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Proceedings of the Klamath Basin Science Conference, Medford, Oregon, February 1–5, 2010

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U.S. Department of the Interior
U.S. Geological Survey

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Edited by Lyman Thorsteinson, Scott VanderKooi, and Walter Duffy

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Conversion Factors—Continued

	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic decimeter (dm^3)	61.02	cubic inch (in^3)
liter (L)	61.02	cubic inch (in^3)
cubic decimeter (dm^3)	0.03531	cubic foot (ft^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
cubic hectometer (hm^3)	810.7	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per year (m^3/yr)	0.000811	acre-foot per year (acre-ft/yr)
cubic hectometer per year (hm^3/yr)	811.03	acre-foot per year (acre-ft/yr)
meter per second (m/s)	3.281	foot per second (ft/s)
meter per minute (m/min)	3.281	foot per minute (ft/min)
meter per hour (m/hr)	3.281	foot per hour (ft/hr)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per year (m/yr)	3.281	foot per year ft/yr)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square	91.49	cubic foot per second per square mile
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
liter per second (L/s)	15.85	gallon per minute (gal/min)
cubic meter per day (m^3/d)	264.2	gallon per day (gal/d)
cubic meter per day per square	684.28	gallon per day per square mile
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
cubic meter per day per square	0.0006844	million gallons per day per square mile
cubic meter per hour (m^3/h)	39.37	inch per hour (in/h)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)

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Chapter 1. An Overview of the Klamath Basin Science Conference

Lyman Thorsteinson[1], Churchill Grimes[2], and Walter Duffy[3]

"An ecosystem view…involves a different framework of ideas derived from other scientific tradition's natural histories, evolutionary biology and ecology. In these traditions, environmental variation is an essential organizing property of living organisms. The purpose of conservation is not to "improve" nature by eliminating variability; it is to protect the interrelationships that allow populations and communities to sustain themselves in a changing world". Dan Bottom (1995)[4]

Introduction

This report presents the proceedings of the Klamath Basin Science Conference (February 2010). A primary purpose of the meeting was to inform and update Klamath Basin stakeholders about areas of scientific progress and accomplishment during the last 5 years. Secondary conference objectives focused on the identification of outstanding information needs and science priorities as they relate to whole watershed management, restoration ecology, and possible reintroduction of Pacific salmon associated with the Klamath Basin Restoration Agreement (KBRA). Information presented in plenary, technical, breakout, and poster sessions has been assembled into chapters that reflect the organization, major themes, and content of the conference. Chapter 1 reviews the major environmental issues and resource management and other stakeholder needs of the basin. Importantly, this assessment of information needs included the possibility of large-scale restoration projects in the future and lessons learned from a case study in South Florida.

Other chapters (2–6) summarize information about key components of the Klamath Basin, support conceptual modeling of the aquatic ecosystem (Chapter 7), and synthesize our impressions of the most pressing science priorities for management and restoration. A wealth of information was presented at the conference and this has been captured in chapters addressing environmental setting and human development of the basin, hydrology, watershed processes, fishery resources, and potential effects from climate change. The final chapter (8) culminates in a discussion of many specific research priorities that relate to and bookend the broader management needs and restoration goals identified in Chapter 1. In many instances, the conferees emphasized long-term and process-oriented approaches to watershed science in the basin as planning moves forward.

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[1] U.S. Geological Survey, Western Fisheries Research Center.
[2] NOAA National Marine Fisheries Service, Southwest Fisheries Science Center.
[3] U.S. Geological Survey, California Cooperative Fish and Wildlife Unit, Humboldt State University.
[4] From "Restoring salmon ecosystems: myth and reality."

This proceedings document is intended for a broad readership, not all of whom may possess strong technical backgrounds but nonetheless are interested in our findings. For this reason, the authors deliberately avoided providing extensive citations but have listed key scientific references as recommended reading at the conclusion of each chapter (see Chapter 1, section, "About this Report").

Background

The Klamath Basin Science Conference was convened in Medford, Oregon, February 1–5, 2010. This timing preceded the signing of the historic Klamath Basin Restoration Agreement (KBRA) and Klamath Hydropower Settlement Agreement (KHSA) and, as such, these impending agreements provided a timely backdrop for the conference. The agreements and scientific needs assessment associated with the Secretarial Determination Process, while important, were not the sole criteria for holding this meeting. The last major Klamath Basin science conferences had occurred in 2004[5] and there was widespread consensus within the user communities about the need for updating and sharing of scientific information. Therefore, the primary purpose was to review the current understanding of the Klamath Basin ecosystem with respect to the most relevant issues for natural resource conservation, ecological restoration, and possible reintroduction of salmon associated with possible dam removals. A watershed approach, couched in an ecological risk assessment framework, was planned by meeting organizers to focus attention of conference presentations on (1) linkages between upper and lower subbasins; (2) ecosystem processes and interactions; (3) drivers, stressors, and high-level indicators of change; and (4) identification of priority needs as they relate to the management of valued resources or environmental conditions. A related goal was to increase basinwide collaboration by building trust and relationships across science and management entities representing the diverse group of stakeholders in the Basin. The geographic scope was the Klamath Basin, although it generally was recognized that environmental factors occurring at much larger scales (e.g., Northeast Pacific Ocean) would need to be acknowledged in light of their influences on salmon and other resources and ecosystem processes. It was anticipated that the ecological information presented at the conference, including our understanding of human activities and land use change, would support the development of a conceptual foundation from which science needs could be appropriately assessed. For now, the emphasis of this conceptualization would be identification of key processes and interactions rather than the quantification of these relations across a unique geography that includes the headwaters of the Klamath River, its major tributaries, estuarine and coastal areas, and adjacent marine waters.

Water is a limited resource with respect to its availability and uses in the Basin. This makes it an extremely valuable commodity and issues surrounding competing needs, resource allocations, and effects of dams have been contentious. The greatest controversies surround competing uses of water for agriculture, such as for irrigation, and ecological needs, or for conservation of endangered fish species. Water quality, quantity, and availability issues have been at the epicenter of resource conflicts that have intensified during recent drought years (2001–2005 and 2010). To illustrate, in 2001, irrigation water was shut off to approximately 1,200 farms in the Klamath Irrigation Project and civil unrest characterized the upper subbasin. The following summer, restored flows in the Klamath River resulted in suboptimal habitat conditions and high levels of mortality in adult Chinook salmon (*Oncorhynchus tshawytscha)*. Large numbers of fish (> 30,000) died prior to spawning, triggering cultural unrest and a renewed sense of urgency among many for dam removals.

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[5] Upper Klamath Basin Science Workshop, February 3–6, 2004, Klamath Falls, OR; and Lower Klamath Basin Science Conference, July 7–10, 2004, Arcata, CA. No proceedings reports were produced.

In 2006, the combined effects of consecutive drought years and above-average water removals impacted salmon production in the Klamath Basin leading to the closure of the West Coast salmon fishery by the Secretary of Commerce. The declaration of a commercial fishery failure by the Federal Government authorized $60.4 million in economic relief to eligible fishery related stakeholders.

Given the history, legalities, and political intensity of the conflicts, the National Academy of Sciences was commissioned to independently evaluate the status of knowledge regarding the hydrology, ecology, and fishes of the Klamath Basin. Two books, one published in 2004 and another in 2008, synthesize existing scientific information, examine available models, and broadly describe science needs. Importantly, in 2008, the National Research Council reported “that the most important characteristics of research for complex river-basin management were missing for the Klamath River: the need for a ‘big picture’ perspective based on a conceptual model encompassing the entire basin and its many components.”

As mentioned, the Department of the Interior (DOI) and its partners also convened two major science conferences in 2004. Their respective purposes were to update scientific information and resource management needs in the upper and lower subbasins. The potential effects of land-use practices on water conditions and ecology of endangered suckers was a focus of the upper subbasin meeting. The emergence of fish health issues associated with an endemic parasite and Klamath Basin salmon provided an impetus for the second conference. An important socio-environmental result of these meetings was how well they demonstrated the basin-level differences in biological and physical settings, communities, and resource management concerns. It was evident from these meetings that more communication and a basinwide approach were needed for integration of science. Simply stated, upstream actions have downstream consequences and these ecosystem relationships needed to be better understood.

Concerns about effects of hydroelectric power generation and other uses of dams on Pacific salmon are signature issues in California and the Pacific Northwest. The effort to forge a basinwide settlement agreement, including the possible removal of four PacifiCorp dams on the Klamath River as early as 2020, has created a more cooperative environment among members of the stakeholder community than existed in 2004. This has involved communication and legitimate efforts for shared understanding about respective water resource needs and economic and environmental concerns. It is not just about endangered fishes or water for agriculture anymore; it is more about the comprehensive needs of the entire Klamath Basin including its human constituents. Solutions are being sought outside the courtroom and, at the time of the conference, there seemed to be recognition of the potential merits of ecosystem-based and adaptive management approaches to restoration that include human economies, cultural needs, species conservation, and watershed health. The loosely-knit partnerships that have formed provide an environment where listening can occur and will be crucial for finding local solutions to Klamath Basin water issues. Moving forward, these partnerships will be important in decisions about water quantity, water quality, ecological needs, land-use planning, and other factors. Once divided by legal interpretations or water dependencies, tribal and other user groups are now attempting to find common ground through information sharing and negotiation. The information shared in these proceedings is meant to assist in these conversations, and to help stakeholders resolve historic conflicts and eventually guide the restoration to more natural conditions.

Secretarial Determination Process

On January 7, 2010, negotiations on KBRA concluded. Public Review Drafts of both the KBRA and the KHSA were made available to more than 30 negotiating partners for review and signatory decision making. Both agreements were signed on February 18, 2010. If fully implemented, the KBRA and KHSA would remove four dams on the Klamath River starting in 2020 (fig. 1-1). In 2012, the DOI Secretary will make a final determination regarding dam removal. Thus, as noted previously, this conference was timely because the science presentations and interdisciplinary discussions would help set a framework for final decision making by the DOI Secretary. The framework will be based on scientific predictions about the environmental consequences of dam removal, and improving science is at the center of the Secretarial decision.

The KBRA is intended to result in effective and durable solutions which will: (1) restore and sustain natural fish production and provide for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin; (2) establish reliable water and power supplies that sustain agricultural uses, communities, and National Wildlife Refuges; and (3) contribute to the public welfare and the sustainability of all Klamath Basin communities. The KHSA establishes a process for the potential removal of four PacifiCorp dams on the middle Klamath River, thus allowing volitional fish passage.

The KHSA requires that the DOI Secretary, in consultation with the Departments of Commerce and Agriculture, must make a determination by March 31, 2012, as to whether the Federal Government supports dam removal and the concepts embodied in the KBRA[6]. This requirement is known as the Secretarial Determination (SD) Process. The DOI has identified November 30, 2011, as the date by which its environmental review for the determination must be completed. During the ensuing period, the Federal Government (in consultation with its non-Federal partners) is gathering new information and analyzing existing data and reports to inform this decision.

A Technical Management Team (TMT) has been created to coordinate the process of collecting and analyzing information for the SD. The TMT is comprised of members of participating Federal agencies and includes technical experts from the U.S. Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS), Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Bureau of Reclamation (Reclamation), and U.S. Geological Survey (USGS). Senior managers from DOI and the member agencies are providing high-level guidance on the SD Process. The TMT has legal, policy, and budgetary support from the respective offices of its constituent agencies.

The TMT is charged with developing and implementing a Project Management Plan (PMP) to assure the broad informational needs of the SD are met. The TMT is led by a Program Manager (USGS) with responsibilities for overseeing planning and conduct of studies and data collection required by the PMP. In addition, a Project Manager (BOR) is responsible for the coordination of the technical and operational activities funded by the BOR in support of the SD. The Program Manager regularly provides status reports to an Executive Management Group comprised of Regional Executives from member agencies to keep them informed.

In addition to the management positions described above, the TMT is led by chairs (or co-chairs) from nine sub-teams that have been tasked with identifying and addressing information needs in specific disciplinary areas: Economics; Environmental Compliance (NEPA/CEQA); Engineering, Geomorphology, Sediment and Hydrology; Biology; Water Quality; Cultural/Tribal; Recreation; Real Estate; and Public Involvement. The nine sub-teams include 45 Federal experts (e.g., economists, engineers, and resource scientists and managers) from eight Federal agencies. The Program Manager,

[6] Updated information about SD activities is available at http://klamathrestoration.gov/home.

Project Manager, and sub-team chairs (i.e., the TMT) are addressing PMP objectives and needs of the SD by ensuring that: (1) information sharing and coordination among sub-teams; (2) resources are properly allocated among tasks; (3) critical timelines are met; (4) studies reflect objective science; (5) reports of data and findings are accurate, comprehensive, and peer reviewed; and (6) collaboration and information exchange with stakeholders and the public is open, timely, and substantive.

The overall purpose of the PMP is to provide a broad framework for organizing and managing a large interagency Federal team tasked with gathering and analyzing the environmental and economic information needed for the SD. Specifically, the PMP is written to address the following four questions: (1) Will implementation of the two agreements advance fish restoration? (2) Is implementing these agreements in the public interest? (3) Can dam removal and site restoration be achieved at or under the estimated project cost of $450 million (in 2020 dollars)? and (4) What liabilities and risks might a Dam Removal Entity face before, during, and after dam removal?

The implementation of the PMP includes extensive reviews of existing information and models and new efforts to address outstanding gaps. Following these reviews of existing models and after consultation with other experts and stakeholders, each sub-team identified priority needs that must be met in each disciplinary area to fully inform the SD. These questions have led, or are leading to new data collection, analysis, and modeling efforts. Examples with respect to dam removal include:

- To what degree (if any), and in what timeframe, would dam removal and implementation of KBRA affect salmonid and resident fish populations in the Klamath Basin?
- How much sediment is stored behind the dams, how quickly would the sediment and associated contaminants be moved downstream if the dams are removed, and what impact might the sediment and any associated contaminants have on fish habitats and human health?
- What is the most economical and effective way to stabilize newly exposed reservoir sediments to minimize adverse effects (short- and long-term) on aquatic biota?
- How would dam removal and KBRA impact water temperatures, seasonal flows, and fish populations in the Klamath River?
- If fish populations respond to dam removal, what are the potential effects of this change on commercial, subsistence, and recreational fisheries (in-river and ocean fishing), local economies, and Tribal culture?
- What are the most probable adverse effects of removing reservoirs on recreation, tax bases, and lakeside real estate?

The TMT is addressing these questions using quantitative approaches whenever possible. For example, quantitative information is needed regarding the volume of sediment in the reservoirs and their associated contaminant concentrations. Predictive capability is needed to determine how reservoir sediments would be transported downstream using available sediment-transport models. In contrast, when a quantitative approach is not possible, because of the lack of models or data, expert panels will be used to review best available information to provide expert opinions (and probabilities) about associated effects or outcomes. The TMT anticipates using expert panels to estimate the likely population responses of at least four fish species if the PacifiCorp dams are removed and the KBRA is implemented.

NMFS[7] is conducting an economic analysis to ensure that the wide-ranging socio-economic effects of dam removal are accurately reflected in the SD. The cost-benefit analysis is considering dam removal costs; benefits to fish populations and fisheries; foregone hydropower; foregone reservoir and whitewater recreation; agricultural, real estate and Tribal/cultural effects; non-use value to the public; and effects on county-level income, employment and tax revenue. Within the cost benefit analysis, NMFS is developing a model to predict the response of Chinook salmon.

Because the SD will have a large environmental impact on the Klamath Basin, a joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis will be performed. An Environmental Impact Statement/Environmental Impact Restoration (EIS/EIR) document will be prepared in collaboration with the State of California. The NEPA/CEQA analysis will focus narrowly on a comparison of impacts associated with removing all four dams and fully implementing KBRA to a “status quo” No Action alternative. Because the SD is a “yes or no” decision and because both KHSA and KBRA must be implemented together and in their entirety, there are not many other alternatives available that would be consistent with the proposed NEPA/CEQA analysis. The information needs for the SD document and a NEPA EIS are largely the same, and preparation of the documents will proceed in parallel by the TMT to ensure consistency and that each final product is self-supporting.

If the Secretarial Determination is affirmative, planning for dam removal in 2020 and implementation of KBRA will be initiated. Many of these planning activities will require additional, more site-specific NEPA/CEQA analyses.

Watersheds and Ecosystems

A watershed is defined as a catchment that drains water, sediment, and dissolved materials to a common outlet at some point along a stream or river channel. Watershed size therefore varies from the very large basins, such as the Columbia River Basin, to very small streams. Broadly defined, watershed ecosystems can be described as communities of organisms (including humans) and their physical and chemical environment interacting as an ecological unit.

Understanding the structural elements and spatial scales of watersheds is essential for integrated science planning[8]. The regional scale is a broad geographical area with common macroclimate and sphere of human activities and interests. From historical and practical perspectives, the Klamath subbasins have served as the “operational” regional-scale units in previous planning efforts. The spatial elements of regions are called landscapes (fig. 1-2). Landscapes are distinguished by repeated patterns of ecological components, which include both natural communities like forest stands and wetlands and human-altered areas like agricultural lands. The dominant and interconnected land cover (e.g., forest) or land use (e.g., agriculture) over the majority of the landscape constitute a matrix. Forest and rangelands are dominant landscapes in the Klamath Basin.

Patches (e.g., wetlands and lakes) occur in, but are different from, the matrix and corridors (e.g., stream corridors) that are usually described as habitats or ecosystems. River and stream corridors and their constituent channels, floodplain, and upland fringes are special types of patches that link aquatic and terrestrial components of the watershed.

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[7] See NOAA Klamath River Basin - 2010 Report to Congress (http://swr.nmfs.noaa.gov/klamath/).

[8] For more information see Federal Interagency Stream Restoration Working Group (1998) report entitled “Stream corridor restoration: principles, processes, and practices” (http://www.nrcs.usda.gov/technical/stream_restoration/newtofc.html).

A collection of patches, none of which is dominant enough to be interconnected throughout the landscape, is known as a mosaic. The mosaic in the Klamath Basin includes headwaters; wetlands, lakes and reservoirs; streams and rivers; and estuary and other coastal waters that might be influenced by freshwater flows. Ecosystems are dynamic and watersheds are altered by natural forces and human activities. Thus, the "shifting habitat mosaic of river ecosystems" conceptual model provides a useful organizing tool for planning watershed restoration and reestablishing connections between river and floodplain.

Ecosystems are continually shaped and reshaped by physical, chemical, and biological processes[9]. Ecosystem processes are any interaction among living and non-living elements of the environment that involve changes in character or state (e.g., fire). Ecosystem processes operate at naturally varying rates, frequencies, durations, and magnitudes that are controlled or constrained by anthropogenic or natural factors. They also operate at different time and space scales (e.g., nutrient dynamics, production cycles, growth and reproduction) and these must be considered in setting restoration goals, target species, and identifying metrics/schedules to assess management success (fig. 1-3). Some anthropogenic factors such as dams, agriculture and forestry, mining, fishing, and climate change are significant parts of the Klamath ecosystem as are their effects on natural processes and their interactions.

Disturbance is a relatively discrete event that disrupts or alters some portion or portions of ecosystems. Healthy ecosystems can accommodate most natural disturbances because they tend to be relatively short in duration and magnitude (for example, annual flooding) and do not severely impact their structure and function.

The Committee on Environment and Natural Resources Subcommittee on Ecological Systems[10] identified five contemporary causes of ecological change and emphasized how understanding their interactions will be critical to ecosystem-based management, consideration of alternative futures, and ultimately, the role of ecological forecasting in the conservation of our natural heritage:

- Extreme Natural Events
- Climate Change
- Land and Resource Use
- Pollution
- Interactive Effects

Forest Management

The possible cumulative effects of timber harvest on Klamath Basin watersheds and fish and wildlife habitat values are of concern. Hydrological and erosional impacts of logging and related road-building activities may move offsite and have downstream effects on fish and wildlife habitats and populations. The degree to which this happens depends on interactions of soils, bedrock geology, vegetation, storm events, logging technology, and human performance. Timber harvest can reduce evapotranspiration and increase annual streamflow resulting in downstream effects. Potential streamside effects can include reduced streamside canopies, increased sedimentation, elevated water temperatures, and reductions in the delivery of woody debris to aquatic habitats. In the Klamath River, these processes have impacted important salmon habitats. Within the U.S. Forest Service (USFS), a new philosophy of

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[9] See "Guidance for protection and restoration of nearshore ecosystems of Puget Sound" (http://www.pugetsoundnearshore.org/technical_reports.htm).
[10] See "Ecological Forecasting: Agenda for the Future" (http//www.ecologicalforecasting@si.edu).

“all lands” management includes an ecosystem approach to evaluation of cumulative effects of planned forest practices that includes areas to be harvested, road building, placement of culverts, and potential effects of human settlements.

Aquatic Habitats

Habitat is the physical, chemical, and biological constituents of a specific unit of environment occupied by a specific plant or animal. They represent structural components of ecosystems that are primarily created and maintained by natural processes. Klamath Basin habitats have been affected by many factors including urbanization, agriculture, forestry, mining, hydropower, and fishing. Dams and other water-control structures have been controversial in this basin and others because of their direct impacts on anadromous fishes such as salmon, steelhead (*Oncorhynchus mykiss*), Pacific lamprey (*Lampetra tridentata*), eulachon (*Thaleichthys pacificus*), and green sturgeon (*Acipenser medirostris*). Dams affect river habitats by creating reservoirs, thus altering temperature and flow conditions and blocking access to upstream habitat. If significant enough, water removals can alter natural flows and ecosystem processes, such as nutrient and sediment transport. These changes may affect aquatic habitat conditions, prey bases, and overall biological productivity.

Water removals and reduced flows directly affect natural habitat conditions by changing water properties, such as dissolved oxygen, temperature, and salinity as well as nutrient loading and contaminant concentrations. For fish, these changes may result in barriers to rearing habitats and migratory corridors or spawning grounds. As habitat volumes shrink and space becomes limiting, cold water species, such as salmon and steelhead, may crowd into cooler thermal refugia. The effects of low dissolved oxygen conditions and pathogen introductions or spread into thermal refugia where fish concentrate may be profound. Reduced flows and water levels will affect stream morphology, affecting channel width, altering stream beds and banks, and potentially changing the composition of streamside vegetation. The resulting impacts on aquatic habitats can include changes in hydrologic properties such as temperature and dissolved oxygen, and simplification of habitat complexity and retentive capacities through changes in the availability of large woody debris. Changing flow and channel structure, increasing stream bank instability and erosion, and altering nutrient and prey sources also degrade river habitats. As flow rates and hydrologic properties change, free-flowing rivers become disconnected from their floodplains, and the hydrologic and geomorphologic processes that sustain fish populations and key habitats may be lost (table 1-1).

Potential impacts of dams to salmon are of particular interest in the Klamath Basin. By blocking upstream access, dams greatly reduce the amount of habitat available for reproduction, feeding, growth, and migration. These are all important processes in the life cycle of salmon and can be extended to other species. Adequate freshwater flow is critical to all life stages, from eggs to spawning adults, so reduced flow can have a negative effect on anadromous fish populations. Current temperature regimes in the Klamath River and its tributaries approach or exceed physiological optima that have been defined for salmon. Temperature extremes and other stressors can act in concert to compromise the immunology, health, and condition of juvenile and adult life stages. In the Klamath Basin, coho salmon (*Oncorhychus kisutch*) are protected under the Endangered Species Act (ESA), and their recovery remains in jeopardy, in large part due to anthropogenic changes in their freshwater habitats.

Fish Health

Infectious disease is increasingly recognized as an important component of the ecology of aquatic animals in the wild; however, the impact of disease among free-ranging stocks has been difficult to investigate. Recently, field and laboratory studies have begun to provide information on infectious diseases that are associated with significant mortality among natural populations of fish in both freshwater and marine ecosystems. This research has also served to highlight the critical role played by environmental conditions in the ecology of fish disease and the synergistic effects of both anthropogenic and natural stressors on the severity of these diseases.

Outbreaks of disease that result in substantial mortality among important stocks of fish in both the upper and lower subbasins are of special concern in the Klamath Basin. In the upper subbasin, losses of adult shortnose and Lost River suckers (*Chasmistes brevirostris* and *Deltistes luxatus*, respectively) have been associated with diseases caused by several endemic bacterial fish pathogens in fish that were highly stressed by adverse water quality following the collapse of large algal blooms. The effects of fish condition and stressors on disease resistance in young-of-the-year suckers are largely unstudied but there is increasing evidence that the presence of cyanotoxins associated with harmful algal blooms maybe involved. Similarly, highly visible losses of adult Chinook salmon in the Klamath River have occurred from endemic diseases in fish that were stressed by low flows and warm temperatures. A high prevalence of parasitic and bacterial infections are seen in juvenile Chinook and other salmonids that are believed to encounter endemic pathogens at higher than normal infection pressures due to altered habitats.

Certain pathogens have already been shown to cause significant mortality in salmonids in the Klamath River. In addition, modeling studies have demonstrated the potential negative impacts on salmon at the population level. During their outmigration as smolts, juvenile Chinook salmon are affected by the myxozoans *Ceratomyxa shasta* and *Parvicapsula minibicornis*, and the bacterium *Flavobacterium columnare*. As returning adults, infections by *F. columnare* and the external parasite *Ichthyophthirius* can result in high mortality under certain conditions. Reintroduction of anadromous fish to the upper subbasin is under active consideration and carries with it additional questions about the introduction, distribution, and transmission of infectious diseases of fish. Additionally, the known fish pathogens, *Aeromonas hydrophila*, *F. columnare,* and *Pseudomonas* spp. have been recovered from moribund adult suckers in the upper subbasin.

Conditions affecting the severity of disease in fish may be very different depending on the pathogen. The myxozoan parasites require alternate hosts to complete their life cycle and the densities or genetic strains of those hosts will influence infection severity in the fish host. Survival of many fish pathogens may be affected by physical parameters such as water quality, temperature, flow, or substrate as well as the availability of alternate hosts. In addition, the infection pressure on the fish host may be affected by factors such as water volume or flow that can control the number of infectious units per unit of water. One management action currently under study proposes to reduce pathogen effects in the Klamath River by releasing water at dams to create flushing flows that would reduce pathogen concentrations, reduce water temperatures, or alter habitat for alternate hosts. This effort will determine when flow increases would be most beneficial and what magnitude or duration would be needed to obtain a quantifiable benefit. In addition, it will be important to understand the full range of other environmental risks imposed by experimental flows.

There is a strong genetic influence in some salmonids on the susceptibility to *C. shasta*. Previous research in the Klamath has demonstrated some populations are more resistant, possibly as a result of their contact with the parasite during early rearing and migration. Little is known about the relative resistance of Chinook salmon and steelhead to *P. minibicornis*. For *F. columnare*, virulence for each species may vary by bacterial strain, and this is uncharacterized for strains from the Klamath Basin. There also is little information on the ecology on these and other important fish pathogens in the Klamath system or the effects of seasonality as it impacts disease resistance. Although temperature is an important component of seasonality, it cannot explain all the variation in immune function observed in salmonids.

Climate Change

Since 1900, temperatures in the Pacific Northwest have increased by 1.0 °C, which is 50 percent greater than the global average. Climate change models project that in the next 30–50 years the Klamath Basin will experience increased winter precipitation—as rain, not snow—and decreased summer precipitation. Imposed on these general trends in the future will be the El Nino/Southern Oscillation and the Pacific Decadal Oscillation (PDO), which influence warm and dry or cool and wet trends in the Pacific Northwest including northern California. Recent rapid, sustained declines in the mass of Cascade Mountain glaciers suggest climate change is already having a greater effect than past PDO-induced variations in the glacier records. Given these long records, the case for climate change having significant impacts in the Klamath Basin is unquestionable.

Increased concentrations of greenhouse gases will significantly change global climate in the next 100 years. Today's choices will decide whether climate change will present overwhelming or manageable challenges in the future. Therefore, effective management will require relevant science to inform mitigation and adaptation to the changes in our planet's climate. Although it is essential to appreciate the physical, chemical, and biological science of climate change, it will be critical to predict the social and economic outcomes of climate change if this information is going to be relevant and useful to decision makers in the Klamath Basin.

The effects of climate change on water temperature, water quantity, and water quality and linkages to atmospheric and meteorological events will bring profound changes to the Klamath Basin. Three key resource management issues in the Klamath Basin will be affected: agriculture, forestry, and fisheries, and these will generate new social, economic, and ecologic concerns overlying others in the Basin. The impacts of rising freshwater temperatures on the physiology of fishes, movement and migratory behaviors, and on physical habitats and their use must be determined to design and evaluate appropriate mitigation strategies. As flows change and temperatures increase, spring-fed rivers and streams and the underlying geology therein will be increasingly important to cold water fishes because of their resilience to changing precipitation, variable runoff, and warming. Groundwater effects on nutrient dynamics and aquatic productivity in spring-fed habitats will be critical for understanding changes in food webs.

The potential for synergistic effects resulting from climate change on key ecosystem processes is an area where predictive tools and scenario evaluations is needed. As an example, the interactions of climate change effects and species migrations and invasions are poorly understood, but may act in concert to change how the ecosystem functions.

Scientific studies are needed to understand, mitigate, and adapt to the effects of climate change on natural resources in the Klamath Basin. Integrated approaches will be necessary to assess credible climate change scenarios and mitigation strategies. Interdisciplinary studies using linked models are needed to address process changes and ecosystem function and should include:

- Surface and groundwater interactions to assess changes in surface flows and groundwater reserves.
- Hydrologic effects on stage and discharge at selected locations through each subbasin.
- Hydrodynamic effects on water depth and currents in key reaches.
- Hydraulic effects on fish habitats for target species and flows.
- Bioenergetics and food web effects on fish response.
- Population dynamics at watershed, region, and population scales. A wide spectrum of climate-induced flow scenarios will be tested.
- Socioeconomic assessments of changing conditions on human activities.

Ecological and socioeconomic linkages between climate change and marine fisheries require further examination. Climate change is already bringing shifts in species ranges towards the poles, and likely extinctions where dispersal capabilities are limited or suitable habitat is unavailable. Changes in resource distribution and abundance will impact the nature and value of fisheries. Populations with fast generational times show a stronger distributional response to temperature warming. Climate change will strongly influence species distribution and abundance as many species—for example, eulachon—may be unable to adapt to the increasing temperatures or other ocean changes such as the restructuring of trophic relationships.

Ecosystem Services

Ecosystem services are the various functions provided by the natural environment that are considered valuable to human well-being. These services include the production of raw materials, water management, nutrient cycling, erosion control, climate regulation, carbon storage, and many others. The United Nation's Millennium Ecosystem Assessment[11] describes four kinds of services provided by the natural environment:

- *"Provisioning services"* are the products people obtain from ecosystems, such as food, fuel, fiber, fresh water, and genetic resources.
- *"Regulating services"* are the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification.
- *"Cultural services"* are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.
- *"Supporting services"* are those that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation.

Ecosystem goods and services are vital to sustaining well-being, and to future economic and social development. This multidimensional way of viewing ecosystems is still evolving, especially with respect to resource valuations, but is attractive for its integration of science, policy, business, and public

[11]See "Ecosystems and human well-being: a framework for assessment" (http://www.maweb.org/en/Framework.aspx).

opinions. Decisions related to resource management, such as water for irrigation, low cost energy, and ocean salmon harvest, can be considered in a broader context of societal priorities, such recreation, employment, and economic activity (table 1-2). The implementation of ecosystem-based management is premised on the conservation of essential ecosystem components, processes, and related services.

Ecosystem Restoration

Success in protecting and restoring fish and wildlife resources and the ecosystems upon which they and human populations depend will continue to elude society until:

- The basic life history requirements of many species are better understood.
- The cumulative effects of human impacts on species and their habitats are quantified.
- Monitoring of ecosystem condition and processes can be implemented at a regional scale.

A multiplicity of management questions important to State, Federal, and tribal resource management agencies remain unanswered as a result of persistent scientific uncertainties. Fundamental information critically needed by managers on the life histories of fish and wildlife is missing. Large-scale restoration programs are unable to prioritize current activities or re-direct future program emphasis because they lack adequate research, monitoring, and evaluation capacities. Consequently, natural resources are under increasing pressure from human population growth and resulting impacts from climate change, contaminants, habitat loss, invasive species, water conservation, and other activities.

A diversity of high quality, connected habitats is necessary for organisms to complete their life cycle and maintain healthy, reproducing populations. Habitats of Klamath Basin fish, wildlife, and plant communities have become increasingly fragmented, reducing the ability of species to successfully migrate, forage, avoid predators, reproduce, and complete their life cycles. Consequently, many populations have declined and much of the diversity (genetic and life history) and resilience of these species to environmental disturbance (as expected to increase with climate change) has been lost. An understanding of the landscape processes that can both fragment and reconnect habitats and the corresponding population responses are critical to future management, restoration, and persistence of biological communities within the Basin and across larger scales.

Habitats of fish, wildlife, and plant communities have become increasingly fragmented, impacting the ability of species to migrate to superior food resources, to find shelter from predators, and to reproduce in dispersed areas that provide adequate rearing habitat. A major hypothesis to be tested is that the increasing reliance on disconnected headwater streams to maintain spring Chinook and steelhead production in the Klamath Basin (and elsewhere) has led to decreased diversity (genetic and life history) and decreased resilience of these species to the type of environmental disturbance expected with climate change. The effectiveness of programs to restore populations and biological communities are diminished by critical uncertainties regarding the role habitat connectivity plays in population function and persistence. This is particularly crucial because climate change, increased demand for water, and habitat loss represent continued challenges to the management of natural resources.

The loss or fragmentation of habitat reduces the ecological services that ecosystems can provide. The species most affected are those that depend on aquatic habitats where humans are most active; these tend to be located in coastal fringes of the United States. Some of the current habitat management and planning efforts underway by the FWS[12], The Nature Conservancy, Reclamation, NMFS, Tribes, and others in the Klamath Basin are presented in table 1-3.

The South Florida Case

An evaluation of whether dam removal will advance the restoration of salmon fisheries, including salmon and steelhead reintroduction into the upper subbasin, is part of the SD. An integrated science framework will be needed to conduct this evaluation and much can be learned from a restoration case history example, outside the basin, to determine how science can best inform decision making and restoration goals. A "lessons learned" presentation from the South Florida Everglades program allowed for comparison of similarities and dissimilarities with the Klamath Basin, a demonstration of the importance of the organization structure and its contribution to the decision making process, and the placement of process-oriented science within that structure in the near term.

An integrated science framework was applied to large-scale ecosystem restoration in South Florida. Restoration planners noted early-on a need for an ecological (science-based) approach that would recover biological diversity, ecological function, and the "defining characteristics" of the natural ecosystem. Humans were recognized in this science planning. Appropriate time and spatial scales were factored into the planning in recognition of the complexities of ecosystems and management institutions. Goal development included a wide representation of stakeholders to define shared visions for desired ecosystem conditions and a governance structure that included substantial public participation. The implementation of the restoration program used adaptive management to achieve desired outcomes by accepting uncertainties and regularly incorporating new understanding of ecosystem conditions. Management decision making was coordinated within government and non-governmental planning and activities.

From the beginning of this planning effort, there was a positive linkage of the environment to long-term economic development. The ecological approach forced management to focus on activities and land use with South Florida landscapes. The focus on restoration of natural processes, stressors and effects, and responses by high-level indicators similarly forced an approach that considered restoration at regional scales and over intergenerational time periods.

Efforts in South Florida to restore large geographic areas present many of the same issues that are encountered in the Klamath Basin. Thus, the South Florida experience provides an opportunity to examine how to move forward in developing a more basinwide integration of research, monitoring, and restoration of a system as big and diverse (ecologically, socially, economically) as the Klamath Basin.

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[12] Management activities include: (1) Habitat Restoration—the rehabilitation of degraded or lost habitat to the original community that likely existed historically, including natural hydrology, topography, and native vegetation; or the rehabilitation of degraded or lost habitat to an ecological community different from what existed before, but which partially replaces original habitat functions and values and consists primarily of native vegetation; (2) Habitat Enhancement - the alteration of existing, degraded habitat to improve and/or increase specific fish and wildlife habitat functions and values; (3) Habitat Creation— the development of habitat types in order to mimic habitats that occur naturally in the immediate area and did not previously exist on the site; and (4) Habitat Management—the periodic, routine, short-term actions that manipulate the physical, chemical, or biological characteristics of habitat to replace or replicate natural events; e.g., wildfire, floods, and drought that occurred on the landscape prior to cultural intervention.

Importantly, from the onset South Florida managers relied on Conceptual Ecological Models (CEMS) to illustrate ecological linkages between the physical, chemical, biological, and social elements of the systems of interest. This allowed a suite of "causal hypotheses" linking the most important stressors with their major ecological effects to be described. By doing this, the managers were able to create a set of measurable indicators of success (i.e., performance measures) and a "level playing field" for evaluating, prioritizing, and funding science components. A CEM clearly identifies the drivers, stressors, effects, and attributes of a system and therefore allows one to link an ecosystem metric to management actions for planning adaptive management.

Many of the challenges encountered in South Florida included lack of data on reference conditions, the inability to identify cause-effect linkages, the inability to implement adaptive assessment when recovery times are long, separating "signal from noise," various technological challenges, and maintaining political and public support when recovery times are long. A key component to the program's success has been monitoring. Interpretation of monitoring in a science-management framework focused on the ability of planners to make informed decisions by providing sound science to (1) guide restoration implementation and operation, and (2) reduce risk and uncertainty.

Restoration efforts in the Klamath Basin will continue to occur with or without the KBRA and dam removal. It is an issue of time and scale. Large-scale restoration to bring salmon back to the basin will require large public expenditures and, as realized in South Florida, a new governance structure that involves all Klamath Basin stakeholders in a science-based, consensus-driven approach to ecosystem management to guide planning, implementation, and oversight processes. Under this structure, the selection of restoration goals and targets and inclusion of adaptive management objectives would be part of the public planning process that includes the many interests of Klamath communities.

Resource Management Concerns

The quantity and quality of the water in many freshwater habitats of the Klamath Basin have been declining for over a century. To illustrate, the draining of wetlands in the upper subbasin began in the 1890s. Farming, industrialization, residential expansion, and flood control have reduced instream flows of fresh water, changed the timing and severity of flood events, and increased the quantity of nutrients and contaminants draining from upland habitats.

Natural resource management issues in the Klamath Basin have been challenging, controversial, and very much water-related in recent years[13]. Dam removal and habitat restoration, climate change, threatened and endangered species, invasive species, fisheries and salmon reintroduction, and water resource uses were among the significant issues identified at the conference (table 1-4).

The resource issues and corresponding science needs were oriented toward aquatic ecosystems due to the KBRA. A commonly held view was that much of the research and monitoring that has been conducted, while legitimate, represents a somewhat scattered and fragmented effort in the collective whole leaving some important science areas little understood. Greater attention to comprehensive planning for ecosystem restoration and better coordination and communication of governmental planning processes are urgently needed. Scientific integrity is valued by Klamath stakeholders and many advocated for more transparency, including assurances about science quality and relevancy of funded activities to Klamath priorities. The stakeholders voiced their support for watershed science that would be integrated geographically, temporally, and across disciplines. Restoration should be process-oriented and management objectives evaluated through adaptive monitoring approaches.

[13] See "Science Needs" extracted from the Lower Klamath Basin Science Conference at http://www.usbr.gov/research/science-and-tech/conference/lowerklamath/rankingresults/sneeds_report.cfm.

Some of the information needs identified were very specific. Collectively, they reflect long-standing concerns for natural resources, local and regional economies, and conflicts with competing uses of water. Growing concern about possible climate change effects and its impacts on restoration and recovery efforts were evident. From a comprehensive planning perspective, the needs can be categorized in broad science areas with interlocked physical, biological, and socioeconomic goals to:

- Examine spatial and temporal trends at all levels of biological organization (e.g., genetic diversity; status and trends of population and communities; status and trends of habitats, landscapes, and ecosystems).
- Characterize and understand biological systems as a basis for management (e.g., molecular genetic studies; population and community dynamics; habitat, community, and ecosystem relationships).
- Examine spatial and temporal trends in the physical environment and how they relate to biological processes (e.g., ocean conditions; climate cycles; interactions among groundwater, surface water, and hydrology).
- Understand causes and effects of resource threats and predict their impacts (e.g., land-use changes, habitat and hydrological alterations and contaminants, invasive species, disease, climate change).
- Develop tools and strategies to facilitate ecosystem restoration and evaluate its effectiveness (e.g., next generation tools, watershed scale and adaptive management approaches, integrated monitoring, metrics of environmental health).

Focal Species for Restoration Planning

A natural focus of fish restoration efforts will be on endangered species and those animals about which biological and ecological information is limited or lacking (for example, fishes that support important fisheries). The focus of research and monitoring in the upper subbasin has been on population recovery efforts for Lost River and shortnose suckers. In the lower river, Pacific salmon (Chinook and coho) and steelhead have received much attention. The possible reintroduction of Chinook and steelhead into the upper subbasin increases the need for much better understanding about these species (e.g., life history, distribution and abundance, and genetic diversity). Pacific lamprey, green sturgeon, and eulachon represent other species requiring special protections and where information is limited. Information about the habitat complexity and competition between bull trout (*Salvelinus confluentus*) and brown trout (*Salmo trutta*) is needed by managers.

Given the aquatic ecosystem focus of this conference and the KBRA, additional attention to the identification of potential indicators of restoration success is needed. In terrestrial environments, avian indicators are being used as large-scale indicators of the Basin’s forest health, habitat use, and status and trends of key bird species. Because many species of fish in the Klamath Basin are long-lived and relatively predictable with respect to their feeding ecologies and habitat use, they too may be suitable indicators of aquatic ecosystem conditions. It is hypothesized that trends in population health and condition and species occurrence reflects the long-term integration of biological effects associated with changing water properties and food webs. Population dynamics research would benefit from inclusion of multi-species interactions (for example, predator-prey, competition, pathogens, and invasive species) and quantification of environmental influences (for example, stream flows and temperatures, hydrography, nutrient dynamics, and biological productivity) in freshwater and marine ecosystems. Linked physical and biological models are necessary to provide the sophistication required to assess aquatic productivity and ecosystem services.

Non-Salmonid Threatened and Endangered Species

The FWS is in the final stages of preparing a Recovery Plan for endangered suckers in the upper basin. Continued monitoring of the population status and trends of Lost River and shortnose suckers is a high priority of this recovery planning. Greater attention to the ecology of these juvenile suckers in Upper Klamath Lake also is a priority. At present, existing data suggest that algal toxins in the lake are affecting juvenile health and condition and may be causing a population bottleneck. A food web link may be involved and interdisciplinary science is required to address this issue (e.g., nutrient dynamics, bloom dynamics, circulation and transport processes, seasonal habitats of juveniles, and feeding ecology).

Construction activities of two large-scale restoration projects were recently completed. Continued long-term monitoring and evaluation of the effectiveness of dike removal at the Williamson River Delta Restoration Project and Chiloquin Dam removal on the Sprague River is needed. The latter effort would provide much needed new information on the spawning ecology and habitat use of the endangered suckers.

Eulachon is a lower basin non-salmonid ESA-listed fish which in the Klamath Basin is near extirpation. This fish was not only an important forage fish but an important part of Yurok tribal culture, being an early season food resource. It is the first fish to be listed that identified climate change as the primary jeopardy factor. Efforts are beginning to establish monitoring.

Salmon and Steelhead

The primary purpose of the KBRA and SD are bringing about salmon recovery in the Klamath Basin. W.F. Thompson visualized the interaction between salmon habitat and life history as “a chain of favorable environments connected within a definite season and place, in such a way as to provide maximum survival.” The image of a chain is important. Imagine a salmon life history-habitat chain with three or four broken links, habitats where the salmon cannot survive or where survival is low. The life history-habitat chain fits well with the “beads on a string” habitat mosaic described in this proceedings report to guide large-scale restoration planning for salmon and other aquatic species.

The life cycle of Pacific salmon forms a critical link in a cyclical, regenerative interaction between land, river, and ocean. The cultural and economic values of this resource in the Basin, including those associated with restoration, are unparalleled elsewhere in the nation. Pacific salmon are a keystone species, and logically their status would be an indicator of aquatic ecosystem health. In this context, one thrust would be to focus on environmental, socio-cultural, and economic conditions in watersheds from an ecological perspective, evaluating land and water practices and assessing dynamic changes (physical, chemical, and biological) in the hydrological system. Restoration science needs to examine environmental flow requirements for multiple stakeholders applying innovations, such as the Ecological Limits of Hydrologic Alteration (ELOHA)[14] method, to direct resources to areas of greatest ecological health or restoration potential. Scientific knowledge and predictive tools for decision making will be the essential foundation to the resolution of the complex and controversial resource issues surrounding salmon recovery.

[14] For information about tools for environmental flows see http://conserveonline.org/workspaces/eloha.

In 2000, the National Science and Technology Council recommended priority science needs in support of the President's Pacific Coastal Salmon Recovery Initiative[15] in a report entitled "*From the Edge*." These needs also hold true for the Klamath Basin and include:

- Definition of critical ecosystem features for the full life cycles of salmon species and stocks.
- Quantitative definition and assessment of risks (natural and human caused) during upstream, downstream, and estuary/ocean life stages.
- Clarification of fundamentals of biological diversity in salmon species, races, and stocks.
- Development of remedial technologies that work with nature rather than replacing it.
- Clarification of the regional variation in the physical, biological, social, cultural, and economic environments of salmon.
- Development of quantitative indicators and analytical methods to assess the status of salmon, characterize risk factors, and evaluate outcomes of remediation efforts to improve environmental conditions or reduce risks.

Adaptive Management and Long-Term Monitoring

Adaptive management is a structured, iterative decision-making process used when decision makers are faced with uncertainty. It is widely used in resource management and it has been specifically recommended for use in the Klamath Basin by National Research Council (NRC) reviews and by others. The basic steps of adaptive management include setting of goals, development of work plans to accomplish goals, implementing work plans and monitoring simultaneously, data analysis and comparison of measures with goals, and modifications of work plans to better accomplish goals. This process is iterative over appropriate time scales. Adaptive management generally is the recommended method of ecosystem management and it provides a structured method of including information that is learned through monitoring in the recovery process.

Many entities have begun to articulate possible restoration goals for the Klamath ecosystem. The Upper Klamath Basin Working Group identified the following goals and they are noteworthy for their community inclusiveness, ecosystem approach, and potential applicability to comprehensive planning:

- Improved water quality through the implementation of accepted Best Management Practices.
- Restoration of wetlands and riparian habitat.
- Enhancement of natural and structural water storage.
- Improvements to irrigation efficiency and water conservation.
- Economic growth and diversity through activities such as value-added natural resource products and ecotourism.
- Enhancement of fish and wildlife.

There is much to be learned from previous planning for the Klamath Basin and for large river ecosystem restoration efforts outside this basin. The Pacific Northwest Aquatic Monitoring Program provides one example of how to lead organized long-term research and monitoring by multiple entities using standardized methodologies and information management technologies. The broad goals described above are supported in greater detail in subsequent chapters.

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[15] From the Committee of Environment and Natural Resources report entitled "*From the edge – science to support restoration of Pacific salmon.*"

Monitoring is an essential part of adaptive management and, in fact, of any type of resource management. The lack of baseline and long-term trend data about ecological conditions has often confounded our understanding of causal linkages between anthropogenic effects and valued ecosystem services. There is widespread consensus that many of the pressing issues in the Klamath Basin would benefit from the implementation of a successful regional scale, integrated monitoring program.

The Klamath Bird Monitoring Network provides an example of successful integrated monitoring that was highlighted at the conference. The Klamath Bird Observatory and U.S. Forest Service have worked with many collaborators to develop the Klamath Bird Monitoring Network, a comprehensive bird-monitoring network in southern Oregon and northern California. This innovative partnership includes tens of thousands of extensive bird and habitat survey stations and dozens of intensive population demographic monitoring stations. Bird conservation objectives are considered within an ecosystem framework in order to inform managers and other stakeholders about avian population responses to changes in watershed processes, such as land-cover and land-use change, fire and flood disturbance, climate change, riparian/wetland ecology, and process linkages. Monitoring data allow the evaluation of species and community responses to large-scale watershed changes. Monitoring birds at different spatial and temporal scales has helped to inform the design of, and measure the effectiveness of, fire-adapted ecosystem restoration efforts; understand the effects of long-term restoration on wetland and riparian ecosystems; and integrate bird monitoring into large-scale anadromous fish and wildlife restoration efforts downstream of the Lewiston Dam on the Trinity River.

Managers of large-scale restoration programs must be able to prioritize current activities or re-direct future program emphases. High-level indicators that are indicative of ecosystem function and health, species status, or restoration goals must be identified within a robust research and monitoring design. Without a comprehensive and adaptive basinwide science approach, the resulting lack of ecological context, learning, and feedback mechanisms will continue to inhibit our ability to translate project scale work into knowledge that could improve restoration effectiveness. In the long run, there are economic impacts associated with piecemeal approaches, and this lack of accountability will quickly bring into question the long-term viability of recovery and restoration efforts in support of ESA-listed species or natural ecosystem conditions, respectively. California Department of Fish and Game and NMFS have recently published a monitoring plan for coastal salmonids which is comprehensive in covering salmonid status and trends as well as monitoring for hatchery and fisheries impacts.

Conceptual Foundation

The NRC reviewed the science related to restoration and management strategies for the Klamath River and called for a “big picture conceptual model” to connect scientific studies in an ecosystem context and to allow critical uncertainties to emerge from analysis of the model. The NRC found that the lack of such a model has prevented the current science from being effective in guiding management decision making and resolution of controversies.

A conceptual foundation is a set of scientific principles and assumptions that gives direction to management activities, including restoration activities, by defining the current understanding of the most important variables and interactive processes, identifying problems, and establishing the range of appropriate solutions given recognition of uncertainties in the science. As noted in the South Florida example, a well-designed, agreed-upon conceptual model provides the basis for informed decision making if it accurately describes key relationships between ecosystem attributes and processes in relation to environmental stressors.

A conceptual foundation or model for the Klamath Basin was presented at the meeting and is described more fully in this proceedings report. The pivotal chapter (Chapter 7) represents our best conceptual thinking at present for restoration of salmon runs and other key attributes of the Klamath River ecosystem. The authors describe boundaries, principles, and assumptions for the Klamath River Ecosystem, with a scientific retrospective analysis serving as the basis for a conceptual foundation for the Klamath ecosystem as derived from our collective understanding of natural and cultural attributes, interactions, constraints, and opportunities in a restoration context. Connectivity of ecosystem attributes and environmental stressors provides a sound basis for planning an adaptive management strategy to assist restoration planning. The watershed approach is central to this planning and provides a unified organizing tool to conceptualize ecosystem structure and function, including natural and cultural characteristics, to guide management activities to return the Basin to a more normal state.

About This Document

Chapter authors relied heavily on information presented during the conference's plenary, breakout, technical, and poster sessions. Additional scientific literature was consulted, as necessary, to support or more fully develop and explore concepts, or document information, presented at the conference. A list of key references is provided for readers seeking additional scientific information. In addition, a number of relevant websites were visited as a source of additional information used to describe aquatic ecosystems and interactions as they pertain to the KBRA and other contemporary natural resource issues in the Basin. The authors' selection of key scientific literature does not imply a comprehensive review of literature. These references are meant to provide a technical guide to readers seeking further information on key areas of scientific interest. Recognizing that not all readers will be natural resource scientists or managers and to promote broad information transfer to all Basin stakeholders, in most instances the key references were not specifically cited within the proceedings narratives. The exception is the Conceptual Foundation chapter. This manuscript was presented at the conference but was originally written for journal publication. Since then, it was extensively reviewed and included in its present form with the permission of the senior author.

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The authors wish to acknowledge all conference attendees for their thoughts and insights about the Klamath Basin ecosystem and sustaining processes. We are especially grateful to those participants who presented information in the plenary, technical, breakout, and poster sessions. Special thanks are extended to the organizing committee for the many months of pre-conference planning to develop the agenda, make local arrangements, and successfully execute the complicated logistics of a meeting of this size: Pete Adams (National Marine Fisheries Service), Debra Becker (USGS), Mike Belchik (Yurok Tribal Fisheries Program), Crystal Bowman (Quartz Valley Indian Reservation), David Busch (USGS), Susan Corum (Karuk Tribe), Clayton Creager (CA EPA, Surface Water Quality Bureau, Regional Water Quality Control Board), Debra Curry (USGS), Ken Fetcho (Yurok Tribe), Tracy Fuentes (USGS), Michael Hughes (The Klamath Tribes), George Kautsky (Hoopa Valley Tribe), Steve Kirk (Oregon Department of Environmental Quality), Curtis Knight (California Trout), Irma Lagomarsino (National Marine Fisheries Service), Dennis Lynch (USGS), William McFarland (USGS), Linda Prendergast (PacifiCorp Energy), Eric Peterson (Bureau of Reclamation), Jim Sedell (National Fish and Wildlife Foundation), Dan Snyder (USGS), Scott VanderKooi (USGS), Tommy Williams (National Marine Fisheries Service), Rod Wittler (Bureau of Reclamation), Doug Woodcock (Oregon Water Resources Department), and David Woodson (USGS). We also wish to acknowledge the financial support of the USGS, National Marine Fisheries Service, and National Fish and Wildlife Foundation for this conference.

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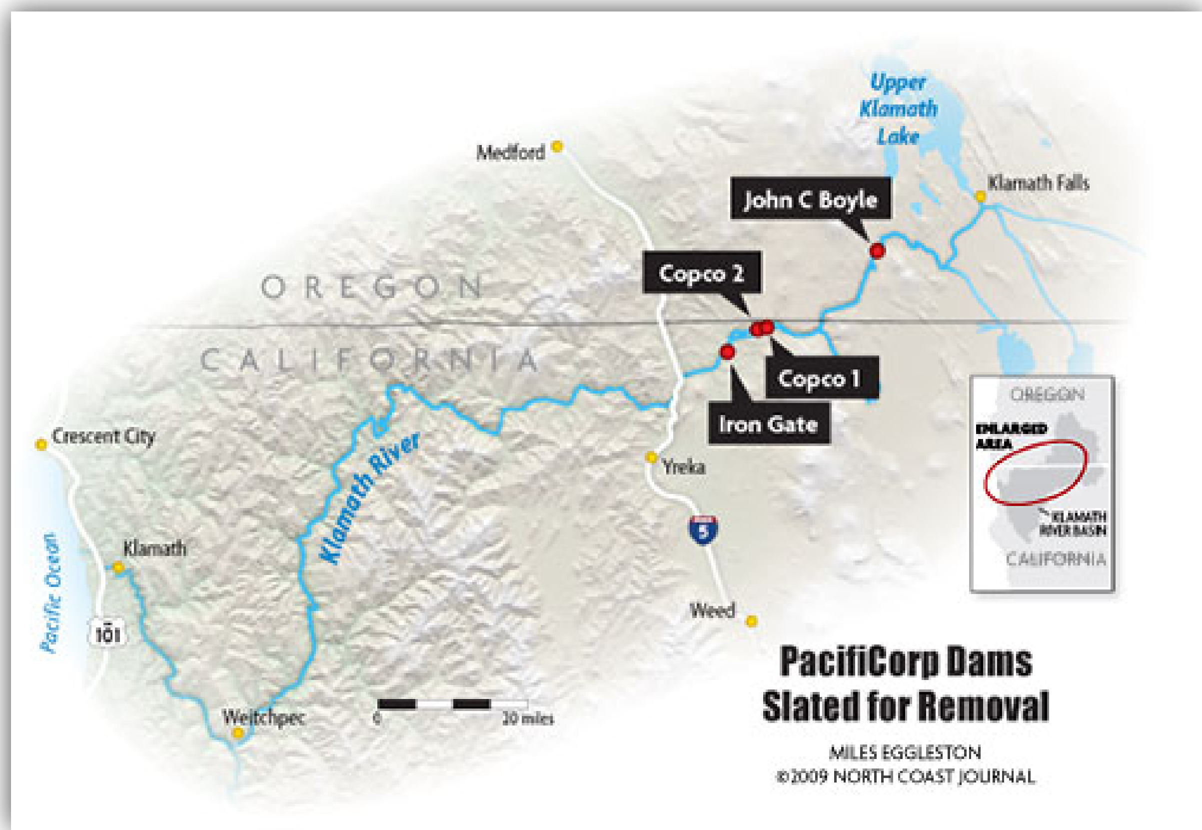

Figure 1-1. PacifiCorp dams slated for removal in the Klamath Basin.

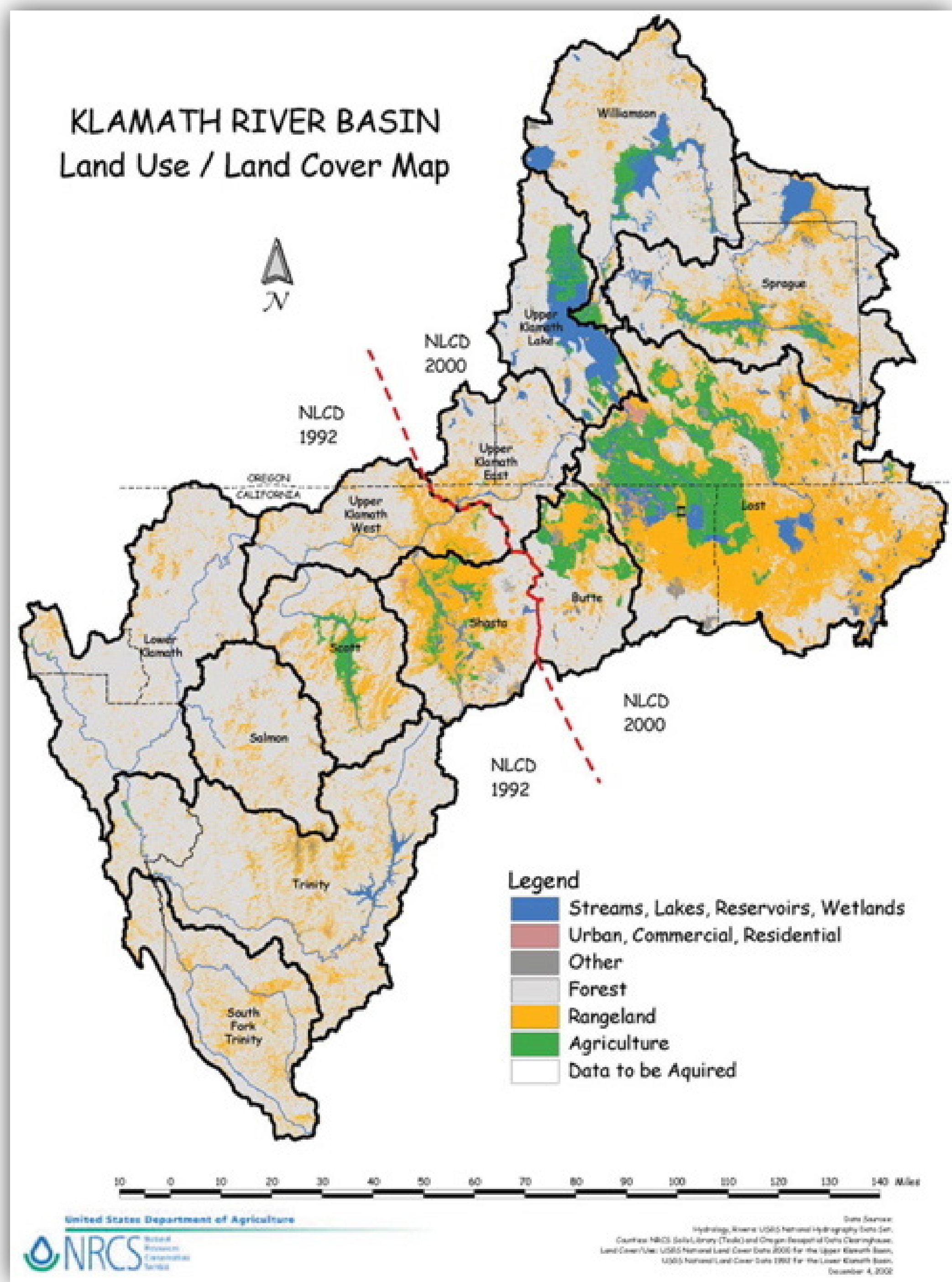

Figure 1-2. Klamath River Basin land use/land cover map.

