if the scientific basis and expectations of the restoration approach chosen are clearly spelled out (this should include which other alternatives were evaluated and rejected and why).

Perhaps the greatest concern the Panel has is its perception that the commitment to monitoring is not sufficiently strong. Without a well-designed monitoring program built on the restoration objectives and well-defined criteria of success, it will be impossible to evaluate the outcome of the restoration effort. The Panel's perception is based on what appears to be weak development of monitoring and assessment methods, insufficient baseline data for comparison, and vague statements of expected outcomes for critical components of the restoration.

Another concern the Panel has is that the restoration effort on the lower Tuolumne River is not well integrated across the various scales of analyses and restoration that are needed to put the project into its wider context. Projects in the gravel-bedded reach need to be linked in terms of their expected contribution to recovery. Furthermore, these projects need to be linked to projects in the sand-bedded reach downstream (tributary scale), and eventually with other parts of the fall-run chinook salmon production system and with restoration efforts on other rivers. In addition, each project’s success needs to be evaluated in terms of its contribution to overall ecosystem functions, with the metrics to carry-out that evaluation built into the monitoring plan. These suggestions should not be seen as reasons to delay the restoration effort on the lower Tuolumne, but as issues on which the restoration team should concentrate during the project implementation phase.

And lastly, but very importantly, the Panel has numerous suggestions on how to improve the restoration projects currently underway and ways to incorporate experiments into the design and evaluation of specific projects.

2. BACKGROUND

Because the field of river restoration is still developing and largely experimental it is important to learn as much as possible from individual restoration efforts. 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 over the past few years to the design and implementation of large-scale river channel and habitat restoration projects in the Sacramento and San Joaquin River watersheds. To increase the information gained from these projects, both AFRP and CALFED have required the projects use an adaptive management process in planning, design, and implementation (CALFED, 2001). So far this process has produced mixed results.

Planning, designing, and implementing these projects using an adaptive management process will have the following benefits:

- It will allow those involved in river restoration (i.e., river restoration groups, staff at AFRP and CALFED, and the scientific community) to evaluate and update the models and methods used to justify, select, develop, and implement these river restoration projects. Subsequent projects can then be revised or redesigned to be more effective and instructive.

- It will ensure that success and failure in restoration projects could be ascribed to specific causes, thereby reducing uncertainty in future projects.

- It will increase the credibility of multi-million dollar river restoration efforts and help develop and maintain support from project stakeholders and the public.

- It will establish an objective process for incorporating new knowledge from carefully designed and monitored projects into future project design and implementation.

To realize these benefits, the AFRP, with assistance from CALFED's Ecosystem Restoration Program and the Information Center for the Environment (ICE) at U.C. Davis, have established an Adaptive Management Forum (Forum) to assist with the planning and implementation of large-scale riverine habitat restoration projects.

2.1 FORUM GOALS AND OBJECTIVES

The goal of the Forum is to help river restoration groups and funding agencies plan, design, and implement large-scale river restoration efforts using a more comprehensive and active adaptive management approach.

The Forum provides assistance to river restoration groups, their consultants, and 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 be used to compare and contrast similar channel and floodplain restoration efforts in different watersheds and recommend design, implementation, and monitoring strategies to address key uncertainties associated with large-scale riverine habitat restoration projects.

2.2 ADAPTIVE MANAGEMENT

Using an adaptive management process does not mean managing by trial and error (i.e., possible solutions to management problems are tried until one that works is found). Managing adaptively is a much more analytical process and can be either passive or active. According to Forum Panel Member Michael Healey, passive and active adaptive management are quite different processes:

2.2.1 Passive Adaptive Management

a. think of plausible solutions to management problems;
b. subject the solutions to some form of structured analysis to determine which offers the greatest promise of success;
c. specify criteria (e.g., indicators, measures) of success or failure of the most promising option;
d. implement the option and monitor the system response according to the criteria of success and failure; and
e. 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

a. think of plausible solutions to management problems;
b. subject these solutions to some form of structured analysis to determine the probable responses of the system and how uncertainty about system response effects the likelihood of success or failure;
c. where uncertainty in system response makes it difficult to distinguish among some solutions, design the management intervention so as to test among one or two or more alternatives;
d. use monitoring data to reevaluate the alternatives and improve understanding of system behavior and optimal management.

2.3 STRUCTURE AND PROCESS OF THE FORUM

The Forum provides a way for river restoration groups and staff from the AFRP and CALFED to interact with a panel of independent scientific and technical experts (Panel) that reviews the restoration projects and provides recommendations on the different phases of conceptual modeling, restoration planning, project design, implementation, and monitoring. The Panel, drawn from both 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 2001-2002 are the Tuolumne and Merced rivers, and lower Clear Creek in Shasta County.

