Jerry Brown
Governor

INSTREAM FLOW DETERMINATIONS FOR HYDROPOWER APPLICATIONS IN CALIFORNIA

PIER FINAL PROJECT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

Improving environmental flow methodologies used in California FERC relicensing is a report for contract number 500-02-004, conducted by the Center for Aquatic Biology at the University of California, Davis. The information from this project contributes to PIER's Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/research/ or contact the Energy Commission at 916- 654-4878.

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Abstract

A key effect caused by dams and water diversions on aquatic species and habitats is the reduction of instream flow. In general, increases in instream flows downstream of a hydropower facility means reduced generation from that facility. Because of the large number of hydropower plants that will be undergoing the Federal Energy Regulatory Commission's relicensing process in the near future, there is a dire need of better methods for determination of appropriate instream flows. The Instream Flow Assessment Program (IFAP) was created to develop a scientific framework for identifying and reducing adverse impacts on aquatic species and habitats from instream flow variations caused by the operation of California hydropower facilities. For effective management of the IFAP, the 5-person Program Management Team and the 11-person Technical Advisory Committee were organized. Research priorities were identified and request for proposals were announced. Four research projects were funded through the IFAP ending date of December 31, 2010. The Instream Flow Assessment Workshop held on December 7, 2010 at the Buehler Alumni and Visitor Center in the University of California, Davis, was organized to disseminate the results of the funded research projects to all interested parties. Through the assistance of the TAC, the IFAP identified the research priorities needed for FERC licensing and relicensing in California. Even with limited funds and especially limited time, the major priorities were addressed by different projects. The overall results of the funded research projects indicate that the efficiency and effectiveness of environmental flow evaluations can be increased, while reducing their costs and providing benefits to both fish and water users. The benefits to California include better predictions of project environmental effects, which can improve fish populations at minimal costs to project operations and provide guidance for stream managers and regulatory agencies to effectively tailor flows for maximal economic, recreational and environmental benefits, and aid in the cost-effective resolution of stakeholder conflicts during hydropower project relicensing proceedings.

Executive Summary

Introduction

A key effect caused by dams and water diversions on aquatic species and habitats is the reduction of instream flow. Variations in stream flows affect multiple environmental factors that can have profound impacts on aquatic life. Hydropower operation affects instream flows mainly through the retention of water behind dams and/or the diversion of water from a stream or river. In general, increases in instream flows downstream of a hydropower facility means reduced generation from that facility. Because of the large number of hydropower plants that will be undergoing the Federal Energy Regulatory Commission's (FERC) relicensing process in the near future, there is a dire need of better methods for determination of appropriate instream flows.

Instream Flow Assessment Program

The Instream Flow Assessment Program (IFAP) was created to develop a scientific framework for identifying and reducing adverse impacts on aquatic species and habitats from instream flow variations caused by the operation of California hydropower facilities. Understanding how instream flow variations impact sensitive species and aquatic communities would allow stream managers and regulatory agencies to effectively tailor flows for maximal economic, recreational and environmental benefits, and aid in the cost-effective resolution of stakeholder conflicts during hydropower project relicensing proceedings.

For effective management of the IFAP, the 5-person Program Management Team (PMT) and the 11-person Technical Advisory Committee (TAC) were organized. Research priorities were identified and request for proposals were announced.

IFAP Research Projects and their outcomes

Four research projects were funded through the IFAP ending date of December 31, 2010. Excerpts from their abstracts are:

1. **Improving environmental flow methodologies used in California FERC relicensing**

   The researchers examined the range of methods available for assessing environmental flows in relation to Federal Energy Regulatory Commission (FERC) licensing processes in California. They sought to integrate insights from allied fields not usually applied to EFMs. A particular goal was to see if EFMs in use in California are consistent with generally accepted practice in the scientific community, especially in their statistical approaches to problems. Their basic findings include: (1) EFMs used most frequently in California are seriously flawed, including their underlying statistical foundations; (2) alternatives are available (e.g., using Bayesian Networks) that are both more effective and likely less costly; (3) The fish assemblages of California streams have a complex relationship to flows but it is possible to manage regulated streams to favor desired fish assemblages (e.g., endemic fishes); (4) Required monitoring programs for FERC projects are generally inadequate and, as a result, have a high probability of leading to erroneous conclusions about the effects of projects on fish populations. The overall results of this research indicate that the efficiency and effectiveness of environmental flow evaluations can be increased, while reducing their costs and providing benefits to both fish and water users. Specific suggestions for improving EFMs are provided.

2. **Evaluating and predicting habitat suitability for California salmon**

   The researchers examined patterns of habitat projections across a suite of contrasting habitat models (e.g. bioenergetics-based vs. logistic) in two California Central Valley rivers, the American and Mokelumne. Different model formulations that included different elements of salmon habitat had dramatically different predictions across different flows, supporting previous work that highlighted the sensitivity of these models. Based on snorkeling observations of fish and their habitat, the most parsimonious model for the study system and fish, includes only water velocity, adjacent water velocity, water temperature, and depth. Researchers also developed a bioenergetics – based habitat model for establishing a flow habitat relationship. This relationship predicts the net energy gain of a fish given prey density, temperature, and water velocity. This project builds on past efforts and hopefully builds the toolbox for understanding the influence of regulated flow regimes on growth potential and habitat availability for threatened and endangered fishes.

3. **21st Century instream flow assessment framework for mountain streams**

   The goal of this study was to show the practical capability and cost-effectiveness of performing instream flow assessment over a reasonably large spatial extent and at high resolution (1-m scale) in a mountain river using a combination of remote-sensing methods and 2D hydrodynamic modeling. Using the available time and resources, diverse creative analyses were undertaken to yield an interdisciplinary and spatially explicit perspective on the status of a testbed river segment. The study domain was ~12.2 river-valley kilometers of the remote and rugged South Yuba River between Lake Spaulding and the town of Washington, CA in the northern Sierra Mountains of California. Every effort was made to investigate stage-dependent patterns and processes ties to multiple spatial scales of fluvial landform nonuniformity. The most important finding is that the geomorphology, hydraulics, and physical habitat of the river segment are linked across four spatial scales (segment, reach, morphological-unit, and 1-m scales). Discrete fluvial landforms at the scale of ~1-10 channel widths in length were identified and found to have an organized distribution along the segment with statistically significant "preferences" for adjacency of occurrence. Hydraulics and availability of preferred physical microhabitat for multiple fish species in multiple lifestages were linked to the revealed pattern of morphological units. In turn, morphological units were linked to reach attributes, which in turn were governed by segment-scale attributes. Perhaps the most important insight from the project is that instream flow assessment requires much more thorough analyses and integration of spatially explicit geomorphology, hydrology, hydraulics, and physical habitat characterization than commonly done at present. Such an integration provides a foundation for not only quantifying current conditions, but explaining their origins and predicting what is necessary to promote maintenance and/or improvement.

4. **Integrating bioenergetics, spatial scales, and population dynamics for environmental flow assessments**

   The research aimed to advance new approaches, using process-based models, for assessing the ecological impacts of alterations in flow. There were two research themes: (i) to formulate and evaluate a *full life cycle* model for Pacific salmon based on Dynamic Energy Budget (DEB) theory; and (ii) to perform simulations that can guide simplified representations of flow-mediated dispersal of benthic macroinvertebrates that comprise the major food source of young salmon. The full life cycle salmon model was based on theory that predicted how rates of physiological processes and transitions between life stages vary among taxonomically similar species. These predictions were tested using literature data from five species: Pink, Chum, Sockeye, Coho and Chinook. Observed patterns both at the embryo stage and the spawning adult stage were well captured by the model. Initial discrepancies between data and model predictions for several variables were resolved by adjusting one parameter value. These findings supported the validity of our approach to model all the different life stages of a Pacific salmon in a common framework. The flow simulations used a validated hydraulic model of the two-dimensional flow field through a restored region of the Merced River. A particle tracking module was added to describe the transport of benthic macroinvertebrates. The transport component was parameterized using a mix of literature data and measurements from previous studies in the Merced region. Model performance was well approximated with a much simpler one-dimensional model, although the one-dimensional model did over estimate average dispersal distances. Researchers explored how dispersal distances and other characteristic length scales potentially influence the spatial scale dependence of macroinvertebrate population dynamics. The project team identified two areas of immediate potential application of the DEB model. It could be extended to describe the effects of oxygen stress on embryonic development and the growth of the youngest fish. It could also be used, in conjunction with temperature data to reconstruct histories of food availability from scales or otoliths. The flow model can be extended to allow improved representations of food delivery to young salmon by accounting for additional flow variability and macroinvertebrate behavior.

Instream Flow Assessment Workshop

The Instream Flow Assessment Workshop (IFAW) was organized to disseminate the results of the funded research projects to all interested parties. On December 7, 2010 the Instream Flow Assessment Workshop was held at the Buehler Alumni and Visitor Center in the University of California, Davis, from 10AM to 4 PM. It was attended by 147 participants from different sectors. All presentations were video-recorded and videos are available on our website http://animalscience.ucdavis.edu/Instream/workshop.htm.

Benefits to California

Through the assistance of the TAC, the IFAP identified the research priorities for California needed for FERC licensing and relicensing. Even with limited funds and especially limited time, the major priorities were addressed by different projects. The overall results of the funded research projects indicate that the efficiency and effectiveness of environmental flow evaluations can be increased; while reducing their costs and providing benefits to both fish and water users. The benefits to California include better predictions of project environmental effects, which can improve fish populations at minimal costs to project operations and provide guidance for stream managers and regulatory agencies to effectively tailor flows for maximal economic, recreational and environmental benefits, and aid in the cost-effective resolution of stakeholder conflicts during hydropower project relicensing proceedings.

1.0 Introduction

1.1. Background

Hydropower is a critical element of the California energy generation system because it provides peaking reserve capacity, spinning reserve capacity, load following capacity, transmission support, and low production costs as well as providing 15% of electricity needs over the last 20 years. California's hydropower system represents 25% of its in-state electricity needs and many facilities are part of a broader multi-use water system providing water supply, flood control, recreation, and other beneficial uses (McKinney 2003). However, these societal benefits have not come without a cost to California's freshwater ecosystems. There is substantial evidence that both hydroelectric and water storage/flood control dams have negatively impacted fish, amphibians, macroinvertebrates and other aquatic biota (Barinaga 1996; Brown and Ford 2003; Graf 1999; Holland 2001; Hunt 1988; Hunter 1992; Kingsford 2000; Murchie et al. 2008; Petts 1984; Power et al. 1996). Long-term effects of dams and reservoirs on downstream environments and their role in fragmentation of riverine networks have been well-documented. Although many factors have contributed to the precipitous decline of California's freshwater fish species, hydropower and associated dams have been identified as a contributing factor.