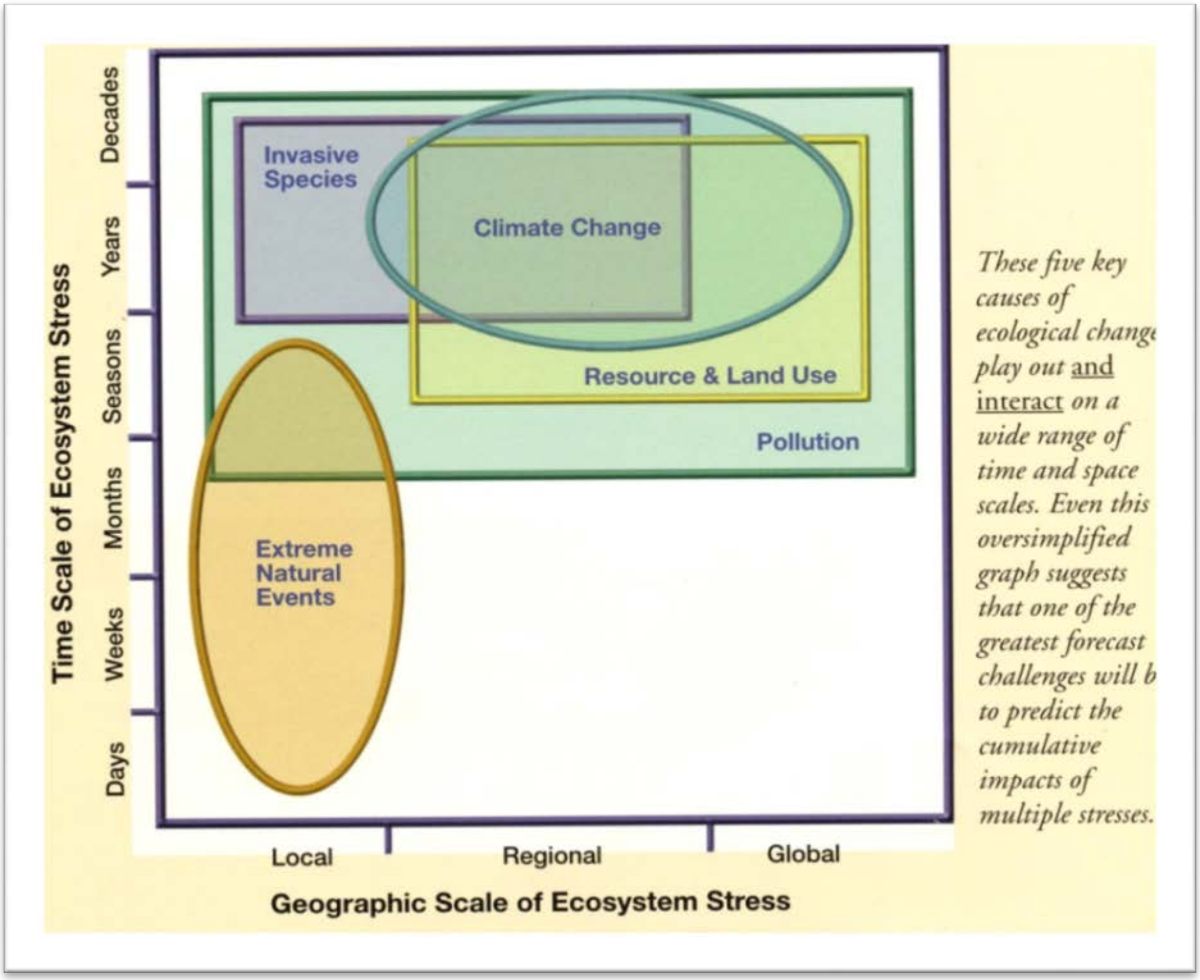

Figure 1-3. Temporal and spatial scales of ecosystem stress.

Table 1-1. Ecological functions performed by different river flow levels (adapted from Postel and Richter, 2003).

Flow Level	Ecological Roles
Low (base) flows	Normal level: • Provide adequate habitat space for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen, and water chemistry • Maintain water table levels in floodplain, soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (living and saturated sediments) Drought level: • Enable recruitment of certain floodplain plants • Purge invasive, introduced species from aquatic and riparian communities • Concentrate prey into limited areas
Higher flows	• Shape physical character of river channel including pools, riffles • Determine size of streambed substrates (sand, gravel, cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate eggs in spawning gravels, prevent siltation • Maintain suitable salinity conditions in estuaries
Large floods	• Provide migration and spawning cues for fish • Trigger new phase in life cycle (e.g., insects) • Provide nursery area for juvenile fish • Provide new feeding opportunities for fish, waterfowl • Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (i.e. , different plant species have different tolerances) • Control distribution and abundance of plants on floodplain • Deposit nutrients on floodplain • Maintain balance of species in aquatic and riparian communities • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organic materials (food) and woody debris (habitat structures) into channel • Purge invasive, introduced species from aquatic and riparian communities • Disperse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture

Table 1-2. Services provided by rivers, wetlands, and other freshwater ecosystems (from Postel and Richter, 2003).

Ecosystem Service	Benefits
Provision of water supplies	More than 99 percent of irrigation, industrial, and household water supplies worldwide come from natural freshwater systems
Provision of food	Fish, waterfowl, mussels, clams, and the like are important food sources for people and wildlife
Water purification/waste treatment	Wetlands filter and break down pollutants, protecting water quality
Flood mitigation	Healthy watersheds and floodplains absorb rainwater and river flows, reducing flood damage
Drought mitigation	Healthy watersheds, floodplains, and wetlands absorb rainwater, slow runoff, and help recharge groundwater
Provision of habitat	Rivers, streams, floodplains, and wetlands provide homes and breeding sites for fish, birds, wildlife, and numerous other species
Soil fertility maintenance	Healthy river-floodplain systems constantly renew the fertility of surrounding soils
Nutrient delivery	Rivers carry nutrient-rich sediment to deltas and estuaries, helping maintain their productivity
Maintenance of coastal salinity zones	Freshwater flows maintain the salinity gradients of deltas and coastal marine environments, a key to their biological richness and productivity
Provision of beauty and life-fulfilling values	Natural rivers and waterscapes are sources of inspiration and deep cultural and spiritual values; their beauty enhances the quality of human life
Recreational opportunities	Swimming, fishing, hunting, boating, wildlife viewing, waterside hiking, and picnicking
Biodiversity conservation	Diverse assemblages of species perform the work of nature (including all services in this table), upon which societies depend; conserving genetic diversity preserves options for the future

Table 1-3. Current restoration activities by habitat type in the Klamath Basin.

Restoration	Project Activities
Riparian zones	Purchase 4,136-acre property (the former Louie Ranch) that includes the main spring sources of the Shasta River and renamed it the Shasta Big Springs Ranch to ensure cold spring water remains in the creek. Reduced irrigation tailwater inputs by 80–90 percent through irrigation system improvements. Water efficiency planning and monitoring are further reducing agricultural diversion of cold spring waters and improving flows. Livestock exclusions are improving emergent aquatic vegetation and salmonid cover.
Riparian zones	Fencing for livestock management; alternative watering sources for livestock; nonnative plant removal/control; native plant establishment/diversification; erosion control; wildlife habitat improvements
Wetlands	Fencing; wetland restoration and enhancement; wildlife habitat improvements
Wetlands	Dike removal on Williamson River
In-stream	Habitat complexity and diversity improvements; hydrologic regime improvements; coarse woody debris and boulder supplementation; artificial barrier removal, modification, and creation: fish screens installation, non-native fish removal (e.g., Lower Klamath Riparian Restoration and Tribal Plant Nursery to improve habitats for threatened coho, Chinook, cutthroat trout, and steelhead).
River floodplain	Geomorphologic and vegetation interaction modeling to evaluate shading effects on the Klamath River
River floodplain	Chiloquin Dam removal
River floodplain	Hydrodynamic modeling to evaluate passive restoration at Big Springs Creek and Shasta River
River floodplain	Trinity River restoration: rehabilitation of banks and side channels by removing riparian berms allowing river to meander again
Upland slopes	Re-establishment of historic contours; silvicultural treatments including prescribed burning, thinning, tree planting, and juniper clearing; native plant establishment/diversification; non-native plant removal/control; fencing; alternativewatering sources for livestock; landslide treatments and erosion control; wildlife habitat improvements
Upland slopes	Surveys of plant species to determine geofluvial influences within the Sprague Basin
Estuarine wetlands	Yurok Estuarine Wetland Restoration Program: enhancing coastal wetland and riparian forest habitats, increasing juvenile salmon rearing capacity and improving hydrologic function of estuary and coastal tributaries
Roads	Road abandonment, decommissioning, and obliteration; road drainage improvements and stormproofing; culvert/stream crossing upgrades

Table 1-4. Resource management issues and science needs identified by Klamath Basin stakeholders at the conference.

Stakeholders[1]	Management Issues	Science Needs
Tribal	Water Resources	• Water quality/quantity monitoring • Groundwater/surface water influences on hydrology (some emphasis on lower Klamath River) • Protect ecological flows/health of aquifer • Non-point source contamination • Ecological effects of water diversions
	Living Resources	• Basic life history and ecology of freshwater fishes (e.g., green sturgeon, Pacific lamprey, eulachon, other species)
	Endangered Species	• Status and trends monitoring • Effects of harmful algal blooms • Delineation of important habitats • Life cycle modeling of population dynamics • Identification of restoration needs
	Hatcheries	• Wild-hatchery salmon interactions • Disease effects on wild salmon
	Sustainable Fisheries	• In-river/ocean stock assessments • Ocean survival of salmon • Estuary/nearshore importance for marine commercial species • Seasonal use of habitats by life history stages • System-wide understanding of salmon productivity and migration processes
	Fire Processes	• Effects of wild fire • Effectiveness of prescribed burns
	Salmon Reintroduction	• Stock selection for reintroduction • Introduction process (embryos or fry, time of year, etc.) • Environmental tolerances and preferences of salmon
	Ecosystem Restoration	• Groundwater effects on biological productivity • Restoration of natural processes • Multi-species interactions • Effects and control of internal/external nutrient loading in Upper Klamath Lake • Next generation tools for in-stream (focus on tributaries) • Develop metrics for environmental health (e.g., high-level indicators)
	Climate Change	• Effects of changing patterns of precipitation • Loss of aquifers and groundwater springs
	Traditional Ecological Knowledge (TEK)	• Incorporation of TEK in science planning and information synthesis
County	Water Resources	• Required allocations for restoration and reintroductions
	Dam Removal	• Short- and long-term effects on Klamath Basin economies (as possible basis for economic aid to impacted counties) • Effects on air quality, groundwater resources, plants, smoke, or other stressors

Stakeholders[1]	Management Issues	Science Needs
		• Integrity of science used in decision making and analysis of alternatives • Conduct "before/after" studies of effects with human dimensions included in research
	Ecosystem Restoration	• Focus on natural processes and human dimensions • Sustainability defined in economic, ecologic, and political perspectives • Improve technical support and assistance to counties
	Communicating Science	• Make data and information available • Clearly communicate scientific relevance • Develop political strategy to educate legislators at local, State, and Federal levels
Federal and State Managers	Water Resources	• Water quality/quantity monitoring • Water reclamation • Groundwater/surface water influences on hydrology (flow and water availability) • Meteorological effects on water supply in upper subbasin
	Dam Removal	• Implement robust mark-recapture program for salmon as part of KBRA • Effects of Chiloquin Dam removal on suckers
	Endangered Species	• Continued monitoring of adult suckers • Effects of harmful algal blooms • Environmental effects on population mortality • Effects of introduced/invading species • Natural recolonization processes for salmon and lamprey; • Control bull trout competitors (e.g., brown and rainbow trout)
	Living Resources	• Basic life history and ecology of freshwater fishes (e.g., green sturgeon, Pacific lamprey, eulachon, other species)
	Sustainable Fisheries	• Improved forecasts for fall Chinook and coho in Scott and Shasta Rivers • Develop population information for salmon and other species in a life cycle model • Maintain existing fish populations and habitats • Fish disease and Basin health • Salmon habitats and productivity in Scott, Shasta, and Trinity Rivers
	Fire Processes	• Effects of asynchrony in fire cycles • Spatial-temporal effects of fire-related debris flows on aquatic habitats and fish productivity • Effects of different fire management strategies • Spotted owl (*Strix occidentalis caurina*) ecology in fire dominated habitats • Old growth forest conditions, edge effects, restoration of old debris
	Salmon Reintroduction	• Effects of flow and ocean conditions on salmon populations • Stock selection for reintroduction • Reintroduction process (locations)

Stakeholders[1]	Management Issues	Science Needs
		• Rearing, survival, and fish passage studies • Determine optimal fish flow-emigration relationships (Chinook emphasis) • Effects of disease
	Ecosystem Restoration	• Next generation tools for in-stream (focus on tributaries) • Integrated monitoring and adaptive approaches to evaluate restoration effectiveness • Reconnecting fragmented landscapes (wetland focus) • Understand effects of grazing • Delineation of cold water refugia and their use by salmon
	Climate Change	• Ecosystem effects on Basin resources and communities • Effects of drier landscapes on fish communities and productivity • Basin-wide vulnerability analysis/effects on restoration activities
Non-Governmental Organizations	Water Resources	• Storage needs from system-wide approach • Sources and effects of nutrients in the Upper Klamath Lake • Agricultural and livestock effects on water quality (upper subbasin emphasis) • Develop nutrient reduction strategies • Economic and ecological effects of taking “land out of production” to increase water to the Upper Klamath Lake • Sources of springs and cold water refugia
	Dam Removal	• Evaluate socioeconomic effects
	Sustainable Fisheries	• In-river/ocean stock assessments • Ocean survival of salmon (new ocean harvest model needed) • Disease effects on salmon • Improved marketing of Klamath Basin salmon resources
	Ecosystem Restoration	• Groundwater/surface water influences on ecosystems • Implement a watershed approach • Evaluate trends in wind, climate, and temperature • Adaptive management and monitoring of Williamson River Delta • Ecosystem strategies to protect ranching, farming, and fish • Ecological significance of the hyporheic zone
	Climate Change	• Effects of invasive species

[1]Tribes represented included: Yurok Tribe, The Klamath Tribes, Hoopa Valley Tribe, Karuk Tribe, and Quartz Valley Indian Reservation. Counties represented included: Humboldt County, CA; Siskiyou County, CA; Klamath County, OR; Trinity County, CA; and Del Norte County, CA. Federal and State Managers represented included: California Department of Fish and Game, Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, NOAA Fisheries, and Bureau of Reclamation. Non-Governmental Organizations represented included: Pacific Coast Federation of Fisherman’s Association, Upper Klamath Water Users Association, Klamath Water Users Association, The Nature Conservancy, Trout Unlimited, and PacifiCorp.

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Chapter 2. Environmental and Historical Setting

Scott VanderKooi[1], Lyman Thorsteinson[2], and Mark Clark[3]

Introduction

The Klamath Basin is a watershed rich in both natural and human resources. The combination of its unique location, complex geology, and diverse geography set the stage for a diversity and abundance of physical and biological resources. These attributes created an environment conducive to initial human settlement and long-term residency as well as the development of many distinct cultures. These same attributes that made the Klamath Basin an attractive home to indigenous peoples for thousands of years also drew more recent arrivals including miners, ranchers, loggers, and settlers to this area. The natural resources of this watershed continue to be of critical importance to the people who live there and competing demands for these resources have been the source of conflict. The objective of this chapter is to provide context and background for both the natural and human history of the Klamath Basin for the remainder of this document. It diverges and expands somewhat from the content of its respective session in the Klamath Basin Science Conference to provide a broader and more inclusive overview. One notable change is that the section focused on the zoogeography of basin fishes was broadened to include the biogeography of the watershed, allowing for inclusion of aquatic as well as terrestrial ecosystems. Another important addition was the expansion of human history to include the histories of the indigenous peoples to characterize all human settlement in the watershed.

Physical Geography of the Klamath Basin—A River Upside Down

The geology and physical geography provide the framework supporting Klamath Basin ecosystems as well as human activities. The unique position of the 40,790 km^2 watershed—on the leading mid-latitude western continental edge and at the complicated juxtaposition of the Basin and Range, Cascade Range, and Klamath Mountains tectonic provinces—has a long history of geologic and climatologic events that have turned the basin “upside down.” Expansive alluvial and lacustrine basins in the hydrologically and topographically complex upper subbasin transition downstream (in an order opposite to most drainage basins) to a steep and closely confined mountain river system in the lower basin. While the overall upside-down basin geometry was probably established by Cenozoic tectonism, volcanism, and capture of the upper subbasin from the Pit River headwaters, much of the character of the natural landscape at the scale of individual basins, river reaches, and hillslopes has been caused by more recent geologic events and processes, such as (1) the massive Mount Mazama eruption of 7,700 years ago which transformed much of the upper subbasin; (2) meteorologically driven hillslope and channel processes from intense Pacific storms, such as the 1964 flood, which shape the more energetic fluvial systems of the lower basin with episodic inputs of water, sediment, and wood; and (3) annual- and decadal-scale climate variations which control hydrologic fluxes throughout the basin.

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[1] U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.
[2] US. Geological Survey, Western Fisheries Research Center.
[3] Oregon Institute of Technology.

Biogeography of the Klamath Basin

The unique physical setting of the Klamath Basin in combination with its complex geology, both past and present, has led to the development of a distinct and rich biogeography. High levels of species richness, biodiversity, and endemism are found in both the flora and fauna of this region. In what could now be considered an early landscape analysis, author David Raines Wallace in *The Klamath Knot* eloquently described the unique geologic and hydrologic features of the Basin and the occurrence and distribution of about 250 plant and wildlife species within its river and forest habitats. This description of richness and ecological relationships, while by no means comprehensive, is indicative of the bounty of natural resources that led to human settlement in this Basin.

The fishery resources of the Klamath Basin are illustrative of the region's diversity. The Klamath Basin was historically home to five species of Pacific salmon and currently has at least six lamprey species (Petromyzontidae), more than any other watershed in the world. Additionally, a high proportion of the Basin's native fishes are endemic, found nowhere else in the world, including several species of sucker (Catostomidae), sculpin (Cottidae), chub (Cyprinidae), and lamprey. Conifers further illustrate similar characteristics having 30 species, seven of which are endemics, in the forests of the broader Klamath-Siskiyou ecoregion. The plant fauna is comprised of approximately 3,500 native plant species including 281 endemics, further demonstrating this point.

The Klamath Basin is internationally known for its abundance and diversity of birdlife. The Klamath Basin National Wildlife Refuges (KBNWR), a complex of six U.S. Fish and Wildlife refuges in the upper subbasin, report 263 species of birds occurring in freshwater marshes, open water, grassy meadows, coniferous forests, sagebrush and juniper grasslands, agricultural lands, and rocky cliffs and slopes. Another 45 species are listed as casual or accidental visitors to the Basin. Wintering bald eagles (*Haliaeetus leucocephalus*) and large concentrations of waterfowl during spring and fall migrations are of special interest. Historically, the upper subbasin was dominated by approximately 185,000 acres of shallow lakes and freshwater marshes. Today, only about 25 percent of these habitats remain and are protected by refuge status and are among the most prolific waterfowl and marsh bird production areas in the Pacific Northwest. Monitoring of the avian resources in the Klamath Basin is providing information about species status and trends and habitat associations for 217 taxa[4].

Other animals also are abundant throughout the watershed. For example, 78 species of mammals have been reported in the KBNWR alone. Although deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), and bears (*Ursus americanus*) are present in the refuges, bats (Vespertilionidae) and squirrels (Sciuridae)—represented by 15 and 10 species, respectively,—are the most diverse of the mammalian species. In addition, six species of amphibians (Amphibia: salamanders, frogs, and toads) and 14 species of reptiles (Reptilia: turtles, lizards, skinks, and snakes) occur in habitats found in the KBNWR. The natural resource inventories for the national wildlife refuges in the Klamath Basin probably account for the most conspicuous terrestrial species within the watershed. They are not however comprehensive with respect to lower trophic levels and are not meant to portray trends in abundance outside the refuges. This information may or may not exist, but has not been compiled at the basin scale.

The accounts above summarize the diversity of the more visible components of the Klamath Basin. Inventories of species at the base of the trophic pyramid (i.e., invertebrates, viruses, and bacteria) are incomplete but critical to ecosystem structure and function. In addition, information about the biodiversity of nearshore waters offshore of the Klamath River is also incomplete and not included in the summaries above.

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[4] From Klamath Bird Observatory (www.klamathbird.org).

Human Settlement of the Klamath Basin

The Klamath Basin has been inhabited by indigenous peoples for thousands of years. Tribal oral histories vary somewhat, but generally state that their people have lived in the Basin since the world was created or time immemorial. Archaeological evidence suggests that the ancestors of Klamath Basin Tribes have been living in the watershed for at least 11,000 years. Each of the Tribes has a rich, unique culture and most have distinct languages. One similarity among the Tribes has been their reliance on the abundant fishes of the watershed for subsistence. Suckers, trout, and anadromous salmon were important food resources for the people of the upper subbasin and a variety of anadromous species (e.g., salmon, lamprey, sturgeon, and eulachon) were, and continue to be, important to those living in the lower portions of the drainage. Unlike the migratory way of life of many North American Tribes, the year-round presence of plentiful foods and other traditional resources allowed most of the Basin's Tribes to lead a more settled existence.

The Klamath Basin's Tribes first came in contact with people of European descent when fur trapping began in the early 1800s. Interactions were initially peaceful, but changed over time. As miners, ranchers, and other settlers arrived in the Basin, tensions escalated and violence erupted. The U.S. Military eventually interceded in these conflicts, which peaked with the 1872 Modoc Indian War. Although many indigenous people died in these clashes, much greater impacts to Tribal populations were caused by the introduction of European diseases. Declines in fisheries also adversely affected traditional livelihoods, given Tribal reliance on fish for sustenance, commerce, culture, and ceremonial purposes. Over time, fish abundance throughout the Basin declined in response to direct activities like overharvest and indirect effects of habitat alteration and destruction through mining, logging, and agricultural practices.

The Klamath Tribes, Hoopa Valley Tribe, and Yurok Tribe had reservations established by way of treaties or Executive Order in the 1850s and 1860s. The transition to a reservation way of life brought hardship to many Tribal people. Most of their historical lands were transferred to the government or Klamath settlers and many Tribal members were forced to move to unfamiliar areas or send their children to government boarding schools. During this period and continuing through the end of the 19th century, the Klamath Basin saw an increase of immigration in the form of miners, loggers, ranchers, and eventually farmers.

Mining began in the lower subbasin with the California Gold Rush in the mid-1800s. Much of the mining occurred in, and had large impacts on, the lower Klamath River and its tributaries including the Shasta, Scott, Salmon, and Trinity Rivers. Commercial logging was widespread throughout the Basin during this same period. Timber harvests occurred on government as well as private and reservation lands. As more people moved into the Basin, agriculture began to be established. Initially, agriculture was limited to ranching in the upper subbasin because the dry climate, short growing season, and lack of irrigation restricted crops that could be grown to those tolerant of the conditions, like grasses. Agricultural development continued in the late 1800s as ranchers began draining the upper subbasin's extensive marshlands and converting them to pasture and farmland to grow hay for cattle feed. Early attempts to develop irrigated agriculture were conducted by private parties and coincided with efforts to drain wetlands.

The majority of agricultural development in the upper subbasin occurred in the 20th century, primarily as part of the Bureau of Reclamation's Klamath Project that began in 1905. The project, which eventually encompassed more than 200,000 acres, was a large and complex undertaking that required the draining of two lakes and thousands of acres of wetlands as well as the construction of several dams and hundreds of miles of dikes, canals, and drains. Markets for crops and livestock were provided by the arrival of the Southern Pacific Railroad in 1909, which connected the upper subbasin to the population centers of California.

The railroad also allowed the expansion of the timber industry in the upper subbasin. The coniferous forests of the region constituted the largest remaining stand of old growth timber in the lower 48 States, and large timber companies like Weyerhaeuser soon established large harvesting and milling operations. As a result of this new economic boom, Klamath Falls became the fourth largest city in Oregon by the 1950s. The rise of the timber industry also benefited the Klamath Tribes, as fees for timber harvesting on their reservation were distributed to Tribal members as annual allowances. In the early 1950s, Klamath Tribal members enjoyed one of the highest per-capita incomes among American Tribes.

In contrast, the economic situation in the lower subbasin was less prosperous. The declining importance of the mining industry, combined with the limited amount of arable land, meant that the population remained small with low average incomes. Local residents felt neglected by the California State government, which to them seemed out of touch with the interests of the region. Interestingly, residents of the upper subbasin harbored similar feelings about the Oregon State government, despite their relative prosperity. The railroad connection from Klamath County to the Portland area was not completed until 1926, and Oregon politics was dominated by the population centers west of the Cascade Mountains.

The result of these frustrations gave rise to the "State of Jefferson" movement of the late 1930s. The movement was centered in counties on the western part of the Oregon/California border, most of them in the Klamath Basin, and revolved around poor roads and lack of economic opportunity. Two X's painted on the bottom of a gold pan were used by the protestors as their symbol. The two X's stood for the people being "double crossed" by Salem and Sacramento, the respective capitols of Oregon and California. Their actions culminated in protests in 1941 in Yreka, California, in which groups of armed young men stopped cars on the main highway and distributed anti-governmental literature. The movement was abandoned after the Japanese attack on Pearl Harbor, and the economic growth brought by World War II meant it was not revived after the war was over.

Both the upper and the lower subbasins participated in the general postwar prosperity of the 1950s and 1960s. The population of the region increased, and logging, farming, and ranching provided many employment opportunities. It was during this time that water-resource management became a primary political issue for Basin residents as California's water needs intensified and the State moved aggressively to satisfy its growing urban and agricultural demands. In the lower subbasin, much of the flow of the Trinity River, a major tributary of the Klamath, was diverted to the Central Valley Project. The Klamath River Basin Compact, ratified in 1957, was specifically designed to prevent water from being removed from the upper subbasin. It also established priorities for water use, with agricultural use coming second, after domestic consumption, and before wildlife, industry, or hydropower uses.

Native Americans did not benefit from the postwar boom and in fact suffered due to declining fisheries and political changes. The continued decline in salmon populations, in part due to the building of additional dams on the Klamath River and its tributaries, was a hardship for the Tribes in the lower subbasin. In the upper subbasin, the Klamath Tribes recognition as a Tribe was terminated in 1954 by an Act of Congress. This led to the end of Federal recognition and supplemental human services, and their reservation land (approximately 1.8 million acres) was converted into the Winema National Forest. The conversion to Federal land was the result of political pressure by local leaders who wanted to prevent large outside corporations from purchasing the land and excluding small local firms from the timber harvest. Members of the Klamath Tribes saw incomes decline and community cohesion suffer in the wake of their loss of Tribal standing.

Local control of the Basin's water resources began to erode in the 1980s. The Klamath Tribes regained Tribal status, and in the US vs. Adair decision in 1984, they obtained recognition of their legal water rights under their original treaty with the U.S. Government. The court noted that the Federal water right reserved by the treaty is a non-consumptive use that entitles the Tribes to "prevent other appropriators from depleting the streams waters below a protected level in any area where the non-consumptive right applies." Similar lawsuits in the lower subbasin led to recognition of Tribal rights there as well. Because Tribal water rights date to "time immemorial," the Tribe's needs were now senior to other claims, posing a major challenge to the existing distribution of water under the Klamath River Basin Compact that favored farmers and ranchers.

At the same time, new environmental regulations were changing the way business was done in the Basin. The Endangered Species Act led to reductions in timber harvesting to protect Northern Spotted Owl (*Strix occidentalis caurina*) habitat, to regulations on river flow to protect salmon, and to restrictions on the level of Upper Klamath Lake to protect suckers. During the 1990s, restriction on water use led to some farmers in the Klamath Basin being cut off from irrigation water. These changes came at the same time that increasing automation was radically reducing the number of workers needed to harvest timber and farm local crops. As a result, farming, ranching, and logging, the mainstays of the basin's economy, did poorly in comparison to earlier years. During the 1980s and 1990s, the region did not participate in the prosperity of the larger American economy, and unemployment rates were high. Local communities increasingly blamed their problems on the intervention of outsiders, particularly the State and Federal Government, and called for greater local autonomy and a rollback of environmental laws.

These trends came together to create the Water Crisis of 2001. As a result of drought and ESA guidelines designed to protect both salmon and suckers, most water to the Klamath Irrigation Project was cut off. The economy of the upper subbasin experienced a severe recession. Local communities organized protests, which placed the blame for the crisis on the Federal Government, the Klamath Tribes, and environmental organizations. Similar in many ways to the State of Jefferson protests of 1941, arguments and symbols of that time were revived for the 2001 protest. The end of the 2001 protest also mirrored earlier events—the terrorist attacks of September 11, 2001, marked their conclusion.

Since 2001, efforts to resolve the complex issues surrounding the basin and its waters have been ongoing, most notably reflected in the negotiation of the Klamath Basin Restoration Agreement, or KBRA. However, the desire for local control and the spirit of the State of Jefferson remain strong, and it is unlikely that these issues will be resolved anytime soon.

Agriculture, timber, commercial fishing, and related industries remain important components of the Klamath Basin's economy[5]. Recent estimates indicate approximately 26 percent of the economic output from the basin is based in natural resource dependent industries. The proportional contributions of these sectors toward the overall economy in terms of jobs and output, however, have declined over the last few decades. Concurrent with increasing populations, the greatest areas of job growth have been in services and wholesale trade in the upper subbasin and in services and construction in the lower subbasin.

Conclusion

Today, six Native American Tribes are formally recognized by the U.S. Government in the Klamath Basin. These include: The Klamath Tribes, Karuk Tribe, Hoopa Tribe, Yurok Tribe, Resighini Rancheria, and Quartz Valley Indian Community. These Tribes represent important partners to Federal and State governments in natural resource science and management and all other sectors of the Basin's economy. Moving forward, government-to-government relationships will be critical to the long-term protection of the watershed's biodiversity and all restoration activities including efforts to return salmon to the upper subbasin. Collaborations will be key to managing the entire basin as an integrated ecosystem with shared emphases on restoration ecology, conservation of natural resources, and the sustainability of Klamath communities.

Acknowledgments

We thank Drs. Jim O'Connor (U.S. Geological Survey) and Doug Markle (Oregon State University) for their contributions to the conference and this chapter. The Klamath Bird Observatory and Klamath Basin National Wildlife Refuges provided important information about wildlife diversity within the basin.

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[5] The National Research Council (2004) provides a single-source reference for economic data and information for the Klamath Basin. Individual websites for each of the counties occurring within the basin provides additional, and in some instances, updated information about more current economic conditions. It was beyond our objectives to further synthesize that information in this report.

Chapter 3. Watershed Characterization

John Williams[1] and Debra Curry[2]

The Klamath River Basin (fig. 3-1) can be divided into two subbasins, an upper and a lower. The two subbasins are dissimilar geologically, hydrologically, and biologically. The upper subbasin is located on the edge of the Great Basin in the rain shadow of the Cascade Range and, for the most part, displays the characteristics of that province: dry and predominantly low relief, punctuated by areas of higher elevation, and in the case of the Upper Klamath subbasin, volcanic buttes. The dominant surface-water feature is Upper Klamath Lake, into which flows most of the subbasin drainage. The lower subbasin comprises the Klamath River drainage basin in which surface water is mostly streams and rivers. The drainage basin occupies the Klamath Mountains physiographic province, an area of high relief, steep canyons, and fast rivers. Precipitation increases rapidly westward from the upper subbasin.

The hydrologic boundaries of the Upper Klamath subbasin are defined by topographic divides of varying elevation on the northwest, north, east, and south. Surface water does not flow across these boundaries, nor does groundwater, except to a negligible degree across the divide between the Upper Klamath subbasin and the Sacramento River basin to the south. The southwestern boundary, near Iron Gate Dam, is loosely defined by the permeability of the underlying rocks to the west, which do not transmit groundwater as readily as the younger, more porous volcanic rocks of the upper subbasin (fig. 3-2). Iron Gate Dam also is the lowermost dam on the mainstem of the river and, thus, marks the upstream limit of where the river is open to the ocean without restriction.

Hydrology of the Upper Klamath Subbasin

Water is a scarce commodity in the Upper Klamath subbasin (fig. 3-3). Scarcity can be a relative concept, however: the earliest inhabitants of the subbasin accommodated their lives to what was available, when it was available, and where it was available. Humans, fish, and wildlife coexisted on a sustainable basis. Beginning in the late 19th century, however, the advent of irrigated agriculture by non-native settlers produced an ever escalating competition for water that continues to this day.

The Upper Klamath subbasin is semiarid (fig. 3-4) because the Cascade Range intercepts much of the moisture from the predominantly eastward moving Pacific weather systems that are the main source of water to the basin. Mean annual precipitation ranges from 65.31 in. (1,658.87 mm) (1909–2010) at Crater Lake National Park in the Cascade Range to 13.91 in. (353.31 mm) (1928–2001) at Klamath Falls. (The precipitation station for Klamath Falls was relocated in mid-2001.) Most precipitation arrives in weather systems that originate over the Pacific Ocean in the fall and winter: November through March precipitation accounts for 71 percent of the total at Crater Lake and 64 percent of the total at Klamath Falls. Most precipitation falls as snow at higher elevations; the snowpack melts in spring and early summer to feed streams and recharge the groundwater system. The interior parts of the subbasin are dry during the spring and summer; mean monthly precipitation at Klamath Falls is less than 1 in. from April through October.

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[1] U.S. Geological Survey, Oregon Water Science Center.
[2] U.S. Geological Survey, California Water Science Center.

Data from the Oregon Climate Center PRISM Group (http://www.ocs.oregonstate.edu/prism/index.phtml) indicates that precipitation in the Upper Klamath subbasin averages about 10 million acre-ft/yr (12.34 km^3/yr) (1971–2000 average). About 7 million acre-ft/yr (8.63 km^3/yr) returns to the atmosphere through evapotranspiration at the location where the precipitation falls, leaving 3 million acre-ft/yr (3.7 km^3/yr) in the system as either surface water or groundwater, although the two are interconnected. Of that amount, about 1.5 million acre-ft/yr (1.85 km^3/yr) returns to the atmosphere by way of evapotranspiration after it has moved through the hydrologic system, about one-half from agricultural fields and one-half from wetlands, leaving about 1.5 million acre-ft/yr (1.85 km^3/yr) to flow out of the subbasin past Iron Gate Dam. A small amount of water, about 30,000 acre-ft/yr (0.04 km^3/yr) annually, is exported from the Klamath River for irrigation in the Rogue River basin. A study of the hydrogeology of the Upper Klamath subbasin estimated that the gross groundwater input to the system is about 1.7 million acre-ft/yr (2.1 km^3/yr), a little more than one-half of the annual runoff. Although the estimate has some degree of uncertainty associated, it highlights the importance of groundwater to the hydrology of the subbasin, especially in dry years with diminished surface runoff.

Surface-Water System of the Upper Subbasin

The Upper Klamath subbasin has several perennial streams with mean annual discharges of hundreds of cubic feet per second (ft^3/s) (>3 m^3/s); the Klamath River at Iron Gate Dam, which comprises the drainage from the entire upper basin, has a mean annual discharge of about 2,000 ft^3/s (56.63 m^3/s) (1961–2010). The subbasin once contained three large lakes: Upper and Lower KlamathLakes and Tule Lake (fig. 3-5), each of which covered areas of 100–150 mi^2 (259–389 km^2), including extensive marginal wetlands.

The surface hydrology of the Upper Klamath subbasin, however, has been extensively modified by drainage of lakes and wetlands for agriculture and routing of irrigation water. The Tule Lake and Lower Klamath Lake basins once contained large lakes fringed by extensive wetlands (fig. 3-5). The Lost River flowed from the upper Lost River basin through the gap near Olene and then south to Tule Lake. The Lost River system received flow from the Klamath River system during floods. Prior to development of the Bureau of Reclamation Klamath Project, Tule Lake covered an area exceeding 96,000 acres. Historical accounts indicate that at high stage Tule Lake drained into the lava flows along the southern margin of the subbasin.

In the early 1900s, the U.S. Reclamation Service (now the Bureau of Reclamation) began to drain Tule Lake. In 1912, a canal and dam were completed that allowed the diversion of water from the Lost River to the Klamath River, cutting off the supply of water to the lake. The only remnant of the lake is the Tule Lake Sump in the southern and western parts of the subbasin, which collects irrigation return flow (fig. 3-6). Since 1942, water from the sump has been pumped via a tunnel into Lower Klamath Lake. The former lakebed is now under cultivation.

The Lower Klamath Lake basin once held a large lake–marsh complex that covered approximately 88,000 acres (356.12 km^2), about 58,000 acres (234.72 km^2) of which were marginal wetlands with the remaining 30,000 acres (121.40 km^2) open water (fig. 3-5). Lower Klamath Lake was connected to the Klamath River through the Klamath Strait, and probably through the expansive wetland that separated the lake from the river elsewhere. In the early 1900s, a railroad dike was constructed across the northwestern margin of the Lower Klamath Lake basin, cutting off flow between the lake and river except at the Klamath Strait. In 1917, the control structure at the Klamath Strait was closed, cutting off flow to the lake. As a result, Lower Klamath Lake is now largely drained, with much of the former lakebed and fringe wetlands under cultivation. Areas of open water remain in the Lower Klamath Lake Wildlife Refuge in the southern part of the upper subbasin (fig. 3-7).

Upper Klamath Lake remains largely intact, and it is an important source of water for agriculture, fish, wildlife, and recreation. About one-third of the wetland area surrounding Upper Klamath Lake, however, had been diked and drained by the end of the 20th century (approximately 31,000 acres [125.45 km^2) as of 1997], although efforts are underway to restore large areas. Upper Klamath Lake and the remaining parts of Lower Klamath and Tule Lakes provide important wildlife habitat, and parts of each are included in seven Klamath Basin National Wildlife Refuges. The Upper Klamath subbasin is an important stopover for waterfowl migrating along the Pacific Flyway.

Principal stream systems in the Upper Klamath subbasin include the Williamson, Wood, Lost, and Klamath Rivers. The Williamson River basin comprises the Williamson River mainstem, the Sprague River basin, and Spring Creek. Together, the Williamson and Wood River systems account for about two-thirds of the annual inflow to Upper Klamath Lake. The Wood River is sustained almost entirely by groundwater discharge in the form of springs. Streamflow in most of the Williamson River basin is primarily snowmelt driven, so flows are low in summer and high during spring snowmelt. Baseflow in the Sprague River outside of the spring snowmelt event is sustained by a small contribution from springs and groundwater discharge through the streambed. About 16 mi (about 25.75 km) from the mouth of the Williamson River, the river is joined by Spring Creek, a springfed stream that has a fairly constant flow over time of about 300 ft^3/s (about 8.5 m^3/s). Together, Spring Creek, the Wood River (fig. 3-8), and, to a lesser extent, springs and seeps in the Sprague River basin and scattered throughout the Upper Klamath subbasin provide the most dependable source of water to Upper Klamath Lake during most of the year. Because of the Williamson River basin's dependence on snowmelt, drought years bring particularly low flows in that system upstream of the Spring Creek confluence, and in years of extreme drought, Spring Creek supplies nearly all flow from this watershed, with a minor contribution from the Sprague River.

The 250-mile-long (402.34 km) Klamath River begins at the outlet of Upper Klamath Lake, which is controlled by the Link River Dam. The first mile downstream of the lake is named the Link River. The river then flows about 2 mi (3.22 km) through Lake Ewauna and then 18 mi through a long, narrow reservoir to Keno Dam, at river mile 233 (375 km) (fig. 3-9). Downstream of Keno Dam, the river is impounded by the J.C. Boyle Dam, at about river mile 225 (362.1 km). The river enters a narrow canyon and flows freely about 20 mi (32.19 km) to Copco Lake (a reservoir). Finally, the river enters the last reservoir, Iron Gate; the dam is located at river mile 190 (305.78 km). The river then flows freely to the Pacific Ocean downstream of Iron Gate Dam.

On a mean annual basis, the Klamath River gains about 300 ft^3/s (about 8.5 m^3/s) of streamflow from Link River Dam at the outlet of Upper Klamath Lake to Keno (primarily from the Bureau of Reclamation Klamath Project and municipal and industrial sources) and then an additional 400 ft^3/s (11.33 m^3/s) to Iron Gate Dam (from springs and small tributaries) (fig. 3-9). Groundwater discharge to the river downstream of Keno Dam accounts for as much as 350 ft^3/s (9.91 m^3/s) of that total.

Groundwater System of the Upper Subbasin

Underlying the Upper Klamath Subbasin is an extensive regional groundwater flow system. The late Tertiary to Quaternary volcanic rocks that underlie the region generally are permeable and compose a system of variously interconnected aquifers. The regional groundwater system is underlain and bounded on the east and west by older Tertiary volcanic and sedimentary rocks that have generally low permeability and do not transmit large amounts of water. Some groundwater probably flows across the southern basin boundary into the Pit River watershed, but amounts are negligible.

Groundwater flows from recharge areas in the Cascade Range and upland areas in the subbasin interior and from eastern margins toward stream valleys and interior drainage basins. Groundwater discharges to streams throughout the subbasin; flow in most streams has at least some component of groundwater (baseflow). Some streams, however, are predominantly groundwater fed from regionally extensive aquifers underlying the western side of the subbasin and have relatively constant flows throughout the year compared to streams that carry mostly snowmelt. Large amounts of groundwater discharge to the Wood River drainage basin, to the lower Williamson River, primarily Spring Creek, and to small streams along the margin of the Cascade Range. Lesser amounts are contributed by seasonally variable springs and seeps in the eastern parts of the subbasin, primarily in the upper Williamson and Sprague River watersheds north and east of Upper Klamath Lake. Bonanza Springs and other, smaller springs provide much of the baseflow for the Lost River watershed, south of the lake. Downstream of Keno Dam, the largest source of baseflow directly to the mainstem Klamath River is the large spring in the "bypass reach" downstream of the J.C. Boyle Dam.

Estimates of gross groundwater discharge in the upper subbasin (before withdrawals and evapotranspiration) are (two significant figures):

- Williamson River basin: 900 ft^3/s (25.49 m^3/s) [650,000 acre-ft/yr (0.8 km^3/yr)]
- Wood River subbasin: 490 ft^3/s (13.88 m^3/s) [360,000 acre-ft/yr [0.44 km^3/yr)]
- Other Upper Klamath Lake tributaries, west of the Wood River subbasin: 120 ft^3/s (3.4 m^3/s) [87,000 acre-ft/yr (0.11 km^3/yr)]
- Upper Klamath Lake miscellaneous seepage and unidentified springs: 350 ft^3/s (9.91 m^3/s) [250,000 acre-ft/yr (0.31 km^3/yr)]
- Lost River basin: 200 ft^3/s (5.66 m^3/s) [140,000 acre-ft/yr (0.17 km^3/yr)]
- Lower Klamath Lake: 35 ft^3/s (0.099 m^3/s) [25,000 acre-ft/yr (0.03 km^3/yr)]
- Klamath River downstream of Keno Dam: 350 ft^3/s (9.91 m^3/s) [250,000 acre-ft/yr (0.31 km^3/yr)]
- Unmeasured, diffuse discharge to wetlands and small tributaries: 410 ft^3/s (11.61 m^3/s) [300,000 acre-ft/yr (0.37 km^3/yr)]
- Total estimated groundwater discharge: 2,400 ft^3/s (67.96 m^3/s) [1.7 million acre-ft/yr (2.10 km^3/yr)]

The groundwater system in the Upper Klamath subbasin responds to external stresses such as climate cycles, pumping, lake stage variations, and canal operation. This response is manifest as fluctuations in hydraulic head (as represented by fluctuations in the water-table surface) and variations in groundwater discharge to springs. Basinwide, decadal-scale climate cycles are the largest factor controlling head and discharge fluctuations (fig. 3-10). Climate-driven water-table fluctuations of more than 12 ft (3.66 m) have been observed near the Cascade Range, and decadal-scale fluctuations of 5 ft

(1.52 m) are common throughout the subbasin. Groundwater discharge to springs and streams (and thus streamflow) also varies basinwide in response to decadal-scale climate cycles.

The groundwater system responds to pumping, especially in areas of pumping for irrigation, where large groundwater withdrawals occur. Annual drawdown and recovery cycles of 1–10 ft (0.3–3.0[5] m) are common in pumping areas. Long-term drawdown effects, where the water table has reached or is attempting to reach a new level in equilibrium with the pumping, are apparent in parts of the subbasin.

Most agricultural land in the Upper Klamath subbasin, about 500,000 acres, is irrigated. Irrigation water comes from a variety of sources. Upstream of Upper Klamath Lake, in the Williamson, Sprague, and Wood River drainages, irrigation water comes primarily from diversion of surface water from the mainstem streams or tributaries. A smaller amount of irrigation water is pumped from aquifers, particularly in the Sprague River Valley and Klamath Marsh areas. In the Langell and Yonna Valleys of the upper Lost River watershed (fig. 3-6), irrigation water comes from Clear Lake and Gerber Reservoirs. Irrigators use groundwater and some surface water in Swan Lake Valley. Groundwater is used for irrigation in areas not served by irrigation districts and to supplement surface-water supplies throughout the area.

South of Upper Klamath Lake most irrigation water comes from the lake by way of the Bureau of Reclamation's Klamath Project, which is the largest single source of irrigation water in the upper Klamath Basin, serving about 200,000 acres (fig. 3-6). Water is stored in and diverted from the Upper Klamath Lake to irrigate land south of Klamath Falls, including the Klamath Valley, Poe Valley (in the Lost River drainage upstream of Olene Gap), and the Tule Lake subbasin (fig. 3-11). Irrigation return flow that ends up in the Tule Lake Sump is pumped to Lower Klamath Lake and is used for irrigation and to supply the refuge wetlands. Water diverted from the Klamath River several miles downstream of the lake also is used for irrigation and refuges in the Lower Klamath Lake basin. Irrigation and refuge return flow in the Lower Klamath Lake basin is routed back up the Klamath Strait drain through a series of pumping stations to the Klamath River.

Some groundwater is used for irrigation on land surrounding the Klamath Project upslope of the major canals. Principal areas of groundwater use surrounding the project area include the southern end of the Klamath Hills, parts of the Klamath Valley, and the northern and eastern margins of the Tule Lake subbasin. Groundwater traditionally has been used for supplemental irrigation in the Project area. Increased water demand during the past decade, due to drought in 2001 and biological requirements for a 100,000 acre-ft (0.12 km^3) pilot water bank[3], has resulted in a marked increase in groundwater removal (fig. 3-12) in and around the Klamath Project with attendant declines in groundwater levels.

Since 2001, groundwater use in the Upper Klamath subbasin has increased substantially. Much of this increase has occurred in the area in and around the Bureau of Reclamation's Klamath Project, where pumping roughly tripled during this period and resulted in groundwater-level declines in excess of 10–15 ft (3.05–4.57 m) in the pumped aquifer between 2001 and 2004. If pumping rates of recent years are continued, the aquifer could achieve a new steady-state condition, but with the effect of streamflow reductions at some locations throughout the subbasin.

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[3] NOAA National Marine Fisheries Service 2002 Biological Opinion for ESA listed coho salmon southern Oregon/northern California (SONC) coho salmon (*Oncorhynchus kisutch*) in accordance with section 7 of the Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531 et seq.) .

Water Quality in the Upper Klamath Subbasin

Upper Klamath Lake

Nearly all water bodies in the Upper Klamath subbasin show the ill effects of 150 years of landscape modification. The Oregon Department of Environmental Quality's 303(d) list of water-quality impaired water bodies (http://www.deq.state.or.us/wq/assessment/rpt0406/search.asp) contains the majority of the upper subbasin's streams and lakes in Oregon, as does the California State Water Resources Control Board list for nearly all Klamath Basin river miles in the lower subbasin. Impairments include temperature, pH, dissolved oxygen deficiency, excessive algal growth, habitat and flow modification, excessive nutrients, and sedimentation. These problems are the result of the removal of riparian vegetation, streambank degradation due to grazing, wetland drainage, irrigation runoff, channelization, road building, timber harvest, and stream rerouting. Poor water-quality conditions have contributed to reductions in the range and abundance of several fish species, most notably (because of their Endangered Species Act listing) the Lost River and shortnose suckers (*Deltistes luxatus* and *Chasmistes brevirostris*, respectively) and bull trout (*Savelinus confluentus*). The most obvious and infamous manifestation of water-quality degradation is the annual summer bloom in Upper Klamath Lake of the blue-green alga (cyan bacterium) *Aphanizomenon flos-aquae*, an indication that the lake has crossed a threshold from a eutrophic to a hypereutropic state (fig. 3-13).

Upper Klamath Lake and its tributaries have historically been eutrophic because the volcanic soils of the upper subbasin are high in phosphorus, an algal nutrient. A eutrophic lake contains a moderately high level of nutrients, which can result in occasional algal blooms, but generally such lakes can support diverse plant and animal communities. During the 20th century, however, phosphorus levels in the lake became sufficiently elevated to cause annual, extensive, nuisance-level blooms of *A. flos-aquae* that result in severely degraded water quality, including pH of 9.5 and higher, dissolved-oxygen concentrations that fluctuate from supersaturation to near anoxia, and high ammonia concentrations. These conditions are likely responsible for occasional die-offs of the endangered Lost River and shortnose suckers, which occur primarily in the northern part of the lake. Additionally, analysis of lake water and algae has indicated the presence of algal toxins (microcystins), probably from *Microcystis aeruginosa*, in concentrations large enough to affect biological organisms, including the endangered suckers, and, at times, high enough to be of human health concern.

A. flos-aquae was first detected in Upper Klamath Lake in the early 1930s and then became abundant by the end of that decade. Since the 1960s, *A. flos-aquae* have been by far the dominant algal species in the lake. In summer, blooms of *A. flos-aquae* turn the lake water an opaque green and can be clearly seen in satellite photographs. The large amount of phosphorus in the water column that in part causes the initiation of the algal bloom in early summer probably comes mostly from lake bottom sediments. The rate of transfer of phosphorus from sediment to the water column is enhanced by bioturbation and metabolic release from myriad bottom-dwelling chironomid larvae and tubificid worms (*Branchiura sowerbyi).* The strength of subsequent blooms may depend on the availability of inorganic carbon. Bloom collapse might be caused by environmental stressors or viral infection, with the latter being most consistent with the rapid decline of algal mass during the collapse. In recent years, the blooms peak around the first part of August and are followed by deteriorating lakewide dissolved oxygen conditions in the following weeks.

Measurements and 3-dimensional modeling of wind-driven circulation in the lake indicate that poor water-quality conditions in the northern part of the lake caused by the bloom collapse, particularly low dissolved oxygen (DO), do not originate locally. Instead, the circulation pattern allows transportation of poor water-quality conditions originating in the southern part of the lake and in the deep trench on the western side of the lake to the west of Bare Island and into the northern part of the lake (fig. 3-14). Lakewide transport of oxygen-deficient water occurs in a matter of days to a week.

Analysis of sediment cores taken from Upper Klamath Lake shows an increase in sedimentation rate and the appearance in the lake of diatom species indicative of increased productivity beginning in the mid-1800s, about the time that settlement of the Upper Klamath subbasin by Euro-Americans began. Settlement brought with it land-use changes that included wetland drainage, channel modification, grazing, irrigation, and timber harvest. The most dramatic changes in the upper subbasin have been the result of agricultural modifications. Since the 1930s, large areas of marsh surrounding the lake have been diked, ditched, and/or drained for agriculture and grazing, leading to the decomposition of organic soils and the loss of wetland functions. Riparian vegetation and wetland areas along tributary streams have been degraded or completely eliminated. Regulation of the lake for irrigation purposes has caused lake-stage fluctuations to be both higher and lower than natural levels.

Large-scale wetland-restoration efforts, however, have begun in the Wood River watershed, the Williamson River Delta (fig. 3-15), and Agency Ranch. Restoration of historical channel alignments in the Sprague River and other habitat enhancements in the northern part of the upper subbasin promise to reduce the input of sediment-borne phosphorus into the lake, thereby reducing the reservoir of phosphorus in lake sediments.

Klamath River above Iron Gate Dam

High levels of nutrients and large amounts of organic materials that are exported from Upper Klamath Lake via the Link River affect the water quality of the Klamath River to Iron Gate Dam. The reach of the Klamath River upstream of Keno Dam experiences poor water-quality conditions in summer, creating inhospitable conditions for fish and other aquatic organisms. The Link River, the Klamath Straits Drain, and the Klamath River at Keno all were classified as having "very poor" water quality in summer by the Oregon Department of Environmental Quality’s Water Quality Index. The Klamath River in this reach was included in Oregon's 2004/2006 303d (http://www.deq.state.or.us/wq/assessment/rpt0406/search.asp) list for problems related to ammonia, chlorophyll (algae), dissolved oxygen, and pH. The Oregon Department of Environmental Quality has instituted a total maximum daily load (TMDL) (http://www.deq.state.or.us/wq/TMDLs/Klamath.htm) to bring the river back into compliance with water-quality standards. Implementation of the TMDL has been delayed pending appeals from stakeholders in the upper subbasin. Water quality modeling for the Keno reach has recently been completed by the U.S. Geological Survey to test several load-reduction scenarios that have implications for future water-resources management in the river basin that may result from the TMDL determination.

Downstream of Keno Dam, water quality in the Klamath River is impaired by nutrients and organic materials from the Keno reach, as well as by impoundment by the J.C. Boyle, Copco, and Iron Gate Dams. The California State Water Control Board has listed the Klamath mainstem from Oregon to Iron Gate Dam as impaired due to excessive nutrients, organics/dissolved oxygen, excessive temperature, and microcystin toxins, and a TMDL determination is in place. These problems are manifested primarily in the reservoirs, where warm, slack water and abundant nutrients are conducive to the growth of nuisance algae and are inhospitable to native fishes.

Although high levels of *A. flos-aquae* and low levels of *M. aeruginosa* exit Upper Klamath Lake to the Klamath River, both cyanobacterial species generally diminish with distance downstream and are replaced primarily by diatoms in free-flowing river reaches upstream of the reservoirs. Directly upstream of the reservoirs, *A. flos-aquae* can still be detected at low levels (relative to Upper Klamath Lake), and *M. aeruginosa* and associated microcystin toxins are only rarely detected, or are detected at very low levels. In the impounded reaches, however, predominantly Copco and Iron Gate Reservoirs, both *A. flos-aquae* and *M. aeruginosa* again increase, with mid-July through September dominance by toxigenic *M. aeruginosa* and associated levels of microcystin that greatly exceed public health guidelines. Calmer and generally warmer conditions created by the reservoirs allow *M. aeruginosa* (which is not a nitrogen fixer) to exploit available nitrogen from the in-river and in-reservoir transformation of upstream nitrogenous organic matter to ammonia and/or nitrate. Copco/Iron Gate algal bioassays indicate that nitrogen alone stimulates growth of *M. aeruginosa*, but higher biomass was often achieved when phosphorus was added in tandem. Available nitrogen and the high ratio of nitrogen to phosphorus relative to Upper Klamath Lake likely explains the dominance switch from *A. flos-aquae*, a nitrogen fixer, in Upper Klamath Lake to *M. aeruginosa* in the Copco and Iron Gate impoundments (fig. 3-16).

M. aeruginosa also has been shown to accumulate in slower velocity river edge habitats, often dominating the phytoplankton in those habitats relative to mid-channel habitats that tended to be dominated by diatoms. In addition, bioaccumulation of microcystin in both freshwater mussels and various fish species has been shown to exceed public health guideline values in both the impounded Copco and Iron Gate reaches and free-flowing reaches downstream.

Hydrology of the Lower Klamath Subbasin

There is no well-defined, natural geomorphic or hydrologic change at Iron Gate Dam, the upper boundary of the Lower Klamath subbasin (fig. 3-2). Iron Gate Dam, however, is near the area where the basin geology begins to change. Whereas the upper subbasin is underlain primarily by permeable volcanic rocks of the Cascade Province, poorly permeable to impermeable metamorphic and consolidated sedimentary and intrusive rocks of Klamath Mountain Province characterize most of the lower subbasin. Thus, the hydrologic characteristics of the lower subbasin are markedly different from those of the upper subbasin.

The Shasta River basin, which is tributary to the Klamath River just downstream of Iron Gate Dam, lies predominantly in the Cascade Province, with the western third in the Klamath Province. This geologic setting and the resultant alluvium produce groundwater supplies akin to those in the upper subbasin. The Scott River basin, the next downstream tributary, also has an alluvial aquifer, but below that, in the middle part of the Lower Klamath subbasin, the dominant source of water in spring becomes snowmelt and rain on snow. Farther downstream in the Lower Klamath subbasin, the warmer climate, steep terrain, and impermeable rocks create a rainfall-runoff based hydrology. As a result, there is less seasonal variation in flows in the groundwater-discharge dominated upper subbasin than in the surface-runoff dominated lower subbasin.

Figure 3-17 shows that the hydrographs for all streamflow-gaging stations on the Klamath River downstream of Iron Gate Dam are similar. The hydrographs for the Klamath River below Iron Gate Dam (11516530) and for the Klamath River near Seiad (11520500) show a spring snowmelt signature, in which flows increase in the spring, whereas flows farther downstream at the Klamath River at Orleans (11523000) and Klamath River at Klamath (11530500) show no such spring increase, reflecting the rainfall-runoff hydrology characteristic of the lower subbasin as the river nears the Pacific Ocean.

Iron Gate Dam is the most downstream dam of the PacifiCorp Klamath Hydroelectric Project, and the flows for the project are tied to Reclamation's water releases from Upper Klamath Lake. Flows at Iron Gate Dam were originally regulated for power production but since 2007 have been regulated to maintain prescribed flows for salmonids. From 1961 through 1998, water regulation at Iron Gate Dam has shifted the average peak flows from April–May to March, reduced low flows from pre-dam levels, and advanced the average period of low flows from August–September to July (fig. 3-18). These changes negatively affected salmonids because they offset the timing of peak flows from the natural condition, placing the peak flows into a warmer period, and lower the pre-dam May flows of about 3,100 ft^3/s (87.78 m^3/s) to around 2,000 ft^3/s (56.63 m^3/s). In the past several years, as a result of water-resource management practices to preserve a higher lake level in Upper Klamath Lake, flows from Iron Gate Dam have been held relatively constant from August through February. For example, on February 2, 2010, the flow at Iron Gate Dam had been 1,300 ft^3/s (36.81 m^3/s) for 125 days.

Four major tributaries contribute most of the inflow to the Klamath River downstream of Iron Gate Dam: from upstream to downstream the Shasta, Scott, Salmon, and Trinity Rivers. In order of streamflow contribution, the Trinity River is largest, followed by the Scott, Shasta, and Salmon Rivers.