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

3. INTRODUCTION

The projects included in the current phase of the Habitat Restoration Plan for the Lower Tuolumne River Corridor (Restoration Plan) constitute an ambitious and novel approach to the physical and biological restoration in the lowland gravel-bedded rivers of California. The approach represents a distillation of concepts developed and tested in field studies over more than a decade. Fundamental assumptions of the design are that it is possible to create a set of geomorphic processes and forms, rescaled in size to the modern flow regime, and that doing this will restore enough natural ecosystem functions to increase production and survival of key channel and floodplain species of plants and animals, principally the fall-run chinook salmon.

To ensure the clearest interpretation and evaluation of these restoration projects, they should be designed as scientific experiments. However, the range of opportunities for restoration, and for testing hypotheses about the effectiveness of restoration, are limited by both the complexity and scale of the lower Tuolumne River and by the history of resource ownership and administration within which the projects have been developed. Beyond the obvious constraint of finite funding, the current flow regime of the lower Tuolumne River is largely beyond the control of the restoration group (the Tuolumne River Technical Advisory Committee) and is fixed by the 1995 Federal Energy Regulatory Commission Settlement Agreement (FSA). The project schedule - driven by pragmatic issues such as funding mechanisms, project management, regulations, and logistics - constrains opportunities for experimentation. Other constraints include various permitting requirements related to water quality and the Endangered Species Act and public values concerning recreation, property rights, and commercial uses of the river corridor.

Nevertheless, the projects still provide a rich opportunity for meaningful experimentation by taking advantage of modeling and staging and distribution of the restoration projects. If careful attention is paid to the development, documentation, and monitoring of the projects presented in the Restoration Plan, they will provide valuable information on methods, pitfalls, opportunities, and results of restoring riverine environments at multiple, linked scales.

Even though it was not possible for the Panel to absorb every detail of the restoration effort for the lower Tuolumne River in the time available for the Forum, the Panel formed a strong, positive view of the plans for the current restoration projects. The recommendations that follow are offered as guidelines or suggestions for increasing the effectiveness of the lower Tuolumne restoration effort, particularly with regard to strengthening its methods and minimizing any ambiguity in interpreting the outcome of the restoration projects.

4. RECOMMENDATIONS

The Panel's comments and specific recommendations on the Restoration Plan are grouped into four main topics:

- Ecosystem Perspective
- Monitoring
- Project Design and Implementation
- Opportunities for Experiments

The Panel's comments and recommendations on fundamental constraints facing the restoration group on the lower Tuolumne River (e.g., funding cycles, time limits, and project selection by the funding agencies, etc.) will be added to similar recommendations for the Merced River and lower Clear Creek and included in the Final Report for the Adaptive Management Forum. The Final Report will also summarize the Panel's recommendations from all three Forum sessions and make recommendations that are applicable across all three tributaries.

4.1 ECOSYSTEM PERSPECTIVE

Although the individual projects are, in most instances, carefully thought through and planned, the Panel is concerned that the individual projects are not designed and implemented with a tributary-scale, ecosystem perspective. This is evident in a variety of ways. For example, the major projects - gravel augmentation, channel and floodplain re-contouring in the gravel-bedded reach, and filling of the Special Run Pools (SRPs) - are not integrated into an overall assessment of their effect with regard to the primary objectives of the Restoration Plan, i.e., the creation, enhancement, and maintenance of fall-run chinook salmon habitat and a self-sustaining, dynamic, native woody riparian corridor. The projects in the gravel-bedded reach are not linked to projects downstream in the sand-bedded reach or, at a larger geographic scale, through the lower San Joaquin River to the Sacramento-San Joaquin Delta. This latter problem may be inherent in all restoration efforts in the Central Valley of California where full integration of projects remains beyond the scope of the river restoration groups and the capacity of the responsible institutions.

Restructuring of channel and floodplain morphology and its evolution under the specified flow regime is not linked to any quantitative expectations for species recovery. Issues of perspective, scale and project level quantitative response are critical to establishing realistic expectations for individual projects and defining appropriate criteria of success or failure for the restoration effort of the entire lower Tuolumne River. For example, if the scale of individual projects is too small to produce a measurable response in total juvenile salmon production, then evaluation can only occur at the tributary scale. Further, if events downstream are sufficient to mask any effects of restoration projects upstream in the lower Tuolumne River, then evaluation can only occur at the lower boundary of the restored portion of the river.

4.1.1 Develop conceptual model(s) for the lower Tuolumne River which integrate the models for the gravel-bedded reach with the model(s) for the sand-bedded reach.

Up-to-date mapping of the river and floodplain, from which a hydraulic model and sediment transport analysis can be performed (among other analyses), will provide important information for understanding the relationship between the gravel-bedded and sand-bedded reaches and evaluating the characteristics of the sand-bedded reach that are (or perhaps are not) important to salmon production.

4.1.2 Define a project's success in terms of its contribution to overall ecosystem functions at the tributary scale.

There needs to be a better integration of the gravel-bedded reach restoration projects with sand-bedded reach projects. Specifically, the potential for the sand-bedded reach to contribute to chinook salmon production in the entire lower Tuolumne River deserves more explicit attention. Currently, the sand-bedded reach projects are described only cursorily and not in the broader context of ecosystem function and restoration at the tributary scale.