A key effect caused by dams and water diversions on aquatic species and habitats is the reduction of instream flow. The term "instream flow" refers to the amount of water flowing in a natural stream or river that is needed to sustain aquatic species and habitats. Variations in stream flows affect multiple environmental factors (e.g., temperature, dissolved oxygen, sediment loads) that can have profound impacts on aquatic life (Poff and Allan 1995; Power et al 1995; Pringle et al 2000; Puckridge et al 1998; Rosenberg et al 2000). The importance of mimicking the natural flow variation cannot be over emphasize (Poff et al 1997; Richter et al 1997). Hydropower operation affects instream flows mainly through the retention of water behind dams and/or the diversion of water from the stream or river. In general, increases in instream flows downstream of a hydropower facility means reduced generation from that facility. Because of the large number of hydropower plants that will be undergoing the Federal Energy Regulatory Commission's (FERC) relicensing process in the near future, hydropower impacts on aquatic ecosystems are receiving increased scrutiny. Approximately 5,000 megawatts of hydropower (one-third of the state's installed hydropower capacity) in California will undergo relicensing by 2015. It is most likely that the most contentious topic for most projects during the relicensing process will be the determination of the appropriate instream flows.

The mission of the Public Interest Energy Research, Environmental Area (PIEREA) program is to develop cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California, and explore how new electricity applications and products can solve environmental problems. PIEREA's goal is to resolve impacts from electricity generation, transmission, and use. The purpose of this **Research on Instream Flow Determinations for Hydropower Applications in California** was to conduct research that identify and reduce adverse impacts on aquatic species and habitats from instream flow variations caused by the operation of California hydropower facilities. Research funds were awarded in the form of solicitations for proposals and sole source contracts.

The Center for Aquatic Biology & Aquaculture (CABA) at the University of California, Davis provides a campus-wide, multidisciplinary approach to research on sustaining California's natural aquatic and support to the state's aquaculture industry. Over 30 campus researchers are affiliated with the center and make use of its research facilities. CABA provided the management and administrative duties needed to implement this Research on Instream Flow Determinations for Hydropower Applications in California program. CABA had the primary responsibility for executing the Work Statement Tasks and designed and implemented the Instream Flow Assessment Program to ensure that the funds were efficiently utilized.

1.2. Instream Flow Assessment Program

The Instream Flow Assessment Program (IFAP) was created to develop a scientific framework for identifying and reducing adverse impacts on aquatic species and habitats from instream flow variations caused by the operation of California hydropower facilities. Understanding how instream flow variations impact sensitive species and aquatic communities would allow stream managers and regulatory agencies to effectively tailor flows for maximal economic, recreational and environmental benefits, and aid in the cost-effective resolution of stakeholder conflicts during hydropower project relicensing proceedings. The specific goals and objectives of the Program were:

- Identify research priorities on the ecological effects of instream flow variations on aquatic habitat and biotic communities;
- Document the ecological effects of existing flow alterations;
- Standardize the application of instream flow determination methodologies by establishing quality control standards for widely-used models;
- Refine and standardize alternative instream flow methods;
- Develop a recommended protocol for assessing possible ecological impacts of instream flow variations;
- Develop and disseminate media needed by agencies, researchers, and industry to access and share information intended to enhance the scientific understanding and assessment of instream flow variations on aquatic habitat and biotic communities.

This Program met the PIER Goal of improving the environmental and public health costs/risk of California's electricity improving assessment. This Program also met the secondary PIER goal of improving the energy cost/value of California's electricity by reducing the time and costs associated with the licensing and relicensing of hydropower facilities by the FERC.

1.3. Program Management Team

For effective management of the IFAP, the Program Management Team (PMT) was organized comprising of the director of CABA (initially with Prof. Douglas Conklin, then Prof. Raul Piedrahita), Commission project manager (Mr. Joe O'Hagan), IFAP Administrative Officer (Dr. Paciencia Young), Mr. Jim Canaday (from State Water Resource Control Board, SWRCB) and Mr. Carson Cox (Natural Heritage Institute). Mr. Canaday, working with the SWRCB, participated in many complex water rights decisions. He was the FERC Water Quality Certification Unit supervisor and worked on FERC projects all over California for 23 years. Mr. Cox has worked in the area of environmental flow management for the past ten years and had been involved in the previous Program, the Commission-funded Pulsed Flow Program. Mr. Cox worked in hydropower relicensing at both the SWRCB and the Department of Fish and Game (CDFG). He has worked for non-profit sector at the Sustainable Conservation and later at the Natural Heritage Institute. The PMT met and communicated through conference calling regularly and discussed the strategy by which the IFAP will be managed.

1.4. Technical Advisory Committee

The PMT also decided to create a Technical Advisory Committee (TAC) to assist the PMT in managing the Program by identifying and prioritizing research needs, by reviewing research proposals and final reports. The TAC was comprised of the following members:

1. Mr. Craig Addley, senior project scientist of Entrix consulting firm, has extensive 1 dimension/2 dimension (1D/2D) fish and frog modeling experience of more than 10 years.
2. Dr. Mark Gard, fish and wildlife biologist of the US Fish and Wildlife Service, conducts instream flow studies for anadromous salmonids in Central Valley streams and use 2D hydraulic and habitat models to assess the success of restoration projects in creating anadromous fish spawning and rearing habitat.
3. Engr. Robert Hughes, outreach specialist and associate hydraulic engineer of CDFG, is an expert on habitat modeling and related issues.
4. Mr. Paul Kubicek, aquatic biologist of the Pacific Gas and Electric Company, is also an expert in habitat modeling and related issues.
5. Dr. Mathias Kondolf, professor at UC Berkeley, is a geologist and a landscape architect whose research is on river restoration in California.
6. Stafford Lehr, regional fisheries biologist of CDFG, has experience applying 1D modeling/PHABSIM and application of 2D modeling to relicensing issues.
7. Dr. Jeffrey Opperman, is a technical advisor for water management of the Nature Conservancy.
8. Dr. Thomas Paynes, senior fisheries scientist of Thomas R. Payne and Associates, is an expert on instream flow and related issues, and authored the instream flow roadmap submitted to the Commission.
9. Mr. Dennis Smith, fish biologist of the Regional Hydropower Assistance Team of the USDA Forest Service, is experienced in working with and applying 1D/2D modeling to fisheries management issues in FERC relicensing.
10. Mr. Gary Smith, retired senior biologist of CDFG, was in charge of the CDFG's instream flow group and the National Instream Flow Group.
11. Mr. Scott Wilcox, senior fisheries biologist of Stillwater Sciences, is a 1D/2D modeler, working on 2D modeling for Desabla relicensing project.

The TAC identified and prioritized the following as instream flow research needs:

1. Research on 1D and 2D models including:
    a. Comparison of 2D habitat index results with both 1D habitat index results and fish population metrics;

b. Replication of the known correlation between 1-D habitat indices and biomass that forms the basis of PHABSIM with 2-D indices to ensure the need for 2-D modeling;

c. Determination of guidelines for use of 1-D and 2-D, including gradient limits, influence of degree of habitat complexity, field date collection constraints and differences in sampling strategies;

d. Determination of the strengths and weaknesses of hybrid modeling methods to identify their optimal applications;

e. Analysis of the relative costs and attributes of 1-D, 2-D and hybrid 1- and 2-D methods when applied to streams of different characteristics. This should include an evaluation of ways to reduce the cost for 2-D down to the cost of 1-D and percentage of streams that can be modeled with 1-D versus 2-D Demonstration Flow Assessment;

f. Quality control, quality assurance, and standardization for 1-D and 2-D models.

2. Standardization and application of PHABSIM (under the IFIM) including:

   a. Development and establishment of quality control standards for PHABSIM through a meta-analysis of existing data, with a focus on reach stratification, study site selection, transect number and placement, and amount and type of hydraulic calibration data;

   b. Development of standard methods for creation, selection, and testing of habitat suitability criteria for many species and life stages; and

   c. Evaluation and refinement of standard methods for results interpretation, such as time series analysis, and incorporate them as part of the IFIM.

3. Comparison of existing habitat suitability curves to determine why they are different, with an emphasis on habitat use versus availability versus preference. Research studies on native species should include:

   a. Tagging to understand movement patterns of native species;

   b. Growth versus temperature relationships; and

   c. Spawning behavior and habitats.

4. Development of a white paper on methodological guidelines addressing different methodologies, criteria curves, PHABSIM transects, and others, in order to:

   a. Provide guidance for use in FERC relicensing process;

   b. highlight tradeoffs and areas of uncertainty;

   c. and identify any necessary additional research needs.

   This should include review of biological validation studies which will document what has been done, and the recommendations and decisions made.

5. Refinement and standardization alternative instream flow methods including the Tenant, IHA and Expert Panel Assessment Methods and other new ecologically-based approaches.
6. Applied research for a "model scientific integration process" that will test different approaches for including and integrating a range of scientific disciplines that consider a range of riverine resources within FERC science processes.

Clearly, the TAC has identified several research priorities needed for management guidance in decisions regarding FERC licensing and relicensing. However, there are not enough experts in the UC system to do ALL these research priorities given the limited funding and especially limited time.

2.0 IFAP Research Projects

After the TAC identified the research priorities, a request for proposals was announced to the UC system through the campus websites, as well as the IFAP website http://animalscience.ucdavis.edu/Instream/main.htm. Additionally, individuals considered as experts were contacted regarding this request for proposals. Initially, there were only three proposals submitted for funding. However, requests for proposals were sent out to individuals and a fourth proposal was received. All research proposals were approved after being reviewed by the TAC members and suggestions for revisions were followed. All research projects eventually had ending date of December 31, 2010.

1. **Improving environmental flow methodologies used in California FERC relicensing**: This proposal was submitted by Profs. Peter Moyle (UC Davis), Jeffrey Mount (UC Davis) and Mathias Kondolf (UC Berkeley) requesting for $166,655 of funding.
2. **Evaluating and predicting habitat suitability for California salmon: Improving models through a holistic perspective**: This was submitted by Prof. Jonathan Moore (UC Santa Cruz) in collaboration with Dr. Susan Sogard (NOAA) and Dr. Joseph Merz (Cramer Fish Sciences) requesting for $123,029 of funding.
3. **21st Century instream flow assessment framework for mountain streams**: This was submitted by Prof. Gregory Pasternack (UC Davis) requesting for $158,738 for funding. In December 2009, Prof. Pasternack requested additional funding of $$9,918. The request was approved making the total funding amounting to $218,640.
4. **Integrating bioenergetics, spatial scales, and population dynamics for environmental flow assessments**: This was submitted by Prof. Roger Nisbet (UC Santa Barbara) in collaboration with Prof. Kurt Anderson (UC Riverside) requesting for $138,400 for funding.

Many members of the TAC assisted in evaluating the proposals and also made valuable suggestions to improve the proposals. We are especially thankful to Gary Smith (CDFG) and Mark Gard (USFWS) for their excellent suggestions.

The administrative officer of the IFAP was in communications with the principal investigators regarding their research projects, funding, quarterly, financial and final reports.