Shasta River

The Shasta River, the uppermost tributary in the Lower Klamath subbasin, is a key contributor to the subbasin's salmonid productivity. The river runs northwestward for approximately 60 mi (97 km) through the 795 mi^2 (2,059 km^2) basin. Geologically, it is at the junction of the Cascades Province volcanics in the east and the metamorphic Franciscan Group of Klamath Mountains Province to the west, which create a canyon through which the river passes just before it reaches the Klamath River. The central part of the Shasta Valley consists of Quaternary alluvium and debris. This complicated geology and hydrology is overlain by human alteration (fig. 3-19). In the upper reaches, Dwinnell Dam was built in 1928 to create Dwinnell Reservoir, now Lake Shastina. Although inflow to the lake is 81 ft^3/s (2.29 m^3/s), most of the water is diverted for irrigation and the outflow is negligible. The diminished flow conditions as well as the dam have created an upper boundary for salmonids and a barrier to their historical spawning grounds.

Parks Creek historically joined the Shasta River downstream of Dwinnell Dam. Today, it has been mostly diverted to enter upstream of the dam. Flows in the creek were critically low 3 ft^3/s (0.09 m^3/s) in summer 2009, and although this was once important habitat for salmon, its current value is much reduced. All flow in the Shasta River downstream of Lake Shastina is from lower tributaries and from groundwater seepage and springs. Although some of the groundwater results from irrigation recharge, the flow is dominated by groundwater discharge from springs and seeps. Springs along Spring Creek and at the Big Springs complex contribute significant flow to the Shasta River downstream of Lake Shastina. Water-quality and temperature analyses indicate that the source of the groundwater is the high Cascade volcanics to the east. The water-bearing formations in the valley—Plutos Cave basalts, high Cascades volcanics, the Ancestral Mount Shasta Debris Avalanche and Alluvium—appear to be hydrologically continuous. October low flows have not varied significantly over the past 60 years, suggesting that this is a stable source of water; however, the amount of groundwater in storage has not been estimated due to the complexity of the region.

The Shasta River is considered crucial habitat for salmon and steelhead populations in the Klamath Basin. In 2009, The Nature Conservancy (TNC) bought the 4,534 acre (18.35 km^2) Big Springs Ranch. The ranch contains 3 mi (4.83 km) of the upper Shasta River, as well as 2.2 mi (3.54 km) of Big Springs Creek. The TNC is collaborating with scientists from the U.C. Davis Center for Watershed Sciences, California's Department of Fish and Game, and California Trout to create efficient water-use methods that will support both ranching and recovery efforts for salmon. Between the gaining reach just downstream of Lake Shastina and the canyon reach at the confluence with the Klamath River is an area with much "put-and-take" from irrigated lands, where water is diverted for irrigation and return flow goes back into the stream. The diversion of water for irrigation in the lower stretch of the Shasta River can be seen by the dip in the hydrograph from April through October despite the relatively constant input from the springs in the central Shasta Basin (fig. 3-20). In this reach, water temperatures can rise to 28°C as it enters the canyon, and these temperatures exceed thermal optima for salmonid species.

Current studies in the Shasta River include Water Master water monitoring, detailed hydrology as part of the TMDL implementation, California Department of Water Resources groundwater study, and, as mentioned above, research and restoration on the Big Springs Ranch.

Scott River

The Scott River, the second largest tributary to the Klamath (813 mi^2) (2,106 km^2), enters the Klamath River downstream of the Shasta Basin. This basin lies totally within the Klamath Mountains Province. Due to faulting of the metamorphic bedrock, the middle part of the valley has dropped down several hundred feet, causing a depression that has filled with sediments, mostly sand and gravel. Therefore, in the central part of the valley, the drainage is characterized by stream channel deposits and valley fill granitic alluvium. These deposits provide some groundwater input; however, the Scott Basin is largely a rain-on-snow dominated basin. Streamflows rise in fall and winter in response to precipitation, rapidly increase in May as the snow melts, then decline to very low in August and September (fig. 3-20). River flows in this drainage also are greatly altered, with the mainstem straightened and rip-rapped through much of the valley. In some areas, levees have been built. Agricultural withdrawals place high demands on groundwater and surface-water resources. Approximately 50 percent of the irrigated acreage is groundwater. As in the Shasta River, portions of the Scott River are now dry during summer and fall. In some years, there is not enough water for adequate fish passage into the canyon. However, since 2006, a collaborative program, the Scott Valley Community Groundwater Measuring Program, has been studying changes in the recharge/discharge balance in the Scott Valley aquifer, and how this balance changes by location, by season, and as a result of inter-annual variations in precipitation and climate.

Salmon River

The Salmon River is a 19.6 mi (31.5 km) long tributary to the Klamath River in western Siskiyou County. Its hydrology is predominantly rain on snow (fig. 3-20). The river's 751 mi^2 (1,950 km^2) watershed is entirely within the Klamath National Forest. Nearly one-half of the watershed is federally protected wilderness area, including portions of the Trinity Alps Wilderness on the south, the Russian Wilderness on the east, and the Marble Mountain Wilderness on the north. Another 25 percent of the watershed is designated as Late Successional Reserve under the Northwest Forest Plan and is managed to enhance and retain old growth forest characteristics and habitat. Unlike other Klamath River tributaries, the river is completely free flowing and it is one of California's most nearly pristine rivers. It retains the only viable population of spring Chinook (*O. tshawytscha*) in the Klamath Basin and offers some of the best West Coast habitat for salmon, steelhead (*Oncorhynchus mykiss*), green sturgeon (*Acipenser transmontanus*), rainbow trout (*Oncorhynchus mykiss*), Pacific lamprey (*Lampetra tridentata*), and other fish.

Trinity River

The Trinity River joins the Klamath River 44 mi (71 km) from its mouth. The basin occupies about 2,035 mi^2 (5,274 km^2); over one-quarter of the Lower Klamath subbasin. The Trinity River mainstem is a mix of distinct channel morphologies, both alluvial and bedrock controlled. Before the introduction of flow modifications, many channel reaches from Lewiston downstream to the North Fork Trinity River were at one time alluvial, where the river had the capability of shaping its channelbed and banks. The natural variable flow regime maintained the integrity of alternate bar sequences, and the topographic diversity of the channelbed surface generated diverse anadromous salmonid habitat. The Trinity River Division of the Central Valley Project, which consists of the Trinity Dam, Lewiston Dam, and Clear Creek Tunnel, were completed in 1964. Completion of Trinity and Lewiston dams had three effects on the river ecosystem. First, Lewiston Dam blocked 50 percent of the spawning habitat to migrating salmonids. Second, bedload transport from 719 mi^2 (1,862 km^2) of the Trinity River basin upstream of the dams was eliminated. Occasional high flows scoured the bed and moved the material downstream with no material moving in from upstream to replace it, and the channel has been immobilized. A third effect was major flow diversion from the Trinity River Basin to the Sacramento River basin: between 37 and 92 percent. The absence of high flows allowed the sediments from tributaries to develop deltas on which trees and shrubs colonized. Within the first 10 years, the decline in salmon and steelhead populations due to this flow and habitat alteration became obvious.

The Trinity River Flow Evaluation Study (conducted by the U.S. Fish and Wildlife Service) is the foundation for the Trinity River Restoration Program (http://www.trrp.net/). The goal of this program is to improve habitat conditions, manage instream flows, and restore naturally spawning populations of salmon and steelhead to near pre-dam levels. In order to recreate inter-annual flow variability, the Trinity River Record of Decision set five water year types ranging from extremely wet to critically dry and recommended typical releases as shown in figure 3-21.

Lower Klamath River Mainstem

The lower Klamath River hydrology is the sum of the parts of the river above it: groundwater from Cascade springs keeps (or once kept where the flow has been altered) summer base flows relatively high, spring snowmelt from the high elevation Trinity Alps in the central Klamath, and rainfall throughout the subbasin. In the lower reaches of the Klamath River, flow is extremely variable and large flood events are frequent, particularly in winter. Major floods occurred in the 1800s as well as in 1955, 1964, 1997, and 2005. Iron Gate Dam does not protect the lower river from these floods; in 1997 the peak flow at Iron Gate Dam was 19,000 ft^3/s (538.02 m^3/s), and at the mouth of the Klamath River, the flow was 575,000 ft^3/s (16,282.19 m^3/s). In 1964, Iron Gate Dam was nearly destroyed. The Trinity River dams, however, do give some protection to the lower Klamath River during floods. In 1997, the inflow at Trinity Dam was just more than 100,000 ft^3/s (2,831.69 m^3/s), and the flow at Hoopa was 108,000 ft^3/s (3,058.22 m^3/s). These flood events, combined with land management, shape the lower river. In the Scott River, groundwater withdrawals minimized the riparian vegetation, and subsequent high flows scoured the channel, cutting it off from the riparian zone. During the 1964 flood, the South Fork of the Trinity River, formerly characterized by scattered, large, deep pools interspersed with shallow pools, riffles, and rapids changed to a gravel-braided stream, flattened due to clear cutting on one side and a large burn on the other. During floods, the lower Klamath River backs into its tributaries and can cause their deltas to disconnect from the mainstem river.

Climate Effects

Climate patterns are highly variable throughout the Klamath Basin, ranging from marine influenced coastal regions with moderate temperatures and abundant winter rainfall to more continental upper basin areas with warm, dry summers and winter snow. Generally, temperatures are warmest in July and coolest in January. December and January are the wettest months and July is the driest.

Long-term climate change caused by warming will affect the natural hydrology of the Klamath Basin. Climate models predict a decline in snowpack at mid- and low elevations due to increases in air temperature and decreases in the amount of precipitation falling as snow. The result will likely be (1) less winter snow accumulation, (2) higher winter streamflows, (3) earlier spring snowmelt, and (4) earlier peak spring streamflow and lower summer streamflows in rivers that depend primarily on snowmelt, which includes most of the rivers in the Klamath Basin except spring-fed streams in the Wood River basin and the lower Williamson River basin (Spring Creek) in the upper subbasin. Small springs in the Sprague River basin also provide some baseflow support.

Spring snowmelt runoff to tributaries contributes to high flows during April through June in normal years, providing cold stream water for spawning migratory fishes. Snowmelt also recharges the local, intermediate, and regional groundwater systems, which discharge to streams in several locations, principally in the upper subbasin. Figure 3-22 shows primary sources of cold water in the Klamath Basin. The blue ovals in the upper subbasin indicate areas of cold groundwater discharge. The green ovals indicate various sources of cool water discharge in the lower subbasin: groundwater in the Big Spring area, snowmelt in the Trinity Alps and the southern mountains of the South Fork Trinity, cold water releases from Trinity Dam (which is dependent on the Trinity Alps snowmelt), and cool water influxes from the fog zone along the coast. As the climate warms, rising temperatures predicted in the mountains possibly will decrease the amount of flow and/or increase the temperature of the water from the Trinity Alps into the Scott, Salmon, and Trinity Rivers, as well as water discharged from the South Fork Trinity. In the future, this will leave only the Big Springs complex and the coastal fog zone as sources of cold water in the Lower Klamath subbasin.

The Klamath Basin is near the southern end of the range of most Pacific salmon runs because temperatures in the mainstem are near the upper limit of the thermal tolerance of anadromous salmonids. Therefore, any increases in stream temperatures are likely to be detrimental to the long-term survival of Klamath Basin populations. Dam removal in the Klamath River, although it will expand the spawning range for salmon and improve habitat, is predicted to result in an increase in summer temperatures in the mainstem. For this reason, maintaining or increasing riparian shade and thermal refugia in streams will be critical in the future.

Effects of the Klamath Basin Restoration Agreement on Water Management

Managing the Klamath Basin's water resources to meet the needs of irrigators, fish, and other purposes has been difficult and contentious. Since 2001, Reclamation has been required to maintain elevations in Upper Klamath Lake to protect habitat for the endangered Lost River and shortnose suckers while simultaneously providing specified flows in the Klamath River to protect habitat for threatened coho salmon. This shift in water-management priorities resulted in substantial reductions in the amount of surface water diverted to the Klamath Irrigation Project in 2001 and 2010 and has increased the likelihood that the project will face water shortages in the future.

In response to changing water-management priorities, Klamath Basin stakeholders have developed, and most have agreed to, the proposed Klamath Basin Restoration Agreement (KBRA), a comprehensive and intricate plan to restore aquatic habitats and recover salmon and other fish populations in the basin. The KBRA also is meant to establish reliable water supplies for agriculture through a combination of diversion limitation, land idling, water-use retirement, increased lake storage, increased efficiencies, conjunctive use, water leasing and purchase, drought-year measures, and groundwater supplementation, among other measures. Implementation of the agreement awaits funding by Congress.

The KBRA's provisions are too numerous to summarize here. Some of the important elements affecting water resources are:

- Its Water Resources Program will limit the amount of water that can be diverted from Upper Klamath Lake and the Klamath River to Reclamation's Klamath Irrigation Project. Proposed limitations on diversion, based on an annual forecast for net inflow to Upper Klamath Lake during the period April 1–September 30, range from 330,000 acre-ft (0.41 km^3) in low-inflow years to 385,000 acre-ft (0.48 km^3) in high-inflow years. An additional 48,000 acre-ft (0.06 km^3) in low-inflow years and up to 60,000 acre-ft (0.07 km^3) in high-inflow years will be diverted to the Lower Klamath Lake and Tule Lake National Wildlife Refuge. This will result in total diversion limitations of 378,000 acre-ft (0.47 km^3) to 445,000 acre-ft (0.55 km^3) during dry and wet years, respectively.
- Its Water Resources Program also includes actions to improve streamflows and maintain the elevation of Upper Klamath Lake.
- Its Water Use Retirement Program will rely on voluntary retirement of water rights or water uses to secure 30,000 acre-ft (0.04 km^3) of water to increase inflow into Upper Klamath Lake.
- The Agreement also identifies an approximately 109,000 acre-ft (0.13 km^3) of Upper Klamath Lake storage that could be achieved through wetland restoration.
- Its On-Project Plan includes a permanent limitation on the amount of water (but consistent with historical amounts) that can be diverted from Upper Klamath Lake and the Klamath River for the Klamath Irrigation Project, as well as criteria to ensure that groundwater development does not have significant impacts on essential environmental flows.

- It includes funding for infrastructure such as streamflow and snowpack gages and for the development of a program and monitoring system that will allow for real-time water management.

Complicating the full implementation of the KBRA, historical water diversions to meet Project and refuge needs have increased while inflows to Upper Klamath Lake have decreased. This primarily relates to climate cycles. Before 2001, diversions from Upper Klamath Lake and the Klamath River (for both Klamath Project and Refuge needs) ranged from about 320,000 acre-ft (0.4 km^3) to about 490,000 acre-ft (0.6 km^3). A comparison of historical water diversion amounts to the diversion limitations proposed in the KBRA indicates a reduction—up to approximately 100,000 acre-ft (0.12 km^3)—in the amount of water that can be diverted to the Klamath Irrigation Project in dry years. Because the diversion limits specified in the Agreement do not limit the applicability of the Endangered Species Act, during drought periods, the diversions may be further reduced to maintain elevations in Upper Klamath Lake and flows in the Klamath River required by Endangered Species Act Biological Opinions.

The Agreement's attempt to provide water for both irrigation and environmental flows will create a sustained demand for groundwater to supplement surface water supplies. Groundwater use in the upper Klamath Basin has increased substantially since 2001 in large part because of programs funded by Reclamation to augment the Klamath Irrigation Project's surface-water supplies. These programs used a variety of methods including groundwater substitution to compensate farmers for using pumped groundwater in lieu of surface water and well owners for pumping groundwater directly into irrigation canals for use elsewhere in the Klamath Irrigation Project. As a result, by 2004, groundwater use in the basin had increased by 50 percent and more than doubled in the area of the project. This sharp increase in pumping resulted in groundwater level declines of 10–15 ft (3.04–4.56 m) over much of this area. If groundwater pumping continues at its present rate, the groundwater system will eventually achieve steady state but this will come at the expense of streamflows from other areas as yet unknown. The U.S. Geological Survey is engaged in optimization modeling to assess the effects of sustained pumping on groundwater and surface-water resources in the upper subbasin. Model results will be used to inform the management of Klamath water resources in light of the requirements of the KBRA.

Conclusions

Water ties the contrasting upper and lower subbasins together and understanding the hydrology of the Klamath Basin is key to developing effective fisheries and water-quality restoration efforts.

Primary issues in the upper subbasin are water supply, water quality, and habitat restoration. The provisions of the Klamath Basin Restoration Agreement will require that the movement and use of all subbasin water resources be well understood and monitored. Expansion of current groundwater–surface water modeling efforts would contribute greatly to that understanding. Maintenance of viable populations of upper subbasin endangered fishes and possibly future populations of anadromous fishes currently confined to the lower subbasin will require the continuance of current efforts to understand the causes of poor water quality and to restore some of the natural functions of the upper subbasin.

Groundwater and surface-water interactions remain poorly known in the Lower Klamath subbasin and require further study. The hydrology of the lower subbasin is not well understood and more quantitative information is needed about (1) the major hydrologic regimes contributing to flow (groundwater, snowmelt, and rain); (2) current and historic mainstem flows; (3) flood events; and (4) the hydrologic characteristics of the Shasta, Scott, Salmon, and Trinity Rivers and smaller tributaries. By late summer and early fall, flows typically are low and thermal refugia are critically important to salmonids and other fish in the lower subbasin. There is no consensus of opinion as to whether the thermal refugia have diminished significantly in many locations in the mainstem Klamath River. Thermal refugia, especially those located in areas of confluence, are dependent on influent groundwater and springs. The location, persistence, and ecological significance of cold water thermal refugia need to be determined. Harmful algal blooms are problematic in both upper and lower subbasins. More research attention to nutrient cycles and their effects on algal production cycles is needed. The effects of cyanotoxins on key natural resources, such as endangered suckers in the Upper Klamath Subbasin, would be a beneficial priority focus of physical and biological studies and large-scale restoration.

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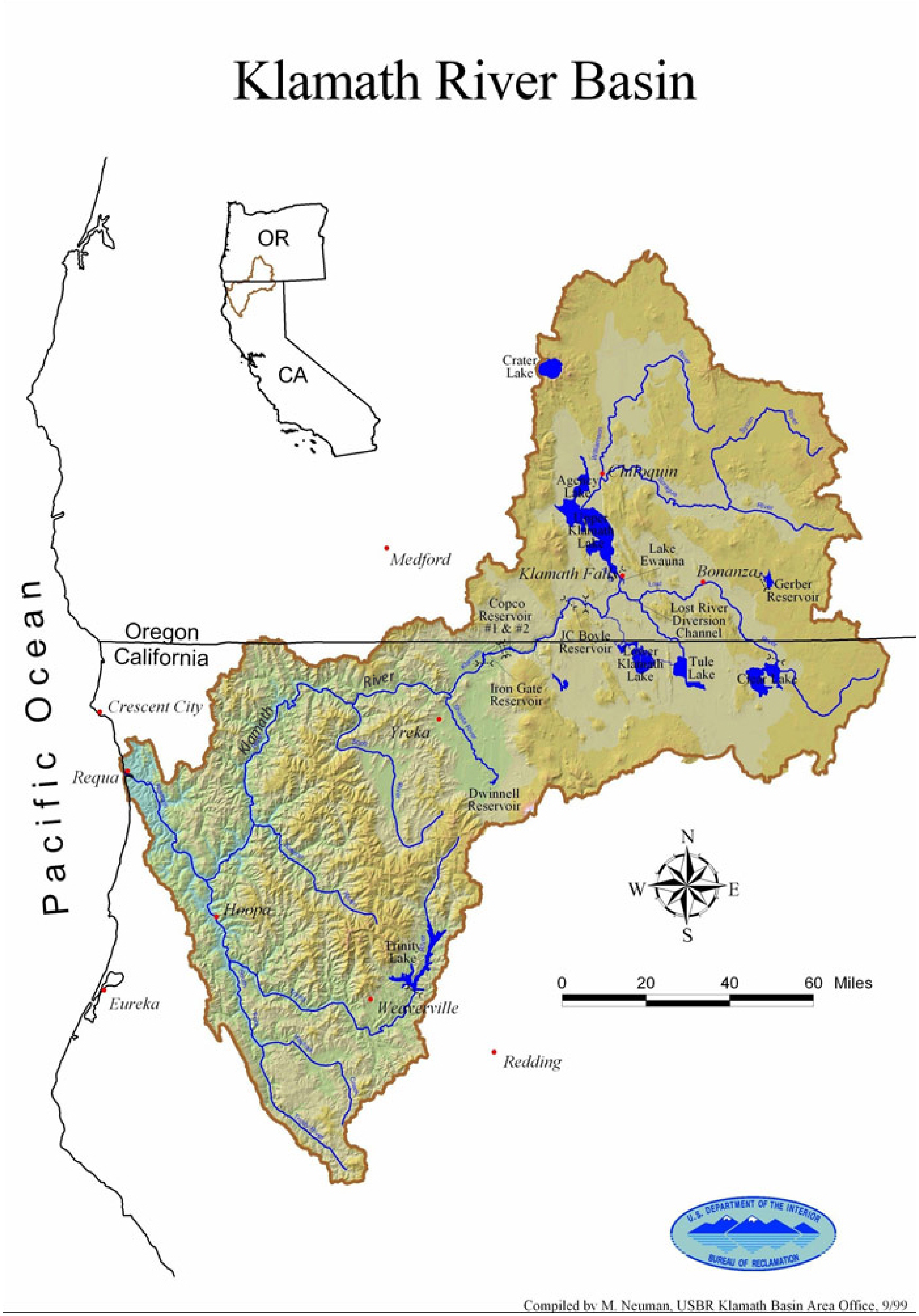


Figure 3-1. The Klamath River Basin, Oregon and California.

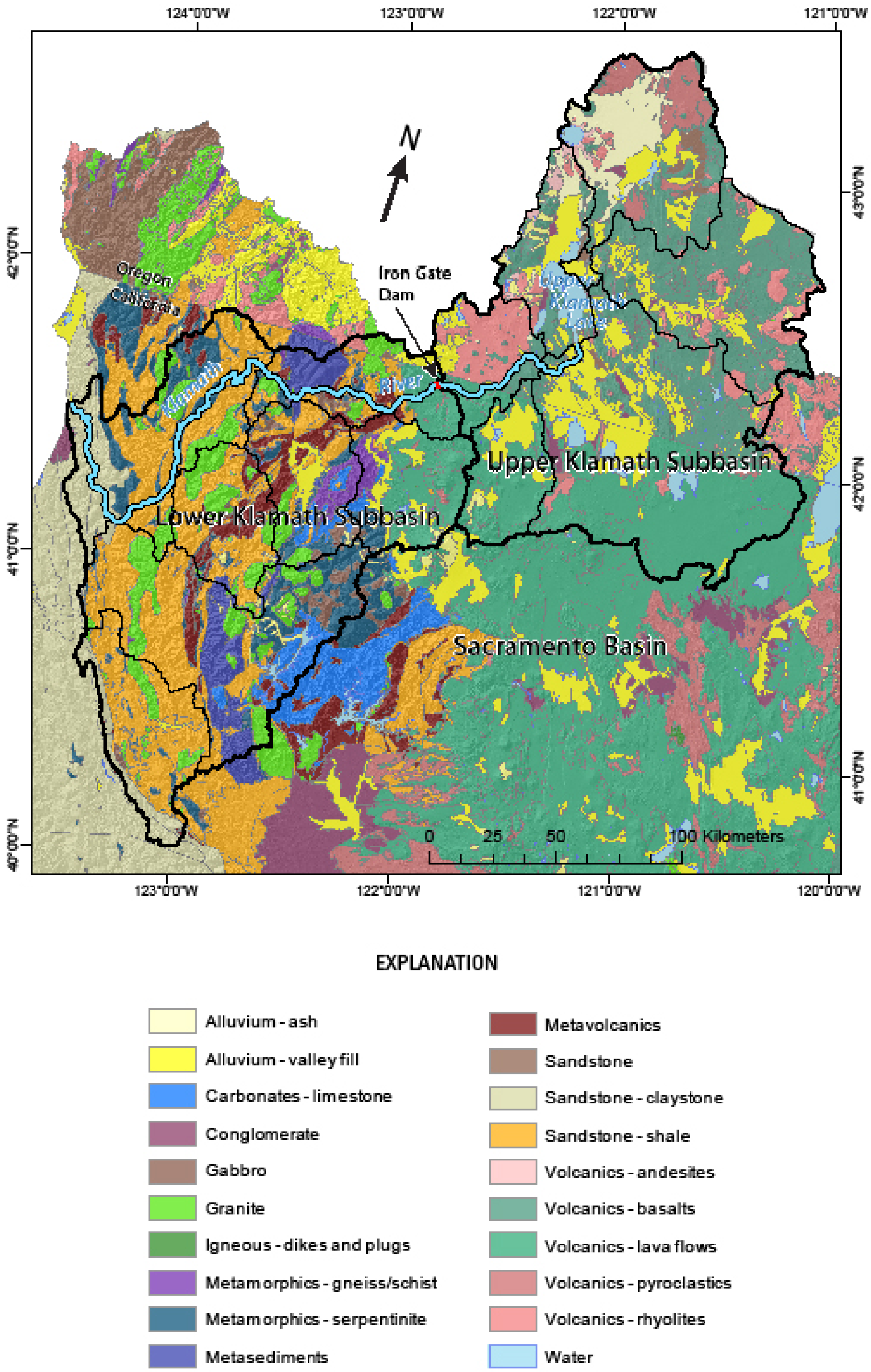
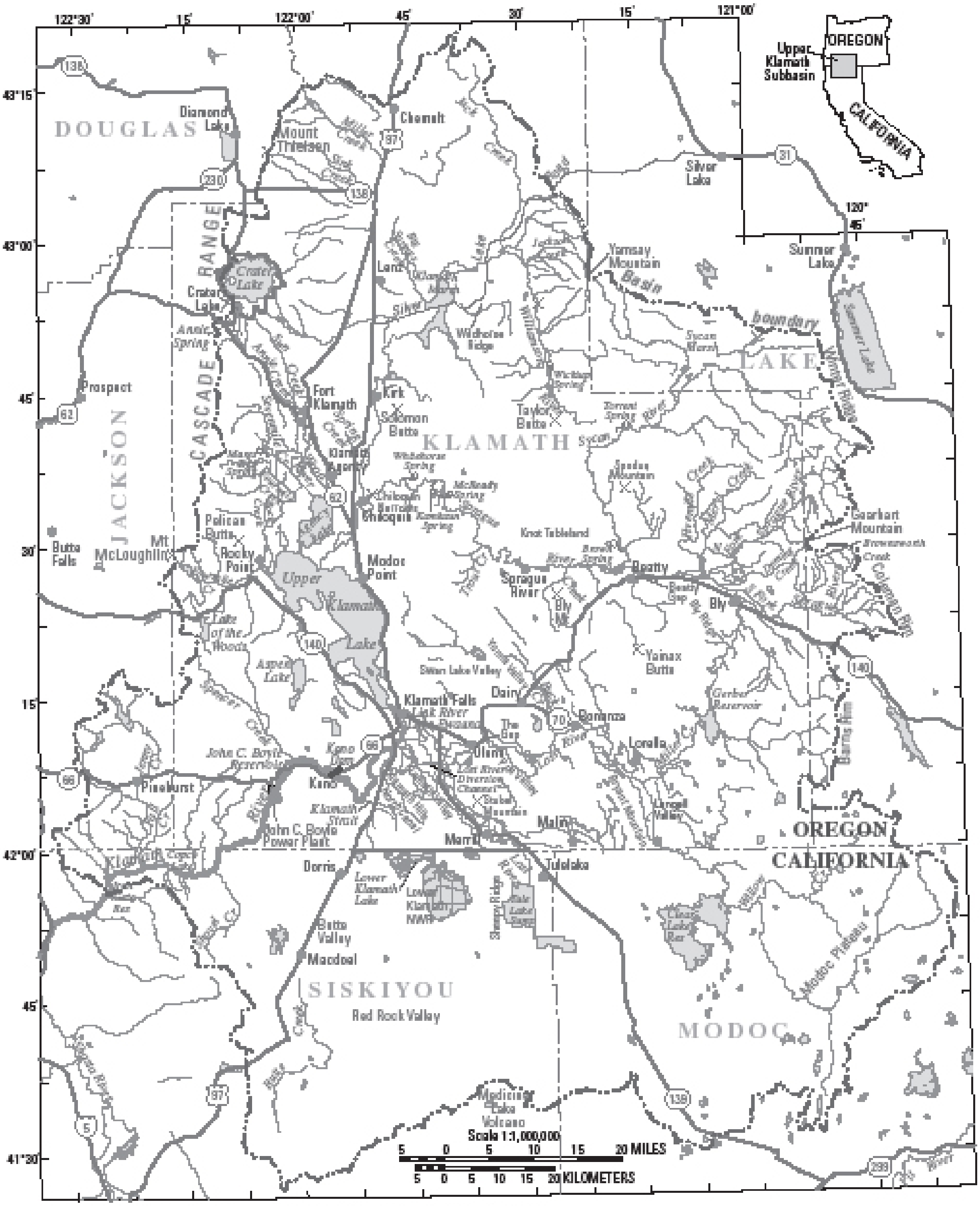


Figure 3-2. Map of the geology of the Klamath River Basin, showing the boundary between the upper and lower subbasins at Iron Gate Dam.



Base modified from U.S. Geological Survey 1:100,000 and 1:24,000 scale quadrangle maps.
Relief from U.S. Geological Survey National Elevation Data Set 30 meter digital elevation model.
Klamath Reclamation Project boundaries are from Bureau of Reclamation, Klamath Basin Area Office GIS data.
Projection: Universal Transverse Mercator, Zone 10, 1927 North American Datum

Figure 3-3. Map of the Upper Klamath Subbasin.

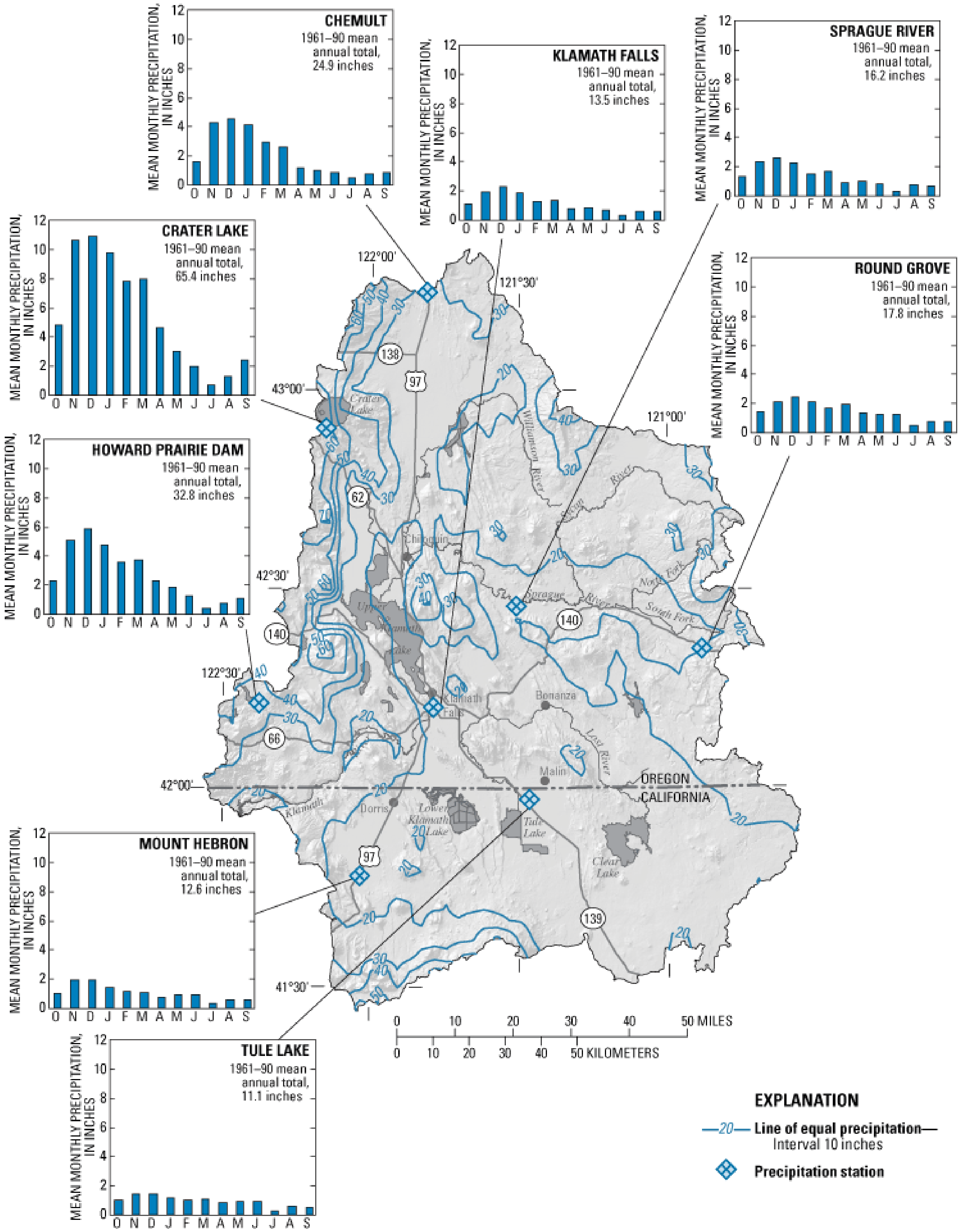


Figure 3-4. The Upper Klamath Subbasin is mostly semiarid; most water in the basin comes from snow that falls in the surrounding mountains, either by way of groundwater discharge or surface runoff.

Figure 3-5. Extensive wetlands once covered the upper subbasin south of Upper Klamath Lake, as shown in this 1905 map.

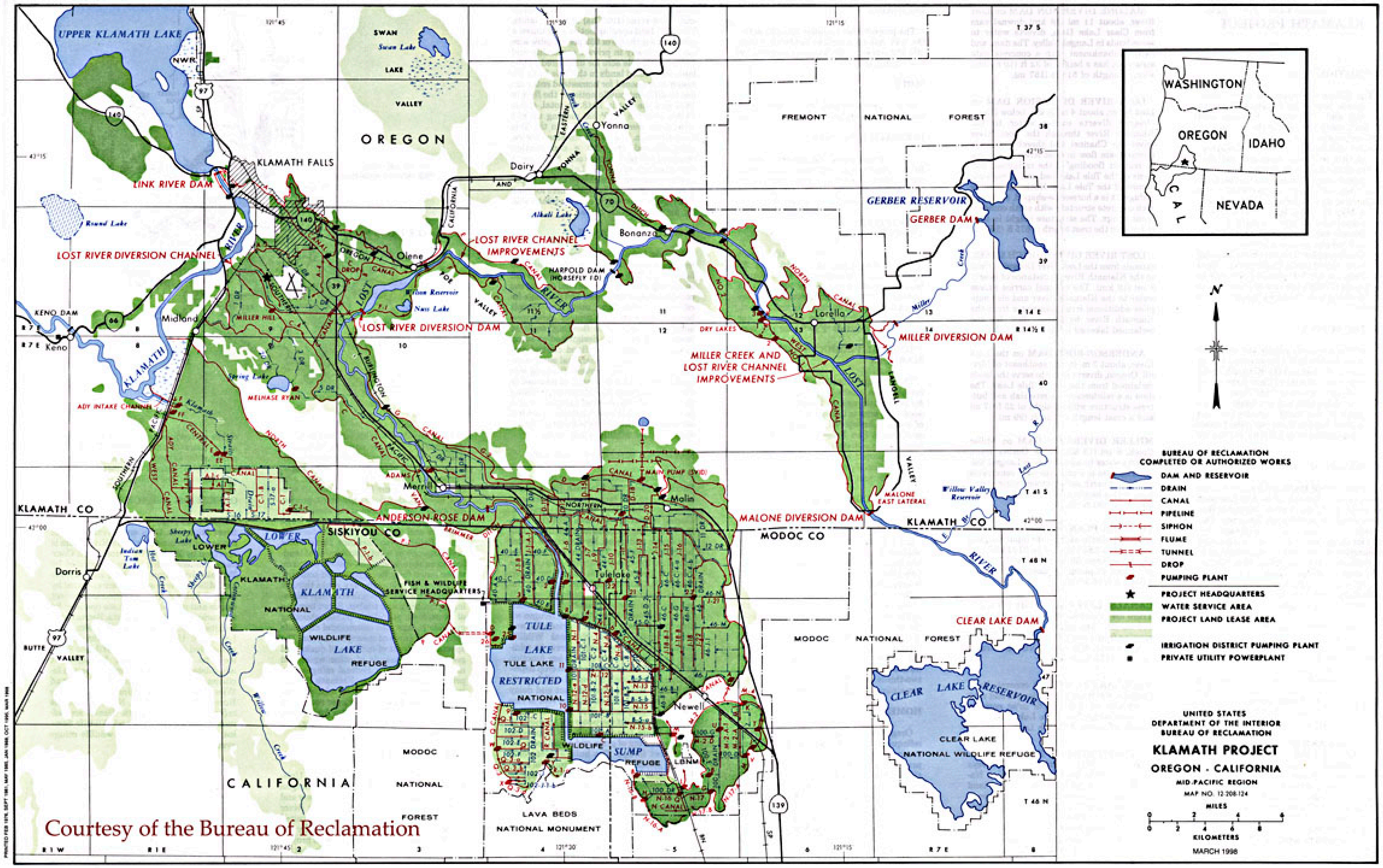


Figure 3-6. This 1998 Klamath Project map shows that about 25 percent of the original wetland area remains.

Figure 3-7. View across Lower Klamath National Wildlife Refuge, a remnant of Lower Klamath Lake. (Photograph by Charles Palmer, USGS.)

Figure 3-8. The Wood River, a spring-fed stream shown here at its source, is one of the two major perennial sources of water to Upper Klamath Lake. (Photograph by Chauncey Anderson, USGS.)

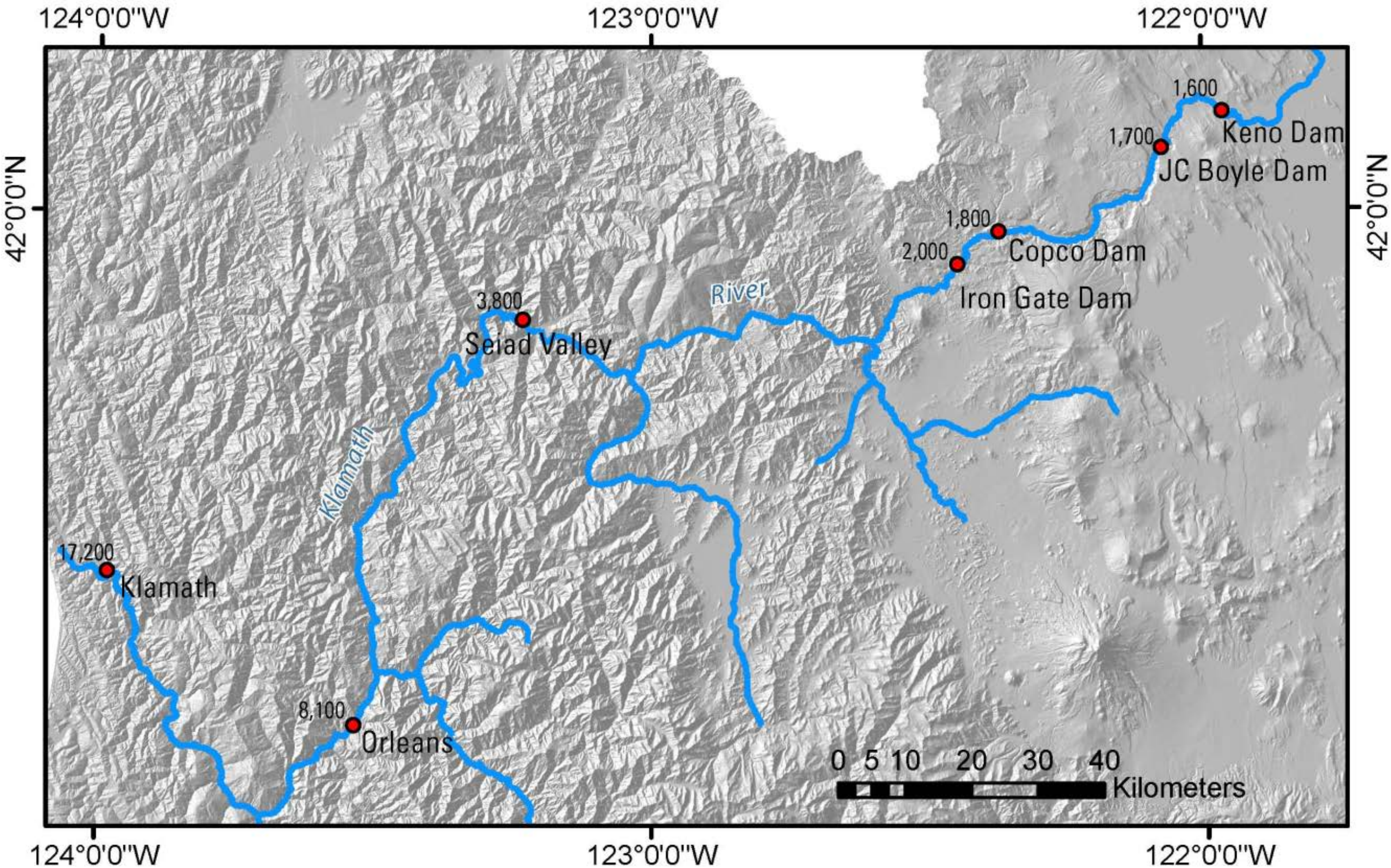


Figure 3-9. Approximate mean annual streamflow (in cubic feet per second) at U.S. Geological Survey streamflow gaging stations on the Klamath River, Oregon and California.

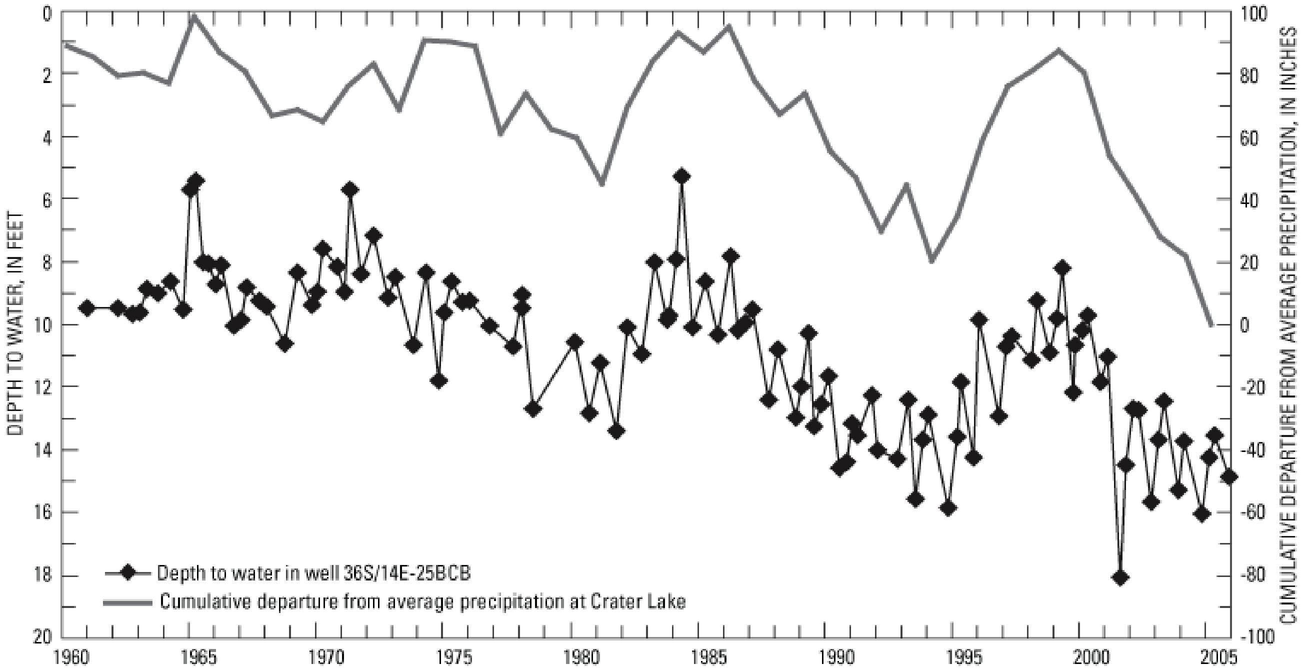


Figure 3-10. Water levels in many wells of the upper subbasin, like this one near Bly, respond to short-term, seasonal pumping fluctuations, annual variations in precipitation, and long-term, decadal-scale climate cycles.

Figure 3-11. Water is moved to areas of need by way of diversion canals such as this one in the Tule Lake subbasin. (Photograph by Charles Palmer, USGS.)

Figure 3-12. One of many irrigation wells installed in 2001 to supplement surface-water supplies depleted by drought. (Photograph by Charles Palmer, USGS.)

Figure 3-13. Upper Klamath Lake supports extensive blooms of *Aphanizomenon flos-aquae* in the summer. (Photograph by USGS.)

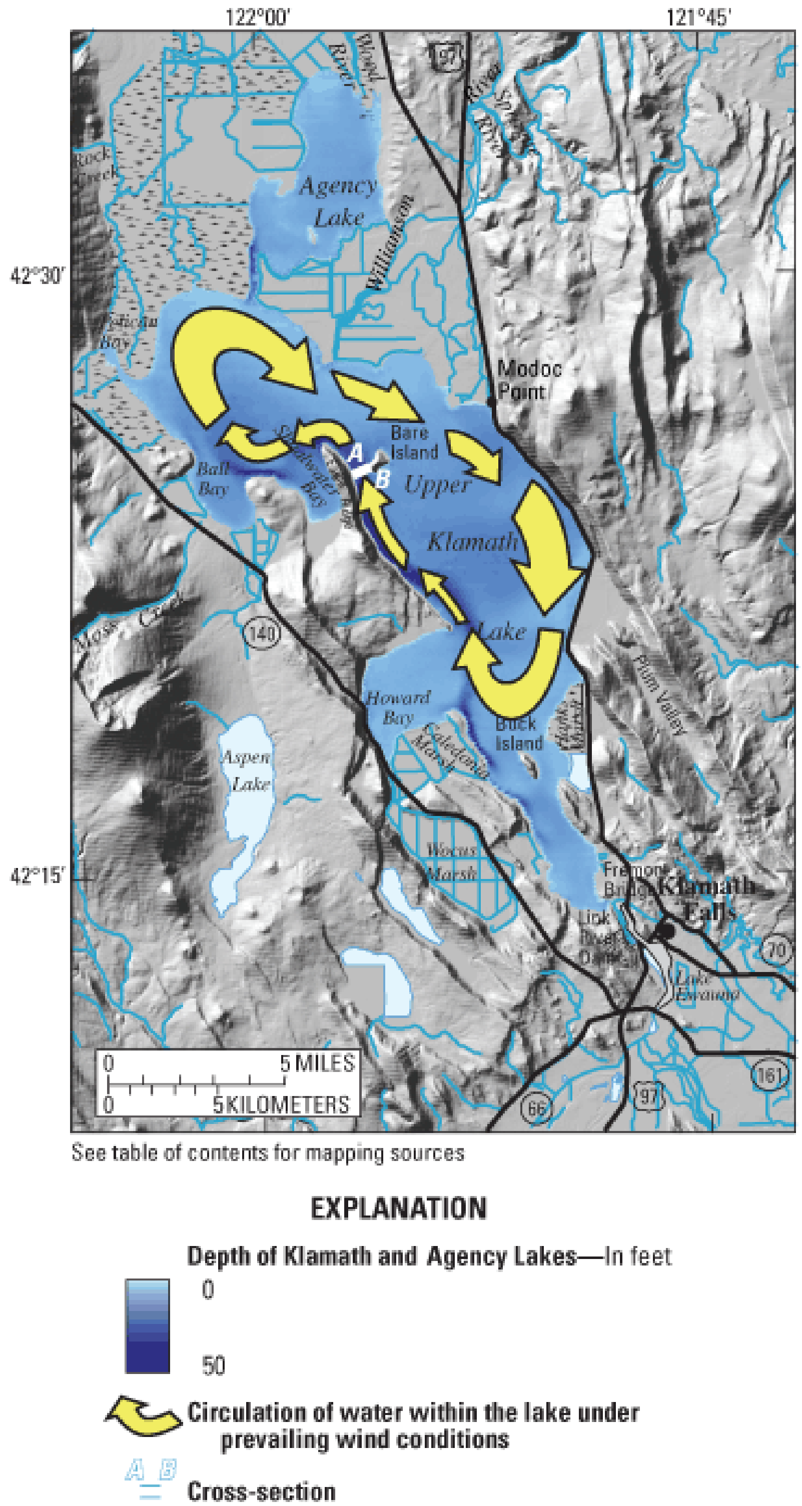


Figure 3-14. Prevailing northwest winds create a clockwise circulation pattern in Upper Klamath Lake.

Figure 3-15. The once diked and drained Williamson River Delta has been reflooded in an effort to restore the natural hydrology of Upper Klamath Lake and to provide habitat for endangered suckers.

Figure 3-16. A Karuk Tribe biologist collects blue-green algae samples in Copco Reservoir.

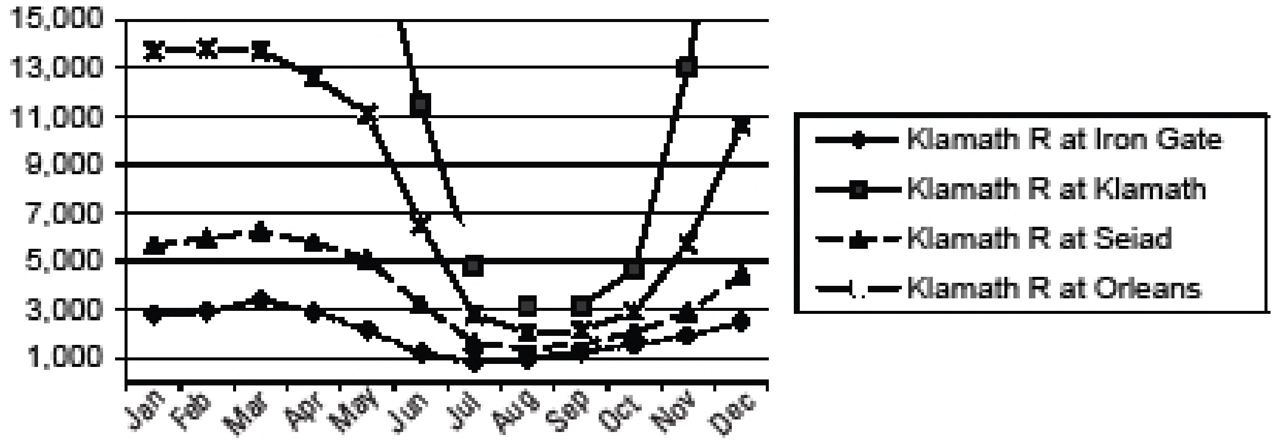


Figure 3-17. Mean monthly streamflows at the four U.S. Geological Survey streamflow gaging stations in the Lower Klamath Subbasin for their periods of record. Data for Iron Gate Dam is from the period after dam installation.

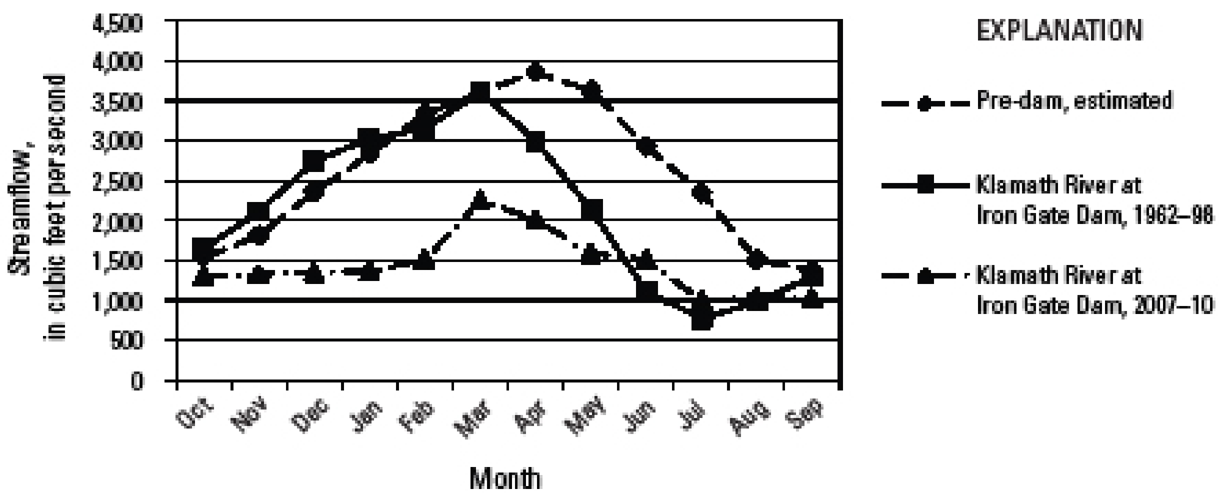


Figure 3-18. Monthly mean streamflows at Iron Gate Dam for three periods of interest.

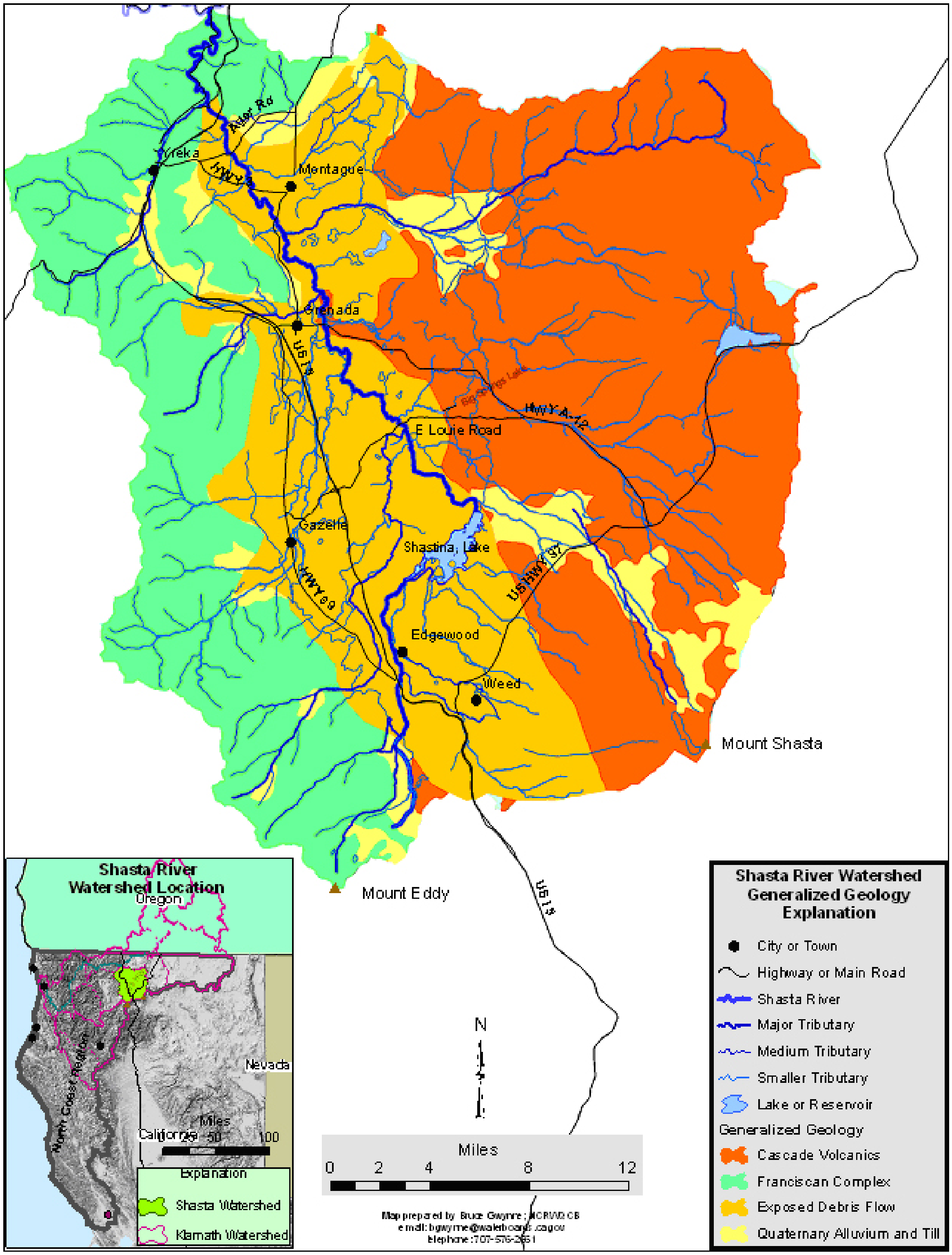


Figure 3-19. Main geological and hydrological features in the Shasta Basin.

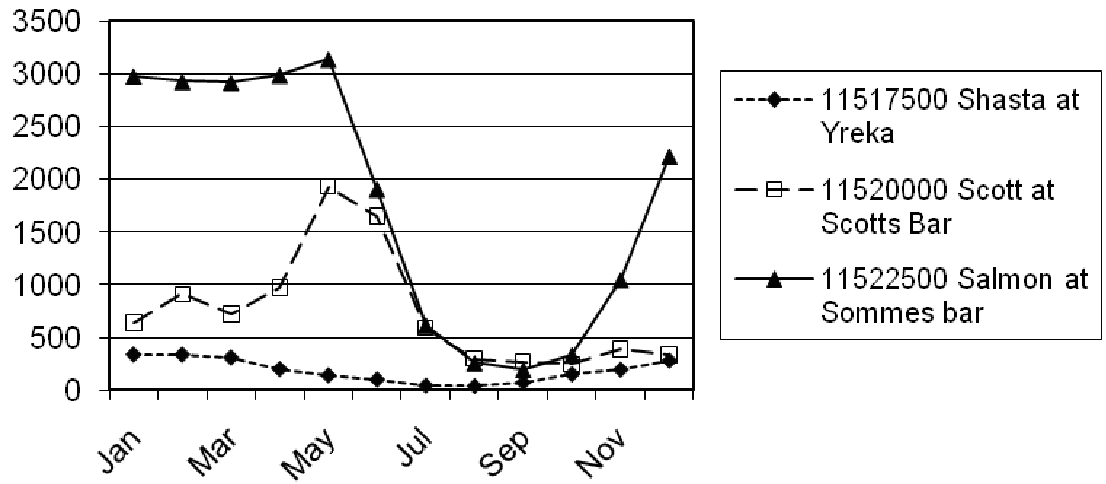


Figure 3-20. Monthy average flows for the Shasta, Scott, and Salmon Rivers for their period of record.