4.1.3 Determine and identify the metrics of ecosystem response to the lower Tuolumne River restoration effort.

One of the objectives of the Restoration Plan is to "restore a natural river and floodplain morphology." At present there appear to be no established criteria for determining either project success or improvement in ecosystem function at the tributary scale relative to this objective. What monitoring criteria will be used to determine if this objective is successfully achieved? For example, will in-stream surveys be conducted to track changes in channel geometry, i.e., bed and bank changes, erosion/deposition rates and sediment volume fluxes? If so, what system or site parameter values define the success threshold?

To evaluate ecosystem response, the following monitoring approaches encompass measurement of the key attributes of ecosystem diversity and productivity:

a. Select monitoring metrics that encompass an array of structural elements and functional processes.

Metrics also should span an array of trophic levels and hierarchical levels of ecosystem organization, similar to the approach suggested by Karr and Chew (1999) in their multi-metric approach to assessing biotic integrity.

The restoration team could monitor population attributes of particular species, as well as record community-level measurements of structure. For example, with respect to riparian vegetation, population dynamics, age structure diversity, and abundance of indicator species, as well as community-level measures such as site species richness (alpha diversity), species turnover across the floodplain (beta diversity), patch type diversity, or vegetation abundance (e.g., vegetation volume) could be monitored. For another example, aquatic invertebrates could be assessed by monitoring abundance of indicator species, species richness, and abundance of various guilds or functional groups.

b. Attention should be paid to selecting appropriate indicator species.

One approach involves selecting species that are indicators of a full range of site conditions and trophic levels (Lambeck 1997). Each species would define "different spatial and compositional attributes that must be present in a landscape and their appropriate management regimes." The indicator species could include aquatic and terrestrial biota, and could encompass longitudinal as well as lateral variation in stream and riparian floodplain conditions (e.g., headwater reaches to riverine deltas; pioneer to late-seral riparian forests). Endangered or sensitive species may be able to serve as a subset of appropriate indicator species. Along the lower Tuolumne River there are a variety of endangered or sensitive aquatic invertebrates, fish, bird, and mammal species that could be assessed to determine the range of ecosystem attributes that each represents, their sensitivity to ecosystem change and restoration efforts, and their suitability as indicator species.

c. Monitoring protocols also could be developed that relate to the key processes and functions that have been identified as being important indicators of healthy aquatic and riparian ecosystems.

For example, aquatic invertebrate standing stock biomass or production-to-biomass ratio could be measured to evaluate invertebrate production in response to restoration efforts, thereby capturing the functional roles of aquatic invertebrates in transforming matter and energy in aquatic ecosystems. For another example, repeat floodplain cross-sectional surveys could be conducted at some set interval (and as needed after floods) and soil analyzed for basic physical and chemical properties over time, to determine whether floodplains are aggrading and soils are developing. And lastly, because another function of riparian vegetation is provision of habitat and slowing of flood waters, specific vegetation alliances or patch types could be identified along fixed transect lines and attributes such as vegetation volume and cover by strata (e.g., canopy cover, ground cover), that relate to habitat quality for various animal species, could be recorded. Thus, rather than simply measuring survivorship of planted trees, more general measurements that relate to ecosystem function could be collected.

4.1.4 Conduct a limiting factors analysis to clarify why restoration of the fluvial dynamics in the way proposed will have beneficial consequences for target species.

Two fundamental assumptions of the Restoration Plan are that species at risk are limited by events that occur within the lower Tuolumne River and that creating a more naturally functioning channel will relax in-stream habitat constraints on species recovery. The second assumption could be considered a hypothesis that will be partially tested by monitoring the consequences of the restoration for the species of concern. The first assumption has not been adequately addressed in the material reviewed by the Panel. A limiting factors analysis that considers the whole life cycle might help to clarify where the bottlenecks to production and restoration occur for listed species and the extent to which restoration of habitat in the lower Tuolumne River can be expected to increase species abundance and resilience.

4.2 MONITORING

The restoration team has done a commendable job of collecting information on a wide range of factors affecting the ecological condition of the lower Tuolumne River. Some of the river-wide assessments, in particular, are very well done and the measurements of adult escapement are exceptional. There currently are difficulties with the measurement of smolt production, however, there appears to be a commitment to addressing the problems and obtaining an ever-improving measurement of emigrating smolts (these data should pay great dividends as the effectiveness of this aspect of the monitoring program improves). But the Panel's questions during the Forum revealed that the restoration team has not yet agreed upon a comprehensive set of monitoring methods. This is an urgent need.

One of the fundamental requirements of an adaptive management program is that sufficient data need to be collected before and after project implementation to learn something conclusive. Projects should not be carried out until enough baseline data have been collected and monitoring methods have been tested so that they enable a reliable evaluation of project success and ecosystem response. In some cases in the Restoration Plan this basic conceptual foundation of adaptive management is not given sufficient attention.