2.1. Improving environmental flow methodologies used in California FERC licensing (UC Davis)

Report written by Drs. Peter B. Moyle, John G. Williams, and Joseph D. Kiernan

2.1.1. Executive Summary

2.1.1.1. Introduction

California faces a wave of (re)licensing of dams for power production, with approximately half of the dams scheduled to be licensed over the next 15 years. The present wave of licensing provides an opportunity to develop a better balance between power generation and stream ecosystem function. The sheer number of projects, the cost of the licensing process, and the increased appreciation of the complexity of stream ecosystems, highlight the need for better methods for determining how much water should to be left in the streams. This project, therefore, deals with evaluating existing Environmental Flow Methodologies (EFMs) used in

California, especially from the perspectives of scientific validity, effectiveness in application to the state's distinctive hydrology, and effectiveness in accomplishing stated goals.

2.1.1.2. Project Objectives

We examined the range of methods available assessing environmental flows in relation to Federal Energy Regulatory Commission (FERC) licensing processes in California. We specifically sought to integrate insights from allied fields not usually applied to environmental flow assessments. A particular goal was to see if EFMs in use in California are consistent with generally accepted practice in the scientific community, especially in their statistical approaches to problems and we investigated ways to improve evaluating environmental flows. More specific objectives we accomplished include:

- Conducting an expanded literature review, beyond what has already been done, focusing on non-traditional methods that could be applied to EFMs;
- As a result of the literature review, providing a guidance document for participants in FERC processes;
- Examining the long-term variability in flows in two regulated streams (Martis Creek, Putah Creek) with annual data, to gain an understanding of results that would be likely if monitoring of the effectiveness of EFMs was performed at greater intervals than one year;
- Conducting a retrospective analysis of the monitoring programs required under recent FERC licensing agreements for their likely effectiveness.

The overall results of this research indicate that the efficiency and effectiveness of environmental flow evaluations can be increased, while reducing their costs and providing benefits to both fish and water users.

2.1.1.3. Project Outcomes

2.1.1.3.1. Environmental Flow Assessments: A Critical Review and Commentary

Environmental flow assessment (EFA) remains an extraordinarily difficult problem, for which no existing methods provide a defensible technical solution; this makes an adaptive approach with careful attention to uncertainty appropriate. The difficulties with EFA spring from the complexity and variability of stream ecosystems, so improved understanding of stream ecosystems and aquatic organisms will be a critical component of a long-term resolution of the problem. Nevertheless, substantial improvements in the state of practice are possible in the short-term in several ways: (1) technological improvements in collecting, displaying and analyzing physical data on stream ecosystems allow for more accurate representations of the systems in EFA; (2) proper attention to sampling can improve the accuracy of estimates developed from field studies, and allow for reporting interval estimates rather than point estimates; (3) Bayesian hierarchical modeling can allow for modeling more complex problems than was possible with other statistical methods; (4) Bayesian Networks have emerged as a promising framework for dealing with complex problems such as EFA.

2.1.1.3.1. Retrospective Analysis of Environmental Flows and Fish Monitoring in FERC Licensing

In this chapter we reviewed thirteen recent FERC hydropower licensing proceedings in California. Our purpose was to assess if fish monitoring requirements were routinely mandated in new FERC licenses and how useful the information collected was likely to be in determining effects of the dams. We found that nearly all new licenses included conditions requiring minimum instream flow releases. While changes to release flows were commonplace, only 8 (62%) of the projects examined contained language in the new license mandating fish monitoring over the term of the license. Of those 8 projects, sampling requirements ranged from a single post-license survey up to 12 surveys over a 40-year term. Management objectives for fishes in hydropower-affected waterways, when stated, were commonly the maintenance of some level of abundance similar to levels determined from previous surveys. However, given the natural variability inherent in stream populations, we believe performance criteria based on fish density or size have the potential to lead to spurious conclusions, even when rigorous statistical methods are applied.

2.1.1.3.2. Factors Affecting the Fish Assemblage in a Sierra Nevada, California, Stream

The fishes of Martis Creek, in the Sierra Nevada of California, were sampled at 4 sites annually for 30 yrs, 1979-2008. This long-term data set was used to examine the hypotheses that (1) the fish assemblage is persistent and resilient through time, (2) native and alien (non-native) fishes respond differently to the flow regime, and (3) the principal determinant of fish assemblage composition is flow regime. Annual changes in fish density and biomass were related to 14 attributes of the flow regime, as well as to 13 habitat variables. Despite high inter-annual variability in mean and peak discharge values, the basic character of flow regime did not change over the period of study. Fish assemblages were persistent at all sample sites but had marked inter-annual variability in density and biomass. Most native fishes declined while most alien species showed no trends. Abundances of native species were tied mostly to habitat variables, while alien species responded to flow magnitude and timing/duration, especially brown trout. Frequency of high-flow events had a negative relationship on proportion of alien species. Our results indicate the need for continuous annual monitoring of streams with altered flow regimes, as well as to have monitoring of relatively unaltered streams for comparison. Apparent successes or failures in flow management may appear in a different light under long-term study.

2.1.1.3.3. Restoring Native Fish Assemblages to a Regulated California Stream Using the Natural Flow Regime Concept

In this chapter we provide an empirical example of how changes to the flow regime successfully re-established native fishes and reduced abundances of alien fishes in a regulated California river (lower Putah Creek; Yolo and Solano counties). We report that a series of wet water years, followed by implementation of a flow regime specifically designed to benefit native species, produced dramatic shifts in the distribution and abundance of fishes. The native cold-water fish assemblage that was previously restricted to habitat immediately below Putah Diversion Dam expanded downstream more than 6 km. Additionally, native Sacramento pikeminnow, Sacramento sucker, tule perch, and hitch that collectively represented a minor proportion of the total fish assemblage in middle reaches of lower Putah Creek before the new flow regime, have since become the numerically dominant taxa. Our results demonstrate that natural flow regimes can be used to effectively manage and enhance fish assemblages in regulated rivers. Further, our study underscores the importance of long-term quantitative fish monitoring programs to assess the outcomes of management actions.

2.1.1.4. Conclusions and Recommendations

Our basic findings include: (1) EFMs used most frequently in California are seriously flawed, including their underlying statistical foundations; (2) alternatives are available (e.g., using Bayesian Networks) that are both more effective and likely less costly; (3) The fish assemblages of California streams have a complex relationship to flows but it is possible to manage regulated streams to favor desired fish assemblages (e.g., endemic fishes); (4) Required monitoring programs for FERC projects are generally inadequate and, as a result, have a high probability of leading to erroneous conclusions about the effects of projects on fish populations. We therefore recommend that environmental flow assessments associated with FERC proceedings should be held to strict standards of scientific accountability, including statistical reliability. This means that different methods are likely necessary other than those currently in use (such as the IFIM/PHABSIM methods). Such methods are either already available or possible to develop using existing analytical techniques (e.g., Bayesian Networks). Part of the improved assessments needed is better, typically more frequent, monitoring. For most projects, annual monitoring should be conducted (pre and post project) until project effects can be determined through both wet and dry periods. Once sufficient data is available, a realistic adaptive monitoring program can be developed that would occur through the life of the project.

2.1.1.5. Benefits to California

The overall results of this research indicate that the efficiency and effectiveness of environmental flow evaluations can be increased, while reducing their costs and providing benefits to both fish and water users. The benefits to California include better predictions of project environmental effects, which can improve fish populations at minimal costs to project operations, perhaps even resulting in cost savings.

2.2. Evaluating and predicting habitat suitability for California salmon: Improving models through a holistic perspective (UC Santa Cruz)

Report written by Dr. Jonathan W. Moore, Michael P. Beakes, Nicolas Retford, Susan Sogard and Dr. Joseph Merz

2.2.1 Executive Summary

2.2.1.1. Introduction

Our primary objective was to produce a suite of habitat projections using a two dimensional hydrodynamic model (River 2D) across different model formulations and examine patterns of these projections under different flow releases for two dam regulated rivers in California. Our project utilized River 2D which correlates composite suitability indices (CSI) with a hydraulic model to estimate weighted usable area (WUA) for a species and life-stage. We modeled rearing habitat for juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*).

We anticipate that these efforts will help improve the application of these important modeling tools under contrasting conditions.

2.2.1.2. Project Objectives

This project focused on three central objectives, 1) *Creating models of suitable habitat across a range of flows for juvenile salmon using River2D and habitat suitability criteria (HSC) provided in published literature focused on California rivers.* Habitat projections from these primary models were compared against others that incorporate alternative HSC. 2*) Generating four contrasting River2D models that include HSC developed from data collected at each study reach via logistic regression, HSC where velocity preference is bioenergetics-based and modeled as positive net energy gain (incorporating prey availability, swimming costs, fish size and water temperature) and both site specific and literature derived HSC including escape cover in lieu of substrate preference criteria. . 3) Confronting contrasting models with data.* These data consisted of large-scale snorkel surveys as well as fish sampling performed by Cramer Fish Sciences across available habitat types (pool, riffle, backwater, etc) in both study systems. We used AIC to determine which set and combination of HSC most parsimoniously describe variation in our observed data as well as assess the relative importance of including water temperature in these models. This model comparison illuminated which models have the best predictive ability under different circumstances.

2.2.1.3. Project Outcomes

2.2.1.3.1. Building Habitat Models (R2D)

We examined the hydraulic model we produced with River 2D for hydraulic anomalies and unrealistic conditions as well as calculate the difference in measured inflow and modeled outflow. Hydraulic anomalies comprised less than 1 percent of the modeled reach by area and our measured inflow and predicted outflow were within 1 percent of each other. We followed the prescribed quality assurance/quality control procedures proposed by Steffler and Blackburn (2002) in order to assure that the hydraulic models were reasonable across the modeled discharges. In addition, the same hydraulic model was used for all contrasting hydrodynamic habitat models and thus we assume our model comparison is not biased.

We acquired HSC from literature focused on rivers in California in an attempt to maximize the applicability to our study sites. We used these literature-derived HSC to integrate into our River 2D models to produce habitat projections across a range of flows using these HSC for both of our study rivers.

2.2.1.3.2. Increasing Habitat Model Complexity

Different habitat suitability data and inputs produced fundamentally different model projections and predictions. Specifically, there were substantial differences between literature-based or observation-based habitat suitability curves. Furthermore, the decision on whether to include, for example, cover or substrate, often made a substantial difference in the location and amount of suitable habitat. Perhaps most illuminating was that the difference between models that included cover or not exhibited fundamentally different relationships between discharge and WUA on the American River. Specifically, models that included cover exhibited an increase in WUA above an intermediate discharge (3100 cfs). Indeed, highest discharges had approximately 20 percent more identified habitat than intermediate discharges. This pattern was fundamentally different for models that did not include cover but rather included substrate. For these models, WUA only decreased as discharge increased. In fact, one model predicted a decrease in WUA by over 60 percent as discharge increased. Thus, the results, even at the most coarse scale, are sensitive to the formulation of the model.