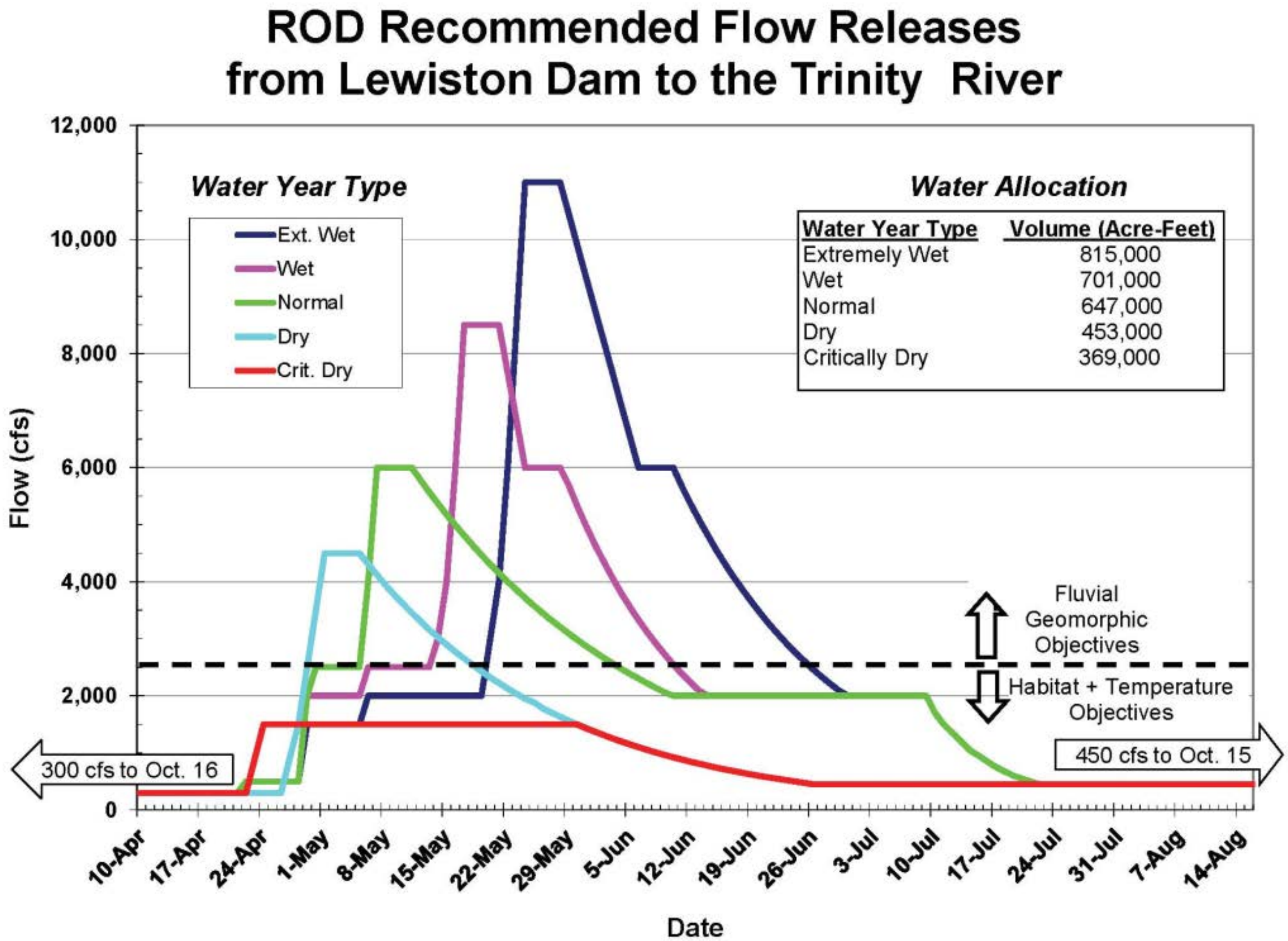


Figure 3-21. Typical flow releases from Lewiston Dam to the Trinity River for each of the five water year types designated by the Trinity River Record of Decision.

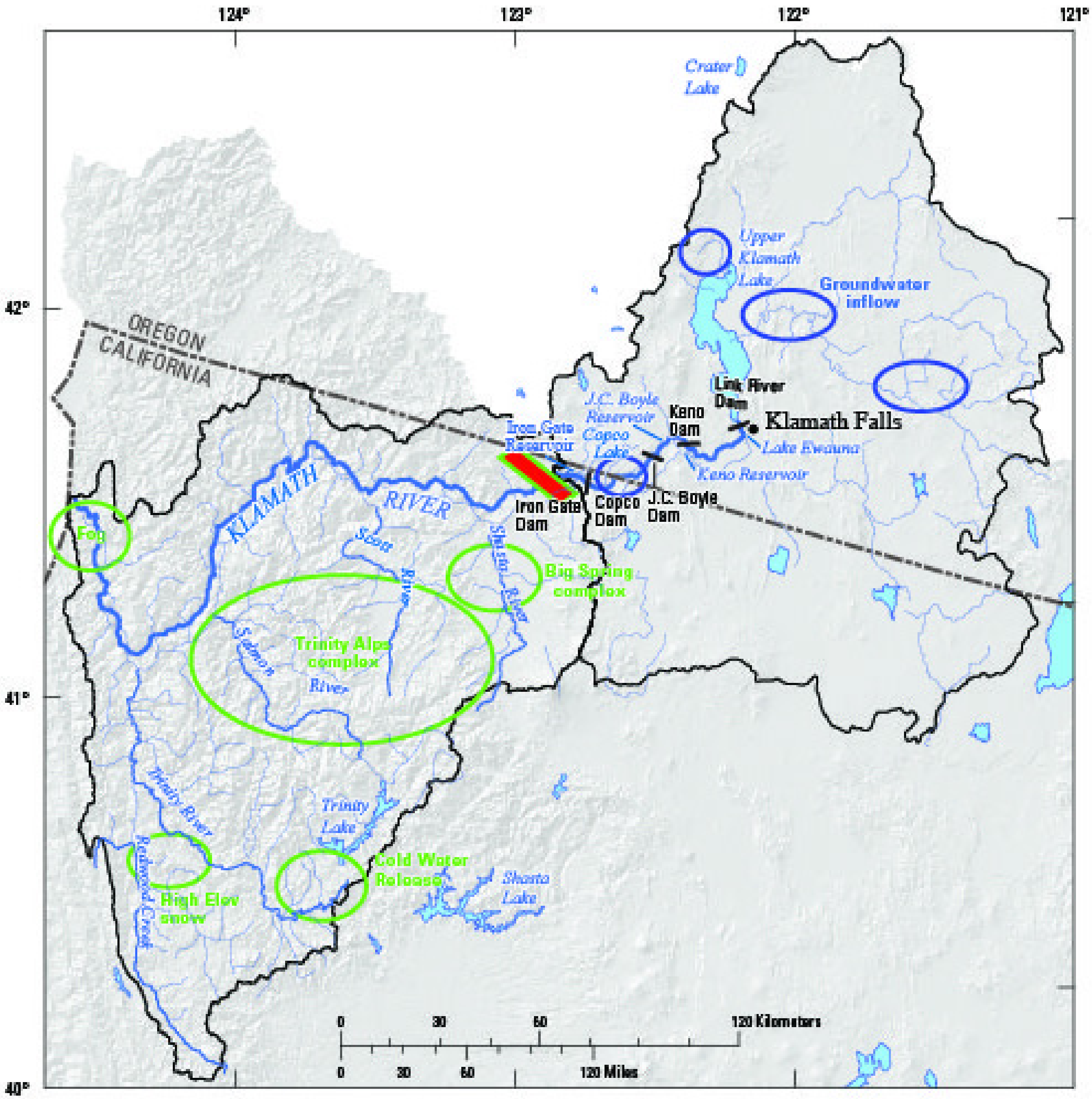


Figure 3-22. Cold water sources within the Klamath Basin.

Chapter 4. Watershed Processes

Scott VanderKooi[1], Lyman Thorsteinson[2], and Eric Janney[3]

"Watershed processes influence the function, spatial pattern, and variability of terrestrial, riparian, and aquatic ecosystems." Michael Hughes (2010)[4].

Introduction

The Klamath Basin encompasses approximately 31,000 km^2 of south-central Oregon and northwestern California, spanning a diversity of landscapes ranging from semiarid high desert at low elevations to dry alpine in high volcanic mountains and temperate rain forest coastally. The Trinity River consists of a more typical alpine climate. This diversity is reflective of significant underlying geologic and hydrologic features and associated ecosystems. The upper subbasin is dominated by volcanic uplands and largely groundwater-fed streams that drain through an extensive network of wetlands and lakes including Upper Klamath Lake, the headwaters of the Klamath River. The Klamath River flows generally southwestward through the Cascade and Klamath Mountains to the Pacific Ocean. The Klamath Mountains, which dominate the lower subbasin, are a dissected rugged sedimentary and metamorphic terrain in which the streams are largely fed by runoff, with only a small component of groundwater. Near the coast, a fog belt zone characterizes the coastal rain forest and lower reaches of the river. The physiography of the Klamath Basin is the reverse of many drainage basins with steep, confined rivers and creeks cutting through mountains in the lower watershed and broad valleys with meandering streams and shallow lakes in the upper reaches. For this reason, it is often spoken of as being "upside down" with 35 percent of the Basin occurring in Oregon and 65 percent in California.

In response to changing water management priorities, Klamath Basin stakeholders have developed the proposed Klamath Basin Restoration Agreement (KBRA), which aims to restore historical fish habitat and populations in the upper Klamath Basin and establish reliable water supplies for agriculture. Restoring natural ecosystem processes and interactions is thematically central to species recovery planning, reintroduction of salmon, and protection of habitats in the Klamath Basin. The structure of ecosystems includes physical habitats, materials, and energy resources and associated biological communities, and these arise from the numerous processes that occur in upland areas, within riparian zones, and in river and stream channels, lakes, or estuaries. Our goal in this chapter is to explore ways in which these processes interact and operate at different scales, rates, magnitudes, and frequencies within the Basin and how they can lead to improved management and restoration outcomes. With respect to the latter goal, an existing watershed assessment method[5] provides an approach to understanding watershed processes, their effects on riverine processes, and the role of humans in their modification and restoration. This approach is likened to an environmental impact assessment for

[1] U.S. Geological Survey, Grand Canyon Monitoring and Research Center.
[2] U.S. Geological Survey, Western Fisheries Research Center.
[3] U.S. Geological Survey, Western Fisheries Research Center, Klamath Falls Field Station.
[4] Michael Hughes (Klamath Tribes) Klamath Basin Science Conference Program description of the Watershed Processes Plenary Session.
[5] Beechie, Pess, Beamer, Lucchetti, and Bilby, Pages 194-225, in Montgomery, David, Restoration of Puget Sound Rivers. University of Washington Press.

watersheds with dual roles of (1) estimating historical and current juvenile salmon production potentials based on habitat quantity and quality, and (2) identifying causes of habitat loss and restoration actions needed to recover salmon. Information about historical and current land cover, distribution of human activities and land-use change, and changing habitat conditions over time are critical elements of the assessment process.

The Endangered Species Act listings of Lost River suckers (*Deltistes luxatus*) and shortnose suckers (*Chasmistes brevirostris*) in the upper subbasin and coho salmon (*Oncorhynchus kisutch*) in the lower subbasin are indicative of large-scale disturbance and environmental change and watershed effects. Ongoing regional monitoring of avian resources in the Klamath Basin provides additional information about bird habitat relationships and population sensitivity to change. Many presenters at this Klamath Basin Science Conference noted the importance of scale considerations in natural resource science and management and the need for improved understanding of process functional responses (i.e., on habitat conditions and biological responses), which includes human activities in an ecosystem analysis. In the future, it will be critical for planners of restoration activities, research, and long-term monitoring to accurately integrate physical habitat, species life history traits and diversity, landscape relationships (e.g., size, connectedness, remoteness, and intactness of surrounding ecosystems), landscape controls (e.g., geology, vegetation, climate), and human activities in a holistic approach for conservation and restoration.

Ecosystem Perspectives

Interactions are the common denominator in all ecosystem perspectives including the watershed approach. Biotic interactions, such as competition and predation, are emphasized in community approaches that focus on biological assemblages or populations in a given area. The structure of watershed ecosystems includes physical habitats, material and energy resources, and associated biological communities. These ecosystems arise from the interactions of numerous processes that occur in upland areas, within riparian zones, and in stream channels, rivers, lakes, or estuaries. It is the interaction between the abiotic and biotic environments that is central to the ecosystem concept and distinguishes it from a community approach. Process-oriented science approaches focus on fluxes of energy and transfer of matter and, because they vary in time and space, require coordination of research and monitoring at multiple scales (e.g., basin, reach, and habitat), along environmental gradients (e.g., elevation) or within biological hotspots (e.g., thermal refuges).

Ecosystem goods and services have different meanings and values to the various Klamath Basin stakeholders. For this reason ecosystem-based management is recommended, and from the watershed perspective, should have scientific prerogatives to develop knowledge and tools to manage water resources for sustainability and ecological flows[6]. Human activities (i.e., fishing, agriculture, forestry, and dams) have subjected the Klamath Basin ecosystem to intense stress. The effectiveness of the restoration will depend on the watershed's recuperative and self-integrative capability to recover hydrologic conditions similar to pre-European contact, or more likely a normative state that best serves the myriad human and natural resource needs of the Basin.

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[6] The next generation of tools for instream flows will be holistic and require scientific approaches that (1) link physical and biological processes, (2) address ecosystem feedback mechanisms, (3) better incorporate spatial and temporal variability, and (4) involve new methods such as dynamic energy budgets to construct models.

The Importance of Ecological Scale

While salmon recovery and reintroduction processes were not the exclusive focus of the conference, the salmon life history model was highlighted to illustrate the importance of scale in restoration planning[7]. This life cycle model also demonstrates the central role of ecological linkages between the upper and lower Klamath subbasins, estuary and adjacent coastal waters in restoration activities (fig. 4-1). Although it is recognized that variability in ocean conditions remains a major source of uncertainty in the population dynamics of Klamath salmon, these conditions will not be affected by restoration activities. Ocean variability, resulting from interactions of processes occurring at multiple spatial and temporal scales, may be geographic or more localized in effect and short term to decadal in duration with respect to environmental change. Many of these large-scale processes also affect Klamath Basin conditions such as precipitation, hydrology, sediment transport, nutrient cycling, and vegetative cover. No matter what temporal or spatial scales are involved, processes can act additively and synergistically to affect all levels of biological organization. For individual organisms, the biological response to changing conditions involves changes in physiological processes such as feeding, digestion, assimilation, growth, responses to stimuli (i.e., orientation and swimming speed), and reproduction. These life processes are dependent on key water properties such as temperature, salinity, light penetration, and oxygen concentration. The population community response is broader and characterized by potential changes in assemblages, competition, predation, and migratory behaviors. From an ecosystem perspective, variable environmental conditions alter fluxes of energy and matter, and if the alterations are significant enough they may alter the equilibrium state. This new state may lead to conditions that offer the potential to adversely affect species–habitat relationships that have evolved over time. The current status of listed salmon and suckers in the Basin reflects population responses to such threshold changes.

Further discussions about the effects of ocean variability on Klamath Basin resources are worthy of mention because of their complexity and potential to confound effective management of migratory species, notably salmon. However, instead, our conference focus on the watershed was defined by geography, freshwater influences, and distribution of human activities. Watershed processes thus included major habitats within the upper and lower subbasins, the estuary and nearshore marine. The importance of marine-derived nutrients from salmon and other anadromous species (e.g., green sturgeon; *Acipenser medirostris*) represents an important coastal and ocean linkage to watershed ecology, salmon reintroduction, and other restoration efforts. A recently described multi-prey source model[8] expands on this by incorporating nutrient subsidies from terrestrial, marine, and headwater/tributary components of Northwest watersheds into aquatic productivity and food web models, conceptually linking foods, habitats, and interactions to salmon production. Other trophic pathways would apply to other fishery resources and apex consumers (i.e., amphibians, birds, and mammals). However, the model's importance is its fundamental approach to understanding ecosystem structure and function in light of key watershed processes (e.g., streamflows, nutrient sources, and trophic pathways).

Resiliency of aquatic ecosystems and biological populations depends on the frequency, magnitude, duration, and predictability of human and natural disturbance regimes on freshwater habitats and their restoration. Anthropogenic disturbance regimes represent threats to resources and, with respect to the Klamath Basin, include exploitation, habitat loss, invasive species, isolation, fire, disease, pollution, and climate change. Because such threats vary unpredictably across space and time, and

[7] Dr. Leslie Dierauf's Introduction to the Klamath Basin Science Conference commenting on the importance of life cycle based models and focus on freshwater, estuarine, and marine survival of salmon.
[8] See Wipfli and Baxter (2010).

because living resources have different vulnerabilities and sensitivities to impact, it has often been difficult to assign a specific cause to species decline, extinction, or other effect. Importantly, the indirect effects of disturbance regimes on species interactions (e.g., predation, competition, parasitism, and symbiosis) may represent the most important, long-term threats to a system's resiliency.

Fire disturbance is an important interaction between physical and biological environments that is strongly influenced by climate and terrestrial vegetation community structure. Fire effects can be far reaching, influencing hydrologic, geomorphic, and other ecosystem conditions. The scale, severity, timing, and duration of fires are key determinants of the magnitude of impact. The loss of vegetative cover and forest litter can dramatically reduce the interception of precipitation, thereby altering rates of evapotranspiration, runoff, and erosion. Increased sediment transport and nutrient loading are commonly observed in aquatic systems following fire. Changes in stream cover, sediment delivery, and nutrient concentrations can alter habitats and productivity. Terrestrial habitats also are affected by burning. Direct impacts on soils can change water infiltration leading to ash clogging soil pores.

The timing, extent, and form of subsequent precipitation events affect a fire's severity. Peak flows post fire can increase by orders of magnitude if heavy precipitation falls in fire-affected areas before vegetation recovery occurs. Many biological processes are affected or even initiated by fire. Among plants these can include regeneration, succession, and competition. Fire scale and severity, as well as vegetation community composition, determine the rates and locations at which these processes occur and underlie the patterns that will emerge. Many long-term effects on animal populations and community interactions can be related to fire-related changes in habitat associated with vegetation succession. The effects are species dependent and can be either beneficial or detrimental as they pertain to a particular species habitat requirements.

Basinwide Physical Processes

At the basin scale, key physical processes are related to the geology, climate, and hydrology of the watersheds. As noted, the geology of the basin is complex and active due to its location at the intersection of several tectonic provinces. Notable geologic processes include an east–west extension of the region, volcanism in the upper basin, and rapid uplift in the lower basin. These processes have created key geographic features. In the upper subbasin, volcanic tablelands, broad valleys, and widespread volcanic deposits were caused by the eruption of Mount Mazama 7,700 years ago. In contrast, much of the lower subbasin's terrain is rough and high gradient with similarly characterized rivers running through narrow canyons.

The climate of the Klamath Basin is closely tied to its geography. Much of the upper subbasin is semiarid because of the Cascade Range rain shadow. Elevation and seasonal temperatures result in about one-half of the annual precipitation falling as snow. The lower subbasin receives much more precipitation and because the seasonal temperatures are warmer, the precipitation is more rainfall than snow. Orographic effects are pronounced and the annual precipitation is quite variable among the Klamath River tributaries. A precipitation gradient establishes from east to west and the Shasta River is generally driest because it is located in the Salmon and Marble Mountains rain shadow. Average annual precipitation increases to the west in the Scott, Salmon, and Trinity watersheds and the coast rainfall can be as high as 250 cm/yr.

Hydrologic processes in the basin are strongly influenced by geology and climate (fig. 4-2). Under unregulated conditions, runoff in the upper Klamath subbasin was buffered by the presence of lakes, wetlands, and large groundwater contributions with peak flows occurring in April as a result of snowmelt. In contrast, the lower Klamath subbasin receives much higher rainfall resulting in peak flows that occur during large winter storms with secondary peaks occurring during spring snowmelt. Dams on the Klamath River and its tributaries have changed the timing and duration of runoff in the Basin. Water withdrawals for irrigation also have affected total runoff and streamflow conditions.

Basinwide Biological Processes

The interaction of biological and physical processes occurs across multiple scales with respect to ecosystem effects. Biological communities are defined, in part, by the interaction of geologic, climatic, and hydrologic processes in terrestrial and aquatic ecosystems. These interactions establish physical boundaries or constraints for biological processes. Biotic responses evolve over time as individual expressions of genetic diversity that reflect a population's ability to live and reproduce within a certain range of environmental conditions. Ecological interactions are evidenced in the richness of the plant and animal communities throughout the Klamath Basin. The distribution of terrestrial plants within the basin reflects successional patterns that relate to precipitation temperature, elevation, slope, soil conditions (e.g., composition and chemistry), light, and other parameters that define the physical environment. Higher elevations in the upper subbasin are covered by mixed-conifer forests dominated by lodgepole (*Pinus contorta*), ponderosa (*P. ponderosa*), and whitebark pine (*P. albicaulis*); Douglas (*Pseudotsuga menziesii*), grand (*Abies grandis*), Shasta red (*A. shastensis*), and white fir (*A. shastensis*); and mountain hemlock (*Tsuga mertensiana*). Western juniper (*Juniperus occidentalis*), rabbitbrush (*Ericameria* sp.), sagebrush (*Artemisia* sp.), and other high desert species are most common at lower elevations. The temperate rainforests of the lower subbasin are also comprised of mixed conifers. Some species found there are also common to the upper subbasin (ponderosa pine, Douglas, grand, and white fir), but others are only present in the lower watershed such as Pacific yew (*Taxus brevifolia*), red fir (*Abies magnifica*), redwood (*Sequoia sempervirens*), Sitka spruce (*Picea sitchensis*), sugar pine (*Pinus lambertiana*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Some deciduous trees also are common including quaking aspen (*Populus tremuloides*) and black cottonwood (*P. trichocarpa*) in the upper subbasin and Pacific madrone (*Arbutus menziesii*), tanoak (*Lithocarpus densiflorus*), Oregon white oak (*Quercus garryana*), and black oak (*Q. kelloggii*) in the lower subbasin.

Similar biological trends in the distribution and occurrence of fishery assemblages within the Klamath Basin can be described. The cold, high-gradient headwater streams in the upper subbasin provide important habitat for bull trout (*Salvelina confluentus*). Lost River suckers, shortnose suckers, and other Klamath Basin endemic fishes tolerant of conditions in the large shallow lakes that dominated the valleys of the upper basin were historically quite abundant. The high-gradient rivers and streams of the lower basin support populations of both anadromous and resident fishes including eulachon (*Thaleichthys pacificus*), green sturgeon, lamprey (*Lampetra* sp.) and coastal cutthroat (*O. clarkii clarkii*), and rainbow trout (*O. mykiss*). Other anadromous species like Chinook (*O. tshawytscha*) and coho salmon, steelhead (*O. mykiss*), and Pacific lamprey (*L. tridentata*) historically used a variety of habitats throughout the basin. Use of particular habitats for these species is often related to specific life history requirements and adaptive strategies for living in specific environmental conditions.

Subbasin Physical Processes

The effects of physical processes at subbasin, reach, and habitat scales are cumulative, area specific, and often more immediately observable than those occurring at larger scales. For instance, the effects of weather, precipitation, and resulting hydrology on river reaches and habitats provides detailed information about how water flows through and affects specific areas of the watershed in response to variable local and regional conditions. A variety of processes can be involved after precipitation falls including interception by plants, evapotranspiration, surficial flows, soil infiltration, and recharge. Water can be stored as groundwater for varying lengths of time in soil or aquifers or as surface water in rivers and lakes before eventually discharging into the ocean. Ocean evaporation completes the hydrologic cycle (fig. 4-3).

Many geomorphic processes at reach and habitat scales are closely linked to hydrology. Erosion and mass wasting processes as well as sediment transport and sediment deposition are affected by precipitation, soil saturation, and the flow of surface water and groundwater. The volume, duration, and frequency of flow events are important, but are not the only parameters affecting the rates and magnitude at which geomorphic processes and change occur. Local climate, valley width and slope, rock and soil types, upland and riparian vegetation density and types, and other factors interact to varying degrees to influence the dynamics of sediment erosion, transport, and deposition. These habitat-forming processes are conspicuous in streams, rivers, and floodplains and drive the formation and evolution of key river features like terraces and alluvial fans at the reach scale and riffles, pools, and cascades at the habitat scale (fig. 4-4).

Hydrologic and geomorphic interactions are important drivers of water quality. High levels of fine sediments can negatively influence water quality by reducing water clarity and limiting the flow of oxygenated water by carrying nutrients to downstream water bodies. Water temperature influences water quality by affecting dissolved oxygen solubility and reaeration rates as well as a variety of abiotic chemical processes. In addition to climate and season, water temperature can be influenced by geomorphic and vegetative shading, hyporheic flow, groundwater inputs, and channel morphology. Other parameters that affect water quality include oxygen and other gasses, major ions and nutrients, rates of transport, and the dynamics of pH and key nutrients.

Subbasin Biological Processes

As at larger scales, biological processes at subbasin, reach, and habitat scales are constrained by interactions with the physical environment. With downscaling, these interactions and their effects may focus less on community and population levels and concentrate more on sub-populations and individual organisms. To survive, reproduce, and conduct other higher level activities, individual organisms must be able to perform fundamental physiological functions. The ability of an organism to respire, feed, grow, and conduct other essential activities is directly influenced by the physical environment. The exact processes in play vary considerably depending on many factors including the type of organism in question (e.g., animal or plant), which habitat(s) it lives in (e.g., terrestrial or aquatic), and its trophic level (e.g., producer or consumer). For example, the biology and physiology of a fish residing in freshwater is strongly influenced by water quality properties, water quantity, flow, and sediment transport. Terrestrial plants are more influenced by soil, precipitation, climate, and topography. It should also be noted that there are numerous geographic and seasonal components in the environmental variability surrounding these parameters and their influences on plants and animals, and these remain poorly described.

Limitations or constraints imposed on individuals by physical processes also can have effects at sub-population, population, and community levels. Stressors that negatively affect individuals can limit growth, the ability to migrate, reproductive output, and survival, which can in turn affect the dynamics of subpopulations and populations. These can be manifest in several ways ranging from local adaptation and expression of multiple life history strategies to reductions in occupied habitat, temporary population declines, altered age structures, and isolation from conspecific populations to localized extinction and subsequent recolonization. Physical processes that affect individuals and populations also simultaneously influence biological processes at the community level. These effects can include direct and indirect interactions both within and among species and can result in changes in food webs, predator-prey interactions, competition, and levels of disease and parasitism.

Ecological Linkages

Conceptual Understanding

Two flow studies for the Klamath Basin were reviewed by the National Research Council[9]. Four major themes regarding science relevance resulted from this review: scale, representativeness of data, connectivity, and a river-basin perspective. Watershed processes, as described above, are multi-scalar and in the case of the Klamath Basin, resolution of those that concern water management, ecosystem maintenance or restoration, and recovery of endangered species will need to be addressed at multiple scales. As an example, a generic nested watershed conceptual model "Basin→Reach→Habitat" was presented by the USGS to focus attention to scale and ecological processes and how these relate to flow-environmental relationships. In this section, we add complexity to this conceptual model by increasing our focus on watershed processes and interactions as they relate to specific Klamath Basin habitats and ecosystems.

The issue of representativeness of flow or other aspects of habitat conditions is complex and difficult to address outside the conduct of a comprehensive research and monitoring program. Differences in ecosystem development relate directly to geology, topography, hydrology, vegetation, stream size, and many other factors (e.g., retentive capacity, amount of woody debris, and sediment transport). As an acknowledgment of these sources of variability, fishery biologists have described four principles for conducting a salmon habitat assessment: (1) all watersheds and streams are different with respect to temperature and flow regimes, sedimentation rates, nutrient fluxes, physical structure, and biota; (2) fish populations have adapted (biochemically, physiologically, morphologically, and behaviorally) to the natural environment and other biota therein; (3) specific habitat requirements differ by species and life history type, season, life history stage, and the presence of other biota; and (4) ecosystems are dynamic. Similar biological insights were used to more broadly introduce the "riverine landscape" as a conceptual bridge between terrestrial and aquatic ecology, land and water interfaces, and the dynamic nature of rivers in the landscape mosaic. Variations in freshwater habitats and biological responses were conceptualized as outcomes of the interactive effects of hydrology (i.e., variable current speeds, directions, forces, and patchiness) on landscape interactions (e.g., shifting floodplains) and adaptations of organisms (i.e., to food availability, flood pulses, and physical force of currents). While the general premise of adaptation to environmental conditions extends to other biota (e.g., plants, other fish, birds, and mammals) there is a need for reliable information on the ranges of natural variability of key biophysical habitat attributes and underlying processes to evaluate the ecological similarity, differences, and representativeness of watershed conditions.

[9] See NRC, 2008. Hydrology, ecology and fishes of the Klamath River Basin. National Academies Press. Washington, DC.

The lack of connectivity of Klamath Basin landscapes is an important characteristic of the Klamath Basin. The cumulative effects of human and natural activities have had broad geographic impacts on ecosystem conditions and functions over the past 100 years. So much so that this Basin's biological integrity or recuperative capacity to "support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and organization comparable to that of a natural habitat of the region"[10] is of national significance with respect to restoration, water resources management, recovery of endangered species, potential dam removal, and reintroduction of salmon. Examples of landscape fragmentation illustrate the impact of human activities within the Basin on watershed function. For instance, "upstream from the Link River Dam and the body of Upper Klamath Lake extensive marshes, formerly functionally connected to groundwater and surface flows, were drained and converted to agricultural use. In the river reach upstream of Keno Dam, construction of a railroad embankment disconnected the Klamath River from its historical flood overflow into Lower Klamath Lake; similarly, historical flow into the Lost River was controlled."[11]

Ecological Considerations for Riverscapes

The *shifting habitat mosaic* is defined as a fundamental process of river ecosystems occurring in a dynamic 3-dimensional matrix that is relatively persistent over time in natural river systems. The dynamic and multidimensional components of the shifting habitat mosaic add complexity and apply landscape ecology principles to improve the understanding of watersheds. Hydrologic regimes such as groundwater and surface-water interactions and discharge patterns are sources of temporal and spatial variability and affect key habitat attributes such as current velocities, routing of sediments, substrate, and structuring of biological communities. These landscape processes interact with the geologic and biologic characters of a watershed and serve as key determinants of channel and floodplain geomorphology (fig. 4-5) and stream classifications (e.g., low-gradient and braided meandering reaches and high-gradient mountain rivers). Acting in concert, this matrix of 3-dimensional forces (arrows in fig. 4-5) shape and control the physical dimensions of a watershed and connect terrestrial and aquatic landscapes; through these interactions consistent habitat patterns emerge. Habitat conditions, though dynamic and variable, represent areas or patches to which natural assemblages of organisms have adapted. The persistence of natural habitat patches is evidenced in similarities of modern substrate conditions to ancient characteristics of corresponding hyporheic zones from Paleozoic channels.

Conceptually, the different fluvial and geomorphic characteristics of a watershed are described as "beads on a string." The "beads" in the Klamath watershed include distinctive reaches extending from headwaters to the nearshore marine. The inclusion of the nearshore marine as a "bead" is an important adaptation with respect to land-sea connections and relative biological and socioeconomic importance of the nearshore marine to the Klamath Basin. This linkage includes natural resources (i.e., anadromous and some marine fishes) and human activities such as West Coast salmon fisheries. It reinforces river, landscape, and ocean connections and the priority need for multi-scalar approaches to natural resource science and management in the Klamath Basin. Finally it presents another dimension to be considered in any assessment of potential consequences of land-based activities in watershed on coastal processes (e.g., sediment and nutrient inputs) and valued resources.

[10] See NRC, 2008. Hydrology, ecology and fishes of the Klamath River Basin. National Academies Press. Washington, DC.
[11] See NRC, 2008. Hydrology, ecology and fishes of the Klamath River Basin. National Academies Press. Washington, DC.

The Process Domain Concept is another important concept in contemporary riverine ecology. It is a multiscale hypothesis which states “that spatial variability in geomorphic processes governs temporal patterns of disturbances that influence ecosystem structure and dynamics.” As described above, regional climate, geology, vegetation, and topography control hydrologic and geomorphologic processes at landscape scales. These interactions result in functional similarities in reaches, which are useful for classifying stream or channel types across the landscape. But as was noted above, the individual responses of specific reaches to similar process variables may differ due to differences in environmental setting. Process domains are spatially identifiable areas characterized by distinct suites of geomorphic processes (“lithologic-topographic units”), and within these regions biological communities respond to distinctly different disturbance regimes.

Patch, stream classification, and ecological domain concepts are applied to the Klamath Basin in the Conceptual Model chapter (Chapter 7). This application divides the Klamath Basin into 11 ecological domains extending from Basin headwaters to the nearshore marine (See fig. 7-5). An important emphasis of this chapter is on the intensity of interactions between the habitat “beads,” domains, and four large ecosystems (Headwater, Upper Klamath Lake, Klamath River, and Ocean) identified in the conceptual model. Conceptually the watershed processes interactions are greatest between: (1) Upper Klamath Lake, lakes/reservoirs between Keno and Iron Gate Dams, and the Klamath River, (2) the major tributaries (Shasta, Scott, Salmon, and Trinity Rivers) and the Klamath River, and (3) headwaters (headwater springs and Sprague and Williamson Rivers and upper subbasin wetlands, other groundwater springs, and mountain and fog belt tributaries). Link and Keno Reservoirs are included in the same domain as Upper Klamath Lake because of the primary influence of upstream processes, especially freshwater discharges related to the hydrology and ecology of Link River and Lake Ewauna.

The broad ecosystem designations incorporate biological interactions and conditions that support distinctive food webs and communities. Within this conceptual framework the estuarine and nearshore marine areas could be treated as separate ecosystems using similar rationale. Instead, the estuary provides a linkage between river and ocean ecosystems and food webs that support key anadromous species such as salmon and steelhead, sturgeon, eulachon, and lampreys. Upland and other terrestrial components of the watershed are not adequately represented in this analysis because of its emphasis on aquatic ecosystems. In general, Klamath Basin habitats become increasingly terrestrial and distinctive with respect to vegetative cover and wildlife as they transition from floodplain and riparian habitats to terraces and hill slopes and then to forest and alpine conditions.

The ecosystem designations are largely determined by food web relationships in the basin. This highlights the continuing need for improved information on prey sources (local, terrestrial, and marine), fish diets, and prey assimilation efficiencies. The integration of these physiological requirements will provide a bioenergetic basis for fish production to be estimated. The seasonal and longitudinal multi-prey models represent tools to describe how salmon prey fluxes vary in quantity and quality through time (daily, seasonal, and annual) and space (within and among drainages), under different riparian, headwater, local stream, and marine conditions. The models also identify major data needs for modeling. At larger spatial scales, adapting this approach to fit other food webs characterized by other apex consumers (e.g., other fishes, amphibians, birds, and mammals) would expand its utility to other species, communities, and ecosystems across the Basin.

Watershed processes have been used to delineate and characterize the major habitats of the Klamath Basin. Basin headwaters are located in the Wood River, North and South Forks of the Sprague River, in the Sycan River, and in the upper reaches of the Williamson River (Spring Creek and Klamath Marsh). The Klamath Basin has been described as an “upside down basin,” and this is because of the low gradient, relatively slow flowing and meandering rivers found in the upper Basin. These conditions are characteristic of Piedmont Valley or Coastal Floodplains more often than characteristic of downstream segments of Pacific Northwest watersheds. Instead, the lower Klamath Basin and its tributaries have Montane Floodplain qualities (e.g., high-gradient, high flows, and canyon channels). Deltaic processes are not evident and the estuary is small and similar to a pulsating or protected lagoon. Spring-fed conditions are more prevalent in the upper subbasin and the Shasta River, while precipitation and snowmelt are the main sources of freshwater in the major tributaries of the Klamath River in the lower subbasin.

Klamath Basin Habitats

The major habitat types, from headwaters and mountaintops through lakes/reservoirs and river channels, are more fully described below with respect to watershed influences. A process-based approach was used to delineate habitats and summarize environmental information related to (1) existing conditions, disturbance regimes and process drivers, (2) ecosystem services, and (3) information needs and science priorities.

Upper Subbasin

The major rivers, their main tributaries, and wetlands are major sources of water for lakes in the upper subbasin. They are also major drainage basins for the headwaters of the Klamath River. Groundwater contributions to base flows are significant, particularly in summer months after winter and spring snowmelt-dominated hydrologic events have waned.

Rivers

The major rivers include the Williamson, Sprague, Wood, and Lost Rivers, and for this presentation the Klamath River downstream to Iron Gate Dam.

Williamson River. The Williamson River is the largest tributary to Upper Klamath Lake and accounts for approximately 50 percent of the lake’s water input. The Williamson River originates upstream of the Upper Klamath Marsh, approximately 56 river km upstream of the lake. Its main tributaries are the Sprague River and Spring Creek. The Williamson-Sprague system drains approximately 7,772 km^2 that is primarily forested but also contains grass- and shrub lands, agricultural-use lands, and wetlands. Inflows into the Williamson River upstream of the confluence with the Sprague River are primarily from groundwater sources, which results in steady base flows. Historically, the lower Williamson and Sprague Rivers supported the largest Lost River sucker and shortnose sucker spawning runs in the basin as well as runs of anadromous salmon and lamprey. Today, anadromous fish cannot reach the upper subbasin due to dams. Sucker spawning in the Williamson River is limited to downstream of the confluence with the Sprague River as water temperatures upstream of the Sprague River inflow are thought to be too cold to support reproduction. The Williamson River is currently the site of a major restoration project that involved dike removal and reflooding of historical lake and wetland areas in an attempt to expand favorable nearshore habitats for juvenile suckers.

Sprague River. The Sprague River originates to the east of Upper Klamath Lake in the Gearhart and Quartz Mountains draining an area of approximately 4,092 km^2. The Sprague River is a low-gradient river (approximately 0.4 m/km) and is characterized by broad valleys with extensive riverine meanders interspersed with low canyons or gaps created by uplifts or block faulting geology. Associated with these uplifted areas is an upwelling of groundwater which recharges the Sprague River as it cuts through these formations. The Sprague River is the principal tributary of the Williamson River and combined they provide approximately 50 percent of the annual inflow to Upper Klamath Lake. Flows in the Sprague are primarily snowmelt runoff. Seasonal flow patterns are more prevalent than in the Williamson and Wood Rivers. A dam was constructed on the Sprague River in 1914 near the town of Chiloquin, OR. This dam served as a diversion structure to supply irrigation water for the Modoc Point Irrigation District. This dam was removed by the Bureau of Reclamation in 2008.

Wood River. The Wood River originates from a large spring north of Agency Lake and provides approximately 16 percent of the annual inflow to Upper Klamath Lake. As the river flows generally south it receives input from tributary streams fed by both springs (e.g., Crooked Creek, Fort Creek) and snowmelt (e.g., Annie Creek, Sun Creek) as well as from direct inflow of groundwater. The headwaters of the Wood are primarily forested, shifting to grassland prairie and marsh on the valley floor. Much of the valley has been converted to pasture since settlement, which has exacerbated the naturally high levels of nutrients flowing into Agency and Upper Klamath Lakes from this drainage. Recent wetland restoration efforts at the mouth of the Wood River have been undertaken in part to help reduce nutrients entering the lakes of the upper subbasin.

Lost River. The Lost River, controlled by releases from Clear Lake and Gerber Reservoirs, flows through areas of intensive agricultural production and irrigable land associated with the Bureau of Reclamation's Klamath Project. Over the past century the Lost River has been modified by dam construction, channelization, water diversions, wetland drainage, agricultural activities, grazing, and urban development. These activities have direct and indirect effects upon water quantity and quality. Two endangered species, Lost River sucker and shortnose sucker, and three species of special concern, Klamath largescale sucker (*Catostomus snyderi*), redband trout (*O. mykiss* subsp.), and blue chub (*Gila bicolor*) exist in the Lost River. Currently the Lost River does not meet the State of Oregon's water quality standards for ammonia, chlorophyll-a, and dissolved oxygen. Beneficial uses designated for the Lost River include public domestic water supply, private domestic water supply, industrial water supply, irrigation, livestock watering, resident fish and aquatic life, wildlife and hunting, fishing, boating, water contact recreation, and aesthetic quality.

Klamath River Mainstem and Reservoirs. The Klamath River begins at the outlet of Lake Ewauna and as it flows generally west it transitions geographically from the Modoc Plateau to the Cascades Range. PacifiCorp owns and operates several hydroelectric facilities that together are referred to as the Klamath River Project. The project consists of four hydroelectric dams on the mainstem Klamath River. These dams were constructed between 1908 and 1962 and include two earthen embankment dams (Iron Gate and J.C. Boyle) and two concrete dams (Copco 1 and 2). Iron Gate and Copco 1 Dams have relatively large reservoirs that have trapped significant amounts of sediment. J.C. Boyle Reservoir is relatively small and narrow and Copco 2, the smallest reservoir of the four, has trapped very little sediment. The Klamath River Project area is located in rural southwestern Oregon (Klamath County) and northern California (Siskiyou County). Copco and Iron Gate Reservoirs experience periodic blooms of the cyanobacteria *Microcystis aeruginosa*. Toxins produced during these cyanobacterial algal blooms are known to cause substantial human health problems. Keno Dam does not produce electricity but regulates the water level in Keno Reservoir as required under the operating license for the project issued by the Federal Energy Regulatory Commission.

The section of river comprising the Klamath Hydroelectric Project flows through 103 km of bedrock canyon channel that is composed of step pool and riffle pool morphology. This section has minor alluvial reaches; however, it is considered non-alluvial and sediment supply generally is limited. Its channel can be characterized as steep, high-energy, and coarse bedded. The location as well as size and shape of pools, riffles, rapids, bars, flows, splits, and side channels appears to have changed very little over time. The channel shape and physical character of this section of the Klamath River is largely determined by local geologic characteristics and infrequent, high magnitude flow events. Changes in the river's flow regime resulting from basinwide water projects have had little impact to the river's geomorphic characteristics. The Bureau of Land Management owns large tracts of land in the vicinity of the Klamath River Project and is responsible for the management of an 18-km reach of river beginning downstream of J.C. Boyle Dam and ending at the California-Oregon border that is designated the Klamath Wild and Scenic Reach.

Lakes and Reservoirs

The major lake and reservoir basins in the upper subbasin include Upper Klamath Lake, Lower Klamath Lake, Clear Lake Reservoir, Gerber Reservoir, and Tule Lake.

Upper Klamath Lake. Upper Klamath Lake is a remnant of the Pleistocene Lake Modoc and is located on the east side of the Cascade Mountain Range in south-central Oregon. At full capacity, Upper Klamath Lake has a surface area of 280 km^2 making it the largest lake in Oregon; however, it is relatively shallow (average depth approximately 2 m). Lake level and flow into the Link River at its outlet was historically controlled naturally by a rock reef but has been regulated by the Link River Dam since its construction in 1917. The combination of its bathymetry and a watershed naturally enriched in phosphorus has led to the conclusion that Upper Klamath Lake has been eutrophic since the earliest records in the mid-1800s. Water quality in the lake has been markedly altered from historical conditions by various human activities in the watershed, particularly the drainage of marshes and wetlands, timber harvest, and water control and allocation related to agricultural development. These changes have created a hypereutrophic system that experiences massive phytoplankton blooms dominated by a single cyanobacterium, *Aphanizomenon flos-aquae*. The algal blooms and their subsequent die-offs produce water-quality conditions that are deleterious to fish health (e.g., low dissolved-oxygen concentrations, elevated ammonia concentrations, high pH). This is of concern to resource managers as the largest remaining populations of endangered Lost River and shortnose suckers reside in the lake. Poor water-quality conditions are thought to have contributed to a number of substantial fish kills in the lake, most recently during the summers of 1986, 1995, and 1997, and to a much lesser extent in the summer of 2003.

Lower Klamath Lake. Located south of Upper Klamath Lake, Lower Klamath Lake was historically connected to Lake Ewauna and the Klamath River on a seasonal basis, which resulted in as much as 380 km^2 of open water and emergent vegetation. Although only about 0.3–0.5 m deep throughout most of the year, Lower Klamath Lake provided extensive marsh and shoreline habitats for many species of waterfowl and fish including Lost River and shortnose suckers. Seasonal flooding into the lake was blocked in the early 20th century by a railroad dike with much of the lake and wetlands subsequently converted to irrigated farmland. The flooded remnants of Lower Klamath Lake are now part of a National Wildlife Refuge and only receive surface water through a series of irrigation conveyances.

Clear Lake Reservoir. Clear Lake Reservoir is located southeast of Upper Klamath Lake and is part of the Lost River subbasin, which spans the Oregon-California border. The reservoir is relatively shallow (average depth approximately 6 m) and turbid and covers approximately 104 km^2 at full pool. Historically, Clear Lake was a natural lake with marsh and meadow habitat along its margins. The lake was enlarged in 1910 when the Bureau of Reclamation constructed a dam near the lake's outflow. Clear Lake now serves as a means of controlling flow into the Lost River as well as creating an evaporation basin that helps reduce flows into reclaimed Tule Lake agricultural areas. Clear Lake also is used to store seasonal runoff that supports the Langell Valley and Horsefly Irrigation Districts' irrigation needs. Average inflow into Clear Lake is 0.14 km^3. Clear Lake Reservoir supports self-sustaining populations of both Lost River and shortnose suckers that have been identified as refuge populations critical to recovery efforts (National Research Council, 2004).

Gerber Reservoir. Gerber Dam was completed in 1925, which created the approximately 15 km^2 Gerber Reservoir. Constructed to store irrigation water for local irrigation districts and to limit runoff to Tule Lake, surface area and depth vary considerably year to year. Minimum lake level thresholds have been established to protect a population of endangered shortnose suckers that resides in the reservoir.

Tule Lake. Tule Lake located east of Lower Klamath Lake is a terminal lake at the bottom of the Lost River subbasin. Historically, Tule Lake was as large as 445 km^2 with depths up to 16 m and supported large populations of Lost River and shortnose suckers as well as many species of waterfowl and fish-eating birds. As part of the development of the Klamath Irrigation Project, most of the lake was drained and converted to agriculture with only about 52 km^2 of lake remaining in the form of two shallow sumps. Small populations of Lost River and shortnose suckers still exist in Tule Lake. With access to historic spawning areas in the Lost River blocked by dams it is unlikely these populations are self-sustaining.

Wetlands and Marshes. Wetlands and marshes are important and extensive habitats in the upper subbasin. Historically, there were expansive wetlands at the margins of the lakes and they varied in area in response to meteorological cycles and more recently with irrigation practices in this subbasin. The wetlands in the headwaters of the basin are important to fish and wildlife and hydrologically serve as nutrient sinks and permeable substrate for water storage and mitigation of flows.

Lower Subbasin

The National Research Council noted that the Klamath-Trinity River system is the largest between the Sacramento and Columbia Rivers in terms of flow, salmon production, and economics, and one of the most highly modified. Runoff production, in terms of average annual runoff, is estimated to be about 16.04 km^3 at the mouth of the Klamath River. Of this, 88 percent originates within the lower subbasin with major contributions coming from the Trinity River. Near the coast, annual precipitation exceeds 250 cm in some of the smaller watersheds. Winter storms often result in significant snowmelt and high-flow contributions to the Klamath River.

Klamath River

The Klamath River from Iron Gate Dam to the Trinity River (i.e., mainstem river) is dominated by a series of step-down rapids. Below this, pool and riffle sequences dominate the riverscape. Mainstem flows show a great deal of daily as well as annual variation reflecting the combined operations of the major dams on the Klamath River. Historically, the Upper Klamath Lake trapped most of the sediment originating from the upper subbasin leaving river tributaries as the primary sources of fine sediment into the river. Low flows over sustained periods resulted in deposition of fine sediments and the establishment of dense beds of rooted aquatic macrophytes. These macrophyte beds are the primary habitats for the polychaete worm that serve as the intermediate host for the myxosporean parasite (*Ceratomyxa Shasta*) that infects salmonid fish in the Klamath River. Releases from Iron Gate Dam are important in maintaining flow conditions to flush the fines and clean the gravels in the river during periods of drought as far downstream as Seiad Valley. Their management could be a valuable tool for controlling densities of the intermediate host.

Additional Habitat Considerations. Water temperature in the lower Klamath River during summer months often approaches or exceeds the physiological tolerance limits of most Pacific salmon species. Reliance of these fish on cold water has been studied extensively. Although the optimal physiological performance of Pacific salmon typically is at temperatures of 14.0–17.0°C, salmon frequently are found occupying habitats where water temperatures reach 23.0–24.0°C on a daily basis. Much of the variation in tolerance to warmer water temperatures in Pacific salmon is attributed to acclimation.

In the Klamath River, water temperature regularly exceeds 25.0°C during July and August. Pockets of cool water that form at tributary mouths are critical to the survival of Pacific salmon during these periods. Coolwater refuges having high abundance (>1,000) of juvenile Chinook salmon, which have been observed at the mouths of Ukonom Creek, Indian Creek, and to a lesser extent Beaver Creek. The confluence of the Scott River and many other tributaries are important. The periodicity in heavy use of coldwater patches by Chinook salmon and their spatial clumping in these areas suggest that habitat selection may be governed by more than water temperature alone. Other factors, such as volume and mixing rates, are important as well. Coldwater patches downstream of gravel bars have been shown to be important in other gravelbed systems in northern California and Oregon, but this has not been demonstrated in the middle Klamath River reach. Verifying the presence or absence of substantive hyporheic cooling zones in the Klamath River is an important area of research, as the ramifications for resource management (i.e., flow management, dam operation and/or removal, gravel augmentation, etc.) are large.

Klamath River Tributaries

River tributaries originating in the Siskiyou, Klamath, and Trinity Mountains of southern Oregon and northern California provide refugia habitat for juvenile salmonids during summer thermal extremes and high winter flows that often occur in the Klamath River mainstem. Off-channel ponds created during flood events by beaver (*Castor canadensis*) activities or by other natural processes also provide important rearing habitat for juvenile salmonids.

Shasta River. The Shasta River flows 64 km through a semiarid agriculture valley in Siskiyou County, California, before emptying into the Klamath River north of the town of Yreka, California. The Shasta River watershed encompasses 2,100 km^2 and more than one-half of its annual flow originates from a series of groundwater springs. Historically, these sources of groundwater inflows provided cool nutrient-rich water during summer and fall months that helped support large populations of Chinook and coho salmon and steelhead trout. Currently, water diversions dramatically reduce streamflow during summer and fall months, but flows rapidly rebound to baseflow conditions at the end of the irrigation season. Streamflow in the Shasta River upstream of Dwinnell Dam is stored in Lake Shastina, and minimal water is released into the Shasta River. During the irrigation season, Big Springs Creek and other springs provide the majority of streamflow to the Shasta River. During winter and early spring, flows become more dominated by rainfall and snowmelt runoff from tributaries. Water temperature trends in the Shasta River are typical of rivers in Mediterranean climates, with spring and summer water temperatures increasing as precipitation and snowmelt runoff decrease. Summer temperatures in the middle section and lower canyon reach of the Shasta River are often too warm to support anadromous fish. Summer water temperatures in the middle reach of the Shasta River are influenced by Big Springs Creek for a considerable distance downstream.

Scott River. The Scott River Valley is located in Siskiyou County, California, west of the Shasta Valley. The Scott River flows 48 km through the Klamath Mountains and is a major tributary of the Klamath River, contributing 5 percent to the Klamath's annual runoff. Some of its larger tributaries include French Creek, Etna Creek, and Kidder Creek. The Scott River Valley floodplain generally is wide and flat and historically featured large areas of now drained wetlands and beaver ponds that provided important rearing habitat for coho salmon. The Scott River continues to provide important spawning and rearing habitat for these fish. The Scott River watershed has no substantial water storage impoundments. Annual discharge in the Scott River averages 452,700 acre-ft; however, base flows have been substantially reduced due to a number of factors including surface diversions, groundwater pumping, and changes in cropping patterns. Seasonal low flows in the mainstem Scott River have been identified as an important factor limiting coho salmon populations. Extensive grazing, logging, unscreened diversions, and hydraulic mining also have been identified as contributing to the degradation of salmon habitat.

Salmon River. Located west of the Scott River, the Salmon River drainage is smaller (1,950 km^2) and less developed than the other main lower river tributaries. The lack of development is likely due to the combination of a landscape dominated by steep mountains and most of the watershed being federally owned. Anthropogenic changes that have occurred in the watershed have largely been related to logging (e.g., roads, bridges, and altered fire regime) and placer mining. These alterations have increased erosion and sedimentation rates as well as altered river and stream habitats critical to fish reproduction and rearing. Despite these changes, the Salmon River still supports spawning populations of important anadromous fishes including spring and fall Chinook salmon, coho salmon, steelhead trout, green sturgeon, and Pacific lamprey.

Trinity River. The Trinity River is the largest tributary to the Klamath River (7,500 km^2 watershed) and historically accounted for nearly one-third of the Klamath River's annual flow to its mouth (4.5 million acre-ft). The Trinity watershed originates in the Trinity Alps and the mainstem flows 200 km through steep canyons and flat valleys in Trinity County, California. Currently, 80 percent of the watershed is federally owned with the remaining ownership being private or Tribal (Hoopa and Yurok Tribes). Historically, the Trinity River hydrograph was dominated by storm runoff during winter and snowmelt in spring. High winter and spring flows scoured the floodplain and prevented mature successional stages in riparian zones and prevented the accumulation of fine sediments. The South Fork is the Trinity's largest tributary and is the largest unregulated watershed in California. The Trinity River

Diversion, consisting of Lewiston and Trinity Dams, was constructed in 1963 to supply water to Central Valley. The Trinity River Diversion initially redirected more than 88 percent of flow into the Sacramento River, but this amount was decreased in 1979. The largest effect of this diversion on Trinity River flows occurs during spring months. The Trinity River hatchery was established in order to mitigate for the loss of historical salmonid production in 160 km of river upstream of the dam sites.

Estuary

The Klamath River estuary has been described as small and short, especially given the size of the watershed that drains into it. Tidal influence only extends upriver to about river km 6.5 during typical high tides with saltwater intrusion ranging from only 4 to 6 km upstream of the mouth. The Klamath River Estuary also has only limited amounts of some of the key features and habitats of larger estuaries including large areas of tidal marshes and tidal flats. Despite these limitations, the estuary serves an essential role to many Klamath River fishes as nursery and rearing habitat. It also functions as a critical staging area for anadromous species as they transition between freshwater and marine environments.

The Klamath River delivers fresh water and sediments to the estuary and coastal waters. Coastal precipitation is high, about 200 cm annually in this part of California. The effects of dams and other human activities (e.g., forestry, mining, and agriculture) on habitat-forming processes, such as sediment transport and habitat conditions (e.g., hydrographic properties, water quality, and nutrients), are considerable and the significance of the land-sea interface is receiving more attention in large-scale river and salmon restoration efforts. Estuaries and bays are especially vulnerable to coastal development, pollution, invasive species, and fishing near the coast.

The Klamath River estuary is a river-dominated system with limited coastal exchange, largely due to a small estuary and an extensive sand bar at its mouth. Within the estuary, wetland, slough, and off-channel habitats provide important foraging areas for juvenile salmon and other brackish water fishes. To illustrate, beaver ponds in many of the small tributaries to the estuary are important seasonal habitat for juvenile coho salmon and steelhead. Estuarine residents include species, such as the threespine stickleback (*Gasterosteus aculeatus aculeatus*), longfin smelt (*Spirinchus thaleichthys*), bay pipefish (*Syngnathus leptorhynchus*), Pacific staghorn sculpin (*Leptocottus armatus*), and several species of gobies (family Gobiidae). Along the northern coast, habitats outside the estuary also are important to Klamath Basin biota and may be directly or indirectly affected by river exports. Their physical structure and location is dependent on topography, geology, and climate effects as well as processes such as erosion and coastal transport and deposition of sediments. Rocky reefs and outcroppings, rocky intertidal, and sandy beach habitats are products of these physical processes and, in combination with other ecological factors (e.g., light, nutrients, biological productivity, and pelagic-benthic ecosystem coupling), provide essential habitats for many fish species.

Historically, the Klamath Basin supported large numbers of Chinook and coho salmon, steelhead trout, green sturgeon, and eulachon. For salmon, the early phases of the seaward migration are believed to be crucial to their transition to marine life and ocean survival. The timing, residence, and condition of juveniles and the quality of estuarine and nearshore habitats are critical to their growth and condition, physiological transition to salt water, and early marine survival. As a hedge against nature (e.g., variable conditions), Chinook salmon have evolved several life history types with respect to freshwater residence periods and timing of outmigration, and thus the different stocks may vary in their reliance on coastal habitats. Knowing the relative contribution of each life history type to the eventual adult escapements would be important information for fisheries management and ecological restoration.

Fish movements and migrations are an important link between freshwater, estuarine, and marine habitats. This is especially true of the anadromous species and contributions of marine derived nutrients to freshwater ecosystems from salmon carcasses. In addition, some marine fishes regularly move between estuarine and marine areas for reproduction and feeding or have critical life history dependencies associated with estuarine and nearshore habitats. Numerous species use embayments, lagoons, and estuaries as spawning and nursery grounds. Bat rays (*Myliobatis californica*), leopard (*Triakis semifasciata*) and brown smoothhound sharks (*Mustelus henlei*), midshipman (*Porichthys notatus*), Pacific herring (*Clupea pallasi*), starry flounder (*Platichthys stellatus*), Pacific staghorn sculpin, surf perch of several species (family Embiotocidae), jacksmelt (*Atherinopsis californiensis*), topsmelt (*Ather inops affinis*), English sole (*Parophrys vetulus*), and several perches (family Embiotocidae) regularly utilize estuarine and inshore coastal waters. These areas are essential habitats for migrating Chinook and especially coho salmon as they travel to sea in spring and summer and on their return to spawning grounds in autumn and winter.

Nearshore Marine

The nearshore marine includes the narrow band of shelf waters off the Klamath River mouth to depths of 100 m. As such, it includes the shallower photic zone and slightly deeper waters adjacent to the coast. The oceanography is highly complex due to regional effects of currents and varying effects of winds, tides, and waves. At the broad scale, offshore waters tend to be colder and primarily affected by the slow-moving and southerly flowing California Current. Nearer the coast, especially in winter, the warmer, northerly flowing Davidson Current has more effect on coastal ecosystems. The physical oceanography of California’s northern coast can be characterized by seasonal wind conditions and periods of intense winter storms (November–March), upwelling (March–August), and diminished winds (August–November). These meteorological patterns have differing impacts on regional and local processes, especially upwelling and downwelling events but generally result in an overall relatively high biological productivity. As an example, more than 500 species of fish have been reported in coastal waters north of Point Conception, California. El Niño events and warming effects of Pacific Decadal Oscillation can bring additional, but infrequent, visitors to the northern coast. Small-scale features, such as fronts and eddies, also can strongly influence the distribution and abundance of marine species. The nearshore marine is physically a dynamic zone that results in much seasonal biological variation in habitat use (e.g., fish, birds, and mammals).

The distribution, abundance, and species composition of biotic assemblages off northern California are being affected by climate warming (more than 40 years of observation). El Niño conditions increase ocean temperatures and sea levels, strengthen onshore and northerly currents, and reduce upwelling and related nutrient deliveries onto the shelf. During such periods, the intensity, magnitude, and frequency of phytoplankton bloom events are changed and can reduce rates of primary production with cascading adverse effects throughout coastal food webs. Similarly, the Pacific Decadal Oscillation, which occurs every 20–30 years, also impacts production cycles and food webs but at the scale of the northeast Pacific Ocean by shifting large-scale temperature regimes by several degrees above or below average conditions. In addition, the potential effects of climate change, including ocean acidification, are of increasing food web and ecosystem concern throughout the Pacific Northwest.