Although there has been some good thinking about how to integrate existing monitoring programs into the Restoration Plan and to add additional monitoring activities, it is the Panel's impression that the data collection and monitoring efforts are following management actions rather than leading them, as in the case of the SRP 9 project. To date there does not exist a comprehensive monitoring program even though projects are currently being implemented. A monitoring program that defines a monitoring network, sampling methods for the data acquisition, or data processing protocol that integrates required monitoring (such as that required by the FSA) with proposed monitoring. A monitoring plan with these elements will allow consistent measurement of the ecosystem response at the tributary scale as well as at the individual project sites and help quantify project performance.

4.2.1 Collect sufficient baseline data to detect change.

Baseline data are a vital component of all projects to: 1) identify existing conditions; 2) establish information to use for project design; 3) compare pre-construction and post-construction conditions to measure project performance; and 4) on the tributary scale, to determine ecosystem response. Lack of sufficient baseline data and development of predictive capabilities will result in any effort at adaptive management becoming simply a trial and error process.

The Panel recommends collecting the following baseline data:

a. Hydraulic Model

One of the fundamental objectives of the Restoration Plan is to produce a naturally-functioning river corridor that operates within an altered hydrologic regime. Given this, the expectation is that the river corridor will establish its own recovery over time. Various restoration concepts are being considered to assist the river in these efforts. They include channel and floodplain reconstruction, floodplain revegetation, gravel augmentation, and the filling of artificial features that capture bedload. All of these projects require that the hydrologic/hydraulic regime of the river be known.

A hydraulic model would be invaluable for evaluating a wide variety of issues related to the Restoration Plan. Such a model would allow the restoration team to quantify the variability in hydraulic conditions along each reach (i.e., flow velocities, depths, top widths), evaluate the extent of inundation in specific areas over the range of flows that are of interest, and would provide the basis for quantifying incipient motion and sediment transport along the reach. Coupled with the field observations that have already been made in these reaches, the results would allow a better integration of the information on the specific sites that have been evaluated into an understanding of the dynamic of the overall lower Tuolumne River. This, in turn, would facilitate development of a more integrated overall Restoration Plan.

A hydraulic model for the lower Tuolumne River, complete with a profile and representative cross-sections for various flow regimes, should be completed to: 1) assist in sediment transport analyses; 2) determine inundation frequencies for various reclamation alternatives, and; 3) determine hydraulic characteristics (depths, boundary stresses, velocities, etc.) in various reaches of the river. If improvement in ecosystem function at the tributary scale is assumed to be the basis for success, then it is important to link project designs to a river-wide hydraulic model. The river-wide model should be constructed in sufficient detail to allow the model to identify hydraulic responses to proposed projects.

Specific data needs will depend on the project but should include: 1) thalweg profiles, 2) cross-sections in sufficient detail and number to accurately model the river reach for design and function prediction, and 3) hydraulic stage modeling for various expected discharges.

b. Topographic Map of the River Bottom and Overbanks.

This is part of the hydraulic model. Mapping of this type was prepared for the main stem San Joaquin River between the mouth of the Merced River and Friant Dam, and this mapping has proven to be invaluable for a wide variety of purposes, including: 1) evaluation of channel profiles and channel geometry along the reach, 2) the relationship between the main channel and overbank areas, 3) development of a variety of models to evaluate in-channel capacity, areas of inundation under various flow scenarios, incipient motion and sediment transport under various flow scenarios, and 4) potential flooding impacts associated with various restoration scenarios including increased riparian vegetation.

c. Vegetation Map

It would be useful to produce vegetation maps for the entire riparian corridor, mapped to the alliance level. A standard classification system, such as the National Vegetation Classification System (Grossman and others 1998), should be used. In this system, mapping is based on a combination of vegetation physiognomy (e.g., forest, woodland, shrubland) and floristics (i.e., species composition).

4.2.2 A stronger commitment to monitoring needs to be made.

The monitoring data being collected in conjunction with specific restoration projects along the lower Tuolumne River in many instances do not appear to be sufficient to justify the high priority given to the projects being undertaken or to evaluate the effects of these projects once implemented. The SRP 9 project illustrates this concern. This project represents a substantial commitment of resources yet appears to have been undertaken without a clear understanding of the overall role these altered habitats play in determining the performance of the chinook salmon population. Bass predation within these pools was estimated by examining stomach contents of bass during the period of salmon migration. The salmon found in the stomachs clearly established the fact that salmon were being taken by the bass. However, the estimate of overall effect of bass predation on salmon survival was based on the measured predation rates (salmon eaten by each bass) coupled with a bass population estimate made during late summer, long after salmon had left the SRPs. Thus, the actual impact of the bass on salmon is not known.

a. A list of variables, every one of which will be analyzed for a specific purpose, should be developed, *a priori*.

Analysis of cause and effect related to a project or multiple projects will require carefully connected observations. It must be clear up front (even if plans change later because a required precision is not achieved, ideas change, etc.) how each variable monitored will be analyzed, e.g., incorporated into a calculation, a graph, a contingency table, etc., and how these analyses will demonstrate project success or failure. The success of the Special Run Pool (SRP) project, for example, must be supportable, i.e., the effect of the site-specific restoration must be measurable. And it is important to get some form of agreement among experts in fish biology on experimental design and monitoring so that projects can be designed which can then be analyzed for success/failure with regard to salmon.

b. Monitor predation at an appropriate scale to detect change.