2.2.1.3.3. Selecting the Best Habitat Model Using AIC

Our model comparison indicated that the best model that explains variation in habitat use on the American River includes velocity, depth, adjacent velocity, and water temperature. We evaluated models with our snorkeling observations and used AIC as a metric of model parsimony. It is important to note that the top five models, although very close in parsimony, all include velocity, temperature, and adjacent velocity. This is evidence that these three factors are important parameters defining habitat selection by juvenile Chinook salmon. These results are supported by past findings; other studies (e.g. Hill and Grossman 1993) described the bioenergetics basis of habitat preference for drift-feeding salmonids.

2.2.1.4. Conclusions and Recommendations

We applied, tested, and compared different salmonid habitat models. Our major conclusions and recommendations include:

- We developed literature-based and field-based HSC for juvenile salmonids in the study rivers. We also developed a bioenergetics-based HSC, which allows the incorporation of water temperature and food availability, without the need for alteration of software currently available to resource managers.
- Different habitat suitability criteria will lead to vastly different model projections. This result supports the findings of previous research, such as by Bovee (1994).
- The location of appropriate salmonid habitat changes at different discharges. Channel morphology will influence the relationship between discharge and suitable habitat. Analyzing the different types of habitat that are suitable at different flow regimes highlights the dynamic nature of "what is good habitat for salmonids".
- Using a model selection approach allows the identification of the model that best describes the data. This model selection exercise illustrated that fish habitat is best characterized by a combination of factors; our snorkeling surveys indicated that the best models included temperature, velocity, adjacent velocity, and sometimes depth and substrate.
- While these models can be insightful, the results are extremely sensitive to the model formulation. Care should be taken to properly parameterize models in order to obtain the most accurate predictions.

2.2.1.5. Benefits to California

The allocation of water resources in the Central Valley is an intrinsically difficult challenge: our water demands potentially conflict with the needs of species such as Pacific salmon. Through the use of hydrodynamic habitat models we can quantify the potential consequences of water releases for Pacific salmon. However, these habitat models necessitate high predictive power to effectively serve this purpose. For example, different sets of models predict that increasing water flows can either decrease or increase suitable habitat. We identified that, for the American River, the most parsimonious model includes velocity, depth, adjacent velocity, and water temperature. We hope that our efforts will facilitate the careful and appropriate application of these models. More generally, our results highlight the importance of a holistic approach to river management; for example, if discharge is controlled by dam operators and channel morphology is being changed by enhancement actions, it is critical to integrate these actions.

2.3. 21st Century instream flow assessment framework for mountain streams (UC Davis)

Report written by Dr. Gregory Pasternack and Anne Senter

2.3.1. Executive Summary

2.3.1.1. Introduction

Environmental conditions in many mountain rivers throughout the world are degraded due to a complex array of historic and current societal uses overlain on natural dynamics, including punctuated disturbance regimes. In the United States, there are no systematic frameworks to account for the diverse impacts of human uses of rivers with regard to environmental conditions. In mountain rivers, hydropower dam relicensing has become a catch-call for regulated rivers in which many stakeholders expect licensees to pay the cost of solving problems far beyond the actual impacts of licensed projects. In addition, hydropower dam relicensing involves making fixed decisions at a given moment that locks in operations for decades, with little to no flexibility for adjusting in light of changing conditions and uncertainties.

Rational, quantitative river assessment has been a rapidly growing component of the hydropower dam relicensing process. Today, river assessments are more quantitative and better than they have ever been. Unfortunately, river science is a very young discipline that is not ready or able to meet the purpose of characterizing natural systems and human impacts on them in the detail required to answer the policy and management questions at hand. River science is presently in the midst of a paradigm shift. Under the old paradigm that began in earnest in the 1940s, diagnosis of river conditions relied on a small number of carefully selected transects (aka cross-sections) and simple empirical equations. At the dawn of the 21st century, a new paradigm is emerging in which advanced remote-sensing technologies and sophisticated computer simulation models are providing a near-census of physical conditions at the 0.01-1 m spatial scale for ever longer lengths of river channel. The rate of technological development is so fierce, that data-collection methods used in 2008-2009 in this study are now almost outdated; replaced with stunningly more precise, detailed, and even lower-cost tools. Today, new scientific theories lag behind technological developments by several years and practical use of even those theories, such as could be done in hydropower dam relicensing, are ~15 years behind that. On one hand, the process of hydropower dam relicensing would be facilitated by standardization of methods and professional licensure. On the other hand, improved outcomes for river assessment in support of hydropower dam relicensing require greater flexibility, adoption of new methods, and more continuing education of professionals.

2.3.1.2. Purpose

The primary goal of this study was to show the practical capability and cost-effectiveness of performing instream flow assessment (that is just one component of a broader river assessment) over a relatively large spatial extent and at a high resolution (compared to what is commonly performed in instream flow assessment practice today) consistent with a concept of achieving a near-census of the physical conditions in a mountain river instead of a tiny sampling. On a practical level, this study served as a proving ground to find out what tools within the new paradigm are presently capable of meeting the needs of hydropower dam relicensing. Is there utility in having ~1-cm resolution digital imagery of a river corridor? Can desktop personal computers handle simulations of rivers that require hundreds of thousands to millions of computational elements? Is it possible to get past the technical challenges of complex methods and get to new scientific interpretations of river processes relevant to hydropower dam relicensing? These were the overarching types of questions that motivated the scientific study. At the same time, this study had to hold back on the full extent of exploration of new spatially explicit methods, because the study also included an exhaustive methodological comparison of three major, quantitative, physical-habitat approaches to instream flow assessment (with 1-2 variations of each method also investigated). The methodological comparison is inevitably controversial, because there is a lack of standardization in their use, so experts can reasonably disagree as to the significance and interpretation of the findings.

2.3.1.3. Project Objectives

The specific objectives of this project involved (1) using remote-sensing and 2D hydrodyanmic modeling as the foundation for a thorough instream flow assessment of a test section of a regulated mountain river and (2) comparing key results from the first objective with results obtained using common methods under the old paradigm founded on transects. In the research proposal, values of water depth and velocity were identified as key metrics needed for instream flow assessment. Further, the proposal stated that Manning's equation and 1D hydraulic computer models are commonly used to estimate/predict depth and velocity in diverse river management efforts, including hydropower dam relicensing. Therefore, the methodological comparisons were to focus on the performance of these tools relative to 1-m resolution 2D hydrodynamic modeling. Once the project got underway, it became apparent that even though Manning's equation is used in some steps in common hydropower dam relicensing studies, it is not relied upon for getting channel hydraulics as much as it is currently used for that purpose in river restoration, which is good. Therefore, a change was made in which the Manning's analysis was abandoned and replaced with a comparison of instream flow assessment using identical depth and velocity values at designated points, but the total number of points were dramatically different and the methods for upscaling from points to overall conditions were different. This alternate test isolated the effect of using transects for sampling hydraulics, which is a common approach used for instream flow assessment in hydropower dam relicensing, which was an important substitution. This study did ***not*** test (and never proposed to test) the complete method known as the Instream Flow Incremenetal Methodology (IFIM) or the program suite known as Physical Habitat Simulation System (PHABSIM). It tested some tools sometimes used in PHABSIM. The results of comparisons are relevant to understanding some limitations of PHABSIM. The investigators did thoroughly study PHABSIM and many specific examples of its applications in recent hydropower dam relicensing studies. It appeared that PHABSIM is not standardized (so any comparison could be slighted as having "done it wrong") and the suite of methods is expensive and time-consuming to perform, when hydraulics have to be measured at 1-3 flows at ~10-30 transects.

In order to achieve the two specific project objectives of the study, many project components had to be enumerated and completed. The first step was a thorough preliminary planning phase with a literature review, site selection, and historical analysis. After that, phases included data collection, map production, hydrological analysis, 2D modeling, 1D modeling, geomorphic analysis, transect-based sampling, 2D hydraulic analysis, hydraulic comparisons, 2D physical-habitat analysis, and physical-habitat comparisons. A lot of work was performed for each component and even more analyses are possible with the dataset beyond what was done. From the time the first useful data was collected on May 4, 2009 until the draft final report was submitted on December 21, 2010, the entire project occurred in just 19.5 months. A significant amount of that time involved scientific and technological trial and error, such that subsequent efforts building on this project with the same methods could be done ~30% faster.

2.3.1.4. Project Outcomes

This study found that not only is it feasible to perform instream flow assessment under the new paradigm of detail-oriented river science, but that doing so enabled a previously unobtainable process-based linking of topography, hydrology, channel organization, hydraulics, and physical habitat. Processes do not occur at transects, so transect-based methods will never achieve a process-based outcome capable of getting at ecological functions tied to physical conditions and dynamics. Furthermore, the processes revealed by the study derive from the expression of multiple spatial scales of landform nonuniformity. Translation: the way a river behaves at a higher flow is not necessarily more intense than how it behaved at a lower flow- more flow does not mean more river action. It is more like multiple personality "disorder" in that there are discrete ranges of flows for which the river behaves a unique way with specific patterns of hydraulics, physical habitats, and processes. Unfortunately, even though this study spanned four orders of magnitude of flows, it was still unable to investigate large enough rare floods to capture all of the relevant "personalities". These high flows are relevant for instream flow assessment, because understanding their behavior and impacts is critical to evaluating the resilience of low-flow habitats to interannual and decadal channel dynamism. Licenses are often issued for decades, over which time dynamism in a mountain river is virtually guaranteed.

2.3.1.5. Background Information

Background information includes the scientific foundation of instream flow assessment, selection and characterization of a study river segment, pre-existing data retrieval, and statement of project constraints. The California Energy Commission previously sponsored literature reviews for instream flow assessment, so those were used to inform this project. In addition, diverse previous instream flow assessments from around the United States as well as newly published concepts for instream flow assessment influencing future directions were considered. The selected study river segment was the upper South Yuba River between Lake Spaulding and the town of Washington, CA. The Yuba River watershed has been investigated for over 100 years, generating ample documents across academic and regulatory systems. Participants in the Drum-Spaulding relicensing effort contributed data to enable this project to proceed as fully as possible.

2.3.1.6. Data Collection

Data collection occurred opportunistically throughout the duration of the project, with the primary effort consisting of a major campaign from mid-June to mid-October 2009. The data that was collected included ~4-cm resolution kite-blimp imagery; LIDAR (Light detection and ranging)-derived ground, water surface, emergent boulder, and canopy-top elevations; LIDAR-derived image intensities; ground-based topographic and bathymetric measurements; discharge measurements, water surface elevation measurements; stage-discharge rating curve development; velocity observations; sediment substrate grain sizes; and streamwood occurrence. Embedded within each dataset are sources of uncertainty, so efforts were made to characterize those uncertainties.

2.3.1.7. Map Production

A detailed topographic map is the most important and basic foundation for environmental analysis of a river. Integrating diverse data sources with different uncertainties into a single digital elevation model involved performing careful quality assurance and quality control. Large automated datasets carry a risk of allowing unnecessary errors to propagate into scientific analyses, so care was taken to avoid that problem, by way of substantial manual inspection of data products. A new method was developed to extract LIDAR-derived emergent boulder points, which greatly enhanced the digital elevation model of the river. In the end, the topographic map of 12.2 km of river valley produced in this study is likely to be among the longest high-resolution maps of a remote mountain river in the world at this time. Other important maps produced in this study include the tree canopy digital surface model and the georeferenced mosaic of kite-blimp imagery.