Sandy beaches and rocky intertidal and subtidal habitats vary in their importance to biota. In large part, these habitats depend on marine contributions of nutrients. Because they are subjected to the combined effects of extreme physical forces and low nutrients, these habitats are characterized by low productivity and patchy conditions. Organisms living on sandy beaches and in the rocky intertidal must be able to tolerate wide ranging temperature, salinity, and moisture conditions. The substrate and slope of beaches are important environmental determinants of biodiversity and, in the intertidal zone, species richness tends to increase with depth. Beach wrack attracts a variety of prey resources (e.g., amphipods, isopods, flies, and beetles) for shorebirds, gulls, and other birds. The habitat quality and productivity of subtidal habitats are affected by nutrient supplies, but light and wave energy are important. Light penetrates the photic zone to depths of about 30 m. Kelp forest communities also are of special ecological significance as algal production is high (350–2,800 g C/m^2), and fish densities between 32.2 and 37.6 g/m^2 are common. Kelp provides important substrate for invertebrates as well as food and shelter for higher level organisms. At the sea surface, floating kelp matts may provide important habitat to juvenile rockfishes (*Sebastes* sp.) and kelp perch (*Brachyistius frenatus*). Residents of the mid-water canopy include blue (*S. mystinus*), black (*S. melanops*), and kelp (*S. atrovirens*) rockfishes and bocaccio (*S. paucispinis*). Nearer to the bottom, gopher (*S. carnatus*), copper (*S. caurinus*), black-and-yellow (*S. chrysomelas*) rockfishes and valued species such as lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), greenling (*Hexagrammos decagrammus*), and Dungeness crab (*Metacarcinus magister*) are found. Storm and wave-induced fragmentation and subsequent decomposition of kelp and seaweeds represent an indirect link between lower-level invertebrate consumers and higher-level pelagic predators, such as fish.

The sea otter (*Enhydra lutris*) has been extirpated from this part of the northern California-southern Oregon coast. It is important habitat for harbor seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), and many cetaceans (e.g., porpoise, family Phocoenidae; gray whales, *Eschrichtius robustus*). It is part of a coastal migratory corridor for many whales observed off this coast and the Klamath River plume is known as an important feeding area for gray whales during migration.

A seabird "conservation gap" has been identified within the California Current System between Cape Mendocino (northern California) and Heceta Bank (southern Oregon). Extending to other species, the nearshore marine and to some degree subtidal zone off the Klamath River remain poorly studied. In recent studies, 40 species of fish were captured over sandy bottom habitats at Gold Bluffs Beach, False Klamath Cove, and Enderts Beach, California. Night smelt (*Spirinchus starksi*) and northern anchovy (*Engraulis mordax*) were most abundant and Dungeness crabs were also common. Sampling at nearby rocky reefs yielded 12 species with catches dominated by black rockfish. Farther offshore, reefs deeper than 30 m are important habitat for rockfish and other marine species. In general, rockfish abundance has substantially declined over time in response to commercial fisheries. The shortbelly rockfish (*S. jordani*) is the most abundant rockfish species on the continental shelf and upper slope of California and is found at reefs at depths of 30–80 m. The pelagic life history stage of larval and juvenile rockfishes is protracted (2–3 months) and represents an important food resource for salmon, seabirds, and marine mammals.

Hard substrate and soft bottom sediments are common on the shelf. These seafloors lack the physical structure and high biological production of kelp forests and rocky reefs. Species that utilize these habitats, especially soft sediments, are subject to shifting sediments through wave action and near-bottom currents. Certain crustacean and mollusc species are able to live in tubes or by creating burrows in these sediments. Other species, such as flatfishes, have adapted to these environments through camouflage and feeding morphologies that make them efficient predators of benthic invertebrates and more pelagic prey.

Some marine species are more ubiquitous and widespread in their distributions. Several sculpin species, for instance, are found in shallow coastal waters and tide pools as well as in kelp forests, on rocky reefs, and over sand and mud bottoms. Another example is the lingcod, which occurs in shallow water reefs to depths of more than 300 m over the continental slope.

Human-Induced Alterations

Human activities can have major impacts on many watershed processes. The spatial and temporal scales of these impacts can vary from local areas to basinwide and short-term periods of a few days to years or even decades. Broad categories of anthropogenic activities that can alter watersheds and associated processes include land use changes like agriculture, logging, mining, urbanization, and road building; hydrologic alterations in the form of dams, diversions, dikes, drained wetlands, and channelized streams; exotic or invasive species introductions whether intentional or unintentional; harvest or over-harvest of native plants, trees, or animals; and release of chemical pollutants associated with activities such as agriculture (herbicides, pesticides, and nutrients), mining (heavy metals), and urbanization (municipal and industrial wastes).

Effects can be direct or indirect and caused by a single factor or the interaction of several factors. Results of human-induced alterations on physical processes in watersheds can include increased erosion, altered sediment transport and deposition rates, altered groundwater and surface-water hydrology, altered water chemistry and quality, and others. Biological processes are in turn influenced by the changed conditions and dynamics of the physical environment. While the relation between cause and effect can be simple and direct, it is often complex and the result of the interaction of multiple, indirect, or even synergistic factors. Providing an exhaustive list of human impacts on biological processes in the watershed is beyond the scope of this document. An informative example is provided for aquatic ecosystems in figure 4-6, which lists key factors (food, water quality, habitats, flow, and biotic interactions) as well as more specific parameters that are needed to maintain biological integrity in these environments. Further, it illustrates how human-induced alterations in general may affect many of these factors and thus influence biological processes at the level of individual organisms, populations, communities, or at multiple levels simultaneously. This same example demonstrates the linkages between the health of salmonids in general as well as each salmon life history stage and their habitat needs and the condition of the habitats and ecosystems in which they live[12]. This salmon model is timely for the Klamath Basin in light of the proposed removal of four mainstem dams and the reintroduction of anadromous species to the upper watershed. It is also informative in regard to helping identify and prioritize restoration needs given the degree of alteration in many of the watershed's subbasins and habitats.

Upper Subbasin

Many of the human-induced changes to the upper subbasin are related to agriculture and efforts to develop agriculture. The earliest ventures to establish agriculture were limited to ranching. The number of cattle in the upper subbasin increased quickly and by the late 1800s overgrazing became problematic, leading to loss of native vegetation, increased runoff and erosion, higher sediment and nutrient levels in streams, and incising channels. To counteract issues associated with overgrazing, ranchers started to systematically dike and drain wetlands to provide pasture and grow hay to feed cattle in the 1890s. These initial efforts were the first steps in what would result in the conversion of several hundred thousand acres of lake, wetland, grassland, and other native habitats to agricultural lands. In conjunction with development of these lands, an extensive irrigation system was also constructed. This system included several dams and hundreds of miles of dikes, canals, and drains that have dramatically altered the hydrology of the upper subbasin. Other human activities that have had far-reaching effects in

[12] See Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

the upper watershed include commercial logging, forest management, and fishing. Intensive tree harvest, especially on steep slopes, road construction, fire suppression, and other practices have had a variety of effects including increased erosion and sediment transport rates, altered terrestrial and aquatic habitats, and increased frequency of high-intensity fires. Overharvest in combination with the major alterations of aquatic environments described above have led to substantial declines in populations of some native fishes, particularly lake suckers.

Lower Subbasin

For the lower subbasin, human activities that have had the greatest impact are those associated with extraction of natural resources. The combined effects of mining, commercial logging, and commercial fishing have permanently altered the physical environment and biological resources of the lower portion of the watershed. Beginning in the mid-1800s, placer and hydraulic mining introduced thousands of tons of sediment into tributary streams and the mainstem as entire hillsides were washed away in search of gold. Early placer mining was replaced by large dredges that excavated deep into the riverbed and left large tailings piles topped with boulders and cobbles in the flood plain that destroyed important aquatic habitats, channelized portions of the river, and choked off sources of gravel and other smaller materials. As in the upper subbasin, logging, road building associated with logging, and forest management practices have had considerable effects on the lower watershed. Extensive sedimentation of salmon-bearing rivers and streams has occurred due to erosion from logging roads and skid trails. High-intensity crown fires associated with management-related changes in forest composition are problematic in parts of the lower subbasin. In addition to destruction of spawning and rearing habitat, declines in Klamath River salmon populations can also be attributed to overharvest. The Klamath was the third most productive salmon river on the West Coast with catches high enough in the early 1900s to support three canneries on or near the estuary. Populations have declined dramatically as demonstrated by the listing of coho salmon as threatened under the endangered species act. Additional human activities have had notable effects in individual tributary watersheds. Examples include agriculture altering terrestrial and aquatic habitats as well as hydrology in the Shasta and Scott River valleys and dam construction altering hydrology and aquatic habitats in the Trinity River drainage.

Watershed Modeling

As described earlier, a generic and broad conceptual understanding of watersheds and their components is useful in helping develop hypotheses about complex processes. More specific understanding and hypotheses can also be developed and visualized in the form of conceptual models. Examples are available where conceptual models restricted to key Klamath Basin issues (i.e., endangered species, water quality, and restoration) have been developed.

Two of the largest factors limiting the recovery of endangered Lost River and shortnose sucker populations in Upper Klamath Lake are adult survival and lack of recruitment into adult populations likely due to poor juvenile survival. A conceptual model characterizing the physical and biological parameters of Upper Klamath Lake, many of the complex interactions of these factors, and how they affect endangered suckers is shown in figure 4-7. Efforts to confirm hypothesized links between algal toxin production and poor juvenile sucker survival have produced preliminary supporting evidence and provide a foundation upon which to base future investigations into key factors limiting the recovery of these species.

Water quality is problematic not only in Upper Klamath Lake but also throughout the length of the Klamath River and in many of its tributaries. Large-scale changes in land use and hydrology associated with resource extraction and development have resulted in the degradation of water quality.

Parameters that have been affected include temperature, nutrients, dissolved oxygen levels, water chemistry (e.g., pH, unionized ammonia), and chlorophyll-a concentrations. These changes have created conditions that are more favorable to the growth or overgrowth of cyanobacteria (including toxin producing species) and algae deleterious to native fishes and other aquatic organisms. Poor water quality in the Klamath River has also negatively affected human uses of the river including activities of Tribes (e.g., fishing, shellfish harvest, cultural practices, drinking water) and recreationalists. The large number of parameters, potential interactions, and outcomes results in a system that is highly complex and difficult to understand. This creates challenges for resource managers looking to take actions that will result in quantifiable improvements in not only water quality conditions but also in resources of interest like fish populations. As part of the total maximum daily load process for the Klamath River watershed in California, several Driver-Pressure-State-Impact-Response conceptual models were developed within an Integrated Ecosystem Assessment approach (fig. 4-8) to help clarify which key water quality parameters affect natural resources of interest and how[13].

KBRA Fish Production Modeling

In March 2012, the Secretary of the Department of the Interior is scheduled to adopt one of two management alternatives described in two recently signed agreements. The management alternatives are (1) current conditions with dams in, and (2) the proposed action with four dams removed and restoration activities described in the Klamath Basin Restoration Agreement (KBRA). The Secretary will decide if the Klamath Hydropower Settlement Agreement (KHSA) and the KBRA will (1) advance restoration of salmonid fisheries, and (2) be in the public's interest. To help inform the Secretarial Determination, a Federal team is evaluating the alternatives using a Fish Production Model (FPM) for fall run Chinook salmon. Harvest estimates from the FPM will be used by economists to evaluate the economic benefits from the two alternatives to various sectors of the local and regional economies. To broaden the economic analysis a non-use evaluation survey has been required. Non-use value is the value attached to resources associated with the two alternatives by the members of the public from across the Nation. The FPM will inform the economists about the likely harvest response of fall Chinook salmon for the non-use survey under the two management alternatives.

The FPM is proposed to simulate the life history of Klamath River Type I fall Chinook salmon. The time period for simulations is 50 years. Type I fall Chinook salmon are juvenile salmon that emerge and begin migrating to the ocean shortly after their emergence from the gravel. Other life history types rear in freshwater longer. The FPM has several model components that include (1) spawning through juvenile production, (2) outmigration, (3) ocean survival and harvest, and (4) adult upstream migration (fig. 4-9). The various model components use a wide variety of data from numerous sources and a series of linked models.

To describe the FPM, a number of linked models representing the full life cycle of fall Chinook salmon from egg to returning adult ready to spawn will be used. The Salmonid Population Model (SALMOD) will be used to simulate the spawning, incubation, rearing, and outmigration of juvenile fall Chinook salmon. The SALMOD simulations will use river flows and water temperatures to represent habitat available for fish. River flows available include observed historical record, simulated future flows using management scenarios for the two alternatives, and simulated flows under selected climate change regimes. Water temperatures are important for the progression of the fish from one life stage to another and water temperatures will be simulated using the HEQ-5Q, a one-dimensional model that simulates mean daily water temperature in the mainstem Klamath River.

[13]http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/klamath_river/100927/staff_report/03_Ch2_ProblemStatement.pdf.

SALMOD simulates egg and juvenile mortality by tracking cohorts of fish originating from eggs across a spatially explicit representation of the river. From the time of emergence, growth of juvenile fall Chinook salmon in SALMOD will disperse from the redds, grow in response to water temperature, and experience several sources of mortality on a weekly time step. Additional inputs of juvenile fall Chinook salmon from tributaries will be estimated using Beverton-Holt or Ricker stock recruitment functions. For production estimates of juvenile Chinook salmon in the tributaries above Upper Klamath Lake, the Beverton-Holt stock recruitment functions will be informed by the Ecosystem Diagnosis Treatment (EDT) model. Inasmuch as historical adult returns and juvenile production of fall Chinook salmon are not available for the upper Basin, the EDT model will use habitat variables to predict production and capacity. Abundance estimates of emigrating Chinook salmon using a mark-recapture method with trapping efforts on Bogus Creek, Shasta River, Scott River, and the Trinity River and corresponding adult escapement estimates to each tributary will be used to develop the stock recruitment functions for inputs to SALMOD. SALMOD will then take all emigrants and predict ocean entry.

The ocean residence and harvest components of the production model will estimate survival as fall Chinook salmon are subjected to natural and fishing or harvest mortality. The Bayesian Population Dynamics blocks in the model schematic (fig. 4-9) indicate a retrospective analysis using empirical data available. During the first two years of ocean residence, fall Chinook salmon mortality is mostly attributed to natural mortality. The simulations will be accomplished using the Klamath Harvest Rate model that incorporates natural and fishery related mortality for specific ages in the ocean. Harvest in the river, tribal, and recreational fisheries for fall Chinook salmon will also be estimated. Adult salmon that survive natural mortality and fishery harvest in the ocean, estuary, and river then enter a model component for adult upstream migration.

The Adult Passage Model moves adult Chinook salmon from the estuary to their natal spawning areas. The Adult Passage Model will move salmon through the mainstem Klamath River to natal tributary streams below Keno Dam. For model simulations of the proposed action with the dams removed, the KBRA anticipates a trap and haul strategy for adult salmon when deleterious conditions exist above Keno Dam and in Upper Klamath Lake. Therefore the model will simulate the trap and haul strategy for the appropriate time periods. Adult salmon will then return to the Wood, Sprague, and Williamson Rivers to spawn and start the life cycle over again in the linked models of the FPM.

Long-Term Monitoring

The complexity of Klamath Basin as highlighted by its unique environmental setting, history of human settlement and development, and diverse resource expectations contributes to the issue of connectivity. In practice, the combination of these features has generally resulted in a fragmented approach to science and natural resource management that currently lacks the geographic cohesion, interdisciplinary linkages, coordination, and long-term commitment required for restoration. Many examples of local or site-specific research and monitoring were presented at this conference and all of these address relevant information needs. At the same time, some examples of regional scale efforts also were described. These studies are addressing the Basin’s geology and hydrology, human dimensions in landscape and ecological change (for example, avian resources and habitat relationships, salmon in the Trinity and Klamath Rivers), and climate variability and fire. The challenge of assembling and synthesizing this information into a greater ecological context is one that must forge watershed linkages between terrestrial and aquatic environments and between upper and lower subbasins to address upstream connections and downstream effects. A “headwaters-to-ocean” systems approach provides the most appropriate context, scale, and integrative properties needed to address the complexity and connectivity of resource issues in the Klamath Basin.

Perspective, or how one “looks” at ecosystems, is critical to science planning, stakeholder expectations, and natural resource outcomes. The case for a watershed ecosystem approach for future research and management was made by the Natural Resource Council in its review of the hydrology, ecology, and fisheries of the Klamath Basin. The possible reintroduction of salmon into the upper subbasin argues for this approach as well. Because habitat restoration is also involved, a process-oriented research and monitoring approach is recommended. Specific habitat attributes such as streamflow, water temperature, substrate, cover, and dissolved materials are the result of physical, chemical, and biological processes operating throughout a watershed and across the landscape. Protecting and restoring valuable habitat attributes requires that natural processes that produce these characteristics must be maintained or restored.

To remain relevant as we move forward (1) our science planning must be transparent; (2) our science must be relevant to management needs; and (3) management must be both adaptive and accountable (e.g. tracking changes in keystone species, stressors, and drivers, etc.). Intensive long-term monitoring is needed to gain empirical knowledge of synergies among threats, the role of indirect effects, and other questions critical to minimizing species loss to assist their recovery or resiliency in the Klamath Basin.

Several existing and proposed monitoring programs need to be maintained or realized if scientists and managers are to be able to quantify, understand, and learn from the large-scale restoration activities that have occurred, are ongoing, or are proposed under the KHSA and KBRA. Examples of programs focused on aquatic environments and fisheries can be found in the upper and lower subbasins, major tributaries, and the estuary and nearshore ocean. These include:

1. Endangered suckers in the upper subbasin. A key long-term monitoring program in the upper subbasin aims to quantitatively evaluate the status and dynamics of Lost River and shortnose sucker populations including assessment of factors that might be inhibiting recovery, such as water quality, toxins, and disease. The primary populations of interest are those in Upper Klamath Lake and Clear Lake Reservoir. Information from this program is being used by managers charged with recovering the populations and managing water resources in the Basin. Maintaining the continuity of this data set will be valuable as researchers and managers look to evaluate the effects of future changes in the Klamath Basin, including those associated with habitat restoration and reintroduction of anadromous species to the upper subbasin as well as climate change.
2. Freshwater phases of the life history of Pacific salmon. Many aspects of the juvenile and adult life history stages of Pacific salmon are routinely monitored in the Klamath Basin. Ongoing efforts are not well coordinated, resulting in a fragmented understanding of key demographic aspects of the Basin’s salmon populations. A concerted effort to coordinate existing monitoring activities having objectives to enumerate spawning escapements (carcass and redd counts) and smolts in the mid Klamath, Shasta, Scott, and Trinity rivers is needed.
3. Klamath River (mainstem and tributaries) water quality. Given the state of water quality in the lower subbasin and its importance to valuable resources like fish populations, efforts to monitor water quality conditions in the lower subbasin have been ongoing for some time. Data collection has been conducted by a number of entities including Federal and State agencies, Tribes, and non-governmental organizations. Until recently, coordination among these groups in terms of methods used, sampling locations, and data sharing was inconsistent. The formation of the Klamath Basin Monitoring Program (see http://www.kbmp.net/; accessed April 28, 2011) has helped facilitate the coordination of water quality monitoring efforts throughout the watershed.

This grassroots effort is helping to improve the quality and relevance of this data set by moving participating entities toward the use of common methods for data collection and storage, helping eliminate redundant efforts, and improving data sharing as well as creating opportunities for collaboration. If proposed dam removals on the Klamath River occur, these data and this framework will provide a valuable means for evaluating the effects of this large-scale restoration effort.

4. Trinity River Salmon Restoration. Habitat loss resulting from the operation of the Trinity River Division of the Central Valley Project has led to substantial declines in Trinity River fish populations. The Trinity River Restoration Program (TRRP), which is comprised of Federal, State, and tribal resource agencies, was established to oversee restoration of anadromous fish in the Trinity River Basin. Several key Trinity River monitoring programs overseen by TRRP are used to evaluate the effects of in-channel habitat restoration and maintaining more natural flow patterns on salmon populations. The timing, abundance, hatchery/wild composition, and condition of outmigrating juvenile salmon and steelhead have been monitored since 1989. This long-term monitoring has been crucial for dam operations and developing flow release schedules that provide more favorable temperatures for outmigrating salmon. Annual redd surveys are conducted to assess run timing and spatial distribution of spring and fall Chinook as well as coho salmon. Age composition monitoring of Trinity River fall Chinook has proven valuable to resource managers assessing the contribution of each cohort to harvest and escapement. Continuation of these monitoring efforts evaluating Trinity River restoration is essential for optimizing over-allocated water resources in the Trinity Basin to develop improved information about ecological flows and salmon production.
5. Estuary/Nearshore. Effects of ocean variability on salmon production cycles and the distributional behavior, movement, and abundance of marine and anadromous fishes should be emphasized in future research and monitoring on select resources in strategic locations and undertaken to understand natural trajectories of change and effects of human interactions. As an example, research in the Salmon River, Oregon, has shown how differences in location of spawning, size, and timing of juvenile Chinook entry into the estuary affects adult survival. Based on juvenile data from 2001 to 2002 and Return Year 2004, young salmon with origins in the upper river and entering the estuary in June through September at sizes of 60–120 mm (FL) were much more likely to return as adults (W. Duffy, USGS, personal communication). Monitoring of physical and biological conditions in the California Current offshore of the Klamath Basin should include a suite of ecosystem indicators that have been shown to be important predictors of coho and Chinook salmon success[14] (fig. 4-10).

Conclusions

A principal goal of the science conference was to address the need for a whole watershed approach for natural resource and restoration science. Recovery plans for endangered fishes in the Klamath Basin, in conjunction with the KBRA and KHSA, support the watershed approach and related need for understanding ecological linkages at multiple scales and for multiple species. Restoration activities will need to focus on watershed processes and their interactions. In this chapter, major physical and biological processes that govern the ecology of the Basin are identified and discussed. The discussions are largely qualitative and future efforts should focus on their quantification. Although the

[14] From John Ferguson, 2007. Major challenges facing the Snake/Columbia System – Environmental flows and ecosystems. NOAA, Northwest Fisheries Science Center. Seattle, WA.

conference emphasis was on aquatic ecosystems and particularly fish, other natural resources can be addressed in a watershed context. Studies are needed to determine the relative roles and importance of terrestrial and aquatic system interactions as they pertain to the natural resources in the Basin. This approach will align well with salmon reintroduction plans under consideration.

Acknowledgments

The authors wish to acknowledge the work of many others whose efforts at this conference or work elsewhere contributed to this chapter. The information presented was obtained from multiple sources of information presented in conference plenary, technical, breakout, and poster sessions. We thank Michael Hughes (The Klamath Tribes) and Tracy Fuentes (U.S. Geological Survey) for their work in organizing and conducting conference sessions on watershed processes and developing an initial chapter outline. Special contributions were received from Dennis Rondorf, Christopher Ottinger, and Russell Perry of the U.S. Geological Survey.

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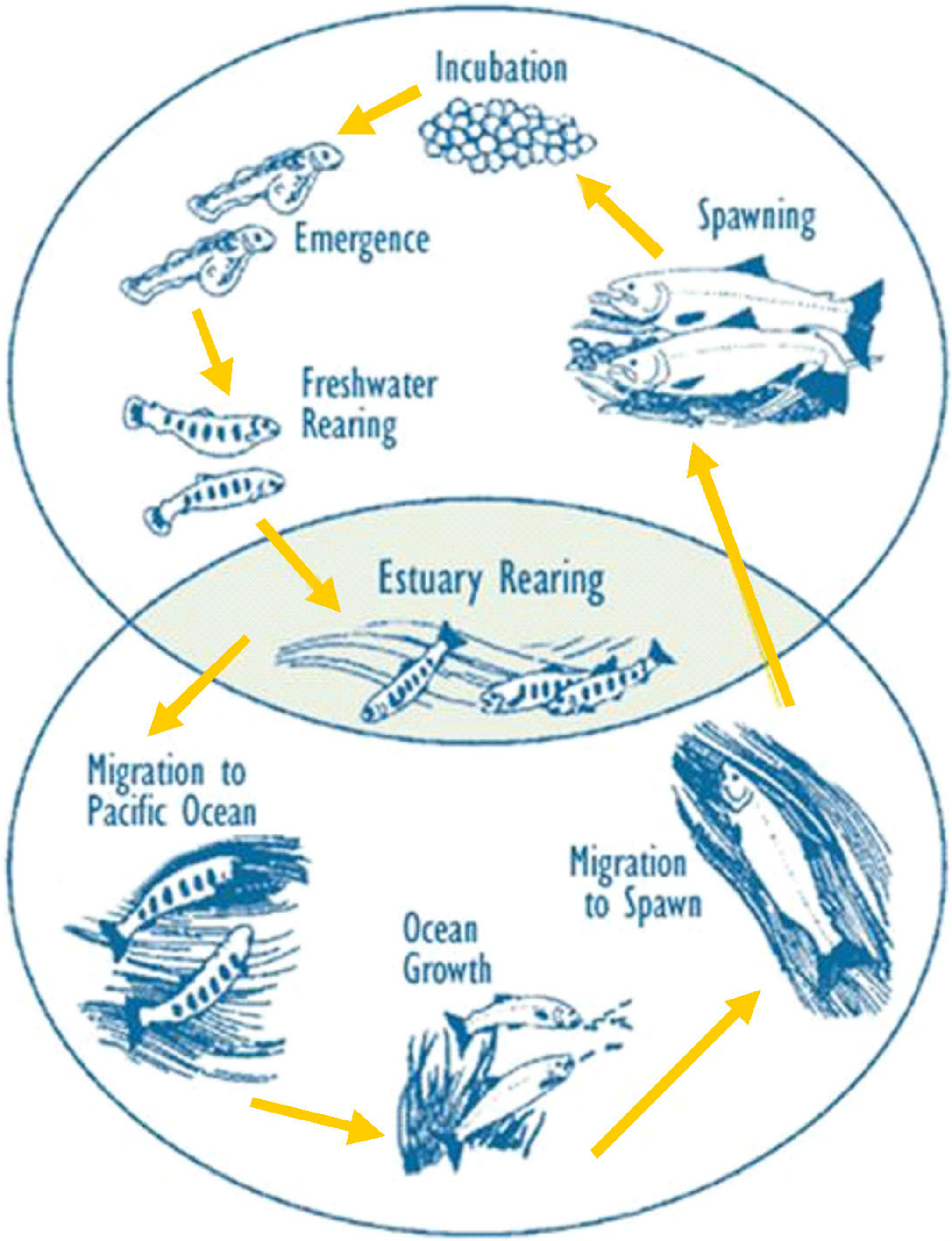

Figure 4-1. Stakeholder communities are encouraged to consider whole-basin ecosystem approaches (headwaters to ocean) that include human dimensions (agriculture, timber, mining, fishing, recreation) in their planning. The generalized salmon life history (that includes habitats from upper reaches to the ocean) typifies this need.

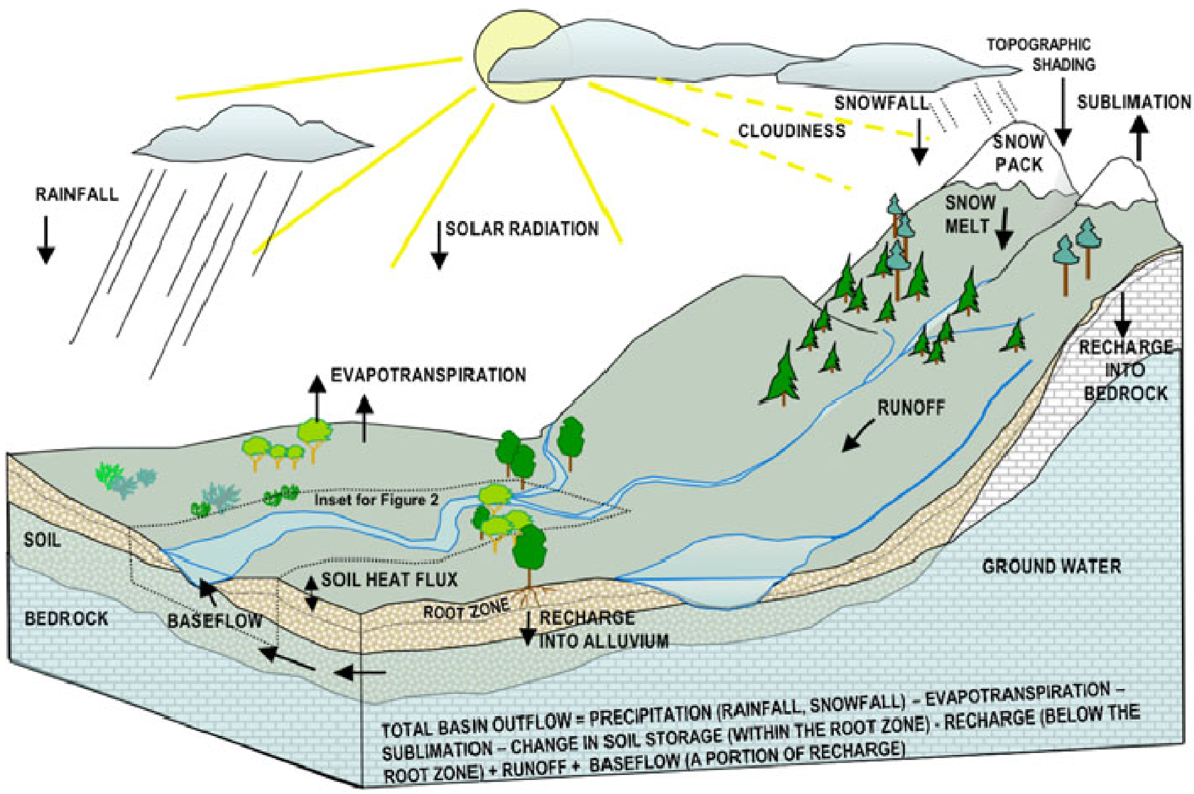

Figure 4-2. Basin-scale ecosystem interactions. A multi-scale and nested approach considers the basin, reach, and habitat scales. For example, in order to consider the effects of climate change on biological processes that occur at the habitat scale, the many processes that occur on scales far larger than the scale of that habitat also need to be considered.

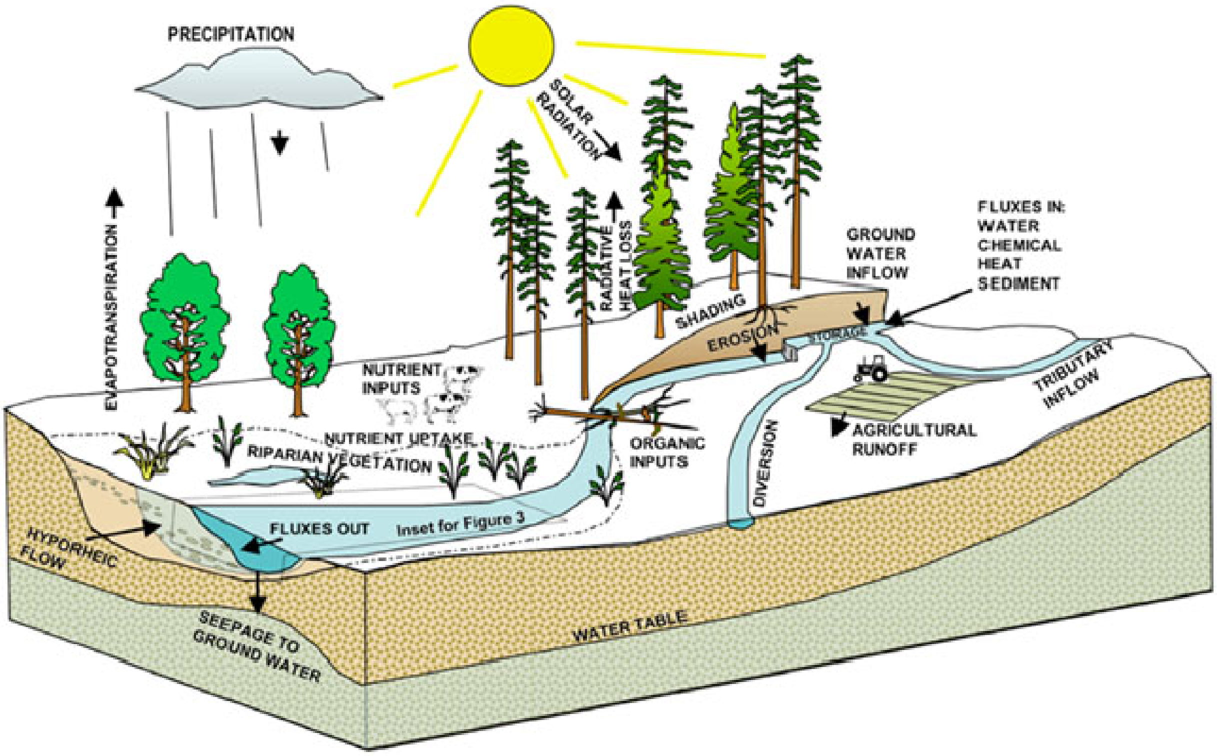

Figure 4-3. Reach-scale ecosystem interactions.

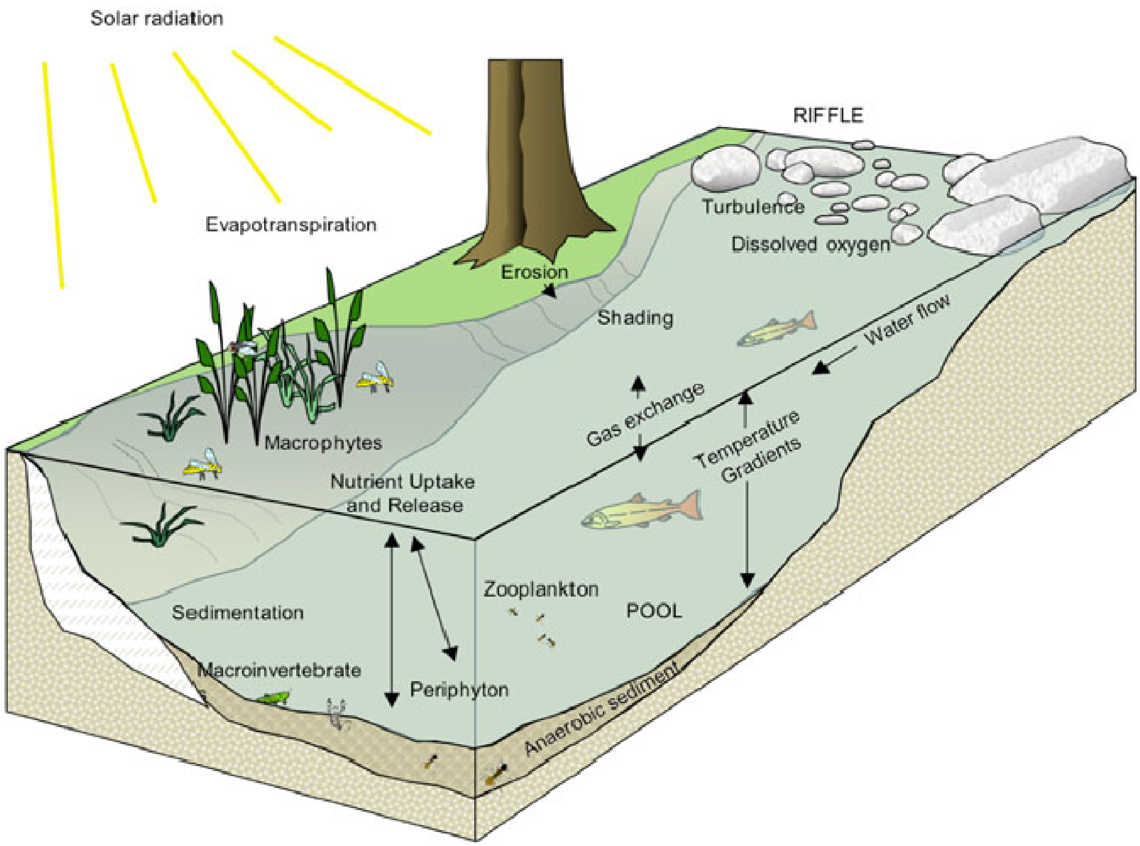

Figure 4-4. Habitat-scale ecosystem interactions.

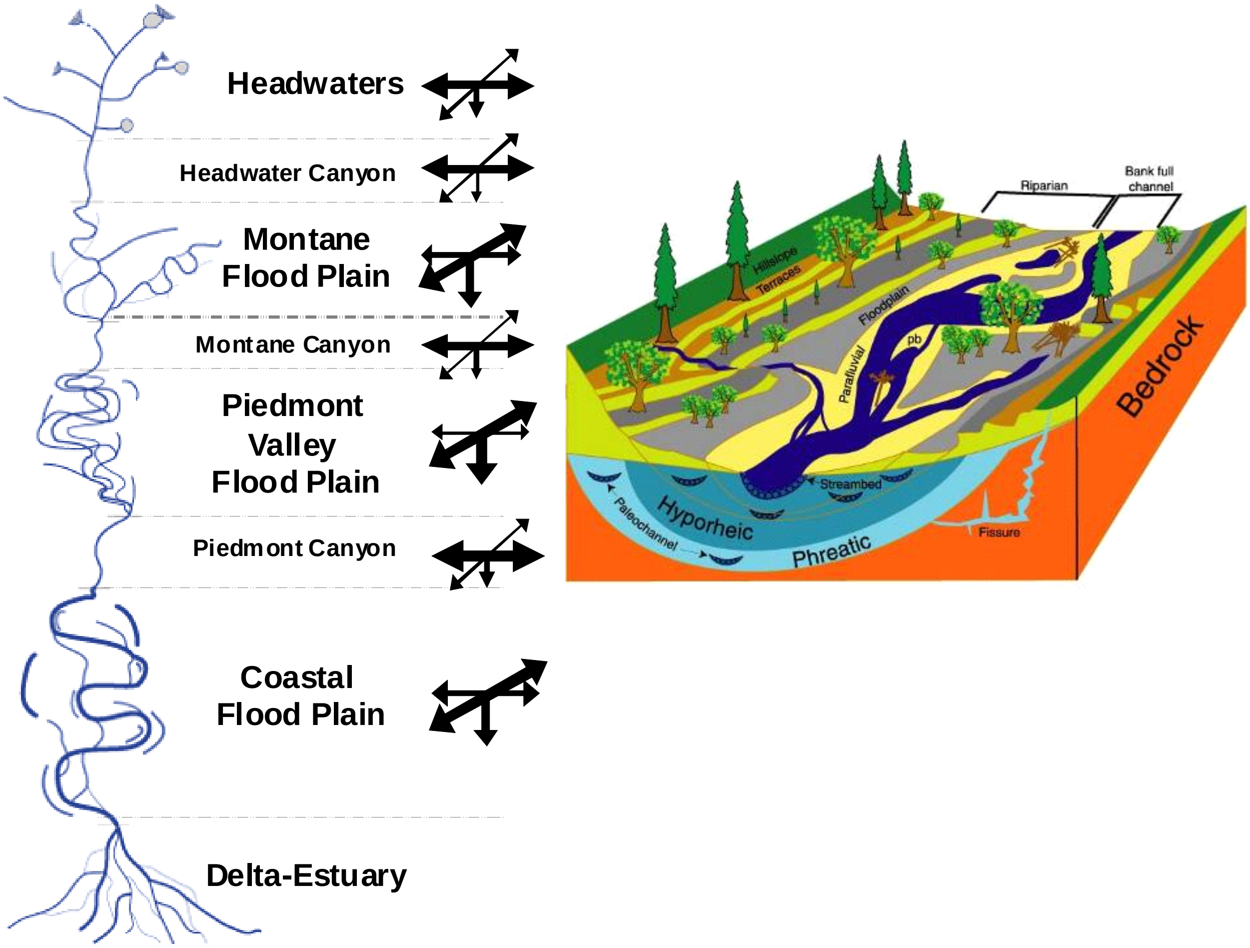

Figure 4-5. Landscape-based stream classifications.

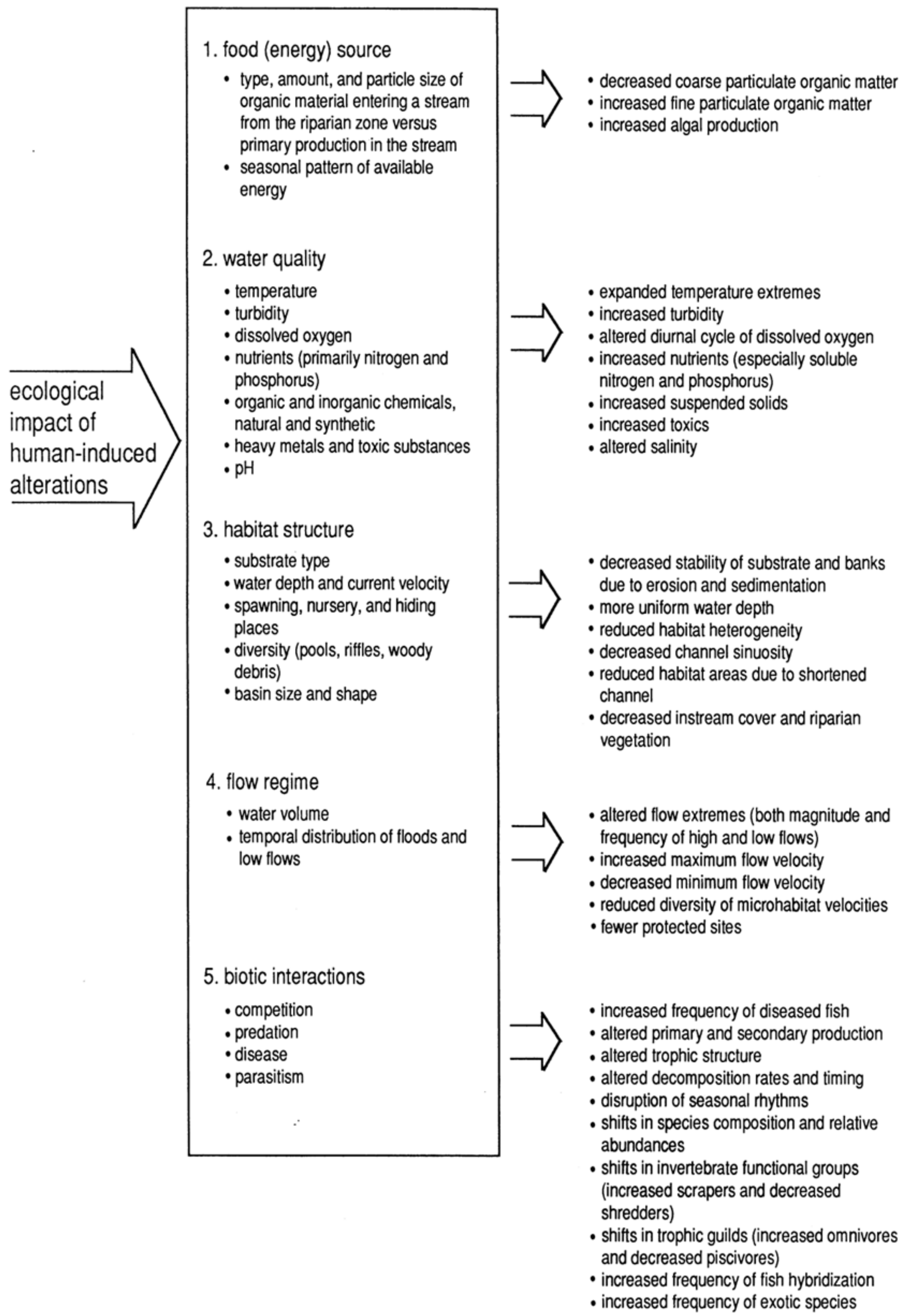

Figure 4-6. Effects of human-induced alterations on aquatic ecosystems (from Karr, et. al. 1991).

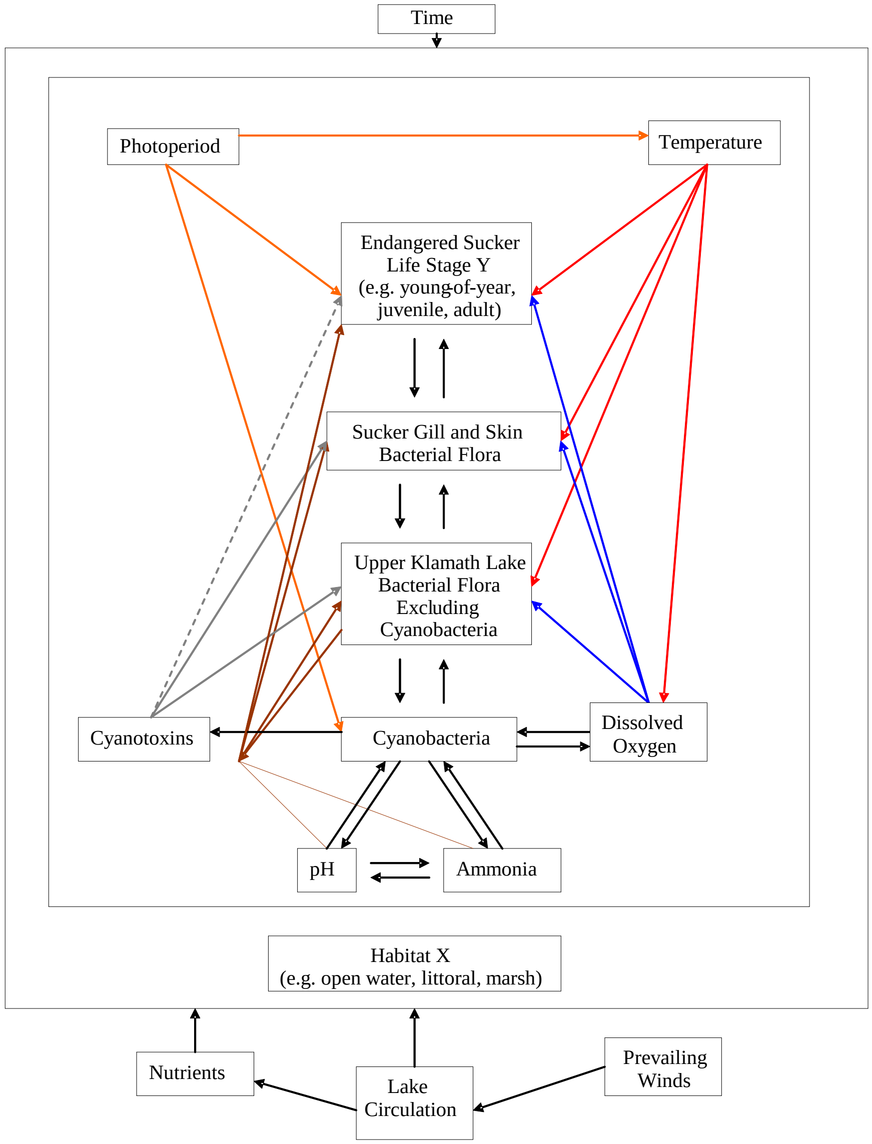

Figure 4-7. The effects of algal toxins on endangered fishes in Upper Klamath Lake.

The USGS began research on the presence, concentration, and dynamics of algal toxins in Upper Klamath Lake, Oregon, and the possible effects of these toxins on endangered fish in 2007. Microcystin, a hepatotoxin (liver toxin), was detected both in samples of particulate material from the lake and dissolved in lake water. Age-0 endangered Lost River and shortnose suckers were examined for histopathology and pathology consistent with microcystin exposure was found in 49 percent of these fish. Evidence of the route of exposure to algal toxins was provided by a gut analysis of fish collected in 2008. Results showed that juvenile suckers had ingested chironomid larvae, which in turn had colonies of Microcystis aeruginosa, a known cyanotoxin producer, in their digestive tracts. Furthermore, the histology of the fish showed numerous gastro-intestinal lesions which were observed when liver necrosis was either present or absent. This suggests the gastro-intestinal tract was the first point of toxin contact. Although the existing data do not rule out other lesion etiologies, they are consistent with hepatotoxin exposure. Cyanotoxin production in Upper Klamath Lake is likely controlled by a complex interaction of numerous physical and biological parameters as illustrated above[1]. Clarification of the factors driving cyanotoxin production and their relation to the health and survival of all life stages of endangered suckers will improve our understanding of key factors thought to be preventing the recovery of these species.

[1]Personal communication, C. Ottinger, U.S. Geological Survey, Leetown Science Center, WV.

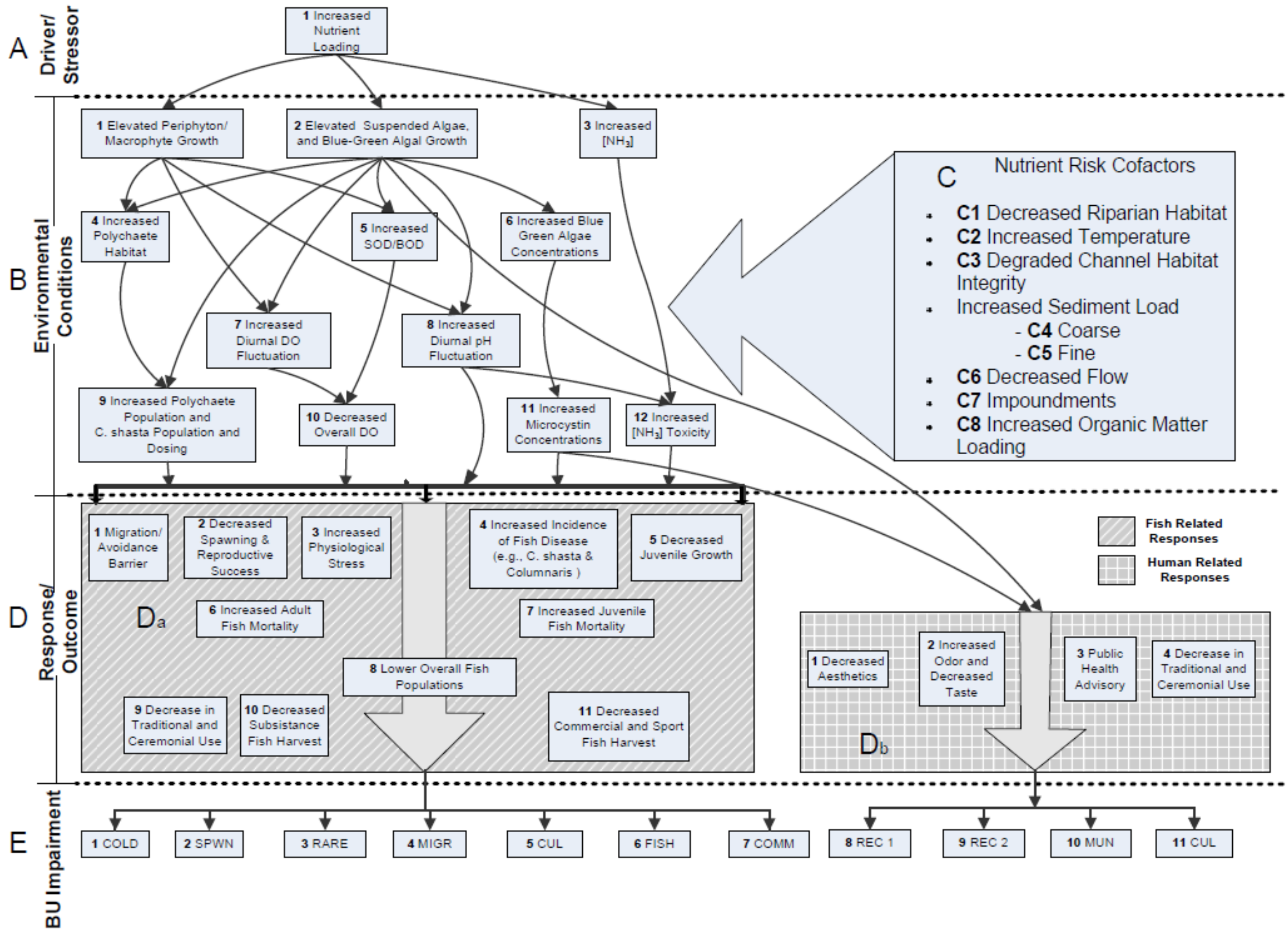

Figure 4-8. Modeling the effects of excess nutrients in the Klamath River.

Total Maximum Daily Loads (TMDL) for temperature, dissolved oxygen, nutrients, and microcystin were adopted for the mainstem Klamath River in California in 2010. The TMDL process is intended to restore the quality of the river's waters and the health of its aquatic environments by prescribing limits on the input of particular pollutants. Water quality conditions, pollution sources, and actions to control or reduce input of individual pollutants in order to restore the beneficial uses of the river are each quantified during the development of individual TMDLs. Several conceptual models were employed as part of this process to illustrate hypothesized linkages between stressors (i.e., pollutants), key environmental conditions, and the eventual effects on ecological parameters of interest (e.g., fish populations, aesthetics). The figure above shows the nutrient model developed for the mainstem Klamath River[1].

[1]See North Coast Regional Water Quality Control Board. 2010. Final staff report for the Klamath River total maximum daily loads (TMDLs) addressing temperature, dissolved oxygen, nutrient, and microcystin impairments in California, the proposed site-specific dissolved oxygen objective for the Klamath River in California, and the Klamath River and Lost River implementation plans, public review draft. Santa Rosa, California. March.

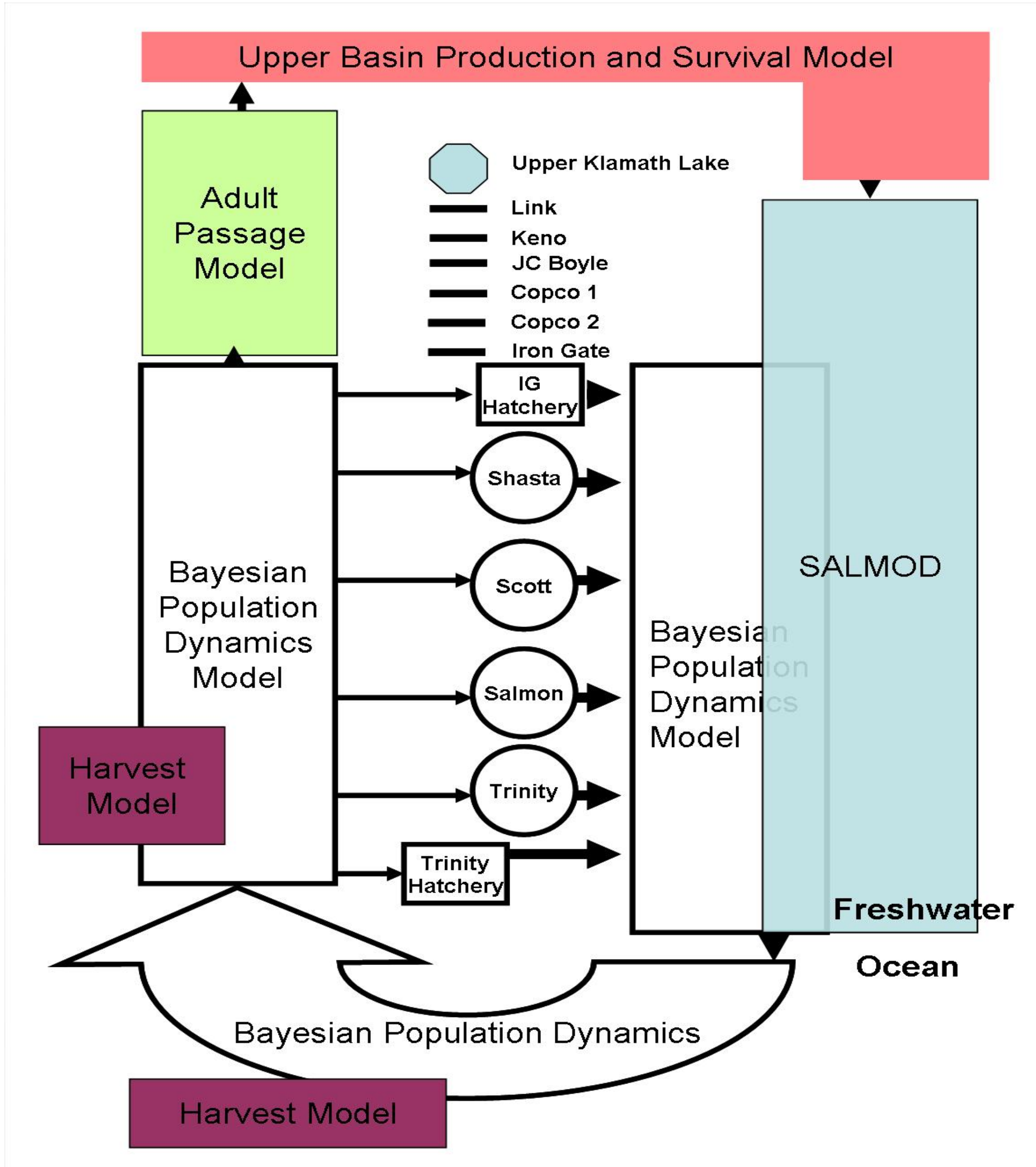

Figure 4-9. Multi-agency Fish Production Model for fall Chinook salmon.

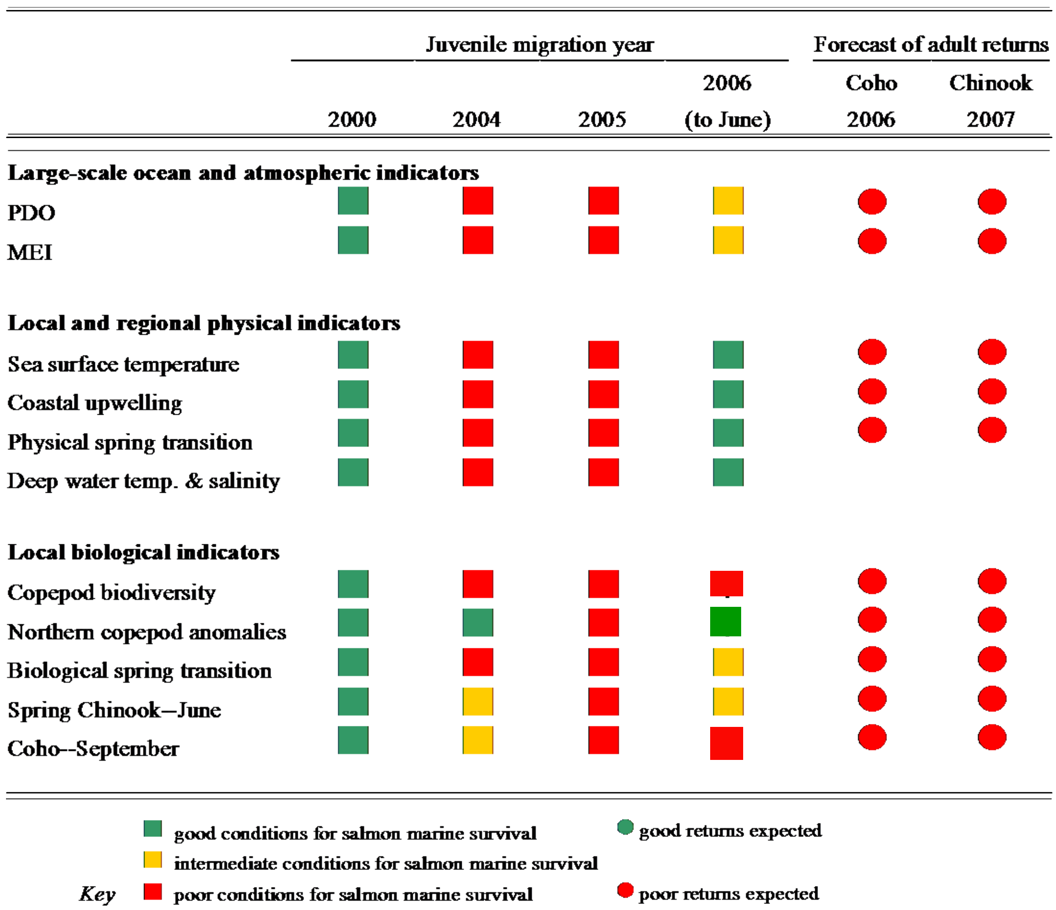

Figure 4-10. High-level indicators for salmon ecosystems in the Klamath Basin nearshore marine (from Ferguson 2007).