Implementation of the SRP 9 project could have been used as an experiment to better understand the true impact of the bass on the chinook salmon if sufficient pre-treatment data had been collected on the fish populations. However, as no usable pre-treatment salmon survival data was obtained, determination of the change in salmon survival after SRP 9 is filled is not possible. Comparison with predation rates or survival in other SRPs may provide some indication of changes in survival at the treated site, but given the variation in physical dimensions of the SRPs, the use of one as a reference site for a treated location is problematic.

The ability to measure the increase in salmon survivorship attributable to the SRP projects is critical. This must be done on a specific pool basis, because it is important to document the incremental success of any SRP treatment. No adequate methodology has been identified that can measure the effect of bass predation on out-migrating smolts. More effort is needed to develop such a methodology. Absent the methodology, there is no way to show that the expensive treatment proposed for SRP 9 is responsible for any potential increase in salmon production.

Other potential sources of predation are not currently being measured at all. There may be significant additional sources of mortality in the river that have not been accounted for. The extent to which predation by birds or mammals contributes to this mortality is unknown. If these are significant agents of mortality, identifying where in the system the fish are vulnerable and how this vulnerability might be reduced would provide the basis for designing future restoration plans. Some exploratory effort over the next several years should be dedicated to better understanding the extent and nature of the impact of predators other than bass.

c. Expand and improve river-wide monitoring.

While project-scale monitoring is important, monitoring at the tributary scale is necessary to measure the effectiveness of individual or cumulative restoration projects. A river-wide monitoring program should be established which includes both biological and physical monitoring elements. This will allow for an individual project or a series of projects to be evaluated at the tributary scale. For example, individual projects may or may not have an effect on the salmon recovery program. What if all projects satisfy project goals but the salmon population does not recover or other measures of success for the river are not achieved? Were the projects ineffective? Were they implemented over too small of an area? Was the project poorly planned or executed? Did the expected benefits not develop because of inaccurate assessment of their importance for river and salmon recovery? These can only be determined by a monitoring program that exists on a scale much larger than that of individual projects.

River-wide monitoring efforts are collecting information that will ultimately prove valuable in evaluating the response of the salmon to the full suite of restoration actions implemented on the lower Tuolumne River. Nevertheless, a much-improved understanding of how the salmon are utilizing the river could be provided by comprehensive assessments of the distribution of juvenile salmon rearing in the river, measures of juvenile salmon size and condition, and measures of food availability.

d. Adequate information on salmon survival or bass predation rates should be accumulated prior to implementation of any future alterations to SRP habitats.

Problems with marking enough fish and recapturing them after release may make the direct measurement of salmon survival in the SRPs difficult. However, improvements could be made in estimating the size of the bass population during the spring, when the salmon are in the SRPs and coupling these data with information collected at the same time on predation rate on the salmon. These data should be obtainable and avoid the problems encountered in attempting to measure survival rate directly. The success of a SRP project could then be evaluated by monitoring changes in the abundance of bass, the age structure of the bass population, and the rate at which they ingest juvenile chinook salmon.

4.2.3 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. 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, SRPs 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.

4.2.4 Avoid metrics that could potentially harm the ecosystem.

Care needs to be taken to avoid monitoring activities that could potentially harm species. Sometimes the desire for ample data to meet statistical assumptions can override this concern. For example, the use of released hatchery fish to monitor population dynamics of wild strains could have negative effects on the wild strains, through competitive interactions. Potential harmful costs of all monitoring techniques should be carefully assessed before a technique is selected.

4.2.5 Develop operation and maintenance (O&M) plans regarding monitoring.

Most restoration projects require some post-construction maintenance to ensure project success. O&M issues discussed during the forum were vague and poorly defined. For example, revegetated areas may need to be reseeded or woody plants may require irrigation during the first few years to become established. Weed control may be required in order for native species to become established in the riparian zone. Woody plants may need to be re-planted if used by domestic animals or wildlife as browse, or if unusually wet or dry conditions result in death. Erosion of structural elements such as dikes or diversion structures may require repair. Does the site need temporary restricted access in order for restoration elements to become established? These issues should be addressed and incorporated into a monitoring plan and should be decided prior to construction of specific projects. Additionally, funding for O&M should be addressed prior to construction to assure that it is executed in a timely manner, under the direction of those with the responsibility for project success (typically the designer or owner).

4.2.6 Consider multivariate design and analysis.

Ecosystems are complex. One species can be influenced by many environmental factors, and the factors can be interactive and additive. In river systems, many environmental factors change in tandem over time and space, i.e., many are temporally or spatially auto-correlated. As a result, it can be difficult to ascribe change in species abundance to one particular environmental factor. Thus, when developing projects and monitoring plans, consider multivariate design and analysis.