2.3.1.8. Hydrologic Analysis

Mountain river discharge includes flow releases from human-operated facilities as well as unregulated flows that accumulate with watershed area. A thorough investigation of flow accretion was a necessary precursor to 2D hydrodynamic modeling. The results of the study showed that ungaged accretionary flows exceed gaged flows in the study area most of the year, except during snowmelt when it is ~20% of gaged flows. Accretionary flows were analyzed to determine the hydrological processes responsible for controlling them and to obtain synthetic empirical equations for estimating ungaged contributions to the study river segment based on gaged flows. Unique equations were statistically generated for each hydrologic season (i.e. dry, wet, and snowmelt). A temporal trend of decreasing accretionary flows was detected 1965-2009, but the rate of that trend turned out to be too small compared with interannual variability to matter to the study. Specifically, when direct observations of flow accretion from 2010 were compared against predictions without accounting for a secular trend, prediction performance yielded three underpredictions, two overpredictions, and two predictions within 10% of observation; no consistent overprediction associated with the secular trend was evident. Total flow accretion predicted by the synthetic empirical equations for each hydrologic season were distributed among tributaries on the basis of proportional watershed area.

2.3.1.9. 2D Hydrodynamic Modeling

2D hydrodynamic models predict the spatial pattern of water surface elevation, depth, velocity X- and Y-components, and associated derived variables (e.g. Froude number, eddy viscosity, and bed shear stress). In this study, the best approach to 2D modeling turned out to involve dividing the river segment into two model areas and then creating a low-flow and high-flow computational mesh with ~1x1 m^2 computational elements. These meshes had between 284,000-468,000 computational elements, which is an order of magnitude more than was commonly used in projects in 1995-2005. Standard procedures were used to obtain model boundary conditions and inputs to run the freeware 2D model known as SRH-2D created by Yong Lai of the U.S. Bureau of Reclamation. Model testing involved comparing predictions of water surface elevations and depth-averaged velocity magnitude against observations made at flows ranging from ~10-1000 cfs (gaged). The quantitative assessment of uncertainty in the digital elevation model served as the baseline reference for judging model performance with water surface elevation prediction, and by that measure, the model performed very well. For velocity, model performance was compared against other published 2D model studies. Despite being used in one of the most difficult river settings that exist- low-flow, complex, bedrock/boulder mountain channel- the 2D model from this study performed as well as others in much simpler settings. Specifically, 2D models tend to show an average velocity error of ~20-30%, with the coefficient of determination (r^2) between observed and predicted between 0.5-0.7. These performance criteria were met in this study.

2.3.1.10. 1D Hydrodynamic Modeling

The original proposal for this study called for the use of the 1D hydrodynamic model known as HEC-RAS, but an opportunity arose to collaborate with a Vietnamese researcher from a university in Japan that substantially leveraged project funds and brought a 1D model specialist into the effort. This researcher, Huy Hoang, has developed, tested, and validated his own 1D hydrodynamic model, including peer reviewed journal articles. Since there is nothing particularly special about any given 1D, this study adopted the Hoang model and used it to simulate cross-sectionally averaged water surface elevation, depth, and velocity at 104 cross-sections (~8 per km). This density of cross-sections was higher than commonly used in 1D studies and therefore is a fair test of the most generous way that a 1D modeling might be used for instream flow analysis at present. Boundary and input conditions for the 1D model were set to be as similar to the 2D model as possible. Beyond the 1D numerical model, a transect-based hydraulic sampling approach was also tested using 916-3175 points, depending on the discharge tested. The transects were selected using a very similar method as described in the study plan for the Yuba-Bear and Drum-Spaulding relicensing process.

2.3.1.11. Geomorphic Analysis

Thorough geomorphic analysis is often neglected in instream flow analysis in favor of a statement that a given river is "stable" and thus suitable for neglecting geomorphology and physical processes. In contrast, this study used 2D model results to invent and thoroughly demonstrate a new way to characterize the geomorphology of a river at a moment in time as well as to infer key physical processes for sustaining physical habitat. Starting from the 1-m resolution 2D model outputs, it was possible to identify laterally varying, flow-independent "morphological units" that serve as the basic building blocks of geomorphic processes at reach and segment scales. Morphological-unit analyses confirmed that these basic building blocks are spatially organized with different types having statistically significant "preference" and "avoidance" for each other. This is a significant advance over the current use of laterally uniform mesohabitat classification. Geomorphic analysis also included description of key processes for sediment transport and channel maintenance, which were assessed in the next chapter along with 2D hydraulic model outputs.

2.3.1.12. 2D Model Hydraulic Analyses

Having identified distinct morphological unit types in the geomorphic analysis chapter, the next step involved characterizing the hydraulics of the river at different spatial scales. Different hydraulics were evident for different morphological units as a function of hydrologic season and flow. When hydraulic results were propagated through appropriate equations to obtain sediment transport regime metrics, the key finding was that the range of flows observed (~5-7000 cfs gaged) was inadequate to reach dramatic channel-changing events (e.g. the 1997 rain-on-snow flood had a discharge of ~30,000 cfs gaged) given the boulder framework of the channel, but it did capture the process of gravel/cobble substrate redistribution among morphological units. A key finding was that the mechanism of stage-dependent flow convergence that is known to provide one mechanism for rejuvenating relief between pools and topographic highs was not fully evident over the range of observed flows. Differences in velocities and bed shear stresses between morphological unit types decreased dramatically from 5 to ~7000 cfs, but higher flows need to be captured to fully evaluate how and if the river segment rejuvenates itself. Further, there was no evidence in the 2D model that local scour around bedrock outcrops is a significant process for channel change for gaged flows <7000 cfs.

2.3.1.13. Hydraulic Method Comparison

The comparison of 1D and 2D numerical models revealed that even with 104 cross-sections, the 1D model performed poorly at predicting cross-sectionally averaged hydraulics and also performed poorly at predicting morphological-unit-averaged hydraulics. The reason for the poor performance is that a mountain river has so many important hydraulic controls in terms of topographic highs and width constrictions that it is infeasible to capture them all with a suitably low-cost field data collection campaign necessary to justify the use of 1D model over a 2D model. Without capturing the channel controls, the model gets the bed slope and channel width controls wrong, and then calculates faulty hydraulics. In the few locations where the river has uninterrupted "uniform" plane bed and bank conditions, then the 1D model performs fine, but those are few and far between for mountain rivers. Across many studies, it is evident that 1D models are only useful when a channel is truly uniform, and that is relatively rare.

In addition to testing 1D versus 2D hydraulic predictions, this study also tested the ability of transect-based sampling to accurately predict morphological-unit-averaged hydraulic metrics. This is a pure test in that it isolates a single question and the only thing changed is a single factor- number of points used. There is another nuance in that in the transect-based methodology commonly used in hydropower dam relicensing, a transect is designated as a single mesohabitat type, with no laterally varying component, which is now proven by this study to be very wrong. Nevertheless, that is how those studies are done, so that method was used here for the transect-based calculations. To provide a generous sampling for the transect-based method, 30 cross-sections were obtained for the 13.52-km study segment. That is ~30% higher than is commonly used, so if this test fails then there is no way that even fewer transects can be successful. At the segment-scale, the result was that transect-based sampling can yield reasonable reproductions of the majority of the depth and velocity statistical distributions, though the performance at the upper tails is poor and performance decreases as discharge increases. At the morphological-unit scale, performance was poor overall. The outcome of the test was that during the lowest flow of 5 cfs the transect method overestimated velocity in plane beds, pools, and inset channels by 595, 400, and 65 %, respectively. Steep inset channel worked best, with only 13% error. At the highest flood flow, the transect-based method had errors of 0.8-21.2%, so substantially better. However, a flood flow is largely irrelevant to physical habitat area estimation for hydropower dam relicensing, because the flow is uncontrolled. The goal of instream flow assessment is often to choose optimal regulated low flows or even the minimal possible flow, for which transect-sampling of depth and velocity was found to perform very poorly at the morphological-unit scale. The poor performance when using ~1000-3000 points compared to a near-census of hundreds of thousands of points in estimating unit-averaged hydraulics is concerning for the continued use of transect-based sampling in hydropower dam relicensing for mountain rivers. However, the performance at the segment scale is encouraging, so the results are mixed. To the extent that society might be willing to never advance beyond simple statistical assessment of habitat and averaging is avoided when using hydraulic samples, then there is some optimism for maintaining current practice.

2.3.1.14. Ecological Analysis

Habitat suitability curves (HSC) for one to four lifestages of rainbow trout, Sacramento sucker, and pikeminnow/hardhead were combined with 2D model results to perform a thorough analysis of physical habitat availability in the study segment. This study did not have the time to fully explore all of the potential spatial metrics possible with 2D-model-based, spatially explicit physical habitat maps. Instead the focus was on performing standard tests of total preferred physical habitat area and percent of wetted area of preferred physical habitat area for each species' lifestage as a function of hydrologic season and flow. Results of these tests show that there is significant variation in what is optimal between species and between lifestages for each hydrologic season. Several different ways of reducing the array of metrics down to summary metrics were used, yielding a summary table that compares the summary metrics. For the dry season, area and percent area summary metrics indicate that either 20 or 10 cfs, respectively, released past the Lang's Crossing flow gage, would yield the best overall balance of habitat conditions. For the wet season, the values were 55 and 15 cfs, respectively. For the snowmelt season, they were 140 and 25 cfs, respectively. These values diverge so strongly, because the wetted area increases significantly as discharge increases. Having more total area of habitat is good, but if the connectivity of that is very poor such that individual fish have to expend too much energy traveling between then, then the total area is not as important as the efficiency of the packing of the habitat area. 2D model results can be used in spatially explicit analysis of habitat patchiness, which would be a major improvement over 1D model and transect-based methods that cannot be used for spatial analysis.

Similar habitat-area analyses were done using the 1D model and transect-sampling methods to the extent feasible, and then all methods were compared. The numerical complication in estimating preferred habitat areas for the alternate methods turned out to reside in the nearly incommensurate utility of flow-independent, laterally varying morphological units only obtainable as part of a 2D modeling study versus laterally uniform mesohabitats commonly obtained from visually inspecting a river, aided by aerial photos or videos. For the methodological comparison, there is a very large degree of variation in the amount of estimated preferred habitat area across all methods. Further, for both the 1D model and transect-sampling methods, there was a large variation in results depending on how habitat quality was extrapolated from sampling sites to the entire river segment. Relative to 2D model performance, the next best outcome was obtained by using a transect-based approach without any statistical averaging. Because of the careful control over methods and independent evaluation of performance of calculating hydraulics, it is possible to attribute the differences relative to the 2D modeling approach to inadequacies in 1D models and transect-based hydraulic sampling for use in complex mountain rivers.