Chapter 5. Freshwater and Marine Habitat Communities

Peter Adams[1], Scott VanderKooi[2], and Thomas Williams[1]

Introduction

The Klamath Basin is the second largest river system in California, and is a complex and dynamic environment from its headwaters to its estuary and out into the nearshore marine environment. The Basin is in a seriously degraded state due to the large number of anthropogenic stresses resulting in fish kills, very low fish population levels, fisheries closures, and large-scale disease epidemics. Biological communities throughout the Basin are all stressed by a variety of environmental impacts, whose effects are not completely understood. The Freshwater and Marine Habitats and Communities Plenary Session of the Klamath Science Conference focused on fish and fish biology. This is because fish provide a good integrated view of the environmental linkages and constraints throughout the Klamath Basin, and because there are a significant number of Endangered Species Act (ESA) listings of fishes: coho salmon, green sturgeon, eulachon, Lost River sucker, shortnose sucker, and bull trout (scientific names and distribution in table 5-1). Also, this is because we have more information on the fish communities than on other animals in the ecosystem due to the cultural, economic, and social values of these fishes. Also, it is thought that the processes and conditions that are beneficial for fish will also be beneficial to the other parts of the aquatic (and terrestrial) communities and will result in the conservation of the Klamath Basin as a whole.

The geographic framework used here is to divide the Klamath Basin into an upper subbasin, a lower subbasin, and an estuary and nearshore marine environment. The demarcation of the upper and the lower subbasins was created by the Copco dams in the early 1900s and later by Iron Gate Dam in the early 1960s. Strong physical and ecological features differentiate the upper and lower subbasins around these dams. The separation between the two subbasins can be plainly seen in the underlying geology, average maximum air temperature, and annual average precipitation. The Klamath Basin has been called “a river turned upside down” due to its unique geology. The upper subbasin is a large alluvial watershed and has a number of slow-moving, shallow streams and rivers above and below Upper Klamath Lake. The Klamath River then pushes through the Klamath Mountains and becomes the much more energetic, deeply-incised system of the Lower Basin. The lower subbasin is a much more active classical fluvial system, receiving rainfall from strong storm systems and periodic inputs of sediment and wood. This is the reverse of what many consider a normal river system where the energetic fluvial system is located upstream and the slower-moving shallow rivers are downstream. The third area, the estuary and nearshore marine environment, is demarked by the impact of salinity from the tidal zone and extends into the nearshore coastal ocean. These three geologic and physical areas result in important and unique biological structuring to the fish communities resulting in large numbers of species, particularly anadromous ones, and some of the largest numbers of endemic species of any river system.

The challenge of this session was to develop a working conceptual model of the biological communities of the Klamath Basin System from these three units: the upper subbasin, the lower subbasin, and the estuary and nearshore environment. This Klamath Basin conceptual model will be a central tool in the current discussion and planning of how to restore Klamath Basin communities given

[1] Southwest Fisheries Science Center, Fisheries Ecology Division, National Marine Fisheries Service.
[2] U.S. Geological Survey, Southwest Biological Science Center.

the substantial anthropogenic impacts that have occurred and are occurring there. The question of dam removal is at the forefront of these restoration considerations, but a long list of impacts (agricultural draining, water quality, toxic algae blooms, water temperature regimes, and others) will also need to be addressed. Finding common ground on how to restore these natural communities and yet maintain the other societal uses of the Klamath River Ecosystem will be difficult. It is important that decisions made for ecosystem restoration be based on our best understanding of species and processes that control this system. A conceptual model of the Klamath Basin that includes biological communities in the geographic framework described above will be central to science planning and decision making processes that endeavor to balance species recovery and societal goals. The conceptual model will need to include the physical, biological, and social-economic attributes of the upper and lower subbasins and the estuary and nearshore environment. In this chapter we describe the fishery resources in each of these sections of the Klamath Basin.

The Upper Klamath Subbasin

The geological and hydrological processes of a watershed in combination with life-history processes are the factors that determine which fish faunas are present. Evidence of this interaction between the physical and biological is demonstrated in the fishes of the Klamath River Basin. The unique “upside-down” features of this watershed, combined with its geologic history have led to unusually high levels of endemism for native fish species. This is particularly true for the Upper Klamath Subbasin: those areas upstream of Iron Gate Dam. The aquatic habitats of the upper portion of the watershed are dominated by large shallow lakes, extensive marshlands, and relatively low-gradient rivers. Other defining features include a semi-arid climate, nutrient-rich volcanic soils, and high elevation ranging from 1,257 to 2,865 m with a mean elevation of 1,545 m, as well as numerous springs and other sources of groundwater inflow. Over geologic time the watershed has drained in a variety of directions: west to the Pacific Ocean, south into the Sacramento River drainage through the Pitt River, southeast into the Great Basin, and northeast into the Snake River.

Historically the Upper Klamath Subbasin harbored at least 19 native fish species belonging to five families including lampreys, minnows, salmon and trout, sculpins, and suckers (table 5-1). Four of these were anadromous fishes that migrated to and spawned in tributaries of the upper reaches of the Klamath River and above Upper Klamath Lake. There is ample evidence that Chinook salmon, coho salmon, steelhead trout, and Pacific lamprey were all present prior to the construction of dams on the mainstem Klamath River early in the twentieth century. Of the resident species, lampreys are notable—the Klamath Basin has the highest lamprey diversity in the world. At least four species are found in the upper basin including the Klamath-Pit brook lamprey, Klamath River lamprey, Miller Lake lamprey, and a likely undescribed Upper Klamath Lake lamprey. Native minnows include the blue chub, tui chub, and speckled dace. Two resident salmonid species, bull trout and redband trout, are native to the upper watershed as are three sculpins, the Klamath lake sculpin, Upper Klamath marbled sculpin, and slender sculpin. The remaining native fishes in the upper basin are four sucker species: the Klamath largescale sucker, Klamath smallscale sucker, Lost River sucker, and shortnose sucker.

Most of the information available on the historic status and distribution of resident fishes in the upper subbasin concerns species targeted for harvest. Anadromous species were seasonally abundant with Chinook salmon and steelhead migrating past Upper Klamath Lake into the Sprague and Williamson Rivers and coho salmon and Pacific lamprey moving as far upstream as Spencer Creek and possibly further. Lost River, shortnose, and Klamath largescale suckers were among the most abundant fishes in upper basin lakes and large rivers. Redband trout were also widely distributed in the streams, rivers, and lakes of the upper basin. Less information is available on other species, but many like blue chub, tui chub, speckled dace, and Upper Klamath marbled sculpin are thought to have been abundant and widely distributed. Others were likely limited in distribution due to specific habitat preferences (e.g., bull trout) or geographic isolation from the watershed (e.g., Miller Lake lamprey).

Settlement by people of European descent and subsequent development in the upper subbasin brought about a number of changes that have directly and indirectly affected native fish populations. Some of these include channelizing, damming and diverting rivers and streams, diking and draining of wetlands, overharvest of native fishes like suckers, and introduction of at least 18 non-native fish species. These changes have adversely affected several fish species at a population level. Effects include the extirpation of anadromous fishes and the associated loss of marine-derived nutrient inputs from the upper basin, the loss of critical rearing habitats for young fishes, habitat fragmentation, degradation of water quality, and the introduction of exotic predators and competitors including fathead minnow, yellow perch, largemouth bass, and brook trout. Substantial declines in populations have also occurred for a number native fish species including Lost River sucker, shortnose sucker, redband trout, bull trout, and slender sculpin. Declines have been severe enough to warrant listing under the Endangered Species Act (ESA) for Lost River sucker (Endangered), shortnose sucker (Endangered), and bull trout (Threatened).

A number of actions have been taken to protect fish in the upper subbasin with the goal of stopping and reversing declines in fish populations. These include reduction or elimination of harvest, legal protections for some species and habitats, changes in land use practices, and habitat restoration. A great deal of time and effort has been directed at restoration activities. More than 400 habitat restoration projects were completed from 1994 to 2008 across the upper subbasin. The vast majority of them aimed at improving conditions for aquatic dependent species. Some are as simple as fencing to exclude livestock from streams or planting willows to stabilize stream banks. Others are large-scale efforts to restore key habitats like the Williamson River Delta Restoration Project or improve fish passage like the removal of Chiloquin Dam.

Efforts to recover and restore key native fish populations are ongoing with numerous restoration projects in progress or proposed in the Upper Klamath Subasin. Areas of emphasis include restoring key habitats and providing access to restored and existing habitats. Likely the largest and most far-reaching future restoration activities are proposals to reintroduce anadromous fishes to the upper basin and remove four Klamath River dams. Dam removal would allow anadromous species unimpeded access to the upper subbasin for the first time in over 100 years.

Dam removal and other large-scale restoration projects are designed to limit or remove some of the major constraints anthropogenic activities have placed on the watershed and the native fishes that live there. These actions, however, won't remove all constraints. This leads to the question of what will fish populations of the upper subbasin, and for that matter the entire Klamath Basin, look like in the future. Given the dramatic changes in the watershed, it's simply unrealistic to think that restoration will turn the clock back and return everything to a pre-development condition. Determining what fish populations will look like if dam removal occurs will require an understanding of what constraints remain basinwide. It will also require careful planning along with research and monitoring to address key uncertainties.

Two plans for reintroduction of anadromous fish have been developed for the upper subbasin; one by the Klamath, Karuk, and Yurok Tribes and another by the State of Oregon. Both plans are part of a process to identify and describe the research and management needs for salmon reintroduction and recovery. These include the method of reintroduction (passive, active, or some combination), stock selection, disease issues, interaction and competition with resident species (native and exotic), restoration and monitoring priorities, and natural resource management strategies with emphasis on water and key species.

The Lower Klamath Subbasin

The geologic nature of the Lower Klamath Subbasin is that of a deeply incised channel into bedrock and this, along with a wetter, more marine climate as one moves west, leads to high flows and cooler temperatures in this part of the basin so that it is more like upper basins of most river systems. Historical fish communities were dominated by anadromous fishes, particularly salmonids, along with a few other cool-water fishes (table 5-1) due to these conditions (T. Shaw, U.S. Fish and Wildlife Service and M. Mohr, National Marine Fisheries Service, personal communication). Chinook salmon, coho salmon, steelhead, and cutthroat trout are among the most abundant fishes in the lower basin. Chum salmon and pink salmon were also present in the lower basin, but may now be extinct. Lampreys were the other group of prominent lower basin fishes, including Pacific lamprey, river lamprey, and Klamath River lamprey. Green sturgeon, white sturgeon, eulachon, and threespine stickleback also were abundant anadromous fishes in the lower subbasin. Other cool-water and estuarine-related species were prickly sculpin, coastrange sculpin, Lower Klamath marbled sculpin, Klamath speckled dace, and Klamath smallscale sucker.

Anthropogenic impacts, including dams and hatcheries, land and water management, and mining and forestry practices have greatly changed the species and abundance composition of the Lower Klamath Basin fish community. Dams have been the main impact in the lower subbasin, cutting off habitat for anadromous fishes and changing flow regimes. Salmonid hatcheries associated with the dams have also had substantial impacts; replacing natural production, reducing effective population size, and promoting disease problems in the Lower Basin. Iron Gate Hatchery has released around 3 million fall-run Chinook salmon annually, starting with numbers below 1 million until 1986, peaking up to 4 million from 1987 until 1992, and averaging 2.3 million up to the present. The releases have been consistently about 85 percent fry and 15 percent yearlings. These Chinook salmon releases are joined with around 2 million fall-run fry from the Trinity River Hatchery in the lower river. Harvest of Iron Gate hatchery salmon peaked at 53,000 in 1988 and has remained in the 100s to 15,000 fish since 1990. Beginning in 1990, the ocean salmon fishery has been restricted in most years to minimize the harvest of Klamath River Chinook.

Disease associated with the myxosporean parasites *Ceratomyxa shasta* and *Parvicapsula minibicornis* are of particular concern for juvenile salmon in the Klamath River. The high prevalence and severity of infections observed in most years likely result in substantial mortality rates among juvenile coho and Chinook salmon emigrating from the Klamath River and its tributaries to the ocean. Although both parasites are native to the Basin, changes in the watershed may have shifted the host-pathogen relationship in favor of these parasites. These disease organisms occur naturally in the Klamath Basin and have coevolved with the fish. However, when water quality deteriorates, the fish are stressed, or when parasite spore loads are extremely high, then lethal disease outbreaks can occur. Water quality conditions that can lead to increased fish stress include crowding in response to diminished flows, elevated water temperatures, low dissolved oxygen conditions, high pH (alkalinity), and unionized ammonia. The 2002 mass mortalities of at least 33,000 Chinook salmon in the lower subbasin were unprecedented events. The direct cause of these mortalities was a pathogen infection resulting from the transmission of disease due to crowding of fish and other stressful conditions associated with low flows, high temperatures, and other factors. The causes of the mass mortality are not completely known.

Anadromous salmonids are dominant members of the lower subbasin fish community and their populations have been substantially impacted by anthropogenic factors. Coho salmon are ESA listed and Chinook salmon and steelhead populations have been considered for listing. Another concern is the low abundance of summer steelhead. In addition, fall Chinook salmon populations are dominated by hatchery fish. Salmon and steelhead provide a useful example to illustrate the connections of aquatic habitat throughout the Klamath Basin and provide a vivid picture of how constraints on these connections can impact the viability of fish populations.

Development of recovery planning is being guided by viability criteria that are recommendations as to the minimum population and Evolutionary Significant Unit (ESU) or Distinct Population Segment (DPS) characteristics that would result in a specific ESU having a high probability of long-term (> 100 years) persistence. The foundation of ESU viability and for restoration of fish populations in the lower subbasin is built upon the ability of populations to function in an integrated manner and persist across the landscape. This integration includes dispersal among populations and habitat throughout the Basin (i.e., connectivity) and a diversity and distribution of habitat types and conditions that allow for the expression of a range of life-history types. In short, for an ESU (or population, or aquatic community) to persist, it must be able to track changes in environmental conditions. When the location or the distribution of a species' (or community's) habitat changes, it can avoid extinction either by adapting genetically to the new environmental conditions or by spatially tracking the environmental conditions to which it is adapted.

Changes in environmental conditions can constrain the ability of a species or community to track changes in the environment. For example, cold water areas can provide seasonal refuge for salmon during critical portions of their life cycle or for occasional warm/drought conditions happening at longer time scales (decadal). When access to cold water areas is constrained or lost, or the cold water areas are lost, this fish species or life stage cannot track the change and is threatened with localized extinction. Anthropogenic changes throughout the Klamath Basin have modified the environmental conditions and have constrained opportunities for aquatic species, particularly fish species in the lower subbasin, to track changes in the environment. Spatial scales can range from localized impacts (e.g., affecting portions of one or a few populations) to regional impacts from severe events such as droughts that affect all populations throughout the basin and adjacent basins. Temporal scales can range from a site-specific impact resulting from a short-term, albeit catastrophic, event (e.g., landslide temporarily blocking passage on a large mainstem river) to interannual variability of various environmental conditions (e.g., marine conditions, annual precipitation patterns), to long-term environmental changes such as climate change that have the potential to impact all populations within the ESU.

Interaction among populations within the lower subbasin and throughout the whole Klamath Basin buffers against catastrophic loss of many populations, maintains long-term demographic and evolutionary processes through connectivity, and maintains sufficient diversity so that the populations have the potential to cope with changing environmental conditions. Some populations need to have sufficiently large numbers of individuals to disperse and provide the needed connectivity among populations. Habitat throughout the Basin serves different life stages of different species to various degrees (e.g., mainstem spawning habitat for Chinook salmon, tributary habitat for coho salmon spawning, mainstem tributary junctions for juvenile rearing habitat, etc.). Barriers to movement across the landscape, either permanent such as a dam or temporal such as seasonal reduction in streamflow, constrain the ability of salmon populations to track changes in the environment. As ecological constraints in the basin result in continued divergence from historical ecological conditions in which these populations evolved, the risk of extinction increases.

Estuary

The Klamath Basin estuary and nearshore marine environment begin at the highest intrusion of saltwater into the basin and extend out into the coastal ocean. The Klamath Basin estuary is relatively small in relation to the size of its watershed compared with other large river systems like the Sacramento-San Joaquin or Columbia Rivers. This is due to the deeply incised and sharply confined nature of the lower subbasin river after it emerges from the Klamath Mountains. The length of the estuary is variable, since saltwater intrusion varies seasonally, but significant saltwater influence only extends about 6 km upriver. The Trinity River, which enters the Basin 32 km upriver, contributes significantly to the estuarine flow. This flow is controlled by the Trinity River Dam.

The Klamath Basin estuary has experienced historical change which probably began shortly after the establishment of a European settlement at Klamath City in 1850; however, overall impact is less than other large rivers, perhaps due to its small size and relatively large volume of freshwater entering the estuary in relation to its size. An early map of the estuary does not look dramatically different than the estuary today; however, the historical change of the estuary can only be documented from 1936 from a time-series of aerial photographs. The overall size of the estuary has varied both larger and smaller over time, but has remained a relatively constant size of just over 2,000 km^2. Erosion has only slightly modified the morphology of the upper and lower estuary during this period. The most dramatic change in the estuary has been the loss of island habitat since 1936, starting with 221 km^2 and reaching a high of 772 km^2 in 1963, then dropping to the 10 to 15 km^2 more recently. There have also been substantial changes in the estuary due to natural variations in river flow. The most extreme flooding event occurred in 1964. From a regional perspective, habitat losses in the Klamath Basin estuary are small compared to the changes in the San Francisco Bay and Columbia River estuaries.

The Klamath Basin estuary can be characterized as a limited exchange system due to its interface with the marine environment. The estuary has a low diversity of fishes compared to other coastal estuaries along the Pacific, probably due to its small size and large freshwater flows. Like other estuaries it is important transitional habitat for salmon beginning their seaward migration and returning adults. Euryhaline and marine native fishes along with introduced fishes known to inhabit the estuary are listed in table 5-1 (M. Wallace, California Department of Fish and Game, personal communication). Many of these native anadromous fishes have severely depressed populations with coho salmon and eulachon now receiving special protections through ESA listings. Green sturgeon is Federal ESA listed immediately to the south of the Klamath River. Chinook salmon are largely supported by hatcheries, but have been at such low levels that the fishery has needed to be closed in certain years. Pink and chum salmon have not been found in the Klamath for several decades. Steelhead and Pacific lamprey are also at low population levels.

The Klamath Basin estuary is not only important habitat for euryhaline and anadromous fishes, but also the endpoint for all of the impacts that have occurred upriver. Well-documented impacts due to changes in flow, and accompanying changes in temperature and water quality, are understood in the lower subbasin, but are not in the estuary. The changes in the flow regime from the headwaters due to Iron Gate and Trinity dams are mitigated somewhat by lower subbasin rainfall. However, the warming of water temperature, increased organic loading, and alteration in timing of flows has impacted the freshwater-saltwater interface of the estuary. The impacts to estuarine habitat associated with increased sedimentation from timber practices and mining are not well understood. Nor is the role of the estuary in the transmission of diseases to migratory anadromous fishes. The cumulative effect of these potential interactions on the fishes using the Klamath Basin estuary are unknown and are a major source of scientific uncertainty. Finally, the largest future impact on the Klamath Basin estuary is climate change induced sea level rise. Average predictions of sea level rise include a 30 cm increase by 2060 and an average “worst-case” scenario of a 1.4 m rise. Clearly, such changes will have a profound effect on the estuary and lower river habitats.

Nearshore Marine Environment

The nearshore marine environment has some of the highest levels of upwelling observed in the California Current. The upwelling process is induced by offshore winds and delivers cold, high nutrient-laden waters to the surface. These conditions support high biological productivity in the nearshore marine. Because coastal waters are dynamic, habitat conditions are patchy with respect to marine productivity. The match and mismatch of ocean conditions with the occurrence of juvenile salmon and other anadromous species has a major influence on population growth and survival during early phases of their marine life history. Patterns of habitat use in the nearshore marine environment are best understood for Chinook salmon. Growth and survival of juvenile Chinook directly corresponds to the abundance of suitable prey. Similar relationships are assumed for other anadromous species. Information about the marine distribution and survival of Pacific salmon and steelhead and other fishes is becoming available through the Pacific Ocean Shelf Tracking (POST) Program. POST is a large-scale ocean telemetry and data management system that operates fixed lines of electronic tag receivers along the West Coast of North America. The program provides new insights into fish movement and migration behaviors.

Finally, there needs to be a cautionary note about the impact of climate change in the nearshore marine environment. Eulachon were the first species listed under the ESA whose principal threat was climate change impacts on the marine environment. We can expect more climate change caused impacts throughout the marine environment. We really have very little understanding of the impacts that climate change will have for these fishes and their ecosystems.

The Klamath Basin estuary and nearshore marine environment are areas of complex ecosystem interactions due to the interface of freshwater and saltwater habitats. These habitats are less studied than their freshwater counterparts upriver. Differences in quality and content of scientific resource information make informed prediction about these environments extremely difficult. The estuary may not have been as dramatically altered as those of other large rivers systems but it is terminal and the integrative endpoint of all of the impacts that have occurred upstream. The nearshore marine environment is very dynamic where small differences in upwelling events influence marine productivity and quality of salmon (and other fishes) habitat. These changes are hypothesized (match – mismatch hypothesis) to impact year-class strength in salmon populations and for other species. Climate change effects may significantly impact estuarine and nearshore marine environments. These impacts can be expected to alter ecosystem structure and function.

Conclusion

The Klamath Basin’s historical fish community was strongly adapted to its “upside-down” geologic nature. The upper subbasin with its habitats of broad valleys, shallow lakes, and low-gradient rivers in a semiarid climate produced a historical fish community, which had a high number of endemic species, particularly of suckers, sculpins, and lampreys. Some of this high level of endemism is also due to landform changes resulting in the separation of upper and lower subbasin habitats over geologic time. Anadromous fishes, particularly salmonids and lampreys, were a prominent part of historical fish communities, providing a biological connection with the lower subbasin and marine environment. The lower subbasin, with its narrow-channel, high-flow nature, led to a historical fish community made up largely of anadromous fishes: salmonids, lampreys, green sturgeon, and eulachon, along with a few other cool-water species. The Klamath Basin estuary was small with a historical fish community of both

Basin fishes and other more common euryhaline and marine species. The distinctive "upside-down" geologic nature of the Klamath Basin led to a unique historical fish community different from any other on the Pacific Coast.

The current Klamath Basin fish community is vastly changed in many ways by anthropogenic impacts including dams, agriculture, land management activities, hatcheries, and introduced species. These impacts have resulted in a loss of diversity and abundance throughout the Basin. Upper subbasin impacts have included damming, diverting, and channelizing rivers and streams, diking and draining of wetlands, overharvest of native fishes like suckers, and introduction of at least 18 non-native fish species. The most obvious cause of lost diversity is the barrier imposed upon anadromous fishes at Iron Gate Dam. In some instances anthropogenic changes in habitat and population size have resulted in ESA listings of key species of fish.

Dam removal would be the largest and most dramatic habitat restoration activity for both the upper and lower subbasins. It is important to recognize that numerous other restoration projects are currently in progress or are proposed in the upper subbasin to restore key habitats and native fish populations. The lower subbasin's largest impacts are from dams. The construction of dams has resulted in loss of riverine habitats and changes in flow regime. Other human activities including hatchery, forestry, and land management practices have also had significant impacts. The Basin's salmonid populations have been dramatically affected by these practices. Access to and the quality of key habitats has been diminished and population abundance and diversity has suffered over time. The effects of aquaculture need continued research. For example, hatchery and wild fish interactions are not well understood but may have genetic and disease underpinnings. Habitat conditions in the Klamath Basin estuary seem to be less affected by the upper and lower subbasins. The nearshore marine environment is vast and has been considered stable but climate change effects may be profound.

Future research planning needs to be conducted at the Basin scale. A piecemeal approach to planning has not provided the resource information that will be needed for large-scale restoration and salmon reintroduction that may be forthcoming. Of course, there are exceptions to this generalization. For example, current efforts in support of disease ecology studies of salmon in the Klamath Basin have involved multi-agency planning to address parasitic infestations at the right time and spatial scales. However, this represents only one aspect of ecosystem management and there are many others that will require watershed understanding.

Unfortunately, at present, basin-level planning must follow a two track process: one that incorporates the dam removal initiative and one that does not until the Secretarial Decision. The Secretarial Decision will have a large impact on whether a Klamath Basin conceptual model will be interconnected or whether it will remain segmented into the upper subbasin, the lower subbasin, and the estuary and nearshore marine environment. Future research planning strongly depends on what the goals and priorities are set for the Basin. This will require a significant effort and multi-organizational governance strategy. Adaptive management is an extremely attractive model for research planning and it will require better initial planning to be successful. A priority objective of watershed restoration for salmon recovery should focus on the natural ecosystem processes that will preserve and enhance resiliency in these populations. Resiliency can be related to population productivity and abundance, variations in life history traits, and genetic diversity. This focus, requiring an ecosystem approach and other related objectives, will need to be identified and described in a formal Klamath Basin Science Plan. Climate change and disease ecology represent science areas that will need to be addressed. The science plan will need to be accompanied by an ongoing organizational structure for the participating agencies and an independent science board to provide overview and advice for future research. All of this will require agreement among the participating agencies.

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Table 5-1. Distribution and Status of Klamath Basin Fishes. Distribution and Status are coded as Present (P), ESA Listed (E), Historically present but currently 'absent' (XX),Introduced (I), Condition unkown (?).

		Distribution and Status		
Species		Estuary	Lower	Upper
Common	Scientific			
White shark	*Carcharodon carcharias*	P		
Big skate	*Raja binoculata*	P		
Pacific lamprey	*Lampetra tridentata*	P	P	XX
Klamath-Pit brook lamprey	*Lampetra lethophaga*			P
Klamath River lamprey	*Lampetra similis*	P	P	P
Miller Lake lamprey	*Lampetra minima*			P
River lamprey	*Lampetra ayers*	P	P	
Undescribed Upper Klamath Lake lamprey	*Lampetra sp.*			P
Green sturgeon	*Acipenser medirostris*	P	P	
White Sturgeon	*Acipenser transmontanus*	P	P	
Wakasagi	*Hpyomesus nipponensia*		I	
Pacific herring	*Clupea pallasi*	P		
Northern anchovy	*Engraulis mordax*	P		
American shad	*Alosa sapidissima*	I	I	
Goldfish	*Carassius aurtatus*	I		
Golden shiner	*Notemigonus crysoleucas*	I	I	
Coho salmon	*Oncorhynchus kisutch*	E	E	E/XX
Pink salmon	*Oncorhynchus gorbuscha*	XX	XX	
Chum salmon	*Oncorhynchus keta*	XX	XX	
Chinook salmon	*Oncorhynchus tshauytscha*	P	P	XX
Kokanee	*Oncorhynchus nerka*		I	
Steelhead	*Oncorhynchus mykiss*	P	P	XX
Redband trout	*Oncorhynchus mykiss nuberrii*			P
Coastal cutthroat trout	*Oncorhynchus clarkii clarki*	P	P	?
Bull trout	*Salvelinus confluentus*	P	P	?
Brown trout	*Salmo trutta*	I		
Brook trout	*Salvelinus fontinalis*	I	I	
Eulachon	*Thaleichthys pacificus*	E/XX	E/XX	
Surf smelt	*Hypomesus pretiosus*	P		
Longfin smelt	*Spirinchus thaleichthys*	P		
Pacific hake	*Merluccius productus*	P		
Pacific tomcod	*Microgadus promimus*	P		
Blue chub	*Gila coerulea*			P
Tui chub	*Gila bicolor*			P
Speckled dace	*Rhinichthys osculus*	P	P	P
Klamath speckled dace	*Rhinichthys osculus klamathensis*		P	
Fathead minnow	*Pimephales promelas*	I	I	I
Lost River sucker	*Deltistes luxatus*			E
Shortnose sucker	*Chasmistes brevirostris*			E
Klamath largescale sucker	*Catostomus snyderi*			P
Klamath smallscale sucker	*Catostomus rimiculus*			P
Brown bullhead	*Ictalurus nebulosus*	I	I	I
Jacksmelt	*Atherinopsis californiensis*	P		
Topsmelt	*Atherinops affinis*	P		

		Distribution and Status		
Species		Estuary	Lower	Upper
Common	Scientific			
Threespine stickleback	*Gasterosteus aculeatus*	P	P	
Brook stickleback	*Culea inconstans*		I	
Bay pipefish	*Syngnathus leptorhynchus*	P		
Striped bass	*Morone saxatilis*	I		
Klamath lake sculpin	*Cottus princeps*			P
Upper Klamath marbled sculpin	*Cottus klamathensis klamathensis*			P
Slender sculpin	*Cottus tenuis*			P
Prickly sculpin	*Cottus asper*		P	
Coastrange sculpin	*Cottus aleuticus*		P	
Lower Klamath marbled sculpin	*Cottus klamathensis polyporus*		P	
Sharpnose sculpin	*Clinocottus acuticeps*	P		
Staghorn sculpin	*Leptocottus armatus*	P		
Sturgeon poacher	*Agonus acipenserinus*	P		
Largemouth bass	*Micropterus salmoides*	I	I	I
Black crappie	*Pomoxis nigromaculatus*	I	I	
Spotted bass	*Micropterus punctulatus*		I	
Smallmouth bass	*Micropterus dolomieui*		I	
Bluegill	*Lepomis macrochirus*		I	
Green sunfish	*Lepomis cyanellus*	I	I	
Pumpkinseed	*Lepomis gibbosus*		I	
Yellow perch	*Perca flavescens*	I	I	I
Redtail surfperch	*Amphistichus rhodoterus*	P		
Shiner perch	*Cymatogaster aggregate*	P		
Striped surfperch	*Embiotoca lateralis*	P		
Walleye surfperch	*Hyperprosopon argenteum*	P		
Zebra perch	*Hermosilla azurea*	P		
Arrow goby	*Clevelandia ios*	P		
Saddleback gunnel	*Pholis ornate*	P		
Pacific sandlance	*Ammodytes hexapterus*	P		
Speckled sandab	*Citharichthys stigmaeus*	P		
Starry flounder	*Platichthys stellatus*	P		
Butter sole	*Isopetta isolepis*	P		

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Chapter 6. Climate Change Effects in the Klamath Basin

David Woodson[1], Kathie Dello[2], Lori Flint[3], Roger Hamilton[4], Ron Neilson[5], and James Winton[1]

Introduction

The Intergovernmental Panel on Climate Change (IPCC) determined that the Earth's climate warmed increasingly during the 20th century and estimated that its average annual air temperatures had increased by 0.6°C. Even though warming and cooling cycles have happened in the past, the most recent warming period has been extraordinary because of how quickly the global change occurred and how closely associated it was with increasing greenhouse gas emissions. To illustrate, in the Western United States average spring and summer temperatures for 1987 to 2003 were 0.87°C higher than observed increases between 1970 and 1986. Considering this history and projected warming trends, the Klamath Basin will likely be sensitive to future climate changes because the current relatively small human population is growing rapidly, as are demands on limited water supplies.

The Fourth Assessment Report (AR4) of the IPCC concludes that (1) warming of the climate system is unequivocal, and (2) most of the observed increase in average temperatures in the 20th century is very likely due to the increase in anthropogenic greenhouse gas concentrations. Most of the increased concentration of carbon dioxide in the atmosphere is from burning fossil fuels. Carbon dioxide has increased from a pre-industrial value of 280 parts per million (ppm) to about 390 ppm today.

Large-scale climate warming is evident in (1) observed global increases in remotely sensed Earth surface temperatures, (2) global increases in average sea levels from tide gauges, and (3) observed declines in Northern Hemisphere snow cover from satellite imagery (fig. 6-1). Global average surface temperatures increased 0.74°C in the 1906–2005 period, with an accelerated warming of 0.13°C per decade over the last 50 years. Warming of the oceans in concert with increased melting of the Earth's ice and snow packs has resulted in a thermal expansion of the sea water and a global average rate of sea level rise of 1.8 mm per year between 1961 and 2003. Northern Hemisphere snow cover has significantly declined over the past century in response to global warming.

The anthropogenic contribution to global warming has been evaluated through comparisons of results from global climate models (GCM) attempting to recreate the observed warming trends projections from the past 100 years. Those GCMs that relied solely on natural climatic forcing processes(e.g., the meridional turnover, explosive volcanism, or solar output) failed to accurately reproduce 20th century warming trends. Conversely, other models simulated natural and anthropogenic contributions to climate change produced results that more closely matched observed trends in temperature change over decadal time steps.

Increasing attention to climate change has led to increased efforts in data collection and concomitant increases in sophistication in the GCMs. Today, scientists have greater confidence in projections of how global climate change occurs over decadal scales. However, policy and decision makers need to understand how climate is changing on a smaller scale, both spatially and temporally,

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[1] U.S. Geological Survey, Western Fisheries Research Center.
[2] Oregon State University, Oregon Climate Change Research Service.
[3] U.S. Geological Survey, California Water Science Center.
[4] University of Oregon, Climate Leadership Initiatives Local Community Climate Program.
[5] U.S. Forest Service, Pacific Northwest Research Station.

and the potential economic and environmental effects of these changes. Downscaling of global climate projections to regional scales is a first step toward understanding potential impacts of change and informing policy and decisions about relevant societal applications.

Pacific Northwest Climate Change: Observations and Predictions

Meteorological records indicate that average air temperatures increased across Oregon and Washington from 1950 to 2006. Using a statistical hind-casting method developed by the Office of the Washington State Climatologist, trends for individual stations were calculated. In this analysis, a similar increasing trend in air temperature was observed from 1950 to 2006 at almost every station where measurements had been recorded in the region. Using the same methodology to study precipitation trends for the same period revealed there is unexpected widespread variability in regional patterns of rain- and snowfall. Further analysis has helped to explain how large-scale interactions of atmospheric and oceanographic processes in the Northeast Pacific affect regional weather patterns. Much of the annual and decadal variability observed in trends in the precipitation record reflects effects of El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

In the 21st century, warming is expected to continue to increase at a greater magnitude than was observed in the 20th century. Investigators at the University of Washington’s Climate Impacts Group (CIG) studied Pacific Northwest (Washington, Oregon, Idaho, and western Montana) temperature trends applying long-term weather data from existing meteorological stations to 21 climate models. The GCMs were used to reproduce the 20th century temperature record and project regional temperature conditions in 2080. The model results suggested an average increase in air temperature of 2.9°C by 2080 (fig. 6-2). Major model assumptions related to continuing increases in greenhouse gases. The investigators concluded that the model projections in temperature might be lower if greenhouse gas emissions are reduced in the future. The GCMs project little change in total annual precipitation through the next century, though point to seasonal changes and changes in the form of precipitation and forecast a future of wetter autumns and winters and drier summers (fig. 6-3).

Understanding seasonal climate changes and possible associated environmental impacts is a science area needing further research. An analysis by the Oregon Climate Change Research Institute (OCCRI) shows a significant negative correlation between spring (March, April, and May) temperatures and subsequent summer (June, July, August) stream flows. An increase in spring temperatures could continue to diminish summer stream flows in snow-dominated basins. Many watersheds in Oregon and Washington are snow dominated systems, and related ecosystem services are dependent on a robust annual winter snowpack. Historical data indicate that the April 1 snowpack has declined over the last half of the 20th century across the region (fig. 6-4). The U.S. Global Change Research Program found the trend of less wintertime precipitation as snow has occurred between 1949 and 2005. An analysis by the Climate Impacts Group (CIG) using the Variable Infiltrated Capacity (VIC) model suggests that this trend will continue and snowpack will decline from 2003 through 2040 (fig. 6-5).

The CIG evaluated hydrologic climate change scenarios to study climate change effects at almost 300 locations in the Columbia River Basin. At one location, The Dalles on the Columbia River, peak river flows were projected to increase in fall and decrease in summer. The pattern was projected through the 2080s.

GCMs are generally characterized by having a very coarse resolution and inability to account for changes in topography. A GCM for the Pacific Northwest models a regional land mass next to an ocean. Because of the model’s resolution, the Cascade Mountains are represented as a gentle slope due to this lack of resolution. GCM outputs are useful for a number of large-scale applications, but the need for finer resolution is imperative to developing understanding about future regional climate change. OCCRI is initiating studies to gain higher resolution in its climate change modeling in collaboration with the North American Regional Climate Change Assessment Program (NARCCAP). NARCCAP is a suite of Regional Climate Models driven by GCMs for North America. These outputs are at a higher resolution (50 km) than typical GCMs, and are useful in that they begin to capture the topography of the continent. Climateprediction.net, housed at OCCRI, launched an effort in 2010 to model climate change at a 25 km resolution for the western United States. At this resolution, relevant features in the Pacific Northwest are captured, including the Coast Range of Oregon.

Hydrologic Implications for the Klamath Basin

The hydrology of the Pacific Northwest, including northern California, is particularly sensitive to changes in climate because of the role of mountain snowpack on the region's rivers. The Klamath Basin is partitioned into two distinct climatic regimes by the Cascade Mountains. The west side of the Cascades on average receives approximately 50 in (1,250 mm) of precipitation annually, while the east side receives slightly more than one-quarter of this amount. The Klamath Basin, like much of the western United States, relies on cool season precipitation (October through March) and resulting snowpack to sustain warm season streamflows (April through September). Approximately 75 percent of the annual precipitation in the Cascades falls during the cool season. A changing climate affects the balance of precipitation falling as rain and snow and therefore the timing of streamflow over the course of the year. By the end of the century annual average temperatures are projected to be higher by 4.5°C while total precipitation is expected to decrease on average 2 in (50 mm) within the basin. Snowpack is projected to decline to less than 20 percent of current levels. The frequency of high-intensity storm events is expected to increase and the frequency of low-intensity storms will decline throughout the Klamath Basin.

Small changes in air temperature can strongly affect the balance of precipitation falling as rain and snow, depending on a watershed's location, elevation, and aspect. The Klamath Basin, and the Pacific Northwest as a whole, is often characterized as having three runoff regimes: snowmelt dominant, rain dominant, and transient. In snowmelt dominant watersheds, much of the winter precipitation is stored in the snowpack, which melts in the spring and early summer resulting in low streamflow in the cool season and peak streamflow in late spring or early summer (May–July). Rain dominant watersheds are typically lower in elevation and mostly on the west side of the Cascades. They receive little snowfall. Streamflow in these watersheds peaks in the cool season, roughly in phase with peak precipitation (usually November through January). Transient watersheds are characterized as mixed rain-snow due to their mid-range elevation. These watersheds receive some snowfall, some of which melts in the cool season and some of which is stored over winter and melts as seasonal temperatures increase. Rivers draining these watersheds typically experience two streamflow peaks: one in winter coinciding with seasonal maximum precipitation, and another in late spring or early summer when water stored in snowpack melts.

Statistical Downscaling

While global simulations indicate large-scale patterns of change associated with natural and anthropogenic climate forcing, they cannot capture the effects of narrow mountain ranges, complex land/water interaction, or regional variations in land use. Thus, it is necessary to develop robust approaches for applying global simulations at a regional scale. To that end, a number of methods, ranging from statistical downscaling to regional climate models, have been applied to bridge the gap between global climate models and local impacts. Global models generally are run at a resolution of 2.5 degree scale ~275 km, and regional studies require a resolution of 10–50 km or finer. For hydrologic impact studies, surface temperature and precipitation are the most important parameters to acquire from the global models for input to hydrologic simulations. For the Pacific Northwest, a resolution of at least 12 km or 1/8-degree is required to resolve the slopes and elevations of the important mountain ranges. For the Klamath Basin, a resolution of 4 km was first obtained using a gradient-inverse-distance-squared (GIDS) method which was further downscaled to 270 m using GIDS for model application.

Translation to the Hydrologic Response

Recharge and Runoff

Climate change is resulting in increases in air temperature and increased variability in precipitation. Model estimates suggest that increases in temperature during the next century will cause snowmelt to begin earlier in the spring and snow accumulation to start later in the summer. This is impacting runoff and recharge through earlier springtime snowmelt, increased evapotranspiration, reductions in total streamflow and groundwater recharge, higher frequency of floods and droughts, and increased sediment transport.

Hydrologic Effects of Climate Change on Hydrology

Hydrologic effects of climate change are occurring now and we can learn from current changes in the hydrologic response. Fine-scale application of climate projections provides options for investigations at multiple scales: from basin to reach to habitat. Climate changes are manifested locally, at much finer scales than upper or lower Klamath subbasins. Although there is uncertainty in the future projected climate, the direction and general magnitude of change has widespread concurrence. The projections indicate that temperature will increase in both upper and lower subbasins and that most of the snow pack will disappear from the upper subbasin by the end of this century. Further, the models project that the total amount of precipitation will not change much in the lower subbasin but will likely increase in the upper subbasin.

Implications for Resource Management

Potential environmental implications for the Klamath Basin include extended periods of summer low flows and high stream temperatures, changes in timing of lakes and reservoirs filling, and rain on snow springtime flooding. The effect of seasonal or long-term water deficits will include changes in vegetation, increased forest die-off and faunistic changes. Characterizing all landscapes under potential future hydrologic conditions will provide ranges in processes and bounds for expected responses. Fine-scale characterization provides information for basinwide prioritization of management objectives and identifies the relative sensitivity of watersheds, landscapes, hill slopes, and species to changes in climate.

Streamflows will increase slightly in the winter. The “wet” season, however, will not last as long as it does currently. Streamflows during the rest of the year will decrease. These patterns, in addition to the projection that individual rain events will be more intense, suggest that flooding flows will be more frequent. The shorter “wet” season is likely to alter fish migration timings [e.g., salmon (*Oncorhynchus* spp.*)*, Lost River sucker (*Deltistes luxatus*), and shortnose sucker (*Chasmistes brevirostris*)] and limit the period of the year that important side channel and floodplain habitats are inundated with water. These effects are likely to decrease young fish survival, particularly in the Sprague, Lower Klamath, Shasta, Scott, Salmon, and Trinity Rivers.

Greater frequency of high-intensity storm events coupled with a shorter "rainy" season will increase the amount of fine sediments carried to streams and rivers. This increase in fine sediment will eliminate some spawning areas for salmon and suckers (they spawn in or over gravels) and will reduce survival of incubating salmon and trout eggs. The effects of increased erosion will be particularly important in the Sprague, Lower Klamath, Scott, Salmon, and Trinity Rivers.

Water flowing from groundwater-fed springs will decrease and small springs that currently flow throughout the year may shift to a flow pattern that stops in late summer and fall. These springs offer critical refuge from warm water temperatures in many parts of the Klamath Basin, particularly in Upper Klamath Lake, the Williamson and Wood Rivers, the Shasta River, and along the Klamath River. Increasing water temperatures in the Klamath Basin will make these cool-water refuge areas more important for fishes. However, decreasing groundwater spring flows will reduce the amount of cool-water refuge provided at each spring. This impact will be particularly harmful to bull trout (*Salvelinus confluentis*), suckers and trout (*Oncorhynchus* spp.) of Upper Klamath Lake, and salmon and steelhead (*Oncorhynchus mykiss*) along the mainstem Klamath and Shasta Rivers.

Water temperatures will be warmer, dissolved oxygen levels will fluctuate more widely, and algae blooms (including blue-green algae) will be earlier, longer, and more intense. These conditions will increase stress on all fishes and most native aquatic animals. Disease incidence in fishes will rise. The period of the year during which cool-water refuges will be needed (for Lost River sucker, shortnose sucker, salmon, steelhead, and resident trout) will increase.

Management implications to consider are reservoir management, groundwater vs. surface water, agricultural competition, water quality (wildfire, sediment transport, salinity), and declines in both fisheries and species. Regional projections based on state-of-the-art science will provide information and insight to enable us to anticipate changes in resources, prioritize management, and develop infrastructure for adaptation to climate change effects on our environment.

Potential Climate Change Effects on Vegetation

Moisture Responses

The Mapped Atmosphere-Plant-Soil System (MAPSS) model solves for the water-limited leaf-area carrying capacity of the ecosystem, assuming that most ecosystems will produce as many leaves as the available soil water will support in an average growing season. This means that ecosystems are almost at a drought threshold under normal conditions. So as temperature increases, both the growing season and evaporative demand increase. But without an increase in water, the plants use all of the available soil water and go into drought stress, which increases the risk of fire and infestations. However, increases in water-use-efficiency (carbon fixed per unit of water transpired) from increased CO_2 concentration could alleviate some of that drought stress.

The MAPSS model simulates the changing distribution of vegetation as climate changes. The coupled CENTURY model simulates the growth and decline of changing vegetation over time, both above and below ground, as the climate varies and generally warms. The fire model simulates fire as a function of the vegetation type and simulated fuel characteristics, load, and dryness. The fire model determines when, where, and how severe any given fire will be, all of which are ultimately based on the vegetation and climate.

Multi-Scale Assessment Future Scenarios

The three IPCC climate scenarios examined were A2, A1B, and B1. A2 is a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. The A1B is a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. The B1 is a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

Three climate models were applied to these scenarios. The Model for Interdisciplinary Research on Climate (MIROC) is from Japan and its projections are hot and wet. The Hadley Centre Coupled Model (HADCM) model from England is an intermediate model and its projections tend to be hot and dry. The Commonwealth Scientific and Industrial Research Organization (CSIRO) from Australia and its projections are relatively cool and wet.

Looking at rainfall patterns for the same models shows more consistency across emission scenarios and greater differences between the models themselves. However, all of the models show increasing rainfall at high latitudes and decreasing rainfall at subtropical and desert latitudes. Unfortunately most of the United States sits between these two zones where there is the most uncertainty and greatest variability. From an ecosystem perspective, the variability of the rainfall may be of greater importance than if the total rainfall increases or decreases. Given the increasing steepness of the wet-zone to dry-zone gradient, the variability and unpredictability will most certainly increase. Also, the expectations are that the dry periods will become longer and much hotter and drier; the wet episodes could also become longer, considerably wetter, and with more intense rains, greatly increasing the possibility of floods.

Thermal Response

To model thermal responses that plants respond to within the basin, we defined six thermal zones: tropical, subtropical, temperate, boreal, subalpine, and alpine. The alpine is a treeless zone, the subalpine is a tree-shrub area that gives way to the boreal zone that corresponds to fir zones in the West. The difference between the boreal and temperate zones is defined by the supercooling freezing point of water, the point where water freezes spontaneously after being supercooled to -40°C and the mean monthly temperature is below -16°C. The difference between the temperate and subtropical zones is based on the freezing point of water, where the temperate zone gets hard frosts every year (cold-deciduous flora). The subtropical zone is a transition zone (mixed deciduous and evergreen flora) to the tropical zone that typically has no frosts in any year (broadleaf evergreen).

In the Geophysical Fluid Dynamics Laboratory (GFDL) Future Climate model all of the zones move north and up in elevation (fig. 6-6). The alpine, subalpine and boreal zones all lose ground becoming much smaller. Growing seasons will increase. Native species will become invaders as they migrate north or up in elevation in response to warming. Plants and animals that currently make use of high-elevation habitats will decrease in abundance and possibly be eliminated as their preferred habitat and temperature needs disappear. There will be an expansion of the subtropical and tropical zones.

Present - Global to Local

Historical vegetation can be simulated at any scale, global to local (50 km to 50 m resolution), with the MC1 (MAPSS-CENTURY, v1) model to examine the impacts of climate change on plant distribution, productivity, drought, and fire. For the Klamath Basin, historical vegetation from 1961–

1990 was simulated and then projected to 2070–2099 to see how the vegetation distribution, fire, and vegetation carbon changed. All projections (fig. 6-7) show a decline in the maritime evergreen needleleaf forest [e.g., spruce-hemlock (*Picea - Tsuga* spp.)—mixed fir-hardwood (*Abies* spp.)] and subalpine forest but, an expansion of the temperate evergreen needleleaf forest (e.g., Douglas fir (*Pseudotsuga menziesii Franco*), various pines, *Pinus* spp.), temperate grassland and subtropical shrubland. Looking at the projections for biomass consumed by fire in the nine scenarios (fig. 6-8), the HADCM projections indicate the largest fire effects but all scenarios show a greater than 20 percent increase in biomass consumption throughout the basin. The increase in fire is also greater in the lower portion of the Basin. The changes in vegetation carbon in all scenarios project declining resources in the lower subbasin and increasing amounts in the upper subbasin (fig. 6-9).

Summary of Vegetation Effects

Warmer temperatures may push alpine and subalpine communities off the tops of the mountains or into microhabitat refugia. There will likely be massive floristic change across the basin and invasions from frost-intolerant vegetation. There will be widespread range expansions of insects and possibly diseases too. Vegetation communities will move to new locations and could be significantly reduced. High-elevation alpine and subalpine vegetation communities, the coastal redwood (*Sequoia sempervirens*), and spruce forests could disappear (or become quite rare) and be replaced by oaks (*Quercus* spp.) and madrone (*Arbutus menziesii*), particularly for the lower subbasin. Plants and animals that currently live in high-elevation habitats will decrease in abundance and may die off or become constrained to small refugia as their habitats disappear. Warmer temperatures and changes in precipitation will result in timing shifts in plant phenology and the emergence of insects. The lack of synchronization between organisms may lead to entire ecosystems being transformed into something else, as yet unknown.

Winters will be wetter in the northern subbasin and drier in the southern subbasin with greater uncertainty and variability in-between. Temperature-induced diebacks are a distinct possibility, as are extreme floods and hillslope erosion. Existing noxious weeds, new noxious weeds, and juniper (*Juniperus communis*) are likely to expand their ranges and increase in abundance. In the Upper Klamath Subbasin, temperate grasslands are predicted to replace temperate shrublands. However, CO_2 -induced increases in water-use efficiency may mitigate diebacks and even enhance woody expansion in parts of the Klamath Basin.

Resource Management Implications

Management faces an uncertain future because the future will not echo the past. Managers will need adaptive management strategies to mitigate as changes occur, but with a view toward the vegetative functions they want as desired outcomes. They will need to improve resilience to rapid change by either planting or managing diversity, both genetic/species diversity and habitat or structural diversity. Additionally, they may wish to consider various forms of "density control" in order to keep the leaf area below its water-limited carrying capacity, while providing a supply of board wood, fiber, or biofuels. All of these "resilience" strategies can be combined in creative ways to limit the spread of fire and its outbreak potential, while maintaining a landscape undergoing continuous change.

Potential Impacts of Climate Change on Infectious Diseases of Fish

In spite of obvious impacts to humans and captive animals, disease is often ignored by fisheries managers as a significant factor affecting the abundance of wild populations because the effects are difficult to observe and quantify. Historically, most fish health research has been directed towards identification, treatment, and prevention of diseases of hatchery fishes; however, more recent studies from marine, freshwater, and terrestrial environments indicate that infectious and parasitic diseases can be responsible for population oscillations, extinction of endangered species, reduced host fitness, and increased susceptibility to predation as well as an important component of natural mortality. The recognition of disease as a population-limiting factor for wild fish is partly the result of the emergence of high profile pathogens and changes in environmental conditions that shift the host-pathogen balance in favor of disease. Among such environmental changes, global warming associated with climate change is seen to be a particularly important threat for poikilothermic vertebrates, such as fish, for which environmental temperature is a controlling factor in their physiology and immune response.

Some of the ways in which global warming can affect the severity and distribution of infectious diseases of fish include: changes in the growth rate of pathogens, changes in the types or strains of pathogens present, changes in the distribution of carriers and reservoirs, changes in the density or distribution of susceptible species, changes in diets that can alter resistance to disease, changes in the host immune response to disease, increases in stress that increase susceptibility to disease, and changes in the physical habitat (water flows, water quality) in ways that affect disease ecology. Two examples of infectious diseases of fish that illustrate these factors include the loss of adult salmon in the Klamath River in California during the fall of 2002, and an increase in disease among adult salmon in the Yukon River of Alaska.

The losses in the Klamath River involved the death of more than 30,000 returning adult Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*) and steelhead in the lower river. A persistent drought led to significant water-use conflicts, and river flows in the lower Klamath River in the fall of 2002 were among the lowest recorded in the past 50 years. The low flows and subsequent increased temperatures caused the fish to concentrate in pools where levels of two naturally occurring fish diseases (columnaris and icthyophthiriasis) began to increase dramatically. These diseases caused the erosion or swelling of the gills resulting in rapid suffocation. The situation was compounded by the presence of a relatively large number of fish of both wild and hatchery origin that increased the transmission rate and amplified the pathogen load, further increasing disease. While the flows and temperatures in the lower Klamath River in 2002 were seen as unusual, it is important to note that the lower summer flows and higher water temperatures are forecast to become more frequent in most climate change scenarios, making this example an unfortunate glimpse of the future.

Another example of a disease condition with links to global warming involves salmon and, potentially, salmon resources in the Northwest. The example, from Alaska, involves the emergence of *Ichthyophonus* infections in adult Yukon River Chinook salmon that are associated with adverse flesh quality and possible pre-spawning losses. Clinical signs of disease were minimal when fish entered the river, but increased significantly when fish reached the middle river. Among fish from the end of the run, the parasite was disseminated and clinical disease was apparent in multiple organs, especially the heart; however, female spawn-outs had lower levels of *Ichthyophonus,* suggesting the most severely diseased fish had died before spawning. Elevated river temperatures in recent decades, now reaching as high as 20°C, were postulated to be an important cause of the emergence and increased severity of the disease. Laboratory studies revealed that infected fish demonstrated more rapid onset of disease, higher parasite load, and a faster death rate at higher temperature (fig. 6-10). In a second experiment to determine the role of temperature on the swimming stamina of *Ichthyophonus*-infected fish, infected trout were reared at 15°C for 16 weeks before being subjected to forced swimming at 10, 15 and 20°C. Stamina was significantly impaired in infected fish as temperature increased. This study highlights the role of environmental stressors, such as climate change, on the ecology of fish diseases as well as the impact of these diseases on fitness traits important to the survival of natural populations.

Thus, we anticipate that the effects of climate change, especially global warming, on fish diseases will include warmer water temperatures and lower flows that will exacerbate diseases caused by endemic parasites and pathogens, increase growth rate of pathogens, favor pathogens or strains that replicate at higher temperatures, and alter the strength and speed of the host immune response to disease. In addition, altered freshwater habitats and ocean conditions will change the distribution or density of hosts as well as the overlap with vectors, carriers, or reservoirs of infection. These altered habitats will produce biotic and abiotic stressors that will lower resistance to disease, and finally, a greater disease burden and associated fitness losses will increase the disease component of natural mortality among populations of fish.

Forecast for Future Conditions in the Klamath Basin

Framework for the Climate Change Futures Project

The Climate Futures Forum is part of a larger initiative aimed at establishing a common method for developing integrated climate preparation plans and policies. The project is coordinated by the Climate Leadership Initiative in the Institute for Sustainable Environment at the University of Oregon, in partnership with The National Center for Conservation Science & Policy (NCCSP) and the MAPSS Team at the U.S. Forest Service Pacific Northwest (PNW) Research Station. In addition to the Klamath Basin, climate preparation assessments have been developed for the Rogue, Upper Willamette, and Umatilla basins. This work will pave the way for collaborative efforts that will increase the resistance and resilience of natural, built, human, and economic sectors to climate change in Oregon and other western States.

The framework for the climate change futures project is designed to assess vulnerabilities across all climate risks of importance to society and to integrate prioritized preparation actions into a comprehensive preparation strategy. The Climate Futures Forum helps citizens from a variety of systems (Human, Built, Natural, Economic, and Cultural) assess climate change projections for their region, identify likely impacts, and propose strategies to cope with them. Human Systems are services like social services, public health, education, and emergency services. Built Systems are manmade structures like buildings, roads, energy and water systems, and other critical infrastructure. Natural Systems include aquatic and terrestrial ecosystems, biodiversity, and invasive species. Economic Systems include agriculture, forestry, retail, commercial fishing, and health care industries. Cultural Systems include communities, species, places and artifacts of cultural importance.

Climate Futures Forums

A series of workshops, known as climate futures forums, were held in several Oregon river basins and are intended to provide a basis for a model to be nationally replicable. The forums, produced in collaboration with local partners, are designed to dramatically increase climate change preparation and adaptation literacy and to build and deliver tools and resources to assist all levels of governments, institutions, and nonprofits in proactively preparing for climate change.

Workshop Products

Reports were developed from knowledge gained at the workshops to inform integrated climate change preparation plans that identify impacts and strategies for increasing resiliency for natural, social, economic, built, and cultural systems. Also included in the reports are scientific data gaps, research needs, and monitoring processes identified at the workshops that are needed to direct further inquiry and measure success.

Model Outputs at Basin Scale: Time Series Graphs, Spatial Maps

For the first time global climate models used by the IPCC have been scaled down to river basins, a scale that is meaningful to local residents. Global climate models used in this report were adjusted to local scales by the MAPSS team at the USDA Forest Service's Pacific Northwest Research Station. Workshop participants used the projected trends in temperature, precipitation, and other parameters to determine likely impacts to natural and community systems. Three global climate models–CSIRO, MIROC, and HADCM–and a vegetation model (MC1) were used to project future temperature, precipitation, vegetation, runoff, and wildfire in the Klamath Basin. Model outputs for the time series graphs were average monthly and annual temperature, annual total and average monthly total precipitation, annual stream flow, annual total area consumed by fire, and percent area subject to change of a specific vegetation type. Model outputs for the spatial maps were mean seasonal temperature, mean seasonal precipitation, vegetation, and proportion burned by fire. Model outputs were converted to local scales using local data on recent temperature and precipitation patterns. The climate model output was applied to the MC1 Vegetation model, which provided data on possible future vegetation types and extent of wildfire.

Klamath Basin Climate Change Projections

Climate change projections were shown as overall averages, as time series graphs over time averaged across the Basin and as maps that show variation across the Basin averaged across years. Climate and vegetation outputs were mapped for the historical period, 1961–1990, and for two future periods, 2035–2045 and 2075–2085.

The projections from all three models point to a warmer future for the Klamath Basin. Mean annual temperature across the basin is projected to rise 1.1°C to 2.0°C by mid century and 2.5°C to 4.6°C by late century when compared to the historical data. Monthly trends in the data showed greater relative warming in the summer than in other seasons (fig. 6-11).

The three models all projected that summers will be drier; however, projections for winter precipitation varied considerably. On average, CSIRO shows a wetter future while MIROC and HADCM show a slightly drier one (fig. 6-12). All models project drier summers in the 2035–2045 time period but in the longer range projections HADCM and MIROC project drier conditions while CSIRO projects wetter conditions.

Annual stream runoff projections varied considerably between models with HADCM and MIROC projecting lower annual stream flows and CSIRO projecting slightly higher flows (fig. 6-13).

Projections for predominant vegetation types and proportion of area burned annually by wildfire were provided by the MC1 vegetation model (fig. 6-14). The maritime conifer forest in the lower basin is projected to decline and conditions are projected to become more suitable for oaks and madrones. In the upper subbasin projections are for conditions to give way to those that favor grasslands away from the sagebrush and juniper that is there now. These changes may take place over decades or even centuries; however, the agents of change will be familiar: fire, insects, and disease. Wildfire is projected to increase from 11 to 22 percent with greater area burned late in the century compared to the historical average. This increase in wildfire may result in as much as 330,000 acres burned, on average, each year.