It may be fruitful to analyze changes in the response variable (e.g. salmon population size) with multivariate statistics to assess contribution of multiple environmental factors such as stream flow levels, turbidity levels, and abundances of predators. Up front, one should measure a variety of potentially influential environmental variables (the context) in addition to measuring the direct treatment variables being applied. There also may be cases wherein one wishes to analyze the response of a suite of response variables (i.e., population sizes of multiple species) to a suite of environmental variables, using ordination techniques such as redundancy analysis or canonical correspondence analysis. Having a clear conceptual model of system dynamics would greatly assist in determining which environmental variables should be monitored.

4.2.7 Document failures and lessons learned.

Using an adaptive management process to restore the lower Tuolumne River will require a clearly-articulated model of how information gained from projects will be used to improve restoration actions in the future. This requires that expectations be specified more clearly and quantitatively than has been done to date, that criteria of project success and failure be specified and that sufficient data be gathered to evaluate success. Acknowledging the possibility of failure is extremely difficult in projects involving multiple interests and hard bargaining. Planning to demonstrate that failure actually occurred is even more difficult. In terms of learning, however, failure is often more revealing than success. The learning plan is rather vague in the present Restoration Plan. It deserves more explicit treatment.

4.3 PROJECT DESIGN AND IMPLEMENTATION

4.3.1 A reach loss-gain investigation is needed.

To ensure that the reconstructed channel will function as desired, gains and losses of river flow should be identified (i.e., tributaries, irrigation diversions and returns, groundwater, etc.) for the lower Tuolumne River below La Grange Dam. This will allow for proper channel sizing and help to estimate the expected performance of the system during the low flow regime.

4.3.2 Ensure that ecological objectives of restoration projects are adequately captured in the engineering design and are the primary consideration during construction.

The SRP 9 project was just beginning construction at the time of the field tour for the Tuolumne Forum, consequently the Panel did not have much information about the success of project construction. Therefore, the following is should be considered advice for the future.

There is greater opportunity to incorporate experimental design into a project if the process of moving from scientific conceptual design to engineering plans and contractor bids to construction are tightly connected. In addition, this connection is critical because if it is not well-established, what actually gets built may differ substantially from what was envisioned or desired by the scientific conceptual designer and stakeholders.

Deficiencies in the design documents can greatly diminish a project's geomorphic or ecologic function and appearance. For example, natural channels consist of varied planform with non-uniform channel width, depth, and meander curvature. These variations offer areas for rearing, resting, foraging, and staging of fish at various life cycles. It is difficult for these variations to be incorporated into construction plans and specifications. Construction of these features requires a knowledgeable contractor experienced in river restoration. For the design engineer to include all of the required details to the plans is difficult and costly. Often what is built resembles a uniform drainage channel rather than a natural river channel.

The contractual process can also affect the work product. Typically, large-scale and public-funded earth moving projects are contracted using the "design-bid-build" format. But river restoration work is usually done under a "time and materials" or a "design-build" format using experienced designers and contractors that are specialized in river reconstruction. Specific portions of river projects such as mass channel excavations, filling of large depressions, mass revegetation efforts in overbank areas can still be bid. However, problems arise in the "design-bid-build" model where construction of the channel includes in-channel structures, such as riffles, pools and runs, and edge roughness elements as part of the bid package. Most large-scale earth moving contractors do not have operators experienced and/or knowledgeable in river structure and river mechanics, therefore the resultant reconstructed structure is often flawed. A natural system will tend to replace poorly constructed bedform during periodic channel forming flows so the poor bed form may be short-lived. However, a channel with controlled discharge such as the lower Tuolumne River may not deliver the necessary stresses to reform bed in the short period of time available for salmon recovery. Under these conditions, construction of idealized plan and bedform becomes more important.

A contractual process that often produces better results in river restoration is one where the basic channel (slope, alignment and width) and possibly riparian area grading and revegetation operations are constructed under the "design-bid-build" process but then the river structure is constructed under a "time and materials" format using contractors experienced in stream building. Establishment of minimum experience requirements for the bidders assures the owner that they will have an operator experienced in stream reconstruction. It is also important to have an experienced stream designer/builder on-site while the "time and materials" work is in progress, to provide direction to the equipment operators. Providing direction to the equipment operator is typically not possible under the "design-bid-build" format.

4.4 OPPORTUNITIES FOR EXPERIMENTS

4.4.1 Low-flow investigations.

Both the Fisheries Studies Report and Summary Report clearly identify the influence of flow levels on chinook salmon survival, however, this was not reflected in the monitoring plans of in the preliminary information collected to justify the projects currently being implemented.

The difference in survival between high and low flow years suggests that fruitful studies might look at factors responsible for these differences. These factors could be identified with a more comprehensive assessment of egg to fry survival, extensive sampling of the distribution of rearing fry, and data on the growth, condition, spatial distribution and migration patterns.

The high survival rates during periods of high flow offer some opportunity to better understand the factors important for salmon survival in the river. What habitat types are available to the fish during high flow years that are not available during low flow years? What is the growth rate of the fish utilizing the habitats available only during time of elevated discharge? Are the migration patterns of the fish different during high flow years than during low flow years?