2.3.2. Conclusions

The primary goal of this project involved breaking new ground on developing spatially explicit, high-resolution instream flow analysis. That goal was achieved. A combination of novel technologies, data-processing methods, mechanistic models, and Geographic Information Systems (GIS)-based spatial and 3D analyses were conducted as a "proving ground" to see what would be the most useful. Based on the experience in producing this study, having as detailed and accurate of a topographic map has to be the single most important tool looking ahead to instream flow assessment in the 21st century. After that, having a mechanistic hydrodynamic model capable of integrating flow inputs and detailed topography is the next most important tool for instream flow assessment. Although this study did not involve a test of IFIM and the PHABSIM software suite, two key tests of the common ways hydraulic data are extrapolated from transects to mesohabitats and ultimately to habitat area metrics found that the methods have some merit and some concerning inaccuracies. The fact that one style of IFIM uses highly accurate, direct measurements of velocity and depth at up to three different discharges cannot overcome two major problems. First, a few hundred sampling points per ~10-100 km of mountain river is inadequate to represent the range of depth and velocity combinations in that complex channel setting. Morphological unit types have different organized hydraulic patterns, so there is no one standard way to pick transects for all types that will capture their joint depth-velocity probability distribution. Second, the current use of laterally uniform mesohabitat classes improperly blends hydraulics from different landform types, resulting in an extrapolation over incorrect habitat areas. No matter how good point measurements of velocity and depth are in the fieldwork conducted for transect-based sampling, the inadequacy of mesohabitat-based extrapolation ruins the final area estimates, as demonstrated by the transect Method A analyses. Beyond assessing the performance of different habitat-area computational methods in a complex mountain river, this study made several new basic discoveries about landform organization and physical processes in mountain rivers.

2.3.3. Recommendations

River science is progressing so fast that it would be unacceptable to standardize methods for instream flow assessment right now. The likelihood that assessment will be reliant on transect-sampling (including transect and 1D model options in PHABSIM) for analysis of physical conditions in 5 years from now is ~50%, in 10 years from now is ~10%, and in 20 years from now is ~0.1%. At some point the philosophy that statistical quantification of habitat by way of a flow-habitat relationship will have to give way to a more effective spatial analysis of habitat and a process-based accounting of ecology. Also, technology is going to make spatial analysis so readily available, that competition among practitioners will necessitate its use. Low-flying remote sensing is going to yield very low-cost topographic point clouds of rivers with 1-cm resolution that can be done over long river segments in water and out of water (proof of concept is available now in 2010). Meanwhile, ever-better 2D and 3D desktop computer models will become available with parallelized computational capabilities, greater direct numerical simulation capabilities for smaller grid scales, and improved sub-grid scale turbulence closure. Even if transect-based depth and velocity measurements are superior to predictions of those variables by models in the future, the measurements are inadequate, because they are far too few to characterize morphological-unit scale metrics, they cannot capture the hydraulic complexity relevant to the spatial pattern of physical habitat, they cannot be used for geomorphic assessment, they must be coupled with poor-quality, laterally uniform mesohabitat delineations to estimate habitat area, they cannot be used to aid river restoration, because they are estimation methods rather than prediction methods (e.g. change the topography and the estimated velocity adjustment factors become invalid), and they can never move beyond statistical analysis to get to spatially explicit habitat evaluation, which is necessary to take into account fish behaviors, such as migration and density-dependent competition and predation. With respect to the specific case study of the upper South Yuba River, this study yielded results tables of habitat area and percent area by species' lifestage as well as summary metrics that will be made available for use in hydropower dam relicensing.

2.3.4. Benefits to California

There are ~1400 dams within California's jurisdiction and each one comes up for relicensing at some point. Californians need all of the societal benefits provided by dams, but they also consistently vote in favor of laws, regulations, bonds, taxes, and user fees that promote environmental conservation and restoration. Instream flow assessment is an essential tool that helps find the balance between societal uses of rivers and their ecological sustainability. Up until now, terrific progress has been made in improving the science and technology of instream flow assessment. Nevertheless, production of methods and theories in river science has accelerated and the gap between peer-reviewed river science and professional practice using river science is widening rapidly. This study illustrates how professional practice can make a leap forward with respect to evaluating links between river flow, landform structure, physical processes, and fish habitat across 1-m to 10-km spatial scales.

2.4. Integrating bioenergetics, spatial scales, and population dynamics for environmental flow assessments (UC Santa Barbara and UC Riverside)

Report written by Drs. Roger M. Nisbet, Dr. Kurt E. Anderson, Laure Pecquerie and Lee Harrison

2.4.1. Introduction

Riverine systems are characterized by dynamic feedbacks among system components, a high degree of spatial and temporal variability, and connectivity between habitats. A major challenge is to identify ways of recognizing these characteristics in practical methodology for environmental flow assessment. The project PIs and others recently proposed that process-oriented ecological models, which consider dynamics across scales and levels of biological organization, can contribute to flow regime management (*Frontiers in Ecology and Environment* **4**: 309-318, 2006). In that review, they also identified areas where further research is required before process-based ecological models will make an effective contribution to environmental flow assessments. This report summarizes progress on research that addresses two of these: *(i)* improving bioenergetic-based models of population dynamics and *(ii)* testing models of the effects of spatial variability on population responses to changes in flow regime.

Previous bioenergetic approaches usually focus on the impact of the environmental conditions on a single life stage. Yet performance at a given life stage is known to impact subsequent life stages and hence the dynamics of the population. This issue is particularly relevant for anadromous fish species with largely unobservable ocean stages.

Changes to flow regimes can also have profound effects on both the spatial structure and total availability of physical habitat. Theory describing explicit links between population dynamics of target species and changes in physical habitat at different spatial scales is available, but is seldom applied.

2.4.2. Project Objectives

The overarching aim of the research was to contribute to new conceptual frameworks based on process-based models that differ from and are complementary to habitat-based metrics. In a one-year project, it would not be possible to develop tools ready for application in the FERC relicensing and decision-making processes. Rather, the research was proposed an essential first step in using recent advances in theory as the basis for new decision-making tools. There were two broad objectives:

1. To formulate and evaluate a *full life cycle* model for Pacific salmon based on Dynamic Energy Budget (DEB) theory. This work to include:
    - Synthesis of data from five salmon species to test the assumptions and predictions of the DEB model
    - Use of information from the data synthesis to parameterize the model for Chinook salmon (*Oncorhynchus tshawytscha*)

- Calculations of sensitivity of salmon population growth rate to changes in food delivery rate that in turn are influenced by changes in flow regime

2. To perform simulations that can guide appropriate representations of flow-mediated dispersal and resulting distributions of benthic macroinvertebrates that comprise the major food source of salmon. Specifically:
   - To use a two-dimensional hydraulic model of a restored section of the Merced River to describe the transport and settlement of macroinvertebrates that are the primary food source for young salmon
   - To evaluate the validity of models based on one-dimensional approximations of Merced River hydrology in describing flow variability and resulting transport and distribution of macroinvertebrates
   - To explore the influence of macroinvertebrate transport in a variable flow environment on dispersal distributions and related characteristic length scale calculations for the Merced River

2.4.3. Project Outcomes

2.4.3.1.Full life cycle model for Pacific salmon

2.4.3.1.1. Synthesis of data from five salmon species to test the assumptions and predictions of the DEB model

The team formulated the full life cycle model. DEB theory makes predictions on how rates of physiological processes and transitions between life stages vary among taxonomically similar species. These predictions were tested using literature data from five species: pink, chum, sockeye, coho and chinook. Observed patterns both at the embryo stage and the spawning adult stage were well captured by the model. Initial discrepancies between data and model predictions for several variables were resolved by adjusting one parameter value. The findings supported the validity of our approach to model all the different life stages of a Pacific salmon in a common framework.

2.4.3.1.2. Parameterization of the DEB model for Chinook salmon (*Oncorhynchus tshawytscha*)

The simulation results for chinook broadly agreed with experimental studies on chinook growth and development rates. However, the fecundity patterns that were initially predicted did not match the field data. Further work will refine the parameter estimates with additional model assumptions relating to food availability and allocation of energy to reproduction.

2.4.3.1.3. Calculations of sensitivity of salmon population growth rate to changes in food delivery rate

The methodology is in place, but the calculations require completion of the next round of parameter estimation for Chinook, as well more detailed description of survival.

2.4.3.2. Simulations of flow-mediated dispersal and resulting distributions of benthic macroinvertebrates

2.4.3.2.1. 2D hydraulic model of a restored section of the Merced River

A hydraulic model (MIKE 21 FM) of the two-dimensional (2D) flow field through the lower 1.7 km of a restored region of the Merced River was calibrated and validated. A particle tracking module was added to describe the transport of benthic macroinvertebrates. The transport component was parameterized using a mix of literature data and measurements from previous studies in the Merced region. The trajectories of simulated macroinvertebrates were dominated by the high velocity core under all discharge conditions. With assumptions on dispersion, the model generated distributions of dispersal distances qualitatively consistent with literature observations.

2.4.3.2.2. 1D models of the transport and distribution of macroinvertebrates

The 2D flow environment was collapsed into a 1D representation that allowed its use in population dynamic models for benthic invertebrates previously developed by two members of the project team. Simulations suggest that distributions of macroinvertebrates will show a strong inverse relationship with flow velocity whose strength is set by other model parameters, namely the rate at which drift dispersal is initiated and the rate at which dispersers settle to the benthos. Surprisingly, these parameters had minimal effects on benthic distributions over the range of parameters examined.

2.4.3.2.3. Influences of flow variability on characteristic length scale calculations for the Merced River

Estimates of dispersal distributions from the 1D and 2D models were compared and were qualitatively similar. One characteristic length scale, the average dispersal distance, was over estimated in the 1D model under most parameter combination. This result is likely owing to an incomplete representation of how dispersion in the 2D model influences settlement in the 1D model.

2.4.3. Conclusions and Recommendations

The outcomes this one-year project represent incremental progress toward the broad goal of developing applicable process-based models. The project team identified two areas of immediate potential application of the DEB model. It could be extended to describe the effects of oxygen stress on embryonic development and the growth of the youngest fish. It could also be used, in conjunction with temperature data to reconstruct histories of food availability from scales or otoliths. The flow model can be extended to allow improved representations of food delivery to young salmon by including additional flow complexity and macroinvertebrate behavior.

2.4.4. Benefit to California

The immediacy of assessments in California of many dam-induced alterations to flow and the short duration of our two projects imply that the primary outcome of the research will be limited to incremental improvements in instream flow needs methodology. Many habitat-based methods require metrics such as weighted usable area (WUA) that attempt to measure habitat quantity and/or quality as a proxy for management concerns such as fish population density or viability. The new research complements this in two distinct ways:

1. The bioenergetic modeling sidesteps the problems of identifying “suitable” habitat by focusing directly on growth of young fish as well as estimating the consequences in later life stages of stress in early life. As described above, it can lead to new ways of directly estimating food availability for fish.

2. A high-resolution temperature and flow model for the Sacramento River could be coupled to the Chinook embryo DEB model to examine how (for example) operation of Shasta Reservoir impacts incubating winter-run Chinook eggs in the reaches of the Sacramento River below the dam.