Sample Climate Futures Forum Workshop Recommendations

- Protect areas with cooler water as air and water temperatures rise. These include stream and lake areas with groundwater-fed springs and well-developed bank vegetation.
- Decommission or re-contour nonessential roads to reduce overall impacts of erosion and sedimentation during severe storm events.
- Reconnect rivers with floodplains, restore wetlands, restore stream-side areas to hold more water during floods, and increase groundwater recharge.
- Protect intact habitats such as roadless areas that provide strongholds for many native species.
- Re-seed areas after disturbance with locally collected, native seeds to re-establish plants that occur in the area and limit the spread of invading species.
- Develop new partnerships across agencies, Tribes, and landowners to encourage landscape-scale planning across jurisdictional boundaries.

Selected Recommendations for Project Priorities

- Prioritize watersheds (or areas of watersheds) that are likely to remain functional over next 50 years.
- Identify priority refugia for protection – e.g., cold-water springs and cold-water spots that can keep streams cool as reduced flows increase water temperatures.
- Reallocate existing water rights – people, species, and agriculture need to be balanced.
- Restore riparian areas, landscape-scale sponges, and springs.

Synthesis and Future Directions

Measured trends and observed responses clearly indicate that climate change is underway in the Klamath Basin and that this change will affect physical and ecological systems. The degree of change will depend in part on the size and rate of future climate change and its geographic variability. Numerical climate change models of atmosphere, ocean, and land generate projections that provide insight into future temperature and precipitation trends as greenhouse gas concentrations increase. The outputs from global climate models vary according to the structure of the model and the atmospheric concentration of greenhouse gasses, mainly CO_2, used in a model. Typically, future conditions are presented as a range of scenarios from several models for specific time horizons.

Temperature and Precipitation Changes in the Klamath Basin

Changes in temperature and precipitation will continue to decrease snow pack, and will affect streamflow and water quality throughout the Klamath Basin. The models projected an increase in annual average temperatures compared to the 1970–1999 period; specifically, a 1.1°C to 2.0°C increase by mid-century and 2.5°C to 4.6°C by late century. Summer warming was projected to be greater than warming during other seasons. Projections for annual average precipitation ranged from an overall reduction of 11 percent to an increase of 24 percent. All models agreed that summers in the future are likely to be drier (a decrease of 3–37 percent) than past summers. Both upper and lower subbasins will increase in temperature with most of the snow being lost in the upper basin by the end of the century. Total precipitation will not change much in the lower subbasin, but is likely to increase in the upper subbasin. However, increases in extreme high precipitation events, falling as rain instead of snow, are projected for the lower subbasin.

Hydrology Changes

Streamflows are projected to increase slightly in the winter. The “wet” season, however, is not projected to last as long as it does currently. Streamflows during the rest of the year are projected to decrease. This pattern, in addition to the projection that individual rain events will be more intense, suggests that flooding flows will be more frequent. Greater frequency of high-intensity storm events coupled with a shorter “rainy” season will increase the amount of fine sediments carried to streams and rivers. The effects of increased erosion will be particularly important in the Sprague, lower Klamath, Scott, Salmon, and Trinity rivers. Water flowing from groundwater-fed springs will decrease and small springs that currently flow throughout the year may shift to a flow pattern that stops in late summer and fall. These springs offer critical refuge from warm-water temperatures in many parts of the Klamath Basin, particularly in Upper Klamath Lake, the Williamson and Wood Rivers, the Shasta River, and along the Klamath River. Increasing water temperatures in the Klamath Basin will make these cool water refuge areas more important for native aquatic animals. However, decreasing groundwater spring flows will reduce the amount of cool water refuge provided at each spring. Water temperatures will be warmer, dissolved oxygen levels will fluctuate more widely, and algae blooms (including blue-green algae) will be earlier, longer, and more intense. These conditions will increase stress on all fishes and most native aquatic animals. Disease incidence will rise and the period during the year in which cool water refuges are needed will be extended.

Changes to Vegetation

The results of vegetation change modeling suggest a number of different possibilities for the Klamath Basin forests. Vegetation communities will likely move to new locations and could be significantly reduced. Vegetation model projections show a shift in growing conditions in the upper subbasin that could favor grasslands in areas currently suitable for sagebrush and juniper. In the lower subbasin, conditions are projected to favor oaks and madrone over the current maritime conifer forest (redwood, Douglas fir, and Sitka spruce), which is projected to decline. There will likely be substantial floristic change across the basin and invasions from frost-intolerant vegetation. Warmer temperatures may push alpine and subalpine communities off the tops of the mountains or into microhabitat refugia. There will be widespread range expansions of insects and possibly diseases too. Plants and animals that currently live in high-elevation habitats will decrease in abundance and may die off or become constrained to small refugia as their habitats disappear. Warmer temperatures and changes in precipitation will result in timing shifts in plant phenology and the emergence of insects. Existing noxious weeds, new noxious weeds, and juniper are likely to expand their ranges and increase in abundance. The lack of synchronization between organisms may lead to entire ecosystems being transformed into something else, as yet unknown.

Wildfire Risk

Fire frequency and intensity have already increased in the past 50 years, and most notably the past 15 years in the shrub steppe and forested regions of the West. All future climate projections predict increases in wildfire in the Klamath Basin, especially east of the Cascade Mountains, due to higher summer temperatures and earlier spring snowmelt. The models project a greater than 11–22 percent area in the Basin burned by wildfire by late century than occurs currently. The increase in fire is also greater in the lower portion of the basin. The changes in vegetation carbon in all of the projections show it declining in the lower subbasin and increasing in the upper subbasin. Drought and higher temperatures will also lead to an increase in outbreaks of insects, such as the mountain pine beetle (*Dendroctonus ponderosae*), increasing the risk of fire.

Effects on Fish

The shorter "wet" season projected by most models will likely alter fish migration timings and decrease the period of the year that important side channel and floodplain habitats are inundated. These effects will likely decrease young fish survival. Shifting streamflow patterns will be particularly important in the Sprague, lower Klamath, Shasta, Scott, Salmon, and Trinity Rivers. Greater frequency of high-intensity storm events are projected, and coupled with a shorter "rainy" season, will increase the amount of fine sediments carried to streams and rivers. This increase in fine sediment will eliminate some spawning areas for salmon and suckers and will reduce survival of incubating salmon and trout eggs.

Water flowing from groundwater-fed springs will decrease and small springs that currently flow throughout the year may shift to a flow pattern that stops in late summer and fall. These springs offer critical refuge from warm water temperatures in many parts of the Klamath Basin, particularly in Upper Klamath Lake, the Williamson and Wood Rivers, the Shasta River, and along the Klamath River. Increasing water temperatures in the Klamath Basin will make these cool-water refuge areas more important for fishes. However, decreasing groundwater spring flows will reduce the amount of cool water refuge provided at each spring. This impact will be particularly harmful to bull trout, suckers, and trout of Upper Klamath Lake, and salmon and steelhead along the mainstem Klamath and Shasta Rivers.

Water temperatures will be warmer, dissolved oxygen levels will fluctuate more widely, and algae blooms will be earlier, longer, and more intense. These conditions will increase stress on all fishes and most native aquatic animals. Disease incidence in fishes will rise. The period of the year during which cool-water refuges will be needed will likely increase.

Future Directions

1. Climate science and modeling are needed to better understand and adapt to climate change in the Klamath Basin. We need to improve our understanding of climate model uncertainty and our understanding of the feedback between physical and biological systems.
2. Characterize and model the response of physical systems, such as hydrologic and atmospheric, to historic and future temperature and precipitation, particularly with regard to ecosystems, freshwater supplies, historical and cultural resources, human health, and infrastructure. Improve understanding of erosion, mass wasting, and sediment transport processes resulting from changes in precipitation and streamflow, sea level rise, and glacier retreat, particularly as they relate to hazards, water quality, aquatic habitat, and impacts to infrastructure.
3. Characterize and model the response of biota, terrestrial and aquatic ecosystems, and biogeochemical systems to changing climate. Characterize the response of species, populations, and ecosystems to climate change. Improve understanding of threats to habitat connectivity and the potential for fragmentation of terrestrial and aquatic habitats. Continue to advance understanding and modeling of changes in fire ecology. Continue to develop understanding of the ecology and potential impacts of invasive species, plant and animal diseases, and epidemic insect infestations.

4. Identify vulnerabilities of specific physical systems, ecosystems, freshwater supplies, human health, cultural resources, and infrastructure to climate change, and investigate ways to adapt or mitigate. Assess the vulnerabilities of terrestrial, aquatic, and nearshore marine ecosystems, as well as individual species and populations, to climate change and non-climate-change stressors. Assess climate-related increases in vulnerability of threatened and endangered species or other species of concern. Identify vulnerabilities of freshwater resources, particularly as they relate to ecosystem needs, human needs, infrastructure, and competing and changing demands. Develop adaptation or mitigation strategies for identified vulnerabilities.
5. Develop or enhance monitoring and observation of key physical and biological systems, and develop systematic methods for analyzing, storing, and serving data. Inventory and evaluate existing monitoring networks, expand and modify networks as necessary, and, where feasible, integrate efforts across agencies. Develop new metrics for tracking the response of physical systems, ecosystems, and individual biota to climate change, and establish new monitoring and observation systems where needed. Develop a data management infrastructure that includes common standards for data collection and processing, formatting, quality assurance, storage and archiving, and data sharing.
6. Data Systems and Modeling: Improve methods for data analysis and storage, modeling, forecasting, and decision-support. This cross-cutting theme relates to science application across the full range of disciplines, processes, and scales. Continue development and application of models of physical and biological systems, and develop an inventory of well-documented, well-tested, and widely used models.
7. Develop strategies for communicating results and current thinking to the full range of agencies, stakeholders, and the general public. Incorporate a variety of tools and techniques to translate and transfer scientific information including scientific publications, fact sheets, websites, webinars, seminars, workshops, and training courses.

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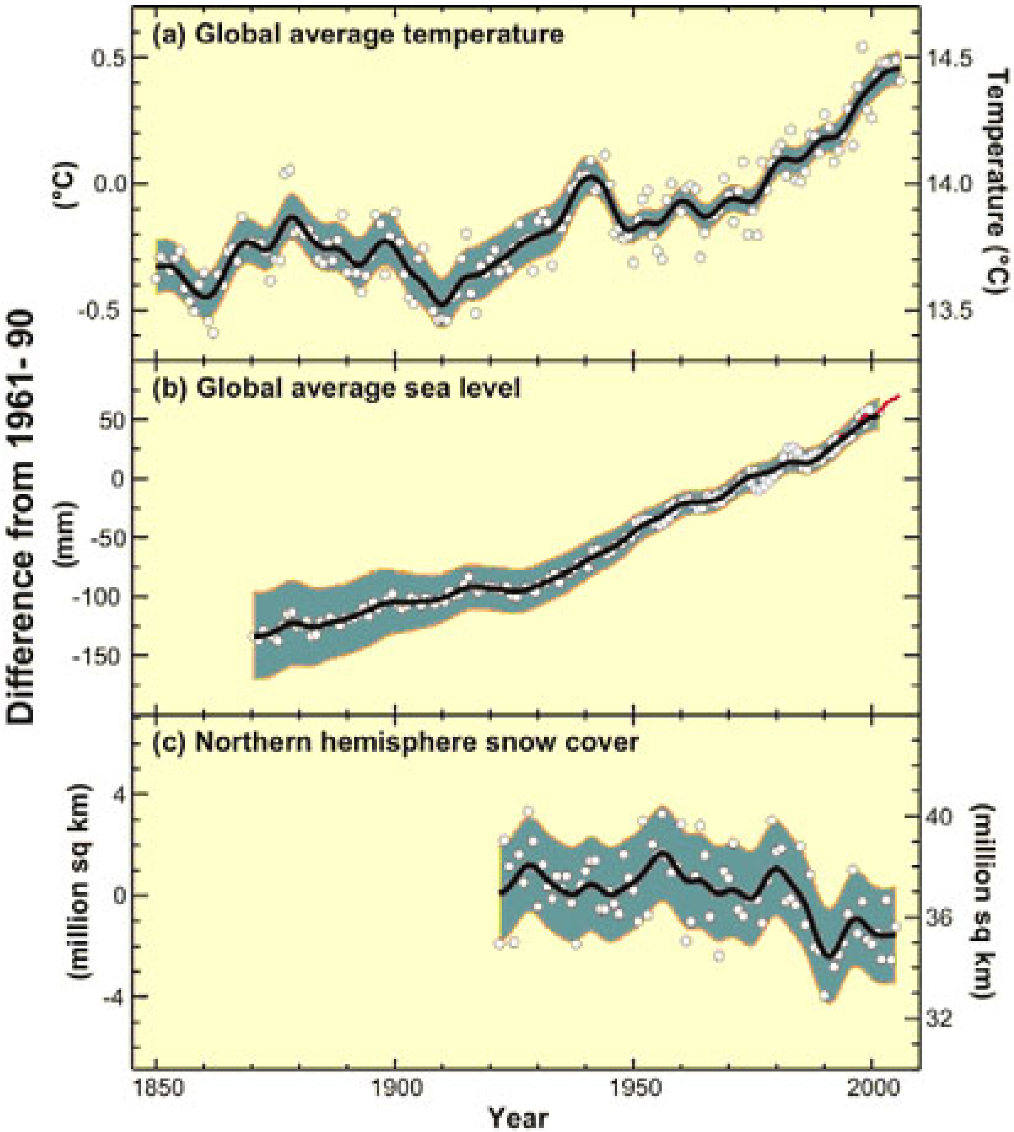

Figure 6-1. Observed increases in global surface temperature, global average sea level from tide gauges, and declines in Northern Hemisphere snow cover (from IPPC, 2007).

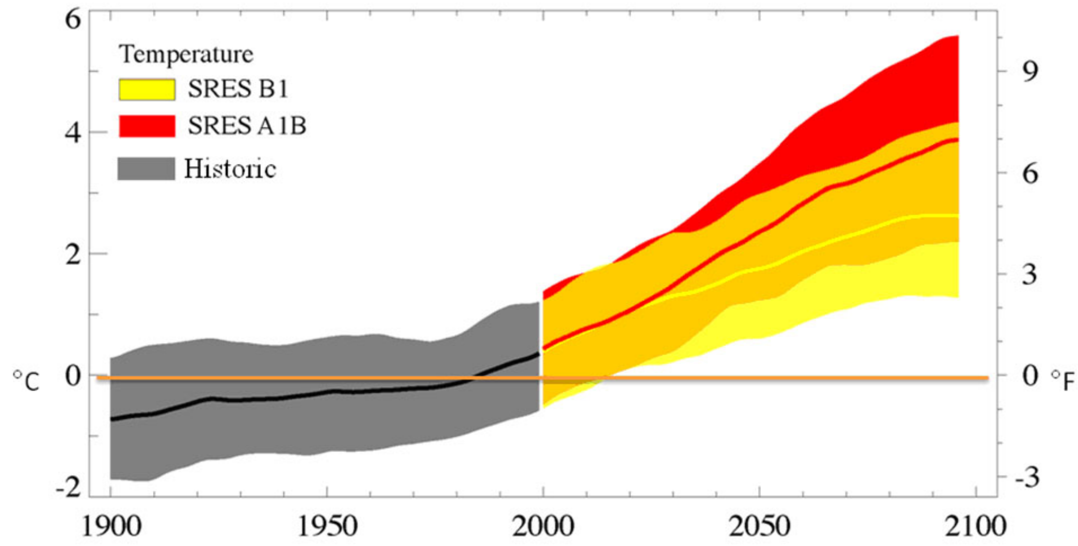

Figure 6-2. Projected increases, using the A1B and B1 scenarios from the Special Report on Emission Scenarios (SRES), in annual air temperature in the Pacific Northwest relative to 1970–1999 average (from Mote and Salathe, 2009).

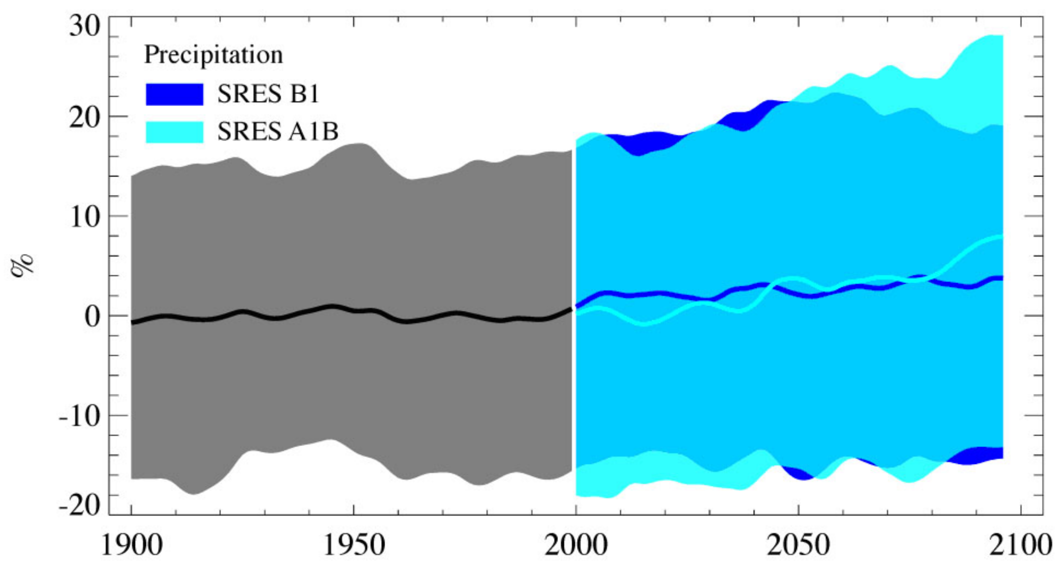

Figure 6-3. Projected changes, using the A1B and B1 scenarios from the Special Report on Emission Scenarios (SRES), in annual precipitation in the Pacific Northwest showing little annual change but larger seasonal changes when compared to 1970–1999 average (from Mote and Salathe, 2009).

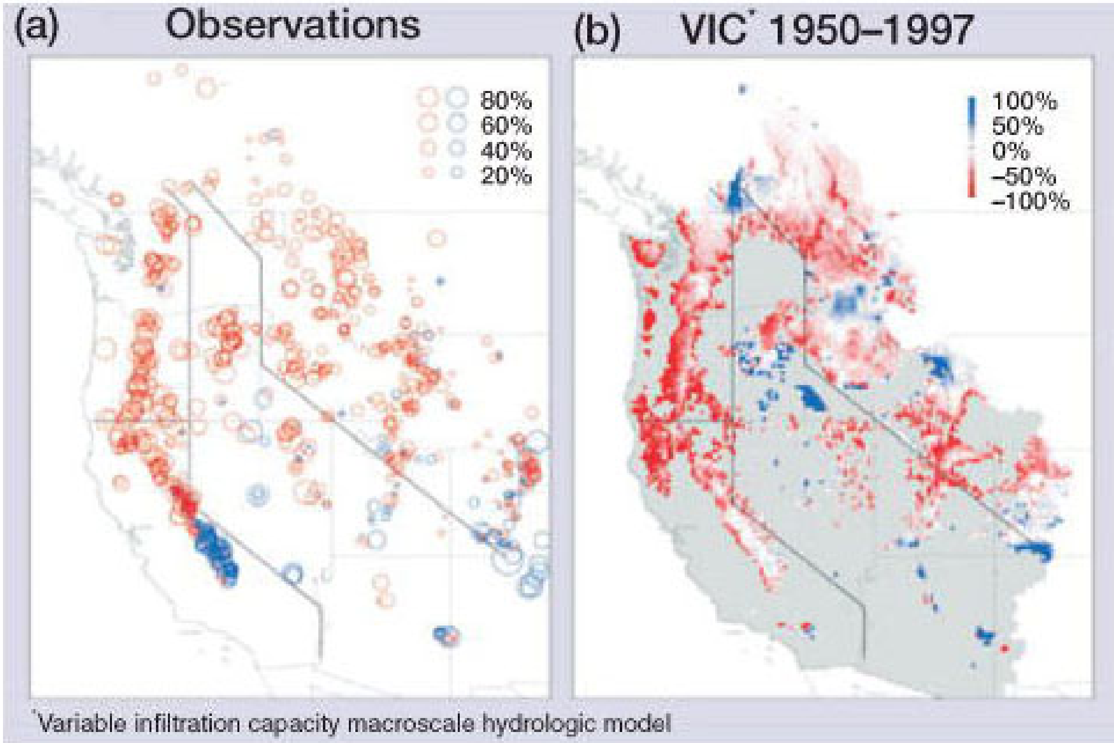

Figure 6-4. The April 1, 1950–1997 snowpack has declined over the last half of the 20th century across the region using the Variable Infiltration Capacity (VIC) model (Mote et al., 2005).

(a) Measured and (b) modeled changes in the amount of water stored in the April 1 snowpack (snow water equivalent) in western North America. (a) Red circles show declines and blue circles show increases; size of the circle denotes the magnitude of the change during the period 1950–1997. (b) Trends in snow water equivalent over the same period, estimated by a physically based hydrologic model.

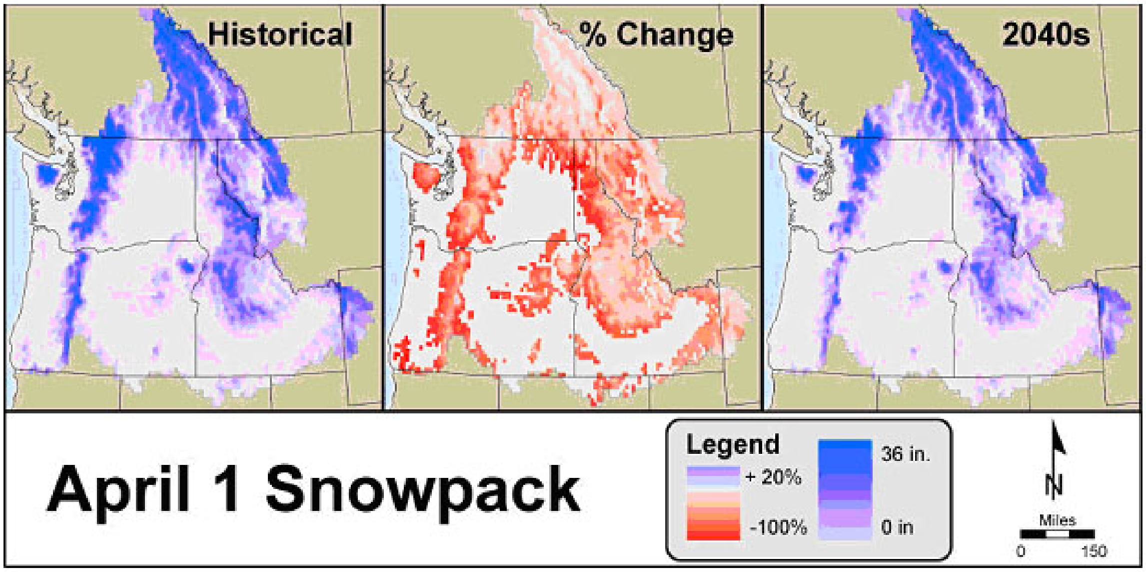

Figure 6-5. An analysis by the Climate Impacts Group at the University of Washington using the Variable Infiltration Capacity (VIC) model suggest that snowpack will continue to decline through 2040 vs. 2003 levels (from Hamlet et al., 2005).

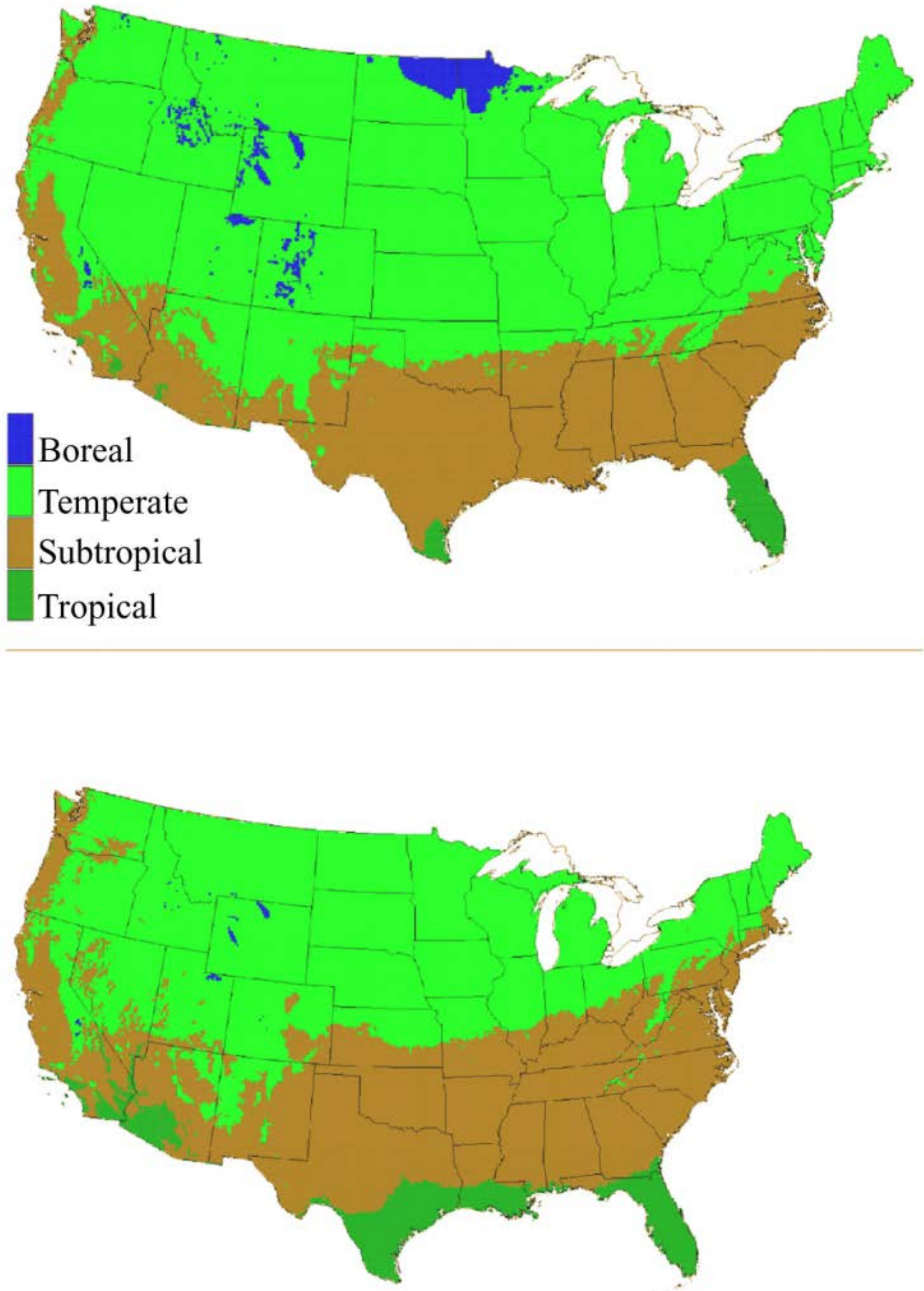

Figure 6-6. One example of a possible shift in vegetation thermal zones using the GFDL, Geophysical Fluid Dynamics Laboratory, future climate model.

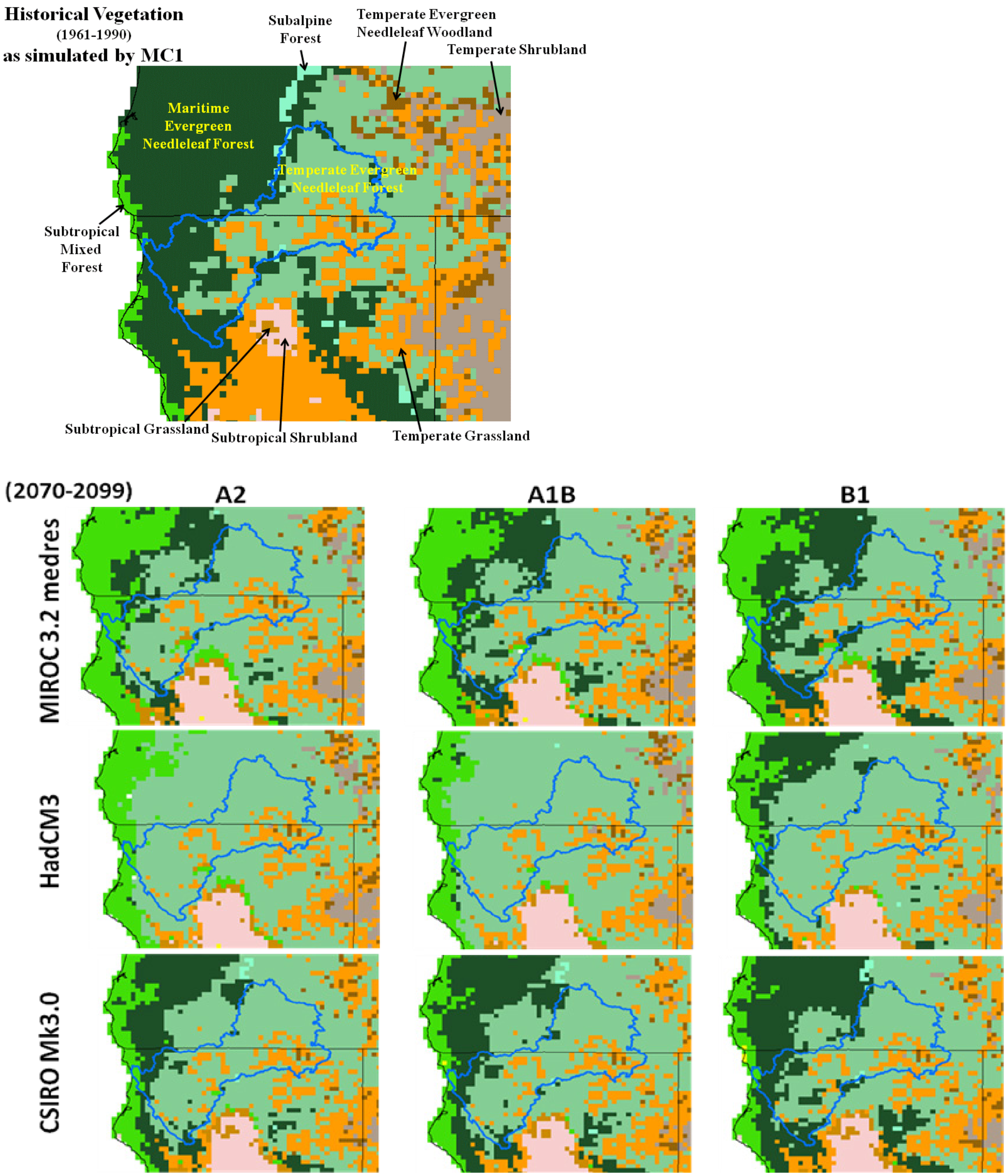

Figure 6-7. Potential future vegetation distributions compared to simulated current distribution using the MC1 (MAPSS-CENTURY, v1) model.

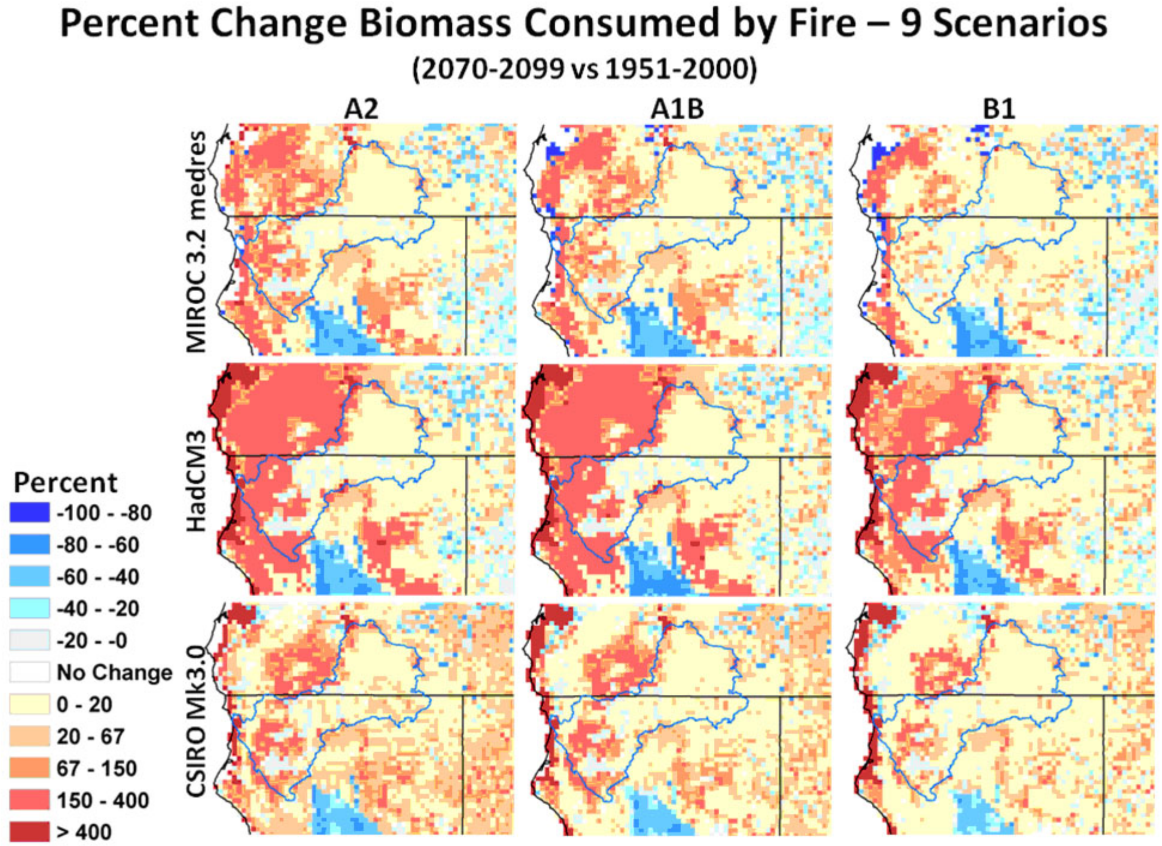

Figure 6-8. Potential future fire impacts using the MC1 (MAPSS-CENTURY, v1) model.

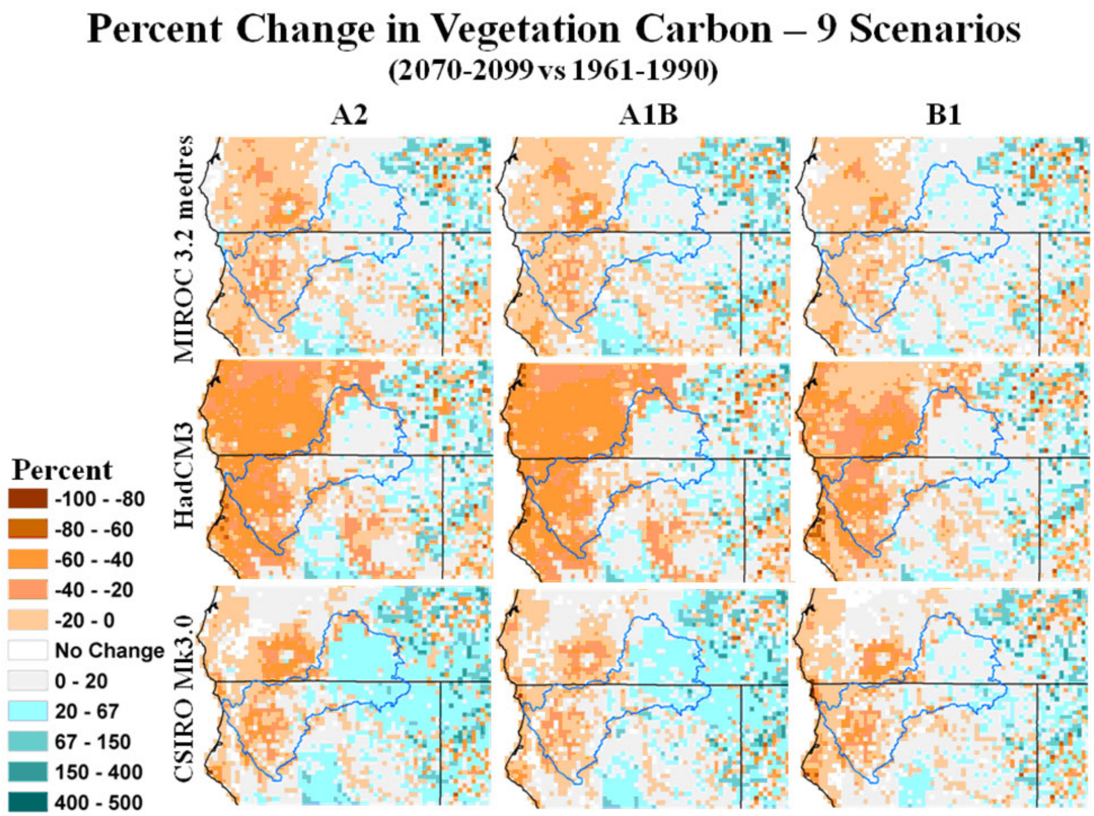

Figure 6-9. Potential change in live vegetation carbon using the MC1 (MAPSS-CENTURY, v1) model.

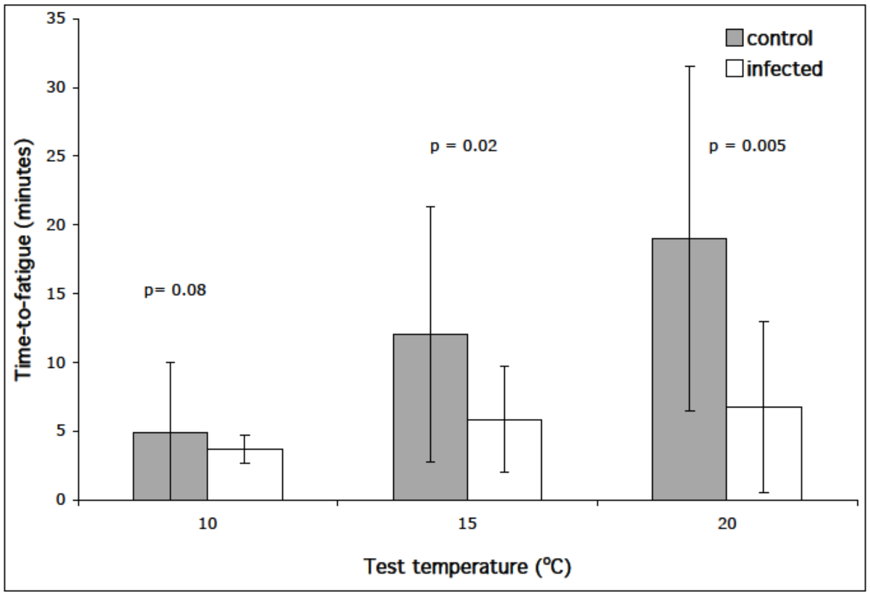

Figure 6-10. Effect of temperature on swimming performance of *Ichthyophonus*-infected and non-infected rainbow trout normalized for body length (Kocan et al. 2009).

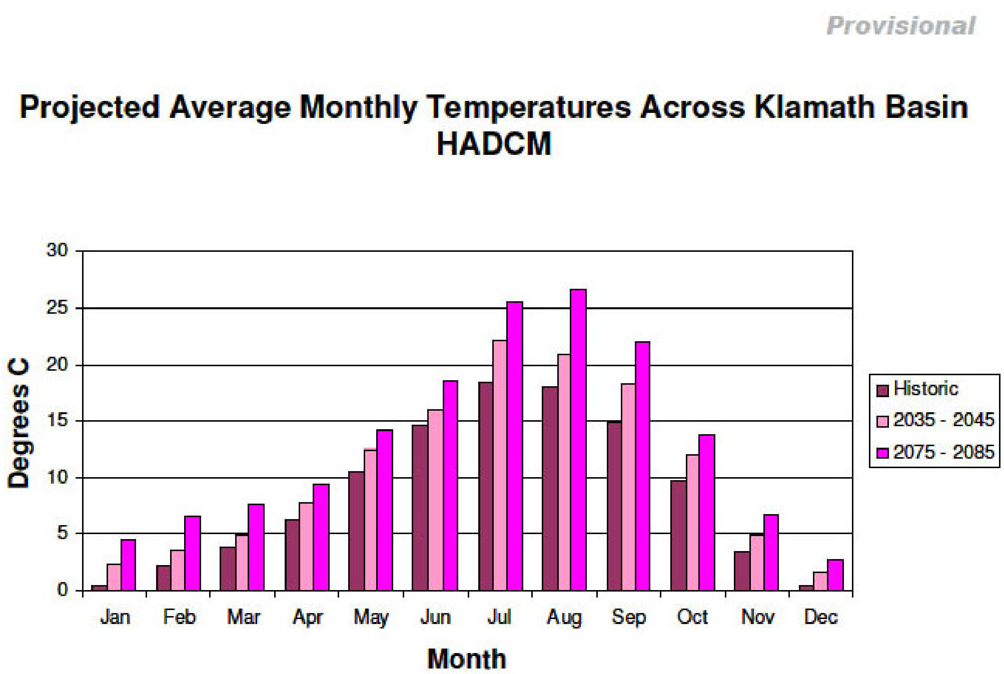

Figure 6-11. Average monthly temperatures project by the HADCM model.

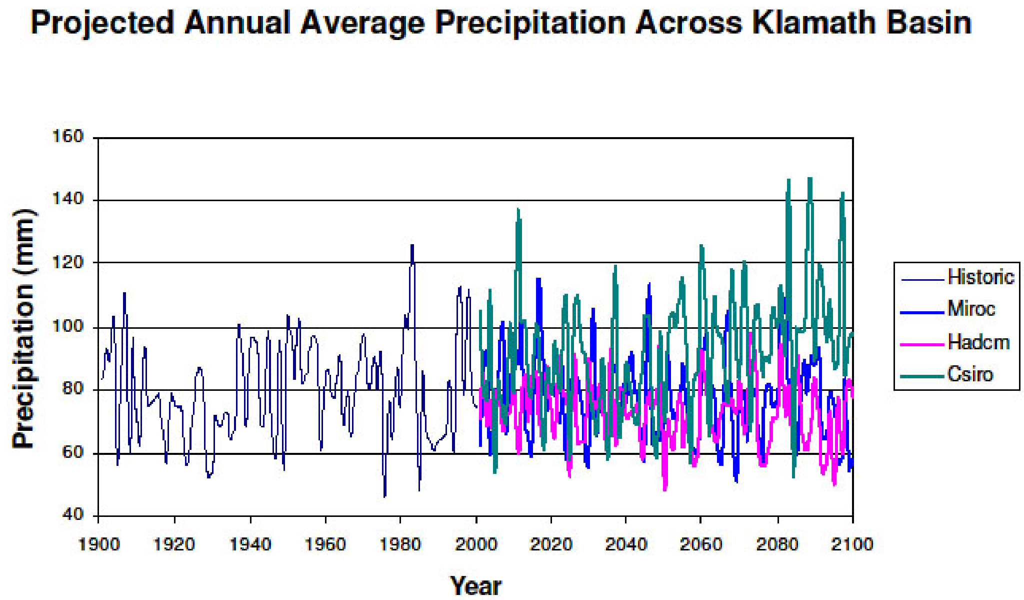

Figure 6-12. Model projections of annual precipitation across the Klamath Basin.

Provisional

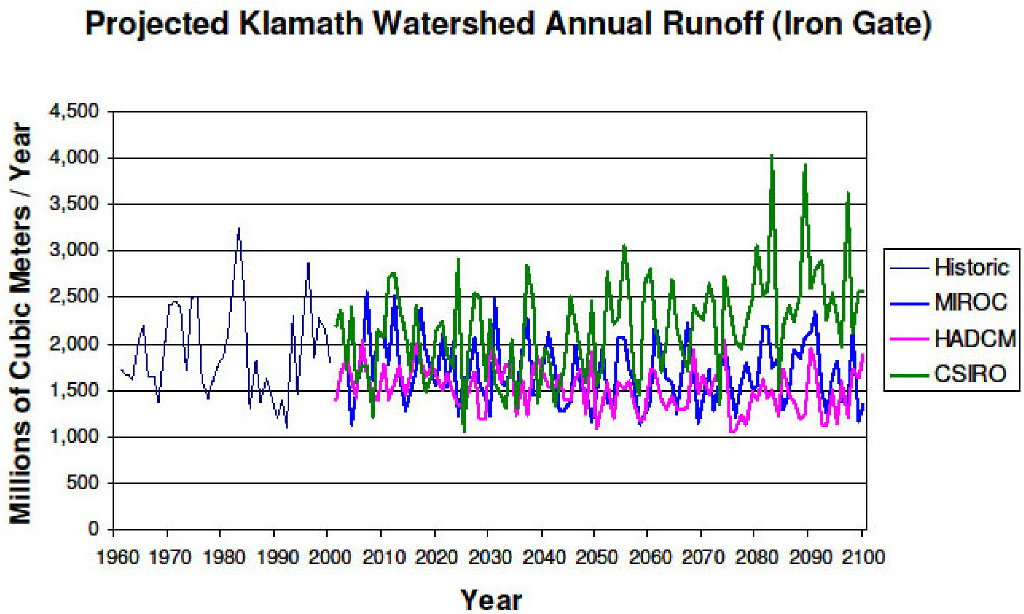

Figure 6-13. Model projections of annual runoff across the Klamath watershed.

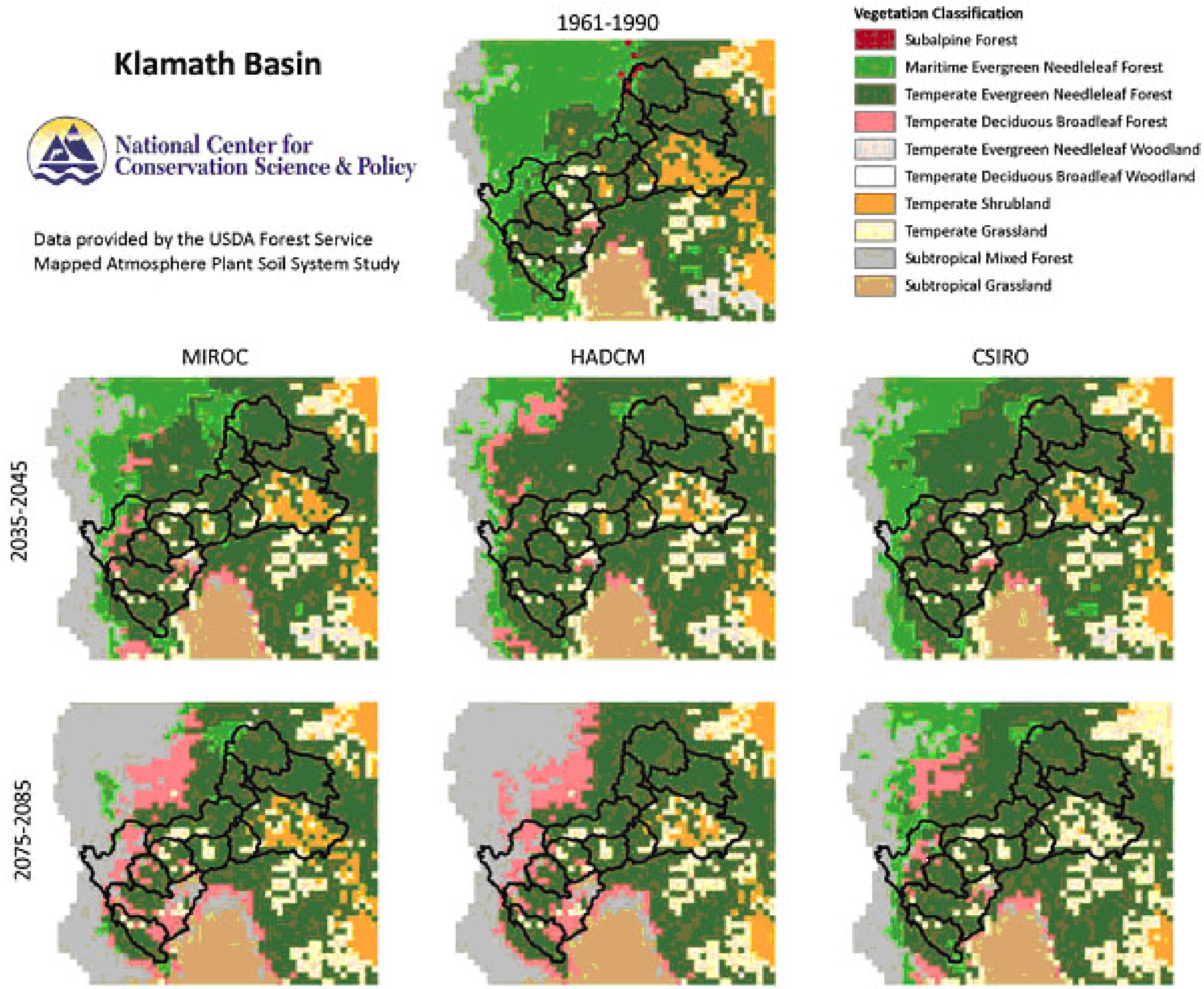

Figure 6-14. Projections of vegetation change using the MC1 Vegetation model (MAPSS-CENTURY v1).

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Chapter 7. Conceptual Model for Restoration of the Klamath River

Jack Stanford[1], Walter Duffy[2], Eli Asarian[3], Brian Cluer[4], Phil Detrich[5], Lorri Eberle[1], Steve Edmondson[6], Scott Foott[7], Mark Hampton[8], Jacob Kann[9], Kevin Malone[10], and Peter Moyle[11],

Introduction

The Klamath River Basin in southern Oregon and northern California has been an epicenter of debate over how to restore and sustain water quality, salmon runs, and other natural goods and services without unduly compromising current uses of water. Despite substantial declines in salmon numbers, the Klamath River remains an important producer of salmon on the West Coast of the United States (not considering Alaska). Historically, the watershed also supported huge numbers of migratory birds and waterfowl in over 750 km^2 of wetlands, marshes, and shallow lakes. Today, water diversions have drained 75 percent of the wetlands and reduced the total annual flow of the river and its major tributaries (NRC 2004). Ten major impoundments facilitate flow alteration to promote agriculture and hydropower throughout the basin. Construction of six dams in the middle reach of the Klamath River increased flow regulation in the lower river and extirpated anadromous fishes from 970 km of potential habitat, including Klamath Lake and upstream tributaries (Hamilton et al. 2005). Altered water flux by human activities in the basin interacts, with other problems, notably nutrient accumulation, high summer water temperatures, toxic algae blooms, hatcheries, and fish diseases. As a result, the ecosystem has changed to the point that sustaining attributes such as high-quality water and wild salmon runs are being compromised. With such wide-scale and in some cases, irreversible change, it becomes difficult to find common ground for providing sustainable goods and services for people while maintaining a functional ecosystem that supports salmon and other desirable features.

The National Research Council (NRC) reviewed the science related to restoration and management strategies for the Klamath River and called for a “big picture conceptual model” to connect scientific studies in an ecosystem context and to allow critical uncertainties to emerge from analysis of the model (NRC 2001, 2007). Both NRC reports stated that the lack of such a model has prevented scientific studies from being used effectively to aid in decision making and resolution of controversies.

The goal of this paper is to provide a conceptual model to underpin plans for restoration of salmon, resident fishes, and other key attributes of the Klamath River Ecosystem. We include boundaries, principles, and assumptions for the Klamath River Ecosystem, with a scientific retrospective analysis serving as the basis for our conceptual model. The authors represent a broad range of professional expertise with many years of research and management experience in the Klamath and other western U.S. rivers.

[1] Flathead Lake Biological Station, The University of Montana
[2] U.S. Geological Survey, California Cooperative Fish and Wildlife Unit, Humboldt State University
[3] Kier Associates
[4] Habitat Conservation Division, National Marine Fisheries Service
[5] U.S. Fish and Wildlife Service, Yreka Fish and Wildlife Office (retired)
[6] National Oceanic and Atmospheric Administration
[7] U.S. Fish and Wildlife Service, California-Nevada Fish Health Center
[8] California Department of Fish and Game, Yreka, CA
[9] Aquatic Ecosystem Sciences, LLC
[10] BioAnalysts, Inc.
[11] University of California, Davis

We start with our view of what a conceptual model should be and then move to descriptions of Klamath Basin physiography and geopolitics. Then we present a retrospective analysis of Klamath biogeography and human influences on aquatic species in relation to functional domains of the river system. The paper concludes with our conceptual model for the Klamath River Ecosystem as derived from our collective understanding of natural and cultural attributes, interactions, constraints, and opportunities.

What is a Conceptual Model?

A conceptual model is an organized set of scientific principles and assumptions that give direction to management activities, including restoration activities, by defining the current understanding of the most important variables and interactive processes (AYK SSI 2006). The model can then be used to identify problems and establish the range of appropriate solutions, given recognition of uncertainties in the science (Ralls and Starfield 1995, Lichatowich et al. 2006, NRC 2007). A well-designed, agreed-upon conceptual model provides the basis for informed decision making if it accurately describes key relationships between ecosystem attributes and processes in relation to environmental stressors (Stanford and Poole 1996, NRC 2007). Ultimately, discussions guided by a clear conceptual model will lead to identification and resolution of critical uncertainties in system science and management (Lichatowich et al. 2006).

Our conceptual model for the Klamath River Ecosystem (given below, last section) summarizes the connections between ecosystem elements and environmental stressors and provides the basis for adaptive management to help shape the scope of restoration efforts. We believe restoration efforts should aim for a “normative state,” rather than a “pristine or normal state.” Normative in the context of fisheries restoration means providing enough ecological connectivity and quality habitat to achieve specified biotic objectives (Stanford et al., 1996). In our view, a conceptual model provides a unified understanding of the ecosystem structure and function, including natural and cultural characteristics, to guide management and restoration to the normative state.[12]

Physiography of the Klamath Basin

The Klamath Basin (41,377 km^2 – fig. 7-1) is a biogeographically complex catchment that includes the Basin and Range, Cascade-Sierra Nevada Mountains, and Pacific Border physiographic provinces of North America (California Geological Survey 2006). The river originates in the “high desert” of southcentral Oregon, largely from springs whose aquifers are recharged in the high snow zone of the Crater Lake area and Cascade Mountains to the west (NRC 2001). Flows from these springs mingle with limited surface runoff and progress downstream into Upper Klamath Lake (232 km^2); from the lake and associated wetlands, drainage coalesces into the main-stem Klamath River that flows west through rugged mountain terrain of the Cascade and Coast ranges to the Pacific. Owing to the rain shadow effect of the coastal ranges, average annual precipitation increases from 41.9 cm in semi-arid headwaters to 156.5 cm in the rain forests near the ocean (Carter and Resh 2005). In long profile, the Klamath River is unique. Its slope is gentle in its vast marshy headwaters, then steep for 200 miles to the Pacific Ocean (fig. 7-2).

The river system may be divided into five geomorphic domains (distinct from “ecological domains” presented below).

[12] The normative state does not imply equilibrium or a static condition. Rather, it implies that although ecological conditions will constantly change, the river will sustain all life stages of native fishes.

Upper Klamath Lake – The first geomorphic domain is Upper Klamath Lake (UKL), including fringing marshes, and three main tributaries that drain agricultural and forested lands upstream of the lake. Stream channels mostly are low gradient and drain volcanic soils. In some places springs from deep aquifers augment surface flows. A basalt dike or sill historically controlled the lake elevation with overflow forming a cataract (Klamath Falls).

Lake level today is regulated by Link Dam, built on top of the sill. The Klamath Irrigation Project (KIP) diverts water from Upper Klamath Lake above Link River Dam into the Lost River Basin, then Tule Lake and the drained basin of what once was Lower Klamath Lake through a complex system of dikes, canals, and pumping stations. The Lost River Basin and its interior lakes and marshes perhaps should be considered a unique physiographic domain of the Klamath River Ecosystem, because historically the Lost River was not a tributary to the Klamath River. However, during some high-flow periods, water from Upper Klamath Lake would spill through Lost River Slough into the Lost River (USBR 2005). Today the Lost River is connected by virtue of the extensive KIP project. Upper Klamath Lake historically was maintained by impoundment of the river by the sill that is now modified by Link River Dam (Kirk et al. 2010).

Canyon Reach – The second distinct geomorphic domain is the very narrow canyon reach from Klamath Falls to the Shasta River. Cool springs in this segment and in side tributaries naturally influence base flows and temperature patterns. This domain today is largely impounded by hydropower dams, with the reach between J.C. Boyle and Copco 1 Reservoir subjected to extreme flow fluctuations from peaking power production. Daily base flow in this reach is about 330 ft^3/s, but peaks to 1,300–2,600 ft^3/s resulting in diel water temperature fluctuations of 6–10°C during summer (Dunsmoor and Huntington 2006).

Free Flowing Klamath River – The third geomorphic domain is the unimpounded Klamath River Canyon (from Shasta River to confluence with the Trinity River) that bisects the Klamath Mountains where precipitation and forest cover increases dramatically in relation to the upstream domains. The river slope is approximately 0.25 percent and the channel is composed of sequences of rapids, pools, runs, and tailouts. These features owe much to large sediment influxes from high-gradient, small tributaries that are routinely scoured by annual flooding and occasional huge spates (ca. 20-year return events) associated with winter rains and snowmelt. In addition, this domain includes the Shasta, Scott, and Salmon Rivers.

Trinity River – The Trinity River (fourth geomorphic domain) is by far the largest tributary, historically contributing a third of the annual flow of the Klamath at the ocean and more than twice the runoff of the Upper Subbasin (NRC 2004). Much of the Trinity also is canyon bound but has 11 alluvial floodplain reaches, giving the Trinity River greater geomorphic complexity than the mainstem Klamath River. The headwaters of the Trinity River are dammed to allow irrigation diversions into the Sacramento Basin. Diverted Trinity River water passes through multiple power facilities which make up one of the most valuable hydroelectric projects in California. The South Fork Trinity River is the largest tributary to the Trinity River and is undammed, punctuated by alluvial reaches, and is the largest unregulated watershed in California.

Coastal Zone – Below the Trinity, the Klamath River enters the coastal zone, the fifth geomorphic domain, flowing through the fog belt associated with the rain forests of the coastal mountains. In this domain the river remains geologically constrained but ultimately meanders into its estuary through a narrow alluvial coastal plain.

Geopolitics

Land ownership in the Klamath Basin is a mix of large Federal [(U.S. Forest Service (USFS), Bureau of Land Management (BLM), National Park Service (NPS)], and private tracts and three Indian (Klamath, Hoopa, Yurok) reservations (fig. 7-1). Four additional Indian Tribes (Karuk, Quartz Valley, Resighini, and Shasta) occupy the basin but do not have recognized reservation lands. Upstream of the Scott River confluence, about 60 percent of the Klamath Basin is agricultural with 930 km^2 of irrigated crops consisting mainly of potatoes, onions, specialty crops, and cattle feeds (one-third of farm income is from cattle production) and the rest in non-irrigated range or private timber lands (http://www.nrcs.usda.gov/feature/klamath/). Land converted to farm-ranching includes at least 75 percent of the historic 750 km^2 of wetlands. Road density in 870 subwatersheds examined in the Klamath Basin averaged 1.5 km/km^2, more than double the national average (http://data.worldbank.org/indicator/IS.ROD.DNST.K2), with almost 10 percent of the subwatersheds having road densities of 2.6–4.2 km/km^2 (Bredensteiner and Strittholt 2002).