Understanding the different behaviors of the fish under different flow regimes may help shed some light on the factors of critical importance in influencing salmon survival. This information could then be used in selecting future restoration efforts, focusing on projects that will provide some of the habitats or other benefits enjoyed by the fish at high flows during periods of low discharge.

4.4.2 Riparian Vegetation Ecology Experiments

The following experiments could be incorporated into restoration plans, to improve restoration success and improve our understanding of riparian plant ecology. In the list below, experiments are grouped by the type of factor to be manipulated (physical factors vs. plants). The over-arching question implicit in many of the experiments, is "Can regulated rivers be managed to allow for natural regeneration of plant species, or is continual intervention in the form of active planting or seeding necessary?" To answer this question, restoration treatments should be incorporated that include 'no planting' treatments, seed additions, and additions of mature plants.

Physical Site Factors

Question 1*:* What pattern of flood timing and draw down rate are needed for establishment of riparian pioneer trees and shrubs, notably cottonwoods and willows?

Design: 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. Abundance (density) and size (height) of riparian tree seedlings in recruitment zones.

Question 2: What flood magnitude, timing and draw down rate are needed to increase rates of recruitment of late successional species, such as valley oak?

Design: Based on literature review, design and release a regeneration flow that will inundate germination safe-sites for late successional species. In addition to the no-plant control, include a treatment that involves planting viable seeds (at appropriate depth).

Monitor: Post-flood recession rate of stream flow and ground water. Abundance (density) and size (height) of riparian tree seedlings.

Question 3**:** Is deep ground water limiting establishment and survivorship of riparian trees?

Background: Deep water tables or extensive water table fluctuation can cause mortality of phreatophytic riparian plant species.

Design: Before implementing restoration plantings or regeneration experiments, monitor ground water depth. If needed, excavate flood plain surfaces such that water tables are near plant rooting zones.

Monitor: Depth to ground water (monthly measurements, at a minimum) across the lateral gradient from the channel to the floodplain/upland boundary; vegetation response variables.

Question 4**:** Is the absence of fine sediments limiting survivorship of particular plant species, overall vegetation cover, or flood plain species diversity?

Background: 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.

Design: 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, species richness.

***Question 5*:** Does topographic diversity at a restoration site influence plant species diversity?

Background: 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.

Design: 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).

Planting and Seeding Experiments

Question 6: Is seed addition a viable alternative to planting mature plants, in terms of cost, effort, rate of plant community development, and habitat quality?

Background: 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.

Design: 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).

***Question 7*:** In areas targeted for irrigated plantings, can the abundance of exotic weed species be minimized by adding native seed mixes?

Background: When 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.

Design: When planting and irrigating trees or shrubs, seed the area immediately around the revegetation 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), species richness.

***Question 8*:** Do plant survivorship and habitat value vary depending on initial planting density?

Background: Some 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 plant population from increased flood resistance and increased humidity, and benefits to wildlife from high cover values and dead 'snags'.

Design: When planting cottonwoods or other plant species, plant over a range of densities.

Monitor: Vegetation volume (including volume of live and dead stems), vegetation height, canopy cover, plant stem density.

***Question 9*:** Is vegetation abundance or survivorship of particular species at degraded sites limited by absence of soil mycorrhizae?

Background: Mycorrhizal fungi improve growth of many plant species, but can be reduced by land use practices such as grazing, agriculture, or mining.

Design: Initially monitor for abundance of soil mycorrhizae. If found to be depauperate, experimentally increase the supply of mycorrhizae by adding spore-rich soil or inoculated plants (plants grown in the presence of the fungi).

Monitor: Vegetation volume, vegetation height growth rate, canopy cover, plant stem density, survivorship rates.

4.4.3 Predation Experiments for the SRPs

The SRP modification projects offer an opportunity to engage in active adaptive management. The number of SRP habitats that will ultimately need to be addressed, the expense of these projects, and the number of possible treatments available to address bass predation make these projects amenable to this approach.

The ability to implement an active adaptive management effort for these projects is based on the ability to devise a method of measuring salmon survival through each pool before and after treatment. Direct measurements of salmon survival would be the best metric. However, logistical difficulties with capturing and marking migrating fish immediately above an SRP and recapturing a sufficient number of the fish immediately downstream from the SRP make this a difficult parameter to measure.

More accurate measures of bass abundance, population age structure, and distribution coupled with better information on predation rates on salmon in each pool could provide sufficient information to evaluate the treatments. Previously, bass populations were measured in late summer or early autumn, after salmon had left the area. Predation rates were measured in the spring. Due to the difference in the time at which the population size and predation rate data were collected, a realistic estimate of overall predation rate could not be made. Collecting data on the bass population and diet on multiple dates each year during the time that salmon are present in the SRPs would enable an accurate measure of the number of salmon taken by the bass. Coupling this information with an estimate of population size of the salmon would enable an estimated impact on salmon survival rate.