Contiguity of habitat will have a major impact and the response length calculations could guide appropriate choices for the size of “minimal” habitat units for habitat-based evaluations.

3.0 Instream Flow Assessment Workshop

The Instream Flow Assessment Workshop (IFAW) was organized to disseminate the results of the funded research projects to all interested parties. Announcements, invitations and programs were posted on several websites such as the our IFAP website (http://animalscience.ucdavis.edu/Instream/index.htm), John Muir Institute of the Environment (http://johnmuir.ucdavis.edu/), Center for Aquatic Biology and Aquaculture (http://caba.ucdavis.edu/), several departments of different UC campuses, and individuals from federal and state agencies, consulting firms, non-profit, non-government organizations and other stakeholders. Because the California Energy Commission does not fund meals during the Workshop, we charged $15 registration fee for each person including the presenters for lunch and snacks.

On December 7, 2010 the Instream Flow Assessment Workshop was held at the Buehler Alumni and Visitor Center in the University of California, Davis, from 10AM to 4 PM. It was attended by 147 participants from different sectors. All presentations were video-recorded and videos are available on our website. The program and abstracts of the presentations are also posted on the IFAP website and attached as Appendix A. List of participants is also attached as Appendix B.

4.0 Benefits to California

Through the assistance of the TAC, the IFAP identified the research priorities for California needed for FERC licensing and relicensing. Even with limited funds and especially limited time, the major priorities were addressed by different projects as such:

1. Instream flow methodologies used most frequently in California are seriously flawed, including their underlying statistical foundations. It is recommend that environmental flow assessments associated with FERC proceedings should be held to strict standards of scientific accountability, including statistical reliability.
2. Alternatives are available (e.g., using Bayesian Networks) that are both more effective and likely less costly. Different methods are likely necessary other than those currently in use (such as the IFIM/PHABSIM methods). Such methods are either already available or possible to develop using existing analytical techniques (e.g., Bayesian Networks).
3. The fish assemblages of California streams have a complex relationship to flows but it is possible to manage regulated streams to favor desired fish assemblages (e.g., endemic fishes);
4. Required monitoring programs for FERC projects are generally inadequate and, as a result, have a high probability of leading to erroneous conclusions about the effects of projects on fish populations. Part of the improved assessments needed is better, typically more frequent, monitoring. It is recommended that for most projects, annual monitoring should be conducted (pre and post project) until project effects can be determined through both wet and dry periods. Once sufficient data is available, a realistic adaptive monitoring program can be developed that would occur through the life of the project.
5. Development of literature-based and field-based habitat suitability curves (HSC) for juvenile salmonids.
6. Development of bioenergetics-based HSC, that allows the incorporation of water temperature and food availability, without the need for alteration of software currently available to resource managers.
7. Channel morphology influences the relationship between discharge and suitable habitat. Analyzing the different types of habitat that are suitable at different flow regimes highlights the dynamic nature of "what is good habitat for salmonids".
8. Best fish habitat models are characterized by a combination of factors including temperature, velocity, adjacent velocity, and sometimes depth and substrate.
9. The likelihood that assessment will be reliant on transect-sampling for analysis of physical conditions in 5 years from now is ~50%, in 10 years from now is ~10%, and in 20 years from now is ~0.1%. The reason is that low-flying remote sensing is going to yield very low-cost topographic point clouds of rivers with 1-cm resolution that can be done over long river segments in water and out of water. Additionally, ever-better 2D and 3D desktop computer models will become available with parallelized computational capabilities, greater direct numerical simulation capabilities for smaller grid scales, and improved sub-grid scale turbulence closure.

10. Transect-based depth and velocity measurements used for mountain stream geomorphic assessment are inadequate, because they are far too few to characterize hydraulic complexity relevant to physical habitat. Furthermore, they cannot be used

to aid river restoration, because they are estimation methods rather than prediction methods, and they cannot move beyond statistical analysis to get to spatially explicit habitat evaluation, which is necessary to take into account fish behaviors, such as migration and density-dependent competition and predation.

11. The specific case study of the upper South Yuba River has yielded results tables of habitat area and percent area by species' lifestage as well as summary metrics that will be made available for use in hydropower dam relicensing.
12. The general practice of instream flow assessment could benefit from thorough analyses and integration of spatially explicit geomorphology, hydrology, hydraulics, and physical habitat characterization than is commonly done at present. Such integration would provide a foundation for not only quantifying current conditions, but also explaining their origins and predicting what is necessary to promote maintenance and/or improvement.
13. The bioenergetic modeling sidesteps the problems of identifying "suitable" habitat by focusing directly on growth of young fish as well as estimating the consequences in later life stages of stress in early life. As described above, it can lead to new ways of directly estimating food availability for fish.
14. A high-resolution temperature and flow model for the Sacramento River could be coupled to the Chinook embryo DEB model to examine how (for example) operation of Shasta Reservoir impacts incubating winter-run Chinook eggs in the reaches of the Sacramento River below the dam.
15. Contiguity of habitat will have a major impact and the response length calculations could guide appropriate choices for the size of "minimal" habitat units for habitat-based evaluations.

Instream flow assessment is an essential tool that helps find the balance between societal uses of rivers and their ecological sustainability. Production of methods and theories in river science has accelerated and the gap between peer-reviewed river science and professional practice using river science is widening rapidly. The research projects illustrate how professional practice can make a leap forward with respect to evaluating links between river flow, landform structure, physical processes, and fish habitat across 1-m to 10-km spatial scales. The overall results of the funded research projects indicate that the efficiency and effectiveness of environmental flow evaluations can be increased, while reducing their costs and providing benefits to both fish and water users. The benefits to California include better predictions of project environmental effects, which can improve fish populations at minimal costs to project operations and provide guidance for stream managers and regulatory agencies to effectively tailor flows for maximal economic, recreational and environmental benefits, and aid in the cost-effective resolution of stakeholder conflicts during hydropower project relicensing proceedings.

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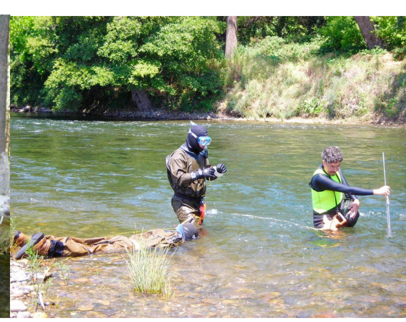
Appendix A: Instream Flow Assessment Workshop Program and Abstracts

INSTREAM FLOW ASSESSMENT PROGRAM

Instream Flow Assessment Workshop

Buehler Alumni and Visitor Center
University of California, Davis, CA 95616
December 7th, 2010, 10:00 AM - 4:00 PM


Instream Flow Assessment Workshop

Buehler Alumni and Visitor Center
University of California, Davis, CA 95616
December 7th, 2010, 10:00 AM - 4:00 PM

Coordinator: Cincin Young, *University of California, Davis*

10:00 -10:10 AM **Welcome Address**
Raul Piedrahita
Director, UCD-CEC Instream Flow Assessment Program
University of California, Davis

10:10 - 10:20 AM **Opening Remarks**
Joseph O'Hagan
CEC Project Manager of Instream Flow Assessment Program
Public Interest Energy Research, California Energy Commission

Improving Environmental Flow Methodologies Used in California FERC Relicensing

10:20 - 10:40 AM **Environmental flows, high variability in stream fish populations, and monitoring: a Conundrum**
Peter Moyle, Joseph D. Kiernan, and John Williams*
University of California, Davis

10:40 - 11:00 AM **Bayesian networks as a framework for environmental flow assessment**
John G. Williams, Joseph D. Kiernman, and Peter B. Moyle*
University of California, Davis

11:00 - 11:20 AM **Fisheries monitoring requirements of New FERC licenses: are they adequate?**
Joseph D. Kiernan, Peter B. Moyle, and John G. Williams*
University of California, Davis

Evaluating and Predicting Habitat Suitability for California Salmon: Improving Models through a Holistic Perspective

11:20 - 11:40 AM **Using models to evaluate the efficacy of habitat restoration for salmon**
Jonathan Moore, Michael P. Beakes, and Nicolas A. Retford*
University of California, Santa Cruz

11:40 -12:00 noon **Prey availability, bioenergetics and hydrodynamic habitat models**
Michael P. Beakes, Jonathan W. Moore, and Nicolas A. Retford*
University of California, Santa Cruz

12:00 - 12:20 PM **Parameterizing fish habitat models with data**
Nicolas Retford, Michael Beakes, and Jonathan Moore*
University of California, Santa Cruz

12:20 - 1:00 PM ***LUNCH BREAK***

Integrating Bionenergetics, Spatial Scales and Population Dynamics for Environmental Flow Assessments

1:00 - 1:10 PM **Overview of the project**
Roger Nisbet
University of California, Santa Barbara

1:10 - 1:25 PM **Dynamic Energy Budget (DEB) model for Pacific salmon**
Laure Pecquerie
University of California, Santa Barbara

1:25 – 1:35 PM	**Linking two-dimensional flow and invertebrate drift transport** *Lee Harrison* University of California, Santa Barbara
1:35 - 1:50 PM	**Flow regime and spatial scales of population response** *Kurt Anderson* University of California, Riverside
1:50 - 2:00 PM	Q & A

21st Century Instream Flow Assessment Framework for Mountain Streams

2:00 - 2:50 PM	**Hierarchical geomorphic, hydrologic, and ecohydraulic analysis of a remote mountainous regulated river** *Gregory Pasternack*, Anne Senter, and Dylan Garner* University of California, Davis
2:50 – 3:00 PM	Q & A
3:00 – 3:10 PM	**BREAK**
3:10 – 3:40 PM	**Panel Discussion** Moderator: *Mark Gard* US Fish and Wildlife Services
3:40 – 4:00 PM	**Concluding Remarks** *Jim Canaday* State Water Resources Control Board California Department of Fish and Game *Carson Cox* Natural Heritage Institute

Environmental flows, high variability in stream fish populations, and monitoring: a Conundrum

Peter B. Moyle, Joseph D. Kiernan, and John G. Williams*
University of California, Davis

ABSTRACT
Standard methodologies for determining environmental (instream) flows for fishes in streams generally have the unstated assumption that flows vary little from year to year or at least that such variability does not matter much in making flow determinations. This makes it relatively easy to develop flow-habitat relationships that assume fish will respond to habitat thus created in a predictable fashion and also makes annual, long-term monitoring programs of relatively low value for managers. To examine these basic assumptions, we analyzed flow and fish population data for two regulated streams with long-term annual monitoring, Martis Creek (30 years) and Putah Creek (18 years). Martis Creek, with regulation of only the peak flows, show wide fluctuations in flows over the study period and dramatic changes in the fish fauna both among years and as a long term trend. Putah Creek had flows determined by a negotiated settlement with a definite goal of re-establishing a native fish assemblage. The flow regime was successful in making native fishes dominant in much of the creek, with considerable year to year and site to site variation. Our study shows that there can be considerable variability in space and time in fish populations in regulated streams and that long-term shifts in species abundances can happen, especially if the flow regime is designed with such shifts in mind. We also show that monitoring, preferably on an annual basis, can be useful for distinguishing faunal changes caused by the flow regime from those that are the result of other factors.

Bayesian Networks as a framework for environmental flow assessment

John G. Williams, Joseph D. Kiernan, and Peter B. Moyle*
University of California, Davis

ABSTRACT

Bayesian Networks (BNs) are numerical models with a graphical user interface that looks very much like familiar “boxes and arrows” conceptual models. The models are quantified with “conditional probability tables” (CPTs) giving the probability that a variable (represented by a box, or “node”) will be in a given state, conditional on the state of other variables that shoot arrows (links) at it. This allows for an approximate but explicit representation of uncertainty in the model. The CPTs can be filled in using information from various sources: data, models, information from other studies, output from other BNs, or expert opinion. Bayesian Networks have various weaknesses. Mathematically, BNs are “directed acyclic graphs,” which means the arrows go only one way, and cannot form a feedback loop. The networks have implicit spatial and temporal scales, and handle dynamic processes awkwardly. Nevertheless, BNs have proved to be useful, especially in stakeholder processes, because the graphical interfaces facilitate communication and visualization of the structure of the model, and the CPTs are transparent. Bayesian Networks have been applied to various resource problems in the US and Canada, and to environmental flow assessment in Australia. We introduce BNs with examples involving PHABSIM and IFIM, because these common but flawed approaches are familiar to many people.

Fish monitoring requirements of new FERC licenses: are they adequate?

Joseph D. Kiernan, Peter B. Moyle, and John G. Williams*
University of California, Davis

ABSTRACT

Among the mitigation measures commonly included in new FERC licenses are minimum instream flow releases intended to maintain or enhance native fish communities, or important recreational fish species. Consequently, post-license sampling of fish and other aquatic resources is also routinely mandated to monitor ecological responses to a new flow regime. We reviewed recent FERC hydropower relicensing proceedings in California to examine general trends (e.g., frequency and duration) in fish monitoring requirements. We found that a common sampling prescription was to frontload fish surveys in the years immediately following the new license (i.e., first 3-5 yrs), followed by additional surveys at regularly spaced intervals (e.g., every 5 years) for the duration of the license. The efficacy of this general sampling approach was assessed using long-term annual fish population data collected from a regulated stream (Martis Creek, 1979-2008). We found that fish populations exhibited a high degree of inter-annual variability and conclusions concerning community dynamics and population trends based on time series of either short duration or irregular intervals can be misleading.

Using models to evaluate the efficacy of habitat restoration of salmon

Jonathan W. Moore, Michael P. Beakes, Nicolas A. Retford*
University of California Santa Cruz

ABSTRACT

Rivers in the Central Valley of California are highly modified systems with heavy demands from multiple users. For example, dams provide energy and reliable water for human use through altering the natural flow regime. Enhancement projects have been increasingly been applied to restore rivers, often targeted to benefit imperiled species such as Pacific salmon. However, these projects are infrequently monitored for success. Here we apply habitat suitability models to evaluate the efficacy of a large-scale restoration engineering project on the American River. These models allow for the quantification of habitat under different river regimes for different life-stages of salmon. In the American River in 2008, an existing side channel was modified with the aim to enhance salmon habitat. Here we develop and apply River2D models to the American River, pre- and post-restoration. Not surprisingly, the alteration of the side channel modified the location of suitable habitat across different flow discharges, within the side channel and upstream. However, across life stage and species, this "enhancement" decreased the amount of predicted suitable habitat. For more efficacious restoration, habitat and flow need to be considered simultaneously.

Prey availability, bioenergetics and hydrodynamic habitat models

Michael P. Beakes, Jonathan W. Moore, Nicolas A. Retford*
University of California, Santa Cruz

ABSTRACT

Previous studies have found that fish may select habitats that maximize their growth rates. Following the methods described in Bratten et al (1997), Hayes et al. (2007), Hill and Grossman (1993) we developed a modified 'Wisconsin' bioenergetics model for Chinook salmon (*Oncorhynchus tshawytscha*). We then used this model to predict the water velocity that optimizes net energy gain as a function of fish size, water temperature, and food abundance during the summer and spring for the American River, California. From these estimates of optimal water velocity we developed habitat suitability curves as a proportion of the maximum growth potential given the aforementioned parameter estimates, where 100% of the growth potential at a given velocity had a suitability of 1.0. We incorporated these velocity suitability criteria in a hydrodynamic habitat model (River 2D) and compared projections of weighted usable area (WUA, Bovee, 1982) for these models and others we developed from published suitability criteria. Our results included a statistically significant reduction ($p < 0.05$, paired t-test SYSTAT 11) in WUA estimates across the range of flows we modeled. This result is most likely attributable to low suitability assignments at low velocities, as a result of low food delivery and subsequently low growth potential. Furthermore, using a bioenergetic approach leads to fundamental relationships between discharge and habitat. This type of bioenergetics approach may be more flexible to a variety of conditions, where changes in temperature and food abundance alter the most beneficial water velocity. As such, a bioenergetics based suitability criteria may be more appropriate for estimating usable habitat in a dynamic and complex system.

Parameterizing fish habitat models with data

Nicolas A. Retford, Michael P. Beakes, Jonathan W. Moore*
University of California, Santa Cruz

ABSTRACT

Habitat suitability models are a powerful predictive tool and are often relied on to develop habitat, flow relationships. However, models often incorporate and equally weight independent parameters. We used a model selection framework to investigate which factors are most important in predicting habitat use by salmonids. We used observations of occupied and unoccupied habitat use during snorkel surveys of juvenile Chinook (*O. tshawytscha*), collected on the American River, measuring six habitat parameters (velocity, depth, adjacent velocity, substrate, escape cover, and mean water temperature). This allowed us to create a combination of 36 polynomial logistic habitat models and compare each for maximum parsimony. We used Akaike information criterion (AIC) scores to compare models. AIC scores incorporate both model fit and model complexity, to give the lowest score to the best fit model. The AIC scores of top five models suggest that three of the six parameters included show the greatest parsimony across all models. Velocity, adjacent velocity, and temperature consistently appeared in top 5 competing models. It also suggested that the more complex models, which included more parameters, had the highest parsimony. In the independent parameter models, temperature was the best independent variable described in our data. These results reflect a strong relationship of stream temperatures and velocities on usable habitat area, and the potential role of ectothermic growth constraints and the bioenergetic cost on habitat choice for the juvenile life-stage of Chinook.

Integrating Bionenergetics, Spatial Scales and Population Dynamics for Environmental Flow Assessments

Roger M Nisbet, Laure Pecquerie*, Lee Harrison* and Kurt E. Anderson**

ABSTRACT

Overview of the project (*Nisbet*)
The research aimed to advance new approaches for assessing the ecological impacts of alterations in flow. There are two research themes: (i) evaluation of a full life cycle model for Pacific salmon based on Dynamic Energy Budget (DEB) theory; (ii) modeling flow-mediated dispersal of benthic macroinvertebrates that comprise the major food source of young salmon.

Dynamic Energy Budget (DEB) model for Pacific salmon (*Pecquerie*)
The salmon model predicts how physiological rates and transitions between life stages vary among taxonomically similar species. These predictions were tested for five species: pink, chum, sockeye, coho and chinook. Data from the embryo stage and the spawning adult stage are well captured by the model. Initial discrepancies between data and model predictions for several variables were resolved by adjusting one parameter value. The model could be extended to describe the effects of oxygen stress on embryonic development and the growth of the youngest fish, and could also be used to reconstruct histories of food availability from scales or otoliths.

Linking two-dimensional flow and invertebrate drift transport (*Harrison*)
Flow simulations were made with a validated two-dimensional (2D) flow model for a meandering reach of the Merced River, CA. A particle tracking algorithm was utilized to describe the transport of benthic macroinvertebrates.

Flow regime and spatial scales of population response (*Anderson*)
The 2D performance was well approximated with a much simpler one-dimensional model, although validation is ongoing. The simplified flow model could allow improved representations of food delivery to young salmon over much longer river stretches than is practical with more detailed hydraulic models.

Hierarchical geomorphic, hydrologic, and ecohydraulic analysis of a remote mountainous regulated river

Gregory Pasternack, Anne Senter and Dylan Garner*
University of California, Davis

ABSTRACT

In modern society, it is expected that science and technology play a central role in balancing societal benefits from hydropower with preservation of a healthy aquatic ecosystem in remote mountainous regions. However, information is limited and science in uncertain. The proliferation of hundreds of variations of methods for instream flow assessment (IFA) reflects the dissatisfaction of scientists and stakeholders with the state of the science. Despite the diversity of approaches that exist, the method known as PHABSIM has become the most widely used IFA tool. A key aspect of PHABSIM is the use of 1D analytical, empirical, or numerical estimates to predict instream hydraulics. This requires extensive, expensive field data collection, and yet the results are inaccurate and often disputed by stakeholders. Meanwhile, a revolution in applied ecohydraulics is demonstrating the potential utility of linking remote sensing and 2D numerical modeling to obtain spatially distributed, 1-m resolution hydraulic and ecological data over large spatial extents.

The goal of this study was to show the practical capability and cost-effectiveness of performing IFA over a large spatial extent and at high resolution (1 m) in a mountain river using a combination of remote sensing methods and 2D modeling relative to traditional cross-section based approaches. The study reach was 12.5 km of the remote and rugged South Fork Yuba River below Lake Spaulding in the Sierra Mountains of California. Airbone LIDAR of the terrestrial river corridor was collected along with echosounder surveys of pools and total station surveys of the remaining wetted channel. Also, ~5-mm resolution blimp imagery was collected and georeferenced. Extensive biological data already exists for this reach, including habitat suitability curves (HSC) for diverse species and life stages. Hydrologic analysis quantified the role of flow accretion from numerous tributaries. Hydraulic simulations were made using both 1D and 2D numerical models. Data and model results were then used to characterize morphological units at the 1 channel width scale, and then investigate the detailed hydrogeomorphic attributes of the system over a range of spatial scales and flows. Special attention was paid for identifying stage-dependent hydrogeomorphic processes in 2D model results. HSC were combined with simulated hydraulics to evaluate microhabitat conditions and intercompare results related to 1D versus 2D approaches. A key outcome of the study is a new framework for IFA blending results related to ecohydraulics and fluvial geomorphology in remote mountain regions using massive, detailed datasets and environmental informatics.

Appendix B. Instream Flow Assessment Program List of Participants

INSTREAM FLOW ASSESSMENT WORKSHOP PARTICIPANTS

NAME	AFFILIATION
Abel, Jae	Santa Clara Valley Water District
Addley, Craig	CARDNO-ENTRIX
Anderson, Kurt	University of California, Riverside
Arsenijevic, Jelica	HDR Inc.
Artho, Dan	US Corps of Engineers
Atkinson, Kristine	California Department of Fish and Game
Barclay, Michael	HDR Inc.
Bauer, Marissa	US Geological Survey
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