Possible SRP treatments that could be evaluated were discussed during the Forum. These included:

- filling the SRPs,
- creating habitat conditions at sites near the SRPs attractive to bass but not salmon,
- capture and removal of bass from the SRPs, and
- reducing water temperature to discourage bass predation.

The first three of these options would attempt to reduce or redistribute bass either by altering habitat suitability and distribution or by simply removing bass from the SRP. The biological response of these efforts could be adequately evaluated with data on bass and salmon populations in individual SRPs before and after treatment. These evaluations also would benefit from information on the physical habitat attributes of the SRPs before and after treatment. These data may provide some indication of the types and extent of habitat alterations required to discourage bass occupancy or limit the interaction between bass and salmon.

Reducing water temperature by increasing water releases from the dams during periods when salmon are migrating through the SRPs also could be evaluated with data on bass population and diet. As temperature is likely to increase in a downstream direction through the SRP reach, changes in bass predation rates with temperature among the SRPs would provide an indication of the relative effectiveness of this method; successively higher predation rates in a downstream direction would indicate a positive response to reduced temperatures. It might be possible to evaluate the effectiveness of reduced temperature when implemented in conjunction with SRP-specific restoration actions (e.g., filling or bass removal). The reduced temperature would be expected to reduce predation rates by the bass. Other restoration methods are directed towards reducing bass population size by redistributing the fish in a manner that segregate them from the salmon. Thus, a change in the number of salmon eaten by each bass without any change in bass population size or distribution would suggest that reduced water temperatures were primarily responsible for any reductions in salmon mortality. An altered distribution of the bass or a reduction in number would point to SRP-specific restoration actions as the key contributor to success.

4.4.4 Spawner Distribution

Spawner and post-emergent fry distributions appear to represent two important areas of uncertainty that could be explored with suitable experiments. In the case of spawner distributions, the concern is that continued aggregation of adults in the upper part of the gravel reach leads to redd superimposition and egg loss. It is not known whether improving spawning gravel quality downstream will effect a better distribution or whether blocking access of some fish to upstream spawning beds will be necessary. The evidence that superimposition is a serious problem seems to be rather weak although it is a reasonable conjecture based on spawner distributions and evidence from the lower Tuolumne River and elsewhere.

Better data on the magnitude of the problem could be gathered before extraordinary measures are taken to redistribute spawners. Experimental investigations could be conducted to help determine the reasons for the highly aggregated distribution of spawners (even in the upper reaches where suitable gravels seem to be abundant), the effects on distribution of improving gravel quality downstream, and the benefits and costs of forcing spawner redistribution by the use of fences.

4.4.5 Nursery Habitat – Fry Retention

Post-emergent fry distribution and abundance in the lower Tuolumne River is being monitored but there seems, as yet, to have been little consideration given to the costs and benefits of attempting to influence fry distribution. Emigration of many fry following emergence in the spring is common. Would it be advantageous in terms of overall survival to encourage these fry to remain in the system (by various forms of habitat restructuring, for example) or would it be better to encourage even more to leave the Tuolumne early? As with spawner distributions there appears to be an opportunity to design experiments to explore this uncertainty.

4.4.6 Gravel Augmentation/Infusion

Based on the information presented at the Forum the Panel's impression is that the gravel infusion project at the upstream end of the reach met with limited success. This may be at least partly related to the specific way in which the gravel was introduced into the system. The restoration team could experiment with other ways to increase the amount of spawning habitat but evaluation of what is needed is currently hampered by lack of a calibrated calculation of the sediment transport to be expected at a range of river flows.

Over the very long term, it may be possible to introduce gravels into the river at the upstream end of a reach and have that gravel redistribute in a manner that would substantially increase the amount of spawning habitat. However, given the relatively slow rate of movement of gravels through a typical gravel-bedded river system, the time scale for this process may be much longer than is acceptable for this restoration effort. Creation of suitable spawning sites (i.e., tailout of pools) in an acceptable time-frame may require site-specific projects, and the nature of those projects will likely require setting up conditions where local scour will create a pool tailout. Appropriate projects may include construction of short spurs or other river training works that will create local flow acceleration and scour, infusion of gravel near the downstream end of bends or near other hard points in the channel where scour may occur.

4.4.7 Riparian Vegetation as Fish Nursery Habitat

In the Restoration Plan's objectives for floodplain design and riparian revegetation seem weakly developed beyond the geomorphic objective of having an "active" floodplain and the nominal desire to have most of the floodplain vegetated. Floodplain could serve a variety of restoration objectives that appear not to have been built into the plan very well. These include: absorbing some flood flows and reducing flood peaks; providing some of the organic carbon base for the riverine food chain; shading the river channel, providing food to fish through insect drop; providing off-channel habitat during high flows; providing a supply of LWD to the channel; filtering and absorbing toxics/nutrients from upland areas; providing habitat and living space for endangered plants, insects, birds, mammals; providing pockets of "wilderness" for human enjoyment; etc. Each of these services implies a different kind of floodplain design and uncertainties abound. With lots of new floodplain to work with, it seems like a number of creative experiments could be designed without compromising any of the major channel restoration objectives.

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