Ten major dams have been constructed to regulate Klamath/Trinity River flows, along with hundreds of small water-diversion dams in tributaries. However, the influence of water diversion and damming on flow quantity and pattern is unclear. Annual water flux at Iron Gate Dam is reduced by 30 percent (370,000 acre-ft) in relation to estimated predevelopment flows (fig. 7-3). Estimates of summer flow reductions from the historical to the present period range from 10 percent in Indian Creek to 18 percent in the South Fork Trinity River and 40 percent in the Scott River (Van Kirk and Naman 2008). Most (ca. 70 percent) of the reduced summer flow in one of the best documented tributaries, the Scott River, has been attributed to increased irrigation withdrawal since the 1950s (Van Kirk and Naman 2008). The unimpaired flow (without diversions and groundwater pumping) of the Scott River in August was estimated to be 154 ft^3/s, compared to the current flow of 19 ft^3/s (NCRWQB 2010). Similarly, NCRWQCB (2010) noted that irrigation diversions have reduced Shasta River flows by approximately 80 percent during late summer. Inter-basin diversion of water into California's Central Valley takes more than 51 percent of the historic flow of the Trinity River (in the past as much as 88 percent was diverted) at Lewiston Dam, the diversion point (NRC 2001). This translates to a current annual flow at the confluence with the Klamath of $4{,}332 \times 10^6$ m^3 (NRC 2004) compared to $5{,}550 \times 10^6$ m^3 annual historical flow, or almost 1×10^6 acre-ft (Bartholow et al. 2005). In spite of this decrease, average flows in the Trinity River during summer and fall are now greater than they were before diversion owing to the regulation scheme. All these diversions have important local effects. NRC (2004) concluded that while the Klamath River overall is not substantially dewatered by water withdrawals, the annual flow patterns in the various domains have changed substantially. For example, the net consumptive use by KIP is only 2 percent of the Klamath River discharge at the ocean (Bartholow et al. 2005) but the pattern of flow clearly has changed. Flow reduction of the Klamath River below Iron Gate Dam during the summer months can be fairly severe. Campbell et al. (2001) using a rough flow-temperature-water quality model concluded that increasing flows below Iron Gate would do little to ameliorate temperature or water quality problems. However, in modeling water quality from Keno Reservoir to the ocean, Dunsmoor and Huntington (2006) reported that dam operation influenced water temperature in the river for more than 200 km below Iron Gate Dam.

In any case, the 150 year legacy of agricultural, commercial timber, and urban development in the Klamath is consistent with observed temperature, nutrient, pesticide, and herbicide contamination of aquatic habitats and biota. Seasonal and spatial effects of these pollutants range from non-existent to severe and even acutely toxic in some places such as the mainstem reservoirs during heavy blooms of blue green algae. Invasive species (e.g., 20 fish species, Moyle 2002) such as fathead minnows (*Pimephales promelas*) and yellow perch (*Perca* *flavescens*) also create problems in relation to food web changes, especially in the upper subbasin and reservoirs (Carter and Resh 2005).

Interactions among changing land uses, water withdraws, highly seasonal climate patterns, pollution, and varying climatic zones create a complex environmental template in the Klamath. The States (OR, CA), Environmental Protection Agency (EPA), USFS, U.S. Fish and Wildlife Service (USFWS) (National Wildlife Refuges), BLM, National Marine Fisheries Service (NMFS), and Tribes all have mandates to ameliorate or regulate attributes of the ecosystem. Key jurisdictions shown in figure 7-1 are patchy. Too often pollution or other management problems cross jurisdictional boundaries making uniform responses difficult.

ESA Listings

The listing of multiple species under the Endangered Species Act (ESA) is an important aspect of the intersection of Klamath Basin science and geopolitics. Lost River suckers (*Deltistes luxatus)* and shortnose suckers (*Chasmistes brevirostris*) were listed in 1988 and coho salmon (*Oncorhynchus kisutch*) were listed in 1997 (NMFS 2007). ESA listing provides a Federal mandate to recover these species to long-term viable status. The USFWS holds the responsibility for restoring the listed freshwater fishes whereas the NMFS (NMFS, a part of the National Oceanic and Atmospheric Administration) is responsible for restoring endangered anadromous fishes such as coho salmon.

The USFWS developed a recovery plan (USFWS 1993) for shortnose and Lost River suckers. Key aspects of the sucker recovery plan include: establishing safe refuge populations within the watershed for both species; researching population and habitat needs; improving habitat conditions through rehabilitation of riparian habitats and wetlands, reducing land use impacts, and improving land management practices in the area; developing and achieving water quality and quantity goals; and improving fish passage and spawning habitat. The sucker recovery plan is undergoing revision at this time. Key aspects of the coho salmon recovery plan (CDFG 2004A) include: hatchery supplementation, water conservation and management, screening to prevent juvenile entrainment, habitat rehabilitation and riparian restoration, fire management and fuel reduction, removal of permanent and seasonal barriers and/or passage around dams, road rehabilitation and/or decommissioning, river flow, and fluvial habitat manipulations to restore floodplain connectivity (Trinity River, Klamath River tributaries), harvest restrictions, restoration of cool, high quality tributary stream flow, and implementation of restorative measures identified through disease research.

The recovery plans do not, however, address how these measures are to be accomplished. It is likely that listed species will continue to be a prime driver of negotiations between stakeholders and managers of the Klamath River.

Klamath Basin Settlement Agreements

The Klamath Basin is an ecologically and politically complex basin with farmers, Tribes, scientists, governments and environmental groups struggling to find common ground regarding how to manage and restore the ecosystem; some significant headway has been made. In January 2008, 26 stakeholder groups released a public review draft of the so-called Klamath Basin Restoration Agreement (KBRA). Then in November 2009, PacifiCorp, the Federal Government, and the States of California and Oregon announced an “Agreement in Principle” for the Klamath Hydroelectric Settlement Agreement (KHSA), which would lead to removal of the four mainstem Klamath Dams owned and operated by PacifiCorp: Iron Gate, Copco 1 and 2, and J.C.

Boyle (see fig. 7-1). Together, the KBRA and the KHSA constitute the Klamath Basin Settlement Agreements.[13]

This initiative is historic in scope and proposes to restore and sustain natural populations of Klamath River anadromous and resident fishes. The agreements call for the removal of four mainstem hydropower dams and also call for maintenance of long-term, reliable water and power supplies for agriculture, communities, and fish and wildlife. Key points of the settlement agreements include:

- Reintroduction of anadromous fish above Iron Gate dam (including the Upper Klamath Lake tributaries);
- Periodic assessment of the status and trends of the fish populations and the effectiveness of the management practices;
- Permanent increase in instream flows and the maintenance of Upper Klamath Lake (UKL) elevation by limiting the amount of water that can be diverted from UKL and the Klamath River;
- Reduction of permitted diversions to 100,000 acre-ft less than current usage in the driest years;
- Keeping Keno and Link dams in place to facilitate the KIP (both have fish passage facilities that would be upgraded, if necessary);
- Voluntary retirement of water rights and enhancement of water conservation and storage to benefit fish;
- Development of a drought plan; and
- Power cost security to assist in maintaining sustainable agriculture communities.

The agreements establish a Klamath Basin Coordinating Council to facilitate coordination, cooperation, collaboration, accountability, and general oversight of the restoration process. Additionally, a clear process for dispute resolution has been established. If enacted, the agreements represent a major step towards recovery of the Klamath River anadromous and resident fishes (*see http://klamathrestoration.gov/*).

Dam Removal

The KHSA sets general criteria for an eventual decision by the Secretary of the Interior as to removal of the four dams listed above. The process of compiling hydrological, biological, and engineering data to inform the Secretary's decision has recently begun. However, a number of key uncertainties associated with dam removal can be listed with speculative comment on effects:

- **The impact on benthic biota and fish of the downstream flushing of reservoir sediment deposits upon dam removal.** Preliminary analyses indicate that the majority of reservoir deposits are sand or finer, with a high percentage of organic sludge from deposition of dead algae and fine clay. Modeling (USBR 2011 Stillwater Sciences 2008) suggests that these fine materials should wash out of the river system very quickly. Former channels should be quickly reactivated in the former reservoirs.
- **The effects of short- and long-term changes in sediment transport and downstream geomorphology.** The watershed does not produce much coarse sediment above the hydropower facilities because most is trapped by UKL. The original river

[13] These settlement agreements were signed by the parties within a few weeks of the date of this presentation at the Klamath Basin Science Conference.

channel below UKL is starved for gravel and cobble that favor salmon spawning and rearing. Bed loading greatly increases at the Shasta and Scott Rivers.

- **Toxic effects of contaminants transported with sediments.** Preliminary bottom cores revealed no significant contamination.
- **Change in river temperatures.** Modeling results suggest slightly warmer spring and mid-summer temperatures (fig. 7-4). Warmer temperatures in spring should benefit fish growth and dam removal will open up new cold water refuges by providing fish access to high volume springs downstream of J.C. Boyle Dam and possibly to others that were inundated by the reservoirs. Additionally, without reservoir volume, water temperatures will be more responsive to air temperature and will be lower during the October-November fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning season.
- **Effects on prevalence of fish diseases in the Klamath River and UKL that seem to be linked to change in temperature patterns.** Dam removal should allow for a wider distribution of spawning Chinook salmon, reducing density of adults below Iron Gate Dam and reducing potential for disease transmission. Dam removal should also allow for more variable flows and could reduce the abundance of the intermediate host for diseases.
- **Bank sloughing in reservoirs associated with drawdown.** This is likely not a major threat because the banks are predominately bedrock.
- **Effects on water quality.** Currently, water quality in the reservoirs is very poor owing to high summer water temperatures and intense algae blooms that elevate pH and create high concentrations of particulate organic matter (POM). Algae and nutrients that cause high concentrations of POM in the reservoirs are exported from UKL and in irrigation return flows from KIP. However, algae also grow prolifically in Copco and Iron Gate Reservoirs, producing toxins and additional POM due to the alteration from a free-flowing river not conducive to planktonic algal growth to lake-like conditions that currently support large blooms of algae. Low dissolved oxygen (DO) concentrations occur in the reservoirs in relation to bacterial decomposition of the POM as it settles to the bottom. After dam removal, POM concentrations will be limited to UKL export and oxygenation and breakdown of POM should be stimulated by conversion to turbulent flow. Thus, water quality, except perhaps for periods of extreme algal production and high temperatures in UKL (see below), should substantially improve in the hydropower reach and further downstream after dam removal.

In summary, it appears that dam removal would be ecologically beneficial to the Klamath River Ecosystem and that it is likely as part of the settlement agreements. While the logistics and liabilities of the removal process are unclear, we have assumed for purposes of developing our conceptual model that dam removal would occur.

The Klamath River Ecosystem: A Retrospective Analysis

Early planning for the conceptual model led to the description of 11 distinct “ecological domains” within the Klamath River ecosystem (fig. 7-5). Each ecological domain has distinctive attributes for production of resident and anadromous fish, but they must be viewed as interconnected and interactive. Together they make up the ecosystem and define its complex character. That character may be expected to change within and among domains as restoration actions, such as dam removals, proceed. In this section we summarize the ecology of each ecological domain and catalog the primary stressors that are limiting production of resident and anadromous fish therein (table 7-1).

1a.Tributaries above Upper Klamath Lake

The Williamson, Sprague, and Wood Rivers are the primary tributaries upstream of Klamath Lake. The Sprague River is technically a tributary to the Williamson River, but is recognized separately here. Seven Mile Creek also contributes flow directly to UKL. The hydrology of these rivers is mainly driven by spring snowmelt, and significant springs also contribute to flow throughout the area. The Sprague is more of an alluvial floodplain river than the Williamson River. The forested upland areas of the watersheds are fire prone owing to the arid nature of the upper subbasin. Nonetheless, these tributaries have cold-water conditions, at least around springs, providing important habitat for endemic fishes including the redband trout (*Oncorhynchus mykiss gairdnerii*) and endangered shortnose and Lost River suckers. However, water diversions have reduced inundation of floodplain aquatic habitat (floodplain-channel disconnection) and years of grazing have reduced riparian vegetation and potentially increased heat loading in these streams through reduced shading. The upper subbasin is dominated by volcanic activity and fault-bounded valleys that contain large lakes and wetlands (including Crater Lake). The basalt formations resulting from volcanic activity (Gannett et al. 2007) apparently contain large, deep aquifers that feed a number of large springs that augment surface flows in the upper tributaries. These groundwater reservoirs are recharged annually via snowmelt, perhaps mostly in the Crater Lake area (NRC 2004).

1b. Upper Klamath Lake (UKL)

Upper Klamath Lake is Oregon's largest lake, 232 km^2, but it is very shallow with a mean depth of only 2.8 m at full pool. Thus, it has a large littoral zone that is essentially a fringing marsh. Large areas of marsh have been diked and drained to facilitate agriculture. Recently, some dikes were breached to allow marsh restoration. The lake is hypereutrophic and massive blooms of blue green algae occur annually, owing to intrinsic fertility related to shallow water, warm climate, and accelerated inputs of nutrients from agricultural runoff (NRC 2004). Much of the water column is hypoxic or anoxic during periods of thermal stratification. Nonetheless, the UKL food web (fig. 7-6) has important benthic and pelagic elements, including chironomids and oligochaetes living in the bed sediments and feeding on organic matter and abundant diatoms and zooplankton in the open water areas. Within the pelagic community, the most dominant species is *Aphanizomenon flos-aquae*, a filamentous blue green algae that overwhelms the planktonic food web and stresses this ecosystem during intense bloom periods (Kann 1998, Kann and Welch 2005). These blooms produce poor water quality including elevated pH (Kann and Smith 1999) and low dissolved oxygen (Kann and Welch 2005). Bloom declines and associated loss of photosynthetic oxygen production and decomposition are directly related to hypoxia (Kann and Welch 2005). Periods of limited wind mixing and current-driven transport of hypoxic water from deeper lake areas has been associated with fish kills, including large kills of the endangered endemic suckers (Kann and Welch 2005; Wood et al. 2006). Nutrient ratios in UKL effluent are determined by the intensity of the algal blooms with concentrations of N generally increasing due to N-fixation by *Aphanizomenon flos-aquae*. The loss of fringing marshes accelerated nutrient loading and has contributed to harmful algal blooms in UKL (Snyder and Morace 1997). The paleolimnological record in the lake sediments shows that blue green algae (though not *Aphanizomenon*) was present prior to any wetland disturbance (Eilers et al. 2004), which suggests the lake was naturally eutrophic. Paleolimnological studies also showed that sockeye salmon (*O. nerka*) were once abundant in UKL about 40,000 years ago (Daniel Shindler, University of Washington, personal communication). The cause of their demise is unclear but may be related to climate change. Historically, Chinook salmon and steelhead (*O. mykiss*) were present in tributaries above UKL (Hamilton et al. 2005, Butler 2010) but were lost with dam construction. Although water quality in UKL is less than optimal during parts of the year, Dunsmoor and Huntington (2006) suggested that migrating adult Chinook salmon could easily access the Williamson River above UKL during spring and fall and that juvenile Chinook salmon would likely migrate out through UKL unimpeded.

1c. Link River Dam to Keno Dam

Link River Dam, located at the outlet of UKL, is situated on the basalt sill that historically controlled the natural lake level. Today the Link River below the dam connects UKL to Keno Reservoir, whose upper extent is referred to as Lake Euwana. Link River delivers UKL outflows to Keno Reservoir, a long, shallow reservoir of approximately 800 acre-ft that facilitates diversion of Klamath River water to the Lost River basin and portions of the KIP. The Lost River Basin (historically a hydrologically closed basin with no surface outlet) is connected to the Klamath River by canals carrying Klamath water to the KIP; on average 400,000 acre-ft annually are diverted to the KIP, with some 100,000 acre-ft of return flows into the Klamath River (NRC 2004). Poor water quality in Keno Reservoir reflects the degraded quality of UKL water and pollution in the return flows. The plankton community is dominated by blue green algae and characterized by low DO concentrations from June to November (peak in early August). High temperatures and degraded water quality may represent barriers for fish migration during mid-summer even if passage over dams is created. However, as in UKL, these extreme DO conditions are seasonally transient and migration windows may exist. Link River Dam does have modern fish passage facilities for suckers and salmonids, while facilities at Keno Dam are ineffective and in need of upgrading if the downstream dams are removed.

2. Keno Dam to Iron Gate Dam (Hydropower Reach)

Below Keno Dam the river flows through a very steep sided canyon into the first of four reservoirs behind small hydropower dams (J.C. Boyle, Copco 1 and 2, and Iron Gate). Water quality improves in the free-flowing portions of this reach. Several large, cold springs enter the river below J.C. Boyle Dam, subsidizing flow and generating cooler temperature patterns. The high gradient creates turbulence that increases oxygen concentrations and ammonium is converted to nitrate (nitrification, Deas 2008). The reach has abundant fishes, notably native redband trout (*Oncorhynchus mykiss newberrii*). These trout also live and may spawn in Spencer Creek, an important spring-driven tributary that currently flows into J.C. Boyle Reservoir. J.C. Boyle Dam has a fish ladder, but anadromous fish movements are blocked at the lower dam (Iron Gate) and its use by resident fishes is poorly documented. Spencer Creek and Shovel Creek are two larger, low-gradient tributaries that may provide excellent habitat for coho salmon if the dams proposed for removal are removed. Dam removal would allow coho salmon to access an additional 109 km of tributary and mainstem river habitat in this domain, assuming they migrate as far as Spencer Creek. It would also allow their access to approximately 37 km of riverine habitat currently inundated by the reservoirs (Cunanan 2009). Spencer, Shovel, and Fall Creeks, along with springs in the mainstem river (currently inundated), deliver cool water that could, with dam removal, contribute to thermal diversity in the reach (Hamilton et al. 2011.

While the very high nutrient (N and P) concentrations from the upper subbasin are ameliorated somewhat by the springs and turbulent flow below Keno Dam, POM, mainly originating from blue green algae upstream, remains elevated when the river water is impounded behind the four hydropower dams. Two of the reservoirs (Iron Gate and Copco 1) are deep enough to stratify in the summer, resulting in toxin-producing cyanobacteria blooms and anoxic hypolimnia. *Microcystis aeruginosa*, *Aphanizomenon flos-aquae*, and *Anabaena* spp. are present but Microcystis usually dominates (Kann and Asarian 2007). The algal blooms can be so intense that the cyanotoxins produced by Microcystis can be a threat to humans and animals (Kann 2006, Kann and Corum 2009). In addition, algal toxins have been shown to bioaccumulate in yellow perch (*Perca flavescens*) in the reservoirs and in salmon, steelhead, and freshwater mussels in the Klamath River below the reservoirs (Kann 2008, Kann et al. 2010, Kann et al. 2011). This entire reach is canyon bound with big springs but there are no large sediment-delivering tributaries and UKL traps most of the sediment from upper subbasin sources. Thus, the historic channel in this reach is probably relatively unaltered by impoundment.

3. Mainstem Klamath River from Iron Gate Dam to the Estuary

The mainstem Klamath River below Iron Gate dam is riverine (no dams) to the ocean and, with respect to restoration, is the key, controversial segment of the Klamath River Ecosystem. Fall and spring Chinook (*O. tshawytscha*) and coho salmon, steelhead, Pacific lamprey (*Lampetra tridentata*) and green sturgeon (*Acipenser medirostris*) are the anadromous fish species of greatest concern in this segment.

Salmon and steelhead enter the mainstem river to spawn in all months of the year (fig. 7-7). Fall Chinook spawn primarily between Iron Gate Dam and the Shasta River (Grove and Magneson 2006) and a few spawn as far downstream as Bluff Creek. It is unknown if their spawning distribution differs from the historical distribution but it was probably truncated by the dams. Spring Chinook apparently used the upper reaches of the larger tributaries (e.g., Salmon and Scott Rivers) and spawned in tributaries to UKL. Coho salmon use the mainstem Klamath River primarily as a migratory corridor, spawning primarily in tributaries, but also rearing in non-natal tributaries (Sutton and Soto 2011). Some coho tributaries are very small (e.g., Willow, Cottonwood Creeks) and of intermittent flows at times and salmon survival in these environments may be very low. Habitat use and survival studies are lacking. Above Iron Gate Dam, Spencer Creek may have represented the historic upper limit of coho distribution (Hamilton et al. 2005. Steelhead spawn and rear in most Klamath River tributaries. They also spawn and rear in the main river with some segregation between winter and summer runs. Information about the spawning distribution of Pacific lampreys is lacking. They are assumed to spawn in the tributaries and in the main channel of the Klamath River although evidence for the main channel does not exist. Pacific lampreys have an observed bimodal distribution of river entry timing which supports the multiple spawning habitats proposed above. Green sturgeon spawn in deep water below Ishi Pishi Falls, thought to be the upper boundary for sturgeon migration, and in the lower Salmon River. Sturgeon generally move into the river in March, spawning between May and June and then moving out with the fall rains. Eulachon (*Thaleichthys pacificus*) spawn in the lower 20 miles of the river between February and April. These fish were formerly abundant but now are almost extirpated (Larson and Belchik 1998).

Iron Gate Hatchery is located just downstream from Iron Gate Dam. Its purpose is to mitigate the loss of 26 km of salmon spawning habitat between Iron Gate Dam and Copco 2 Dam. However, the potential effects of hatchery salmon on native stocks are unknown but presumed to be negative (NRC 2004). One indication of negative impact is that the percentage of returning hatchery fish in all runs of salmon and steelhead is increasing as wild fish numbers decline (R. Quinones, Univ. Calif. Davis, personal communication). Generally, hatchery fish (ca. 6 million Chinook annually: 5 million smolts and 1 million yearlings with a survival rate of 0.4 percent overall based upon coded wire tag returns) are released after mid-May, depending on growth rates. Releases after June may experience adverse water quality conditions (warm water) and low flows that likely reduce survival, increase crowding, and increase the probability of exposure to disease. Hatchery fish compete with wild salmon and steelhead for food and space with probable effects on growth and survival (NRC 2004). Wild salmon and steelhead returns outnumber hatchery fish and have greater smolt-spawner survival. Nonetheless, large percentages of the ocean commercial and Native American in-river harvests of Chinook salmon derive from Iron Gate and Trinity River hatcheries.

The mainstem Klamath River is mostly a confined channel within steep canyon walls with a few cottonwoods (*Populus* spp.), willows (*Salix* spp.), and some conifers (*Pinus* spp., *Pseudotsuga* spp.*)* fringing the single channel. The bed morphology is gravel-cobble with large colluvial chunks creating particularly complex edge habitats between riffle-rapids-pools-runs-tailouts over gravel bars. The in-channel alluviation (organization and size of gravel bars) increases with distance downstream because bedload increases as high-gradient tributaries in the Cascade and Coast ranges deliver more sediment. In a few locations the river aggrades into gravel-cobble flood plains where back channels (both natural overflow channels and remnants from gold dredging) add to the habitat complexity. No quantitative information has been published about riverine food webs in the mainstem river, but productivity is most likely driven by strong interactions between allochthonous inputs from the riparian zone, algae, and other microbiota growing on rocks (aufwuchs), and a microbial loop involving fine particulate organic matter (FPOM) and fine sediments (fig. 7-8). The mainstem river is characterized by highly unpredictable flows and, as mentioned above, natural flooding of the Klamath River results from spring snowmelt in high elevation areas and fall-winter pluvial (rainfall) events common in the middle and lower reaches. Dam operations have little to do with the management of large flood events because of their lack of storage capacity (except in the Trinity River). However, power and diversion dams do significantly reduce variation of mid-range to base flows (NRC 2004).

Historically, the dam operator, PacifiCorp, maximized mid-winter (November through February) power generation in the hydropower reach. This practice changed in the 1980s when the UKL suckers were listed as endangered. Since the 1990s fall-winter releases for power generation were discontinued to increase lake levels in UKL to improve habitat conditions for the suckers. This action, coupled with the reregulation of flow in the reservoirs downstream, stabilized the mid-winter flows in the mainstem. Moreover, with the listing of coho salmon, more water is required in the mainstem Klamath during periods of salmon emigration. This reduces the certainty of restoring UKL levels and requires a cautious approach to water management to ensure stable flows near the required minimums during fall and winter months. With this approach, there may be a reduction in usable habitat for fish in the mainstem. An exception would occur during very wet years when the river floods in spite of Link River Dam. PacifiCorp generally initiates water passage through the dam once the lake is full, which usually occurs in concordance with snowmelt. If there is a rain on snow event during this time, the flow can surge dramatically. However in most years the reach from Iron Gate to the Shasta River remains at or near base flows throughout fall and winter. Down river rainfall generally controls flows downstream to the ocean. In dry years some portions of the Shasta and Scott Rivers cease to flow entirely and with little input from the other major tributaries, releases from Iron Gate dominate the flow pattern to the ocean.

The timing and magnitude of the flow releases from Iron Gate Dam can have a significant influence on juvenile fish survival. High spring flows (high enough to inundate riparian willows, *Salix spp*.) appear to correlate with increased Chinook survival (perhaps owing to more food in the riparian areas or more cover from predators). Flows can also influence the transit time of fry and smolts. Juvenile salmon often emigrate by swimming facing upstream, allowing the current to take them downstream while they feed. When flows are low, transit times are increased or smolts must actively swim and thereby increase their energetic demands.

In addition to flow, temperature is another controlling habitat variable in this reach. Moderated heat flux related to reservoir volume results in a thermal lag in the temperature pattern below Iron Gate (fig. 7-4). In the spring, warming is delayed and daily temperatures are less variable. In the late summer and fall, dam operation delays cooling to temperatures favorable to salmon migration (Bartholow et al. 2005, Dunsmoor and Huntington 2006). The flow regulation causes a dampening of short-term temperature fluctuations, particularly during late spring through early fall and the dams create a smoother rise to peak temperature. In the summer, reservoir transit eliminates the historic diel variation in temperatures; nocturnal cooling does not occur. In the fall, the water stays warm until the onset of the elevated winter flows that cool the water, creating a temperature lag of about three weeks (Bartholow et al. 2005, Dunsmoor and Huntington 2006). This three week temperature shift closely matches the difference in the dates of peak fall Chinook catch reported during the early 1900s (August 14–27, Snyder 1931) and peak catches during recent years (September 9–16, CDFG 2010) and is further documented by Shaw et al. (1997). Dunsmoor and Huntington (2006) concluded that this shift in run timing is the result of warmer water temperature during fall in recent decades and attributed warmer fall temperatures to dam operation. If the temperature shift is in fact affecting run timing it could be increasing the susceptibility of adult salmon and steelhead to disease transmissions by crowding them into cold-water refuges during hot periods (Guillen 2003). In summer and early fall, the presence of cold-water refuges is critical to fish survival as long as disease outbreaks do not occur (Belchik 1997, Belchik 1998, NRC 2004).

The main diseases affecting Klamath River salmon are caused by the myxozoan parasites *Ceratomyxa shasta* and *Parvicapsula minibicornis*, with many fish having dual infections. Both myxozoan parasites have the same polychaete alternate host that lives in the river benthos. The reach from the Shasta River to the Seiad Valley is dubbed the “hot zone” for high infection rates (Atkinson and Bartholomew 2010). Also, adult Chinook salmon returning to the Iron Gate hatchery congregate just below the dam and on Bogus Creek, enhancing the likelihood of completion of the *C. shasta* life cycle. Hypotheses developed for reducing rates of infection include reducing the polychaete host populations through flood mediated benthic scouring or low flow events that might encourage desiccation, reducing exposure to actinospores and removing the myxospores (found in carcasses) from the “hot zone.” It should also be noted that the removal of Iron Gate Dam would allow flushing flows could reduce the diatom concentrations that feed the polychaete, potentially reducing polychaete populations and *C. shasta*.

However, the largest mortality event for adult salmon on record in the Klamath River was not caused by *C. shasta*, but by bacterial and parasitic gill infections (Guillen 2003). The event was related to fish crowding in cool-water areas, such as tributary confluences, during periods when the majority of the river’s water was lethally warm. In September 2002, low flows and high temperatures coincided with high numbers of returning Chinook salmon in the river downstream of the Trinity confluence. The salmon congregated in cooler waters from the fog belt tributaries, notably at the mouth of Blue Creek. The gill infections spread rapidly among the fish, killing at least 30,000 salmon prior to their spawning (CDFG 2004B).

Exactly what flow-temperature pattern can be considered normative for the Klamath River mainstem is uncertain. There is a growing consensus that the current long-term stable (regulated) flow in the summer is not beneficial because constant flow enhances luxuriant growth of periphytic algae and bacteria (aufwuchs) and ultimately high conditions that promote densities of the polychaete host of *C. shasta*. However, how juvenile salmon would react to variable temperature flow patterns that can change fish growth and migration behaviors is not clear. Mainstem flow-temperature patterns would be more tightly coupled to tributary dynamics once the dams are removed, and this would probably reduce the potential for disease transmission in salmon through overall improvements to habitat.

Modeling of water quality with dams in place and without suggests that summer and fall river temperatures will be more favorable in the mainstem to salmon after the dams are removed (Dunsmoor and Huntington 2006). They note, however, that water quality will very both spatially and temporarily with meteorological conditions. Flows are likely to be lower (and warmer) at some times of year and climate change may further raise river temperatures 2 to 3°C by 2080. Thus, it should be assumed that large stretches of the lower river are going to be unsuitable for salmonids at certain times of the year no matter what actions are taken. Persistence of most runs will depend on access to cold-water refuges during the warmest times of year.

4. Shasta River

The Shasta River headwaters are in a mountain reach that feeds Dwinnell Reservoir and valley springs; below the dam the river meanders through a valley-bottom reach and from there the river flows through a canyon to its confluence with the Klamath River. The flow pattern has a significant snowmelt peak in the spring and base flow is maintained by springs whose sources generally originate from glacial melt on the slopes of Mount Shasta (NRC 2004). Springs allow this river to remain cooler in the summer and warmer in the winter while also providing nutrients that drive high natural productivity. Invertebrates, especially amphipods, are abundant and the benthos is notably diverse, particularly Odonata (20+ species at Big Springs). Historically, large numbers of coho (100s), Chinook (1,000s) and steelhead (100s) spawned in the lower canyon and upper valley reaches near the source of spring flow inputs, although numbers are much reduced today. Juvenile salmonids have very high growth rates in this river, likely associated with the abundant invertebrate populations.

The montane reach of the Shasta River has flows maintained by a significant number of springs, as well as snowmelt runoff. However, Dwinnell Dam has cut off this reach from salmon and steelhead migration. The reservoir is used mostly for irrigation although there is some use for drinking water and recreation. Algal blooms occur in the reservoir over much of the summer. The reservoir is known to leak significantly (holds 50,000 acre-ft and leaks 30,000), and the leaking water could be feeding springs elsewhere in the system although there is little evidence that much of the water winds up back in the river (NRC 2004). Parks Creek below the dam is a similar, highly diverted stream, and has considerable potential for salmon production, as does the Little Shasta River, which is diverted to lakes managed by the California Department of Fish and Game (CDFG) for bass (*Micropterus* spp.) fishing and waterfowl.

The Shasta River was a major contributor to salmon and steelhead production in the lower Klamath because of its extraordinary productivity and near-optimal year-around temperatures (C. Jeffres, UC Davis, personal communication). Growth and survival rates of juvenile salmonids were historically very high and the Shasta produced 50 percent of the Chinook in the entire Klamath Basin. This is of particular note, considering that the flow of the Shasta at its mouth is only 1 percent of the total flow of the Klamath River. In the 1930s, the Shasta produced 80,000 Chinook (NRC 2004). Fall Chinook spawn throughout the valley and canyon reaches. Coho spawn in the upper reaches of Shasta Valley, above the County Road A-10. However, in some years spawning has been documented in the lower canyon as well. Progeny of coho that spawned in the canyon reach generally do not survive because of excessively warm summer temperatures (C. Jeffres and P. Moyle, *in press*). Little is known about the life history of Shasta steelhead but it is believed that they move to sea at age 1+. However, because growth rates are high for steelhead, coho, and Chinook, and many juveniles emigrate from the Shasta at age 0+. See figure 7-7 for a summary of run and spawning timing.

The major habitat issues on the Shasta River include dewatering, fine sediments, grazing impacts, warm irrigation return water, and the presence of numerous small diversion dams. Restoration efforts have focused on screening and improving diversions, management of irrigation returns, and riparian fencing. Water availability is an issue and some summer months flow is decreased by as much as 80 percent (NCRWQCB 2010). There is a long list of priority water rights for the Shasta's water. The water withdrawals have contributed to fish mortality through strandings, high temperatures, dense growth of macrophytes causing diurnal hypoxia, and high pH conditions. Temperatures have exceeded 30°C in the canyon during low flow events in summer. The recent acquisition of two ranches associated with Big Springs Creek by The Nature Conservancy has changed the management of the land and water, resulting in dramatic improvement of rearing conditions for salmon and steelhead in the creek and river for several miles below it. As with the other Klamath tributaries there is a strong link between the conditions in the mainstem Klamath and the ultimate survival of juvenile Shasta River fish.

5. Scott River

The Scott River is a snowmelt dominated river system whose headwaters originate in the Marble Mountain, Russian, and Trinity Alps Wilderness Areas. It is an alluvial river with agriculture focused in the naturally aggraded middle reaches (Scott Valley) and with Wild and Scenic River designation in the lower, canyon reach. Primary mainstem tributaries occur on the west side of the Scott Valley (NRC 2004).

The anadromous fishes found in the Scott include Chinook, coho, steelhead (fig. 7-7), and Pacific lamprey. Agricultural demands impose significant water withdrawals in the valley reach and many of the ubiquitous diversions (including push-up dams) are migration barriers. This river experiences such severe dewatering that certain sections along Scott Valley are dewatered completely during summer and early fall. The low flows on the Scott, particularly in the fall, can also create "natural" barriers to fish passage in the canyon reach forcing fish to spawn in the lower six miles of the river where incubating eggs and embryos are more vulnerable to scour during winter floods. In years when flows are higher adult salmon are able to reach the alluvial reaches in Scott Valley; most of the Chinook spawn either in the lower reaches of the valley downstream of Ft. Jones or in the upper reaches of the valley near the town of Etna. The loss of water moving downstream in this reach is primarily due to agricultural dewatering. Historically, beaver (*Castor canadensis*) were abundant in the Scott Valley (CDFG 1979) and their activity probably contributed to maintenance of base flows in the alluvial reaches (NRC 2004). Beaver are still present in the Scott Valley, albeit in greatly reduced numbers.

Other issues on the Scott include a lack of fencing, extensive dredger mining tailings in the upper valley, fine sediments (particularly in spawning reaches), channelization, and wells extracting groundwater with close connections to the river water. In summary, the major bottlenecks for the Scott are sedimentation, dewatering, groundwater withdrawals, and lack of connectivity of tributaries to the mainstem at times (NRC 2004). Efforts have been made to screen diversions, fence streams, purchase water rights, and work to restore floodplain connectivity. However, in both the Shasta and Scott Rivers, agricultural dependence on water withdrawal sometimes creates a contentious management environment.

6. Salmon River

Unlike the Scott and Shasta, the Salmon is mostly constrained in a granite canyon with high-gradient channel which includes some Class V whitewater rapids. It is a mountain snowmelt river with very clear water year round. The primary species present in this river are Chinook (spring and fall run – fig. 7-7), steelhead (summer and fall), green sturgeon, Pacific lamprey, and low numbers of coho. This river is considered the most natural river for Chinook salmon, especially spring run, in the Klamath Basin.

The Salmon River is subject to both historic and current mining practices including suction dredging for gold (temporarily banned). However, few people actually live in the valley. Other issues on the Salmon River include sedimentation, logging roads, fire, and exotic weeds (table 7-1). Restoration efforts have particularly focused on forest roads and stream crossings. In general, water quality is good on the Salmon, and in years with average and above snowpack, the river waters remain cool. Also, topographic shading helps maintain cooler temperatures. Nonetheless, water temperatures exceeding 22°C have been recorded in some areas. In addition, salmon smolts (especially fall Chinook) often encounter stressful temperatures when entering the Klamath River in June and July. High mortalities of Salmon River fish in the Klamath River may partially explain why stocks are declining in the Salmon River.

7. Trinity River

The largest tributary of the Klamath, the Trinity River meets the mainstem 69 km from the ocean. This river drains the high snow zones of the Trinity Mountains and interior coastal ranges. Geology is metamorphic and waters are well buffered. It has a spring snowmelt peak in the hydrograph but also a pluvial signal in the fall many years. The channel gradients are high in the headwaters but the mainstem has alluvial reaches with more extensive flood plains and riparian zones compared to the mainstem Klamath. Water quality is generally good but rich enough to support a productive food web. The major issue is the substantial dewatering by transbasin diversions summarized above. Reduced flows have caused the channel to degrade, losing contact with the historical flood plains. Other issues include erosion (from logging, grazing, placer mining), fire, and dam-related issues including water diversions, inaccessible upper river salmon habitat, lack of gravel recruitment for the lower reaches, and reduced channel-forming processes. An aggressive Trinity River Restoration Program has substantial funding and uses adaptive management to diversify fishing habitats by reconnecting the flood plains with the channel (NRC 2004).

The Trinity River is home to important stocks of wild coho, Chinook, and steelhead (fig. 7-7), but all of these species are in decline. Hatchery releases of large numbers of juveniles are routine for all three species with little evaluation of their interactions and effects on wild stocks. However, as wild populations have declined, hatchery fish make up an increasing proportion of the salmon and steelhead runs (R. Quinones, Univ. California, Davis, personal communication).

As is the case with other tributaries, the growth and survival of Trinity River fish is dependent on the conditions of the lower Klamath River and its estuary. Generally, the Trinity River ameliorates flow and temperature problems on the mainstem Klamath but the effectiveness is strongly linked to artificial flow patterns and inter-basin water negotiations associated with the large storage reservoirs in the Trinity headwaters.

8. Mountain Tributaries

Bluff, Red Cap**,** Camp, Clear, Dillon, Unkonon**,** Elk**,** Indian, Beaver, Thompson, Seiad, Grider, and Horse Creeks are the largest of the suite of mountain tributaries that enter the mainstem Klamath River between the Shasta and Trinity Rivers. In general, these are relatively unproductive, high-gradient streams that are important sources of base flow for the mainstem Klamath as well as diluting pollution (Asarian et al. 2010). Headwaters include the Siskiyou Wilderness Area but fire, roads, roading for timber harvest, mining (particularly within the Dillon, Indian, and Clear Creek watersheds), and sedimentation (exacerbated by clear cut logging and roads on steep mountain slopes) are major problems outside the wilderness areas. The westernmost streams all flow through the Franciscan Formation (Strand, 1963), which is highly erodible causing significant turbidity and sediment issues that are exacerbated by heavy logging and high road densities.

The mountain tributaries are spring snowmelt streams that are primarily inhabited by winter run steelhead, but Elk and Beaver Creeks also are coho streams and coho juveniles from areas upstream often move out of the mainstem Klamath to rear in the lower ends of these streams. Occasionally, spring Chinook are seen but there is little evidence that local stocks exist. Bluff and Red Cap Creeks have alluvial lower reaches that are especially important for coho rearing (perhaps immigrants from the mainstem) and they have a late fall run of Chinook. Summer steelhead occupy the lower reaches as well, and these reaches may be of particular importance to lamprey.

9. Fog Belt Tributaries

The Fog Belt tributaries, which join the Klamath below the Trinity, differ from the mountain tributaries in that they are rain dominated (pluvial) systems. Historically, condensation in the massive forest canopies added runoff but this has been moderated by heavy logging. High flows in the mainstem Klamath apparently retard sediment transport out of these basins and they have rather well-developed flood plains with good salmon rearing habitat in their lower reaches. Moreover, the maritime climate produces foggy, wet conditions resulting in summer-cool and winter-warm water temperatures in the optimal ranges for salmon growth. These streams are particularly important as overwintering habitat and refuge from mainstem flooding, especially for juvenile coho. Heavy logging activity, high road density, and erosive soils (Franciscan formation, again) produce excessive sediment loading in some of the streams.

Blue Creek is one of the major tributaries in this reach and it stands out from the others in that it is more like a mountain tributary by providing cold water to the mainstem Klamath. Cutthroat trout (*O. clarkii*), steelhead, coho, and Chinook spawn in this creek and its ouflow is a thermal refuge for adults migrating in the mainstem Klamath. At times thousands of Chinook and steelhead hold in the cooler water near the mouth of the creek until more favorable conditions allow them to continue migrating to the Trinity River and further upstream. Recently a late October run of Chinook has been observed with focused spawning and rearing in Blue Creek. These fish are genetically distinct from other Klamath Chinook and their freshwater migration begins after harvesting is closed. Thus, their spawning is not influenced by high summer temperatures. They are called “Blue Creekers” even though they are also found in Red Cap and Bluff Creeks in the mountain tributary domain.

10. Estuary

The Klamath River estuary is relatively small (320 ha) and brackish water only extends a few miles upstream even with high tides and low river flows. High temperature and nutrient and POM loads from the river may be impairments, but potential effects on the food web or other biogeochemical responses have not been studied and little is known about salmon behavior here. Estuarine ecology is a key knowledge gap in the Klamath story (NRC 2004).

11. Ocean

Changing atmospheric and oceanic processes constantly modify and “reset” ocean conditions, such that salmonids entering the ocean may encounter a different set of conditions every year (Lichatowich et al. 2006). This can have a tremendous effect on the survival of anadromous fish and the number of fish that are able to return to the river. In addition, there is uncertainty about where Klamath smolts go after they enter the ocean. It is presumed that most stocks stay in the California current upwelling zone, near shore between San Francisco and the Fraser River in British Columbia. Some evidence suggests that Chinook stocks from the Klamath will stay in coastal waters between Cape Falcon, Oregon, and San Francisco. The food web in these areas has been studied (fig. 7-9) and productivity is tied to the strength of the upwelling. Productivity of the marine food web varies on decadal and longer cycles associated with mid-ocean warming and cooling (Pearcy 1992, Mantua et al. 1997).

Harvest of Klamath River fall Chinook salmon is initialized each year by the establishment of ocean fishing regulations for Federal waters by the Pacific Fishery Management Council (PFMC). Ocean fisheries within three miles of the coast are managed by the States of Oregon and California, the Klamath in-river recreational fishery is managed by the State of California, and the tribal fisheries are managed by the Yurok and Hoopa Valley Tribes (KFMC 1992). Management is predicated on the concept of maximum sustained yield (MSY) with a goal of maximizing the long-term average catch under prevailing ecological conditions (Prager and

Mohr 2001, PFMC 2003). Each year, the PFMC predicts stock abundance using escapement information from the previous year and models the harvestable surplus amongst the fisheries using what is known as the Klamath Ocean Harvest Model (KOHM). The PFMC recently modified the management objectives for Klamath fall Chinook with the adoption of Amendment 16 to the Pacific Salmon Plan. This management regime follows a control rule that targets MSY (40,700 natural spawners) during most years, with *de minimus* fisheries allowing spawner reduction rates ranging between 0 and 25 percent during times of lower stock abundance.

In recent history, estimates of Klamath River fall Chinook harvest in the ocean fishery have been greater than in the river fishery, but ocean harvest has also been more variable. Escapement of fall Chinook has also fluctuated and reached or exceeded the "floor" value of 35,000 natural spawners[14], in less than half the years since 1978.

A Conceptual Model for Restoration of the Klamath River Ecosystem

The Klamath River ecosystem is a notably complex ecosystem owing to its great geologic age, "upside down" hydrology (downstream portions of the watershed are steeper gradient and produce more water than the headwaters) and great landscape variation. Biophysical complexity that evolved through millennia is substantially influenced by human-mediated stressors today, notably water pollution, flow reductions, and high water temperatures associated with conversion of natural landscapes to agriculture, managed timber lands, and other uses in the upper portions of the basin and in most of the largest tributaries (fig. 7-1). Hypereutrophication of Upper Klamath Lake and the reservoirs of the upper river, coupled with water diversion and removal, heat loading, and other effects have cascaded downstream, causing gradual loss of the ecosystem's ability to support large populations of salmon and native fishes and to maintain other desirable characteristics. The stressors influence all of the ecological domains of the ecosystem, although the intensity of stress varies (table 7-1). Thus, issues related to conservation and restoration also vary among the ecological domains. However, understanding interactions of stressors among the domains in an ecosystem context, and in addition to interactions within domains, is the essential aspect of our conceptual model. In a salmon life history context, the ecosystem could include all of the ecological domains if barriers to migration were removed, thereby restoring the historic condition.

Our conceptual view of the ecosystem in its current, stressed condition is summarized in figure 7-10, where we have collapsed the ecological domains into three primary ecosystem components: UKL and tributaries; the river system, and the ocean, with the estuary as a potentially important modifier of energy and materials fluxes in both directions. In developing this interactive model, we implicitly include key principles of contemporary ecology, notably energy flux and the transfer and transformation of materials among trophic assemblages (food webs). In this case salmon are keystone species (i.e., salmon exert scalable influences far beyond average standing crop biomass) and a primary driver of conservation outcomes.

The explicit goal of the conceptual model is to develop hypotheses as to how to enhance the productivity of the full suite of resident fish and wild Klamath salmon and steelhead stocks. Results of testing these hypotheses will inform restoration efforts in the basin. To accomplish this goal, the effects of the full gamut of stressors (table 7-1) will have to be substantially moderated or eliminated. Substantial improvement of water quality and other ecosystem goods and services (e.g., healthy forest, fertile soils, diverse fisheries and wildlife) should be coherent within this view. An adaptive, whole-system approach to management and restoration that is science-based (sensu Stanford and Poole 1996, AYK SSI 2006.) is the key. To what extent current agreements, recovery plans, and other actions are likely to help accomplish this overall

[14] In this context, natural spawners are fall Chinook that spawn in the river, irrespective of their origin.

goal have not been evaluated in light of this conceptual foundation. Moreover, a number of key uncertainties or assumptions are inherent in our conceptual model.

First, we assume that ocean conditions, with the exception of ocean fisheries, are largely beyond our control or ability to predict.

Currently, while NOAA is investigating influences of the ocean domain on salmonid populations, their findings have not been applied to management. But, in any case, beyond providing for ecological connectivity between the ocean and all of the Klamath ecological domains, a primary task of managers clearly is to improve conditions in freshwater environs.

A robust spawner-recruitment relationship cannot be clearly demonstrated for most salmon stocks, worldwide, owing to highly variable ocean survival from year to year. Good and bad ocean phases for salmon growth and survival appear to cycle in decadal or longer time steps (Mantua et al., 1997; Quinn 2005). In strong upwelling years, ocean productivity is enhanced by abundant, labile nutrients in the upwelling water and the probability of strong salmon runs is thereby increased by a persistent, robust food web (fig. 7-8).

Moreover, about half of the salmon in the North Pacific Ocean in recent years are from hatchery releases. This increases the likelihood of density dependent growth and survival in the ocean: high fish densities reduce growth and survival rates owing to food limitation. How ocean-freshwater interactions play out in the Klamath Basin remains unclear.

Second, we assume that the Klamath Settlement Agreements will provide a management (institutional) structure that will produce actions to reduce the effects of many stressors. While the removal of the mainstem dams as barriers to migration is a major focus of the agreements, the likelihood of the removal remains uncertain, especially within the next 15 years. This means that managers have to be working towards providing a normative flow regime and other positive conditions for desirable fishes, whether or not the dams are removed. By normative we mean a predictable (within limits) flow regime in the mainstem Klamath River and its tributaries that will support enough quality spawning and rearing habitat to maintain present diversity of stocks of wild salmon, steelhead, sturgeon, Pacific lamprey, and suckers. A normative flow regime would allow evolutionary processes to continue, accommodate adaptation to change (including climate change), and increase total production of anadromous and resident fishes in the context of supporting other desirable ecosystem characteristics. Quality freshwater habitat in the Klamath Basin first and foremost means cooler water in most domains during the hot summer months or temperatures cool enough to allow access to cold-water refuges. Juvenile salmon can survive warm water, particularly if food is abundant, allowing them to meet energy demands. However, their access to cold water is absolutely critical to long-term survival (Belchik 1997, Belchik 1998, and NRC 2004). In the short term, adult salmon can also tolerate warm water and have a temperature threshold of around 22°C (Groot and Margolis 1991). During 2004 and 2005, fall Chinook initiated migration in the Klamath River when daily mean water temperatures were 21.8–24.0°C (Strange 2010).

While we underscore the strong relationship between flow and temperature and the importance of access to cold-water refuges produced by springs and forested tributaries, we also recognize that watershed-level habitat improvements are also necessary (next section). Life history diversification should occur naturally as habitats improve and stocks strengthen, allowing recolonization of currently depopulated areas.

Third, we assume that reduction of stressors will substantially improve salmon productivity. Salmon clearly are resilient organisms, having radiated during the rigors of the Pleistocene ice advance, and they are keystone species throughout their range (Quinn 2005). Salmon and steelhead are now dominant in many non-native habitats, such as the Laurentian Great Lakes, New Zealand, and Patagonia (Chile and Argentina). Because of this well-documented resiliency (Quinn 2005), reducing stressors for spawning and rearing should substantially strengthen the Klamath stocks.

Fourth, the problem of variable survival related to ocean and freshwater stressors is compounded by harvest. Most wild salmon stocks worldwide have a long legacy of overharvest; exploitation rates routinely are above 70 percent (Gesh et al. 2000), although harvest rates in the Klamath have not exceeded that rate in recent decades. Managers should embrace the precautionary principle of favoring spawner escapement in order to ensure high export of smolts from freshwater to the ocean. Current management goals for Klamath River fall Chinook were established in 1986 (Prager and Mohr 2001) during a period of relatively high escapement. Given the present status of wild salmon and steelhead in the Klamath Basin, harvest management should be reviewed in the context of goals articulated in the KBRA, even though harvest goals have recently been substantially revised.

Fifth, hatchery salmon have significant impacts on wild salmon populations, which are just beginning to be fully understood. There is growing evidence that hatchery programs largely replace wild fish populations rather than supplement them. Fisheries favor hatchery fish because harvest rates can be higher than for wild fish, although hatchery selection results in fish with poor survival rates in the wild. Thus the long-term impact of hatcheries may be fewer total salmon available for harvest and loss of wild populations that are most capable of adapting to changing conditions.

Finally, attempts to reduce stressors by better water and harvest management can be trumped by climate change. The Klamath Basin is getting drier and hotter, making it likely that the mainstem will be too warm to support salmon of all life stages during summer (Barr et al. 2010). With more variable precipitation, especially as snow, there simply may not be enough water in many years to manage for desirable environmental conditions for salmon in much of the basin, especially if present rates of diversion continue.

Maintaining biocomplexity in the Klamath Basin in the context of the natural and cultural values explicit in the conceptual model is a daunting undertaking. The settlement agreements, including removal of the dams to allow restoration of ecosystem connectivity, could be a great step forward, provided many uncertainties are resolved. A valuable next step would be to transform this conceptual model (fig. 7-10) into a series of testable hypotheses and then to develop a simulation model to test them. The model would have to formalize current understanding of processes and interactions (e.g., flow-temperature-productivity) among natural and cultural attributes of the ecosystem. Such a model could be used initially to provide tests of hypotheses related to ecosystem responses to dam removal, as well as to major restoration actions and to climate change, on both ecological and economic grounds. Such an approach should also help to develop new research programs to resolve uncertainties.

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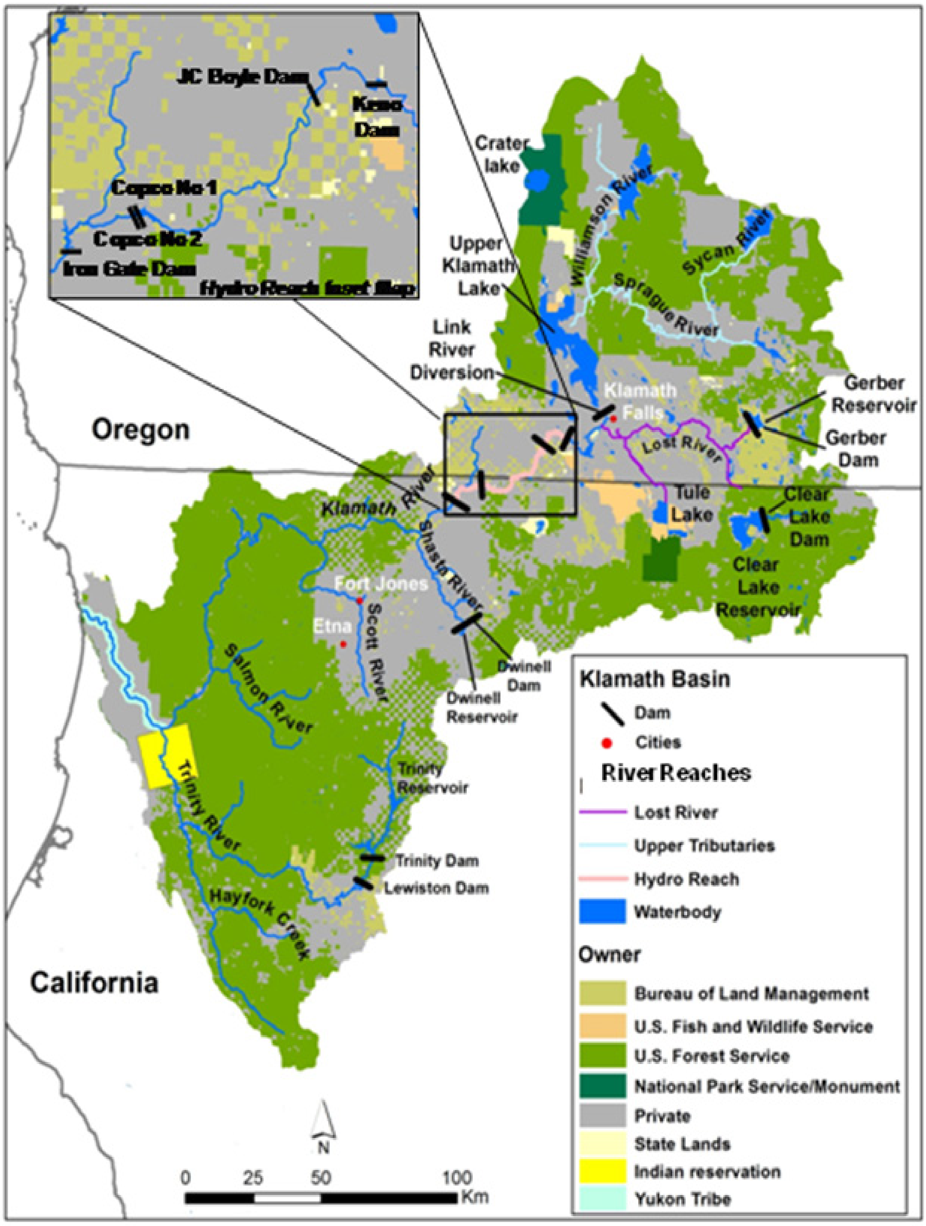


Figure 7-1. Key features and jurisdictions of the Klamath River Ecosystem. Dams slated for removal are Iron Gate, Copco 1 and 2 and J.C. Boyle, detailed in the inset. Keno Dam and Reservoir are needed to facilitate the Klamath Irrigation Project.

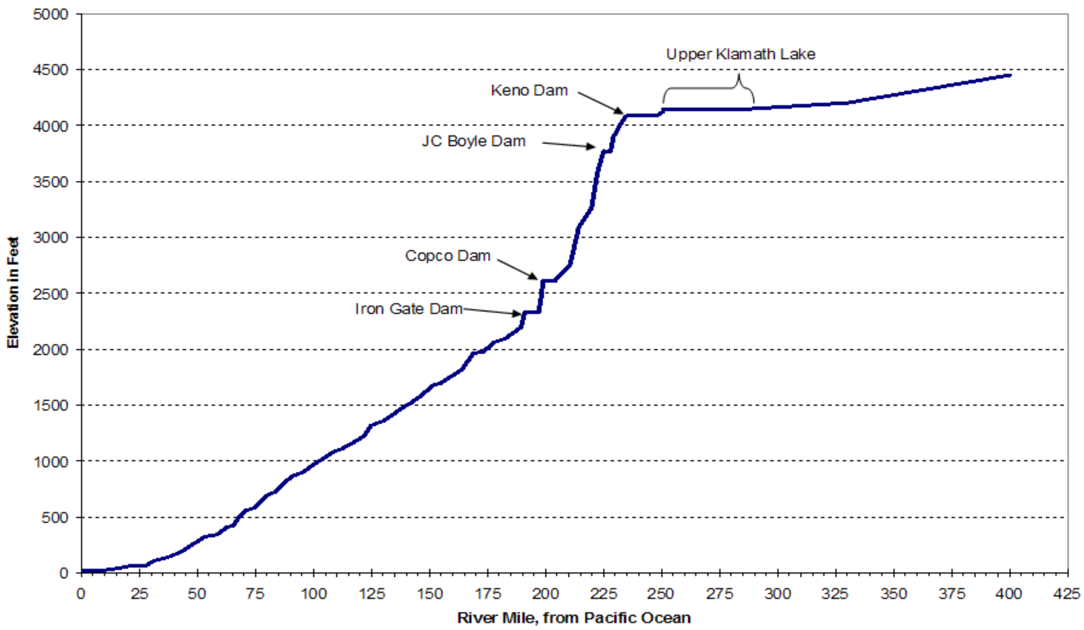


Figure 7-2. Slope of the Klamath River from Upper Klamath Lake to the Pacific Ocean. Note the gentle slope upstream from the reservoirs compared to the slope downstream. This is opposite of most watershed settings and is important context for the production of deposits stored in the reservoirs, as well as the transport of deposits by the river if released upon dam removal.

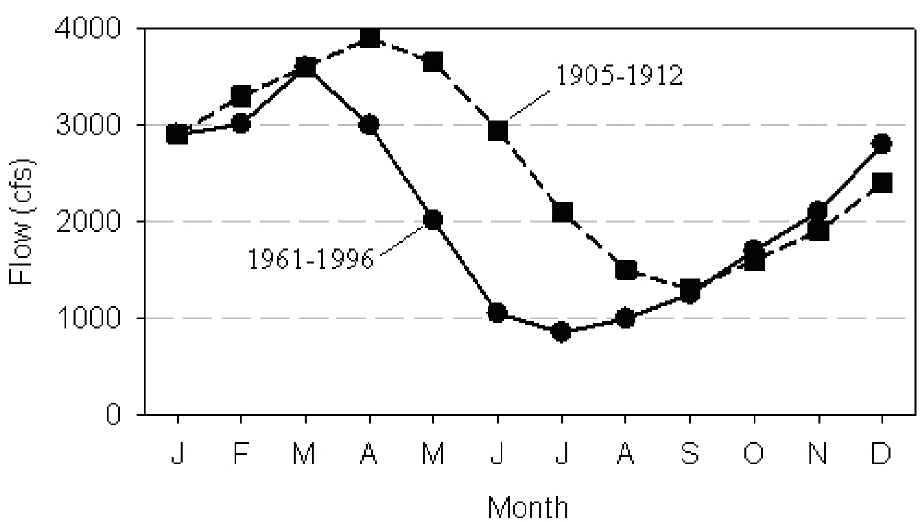


Figure 7-3. Mean monthly flows at Iron Gate Dam in 1961–1996 compared with reconstructed flows for 1905–1912 (From Hardy and Addley 2001).

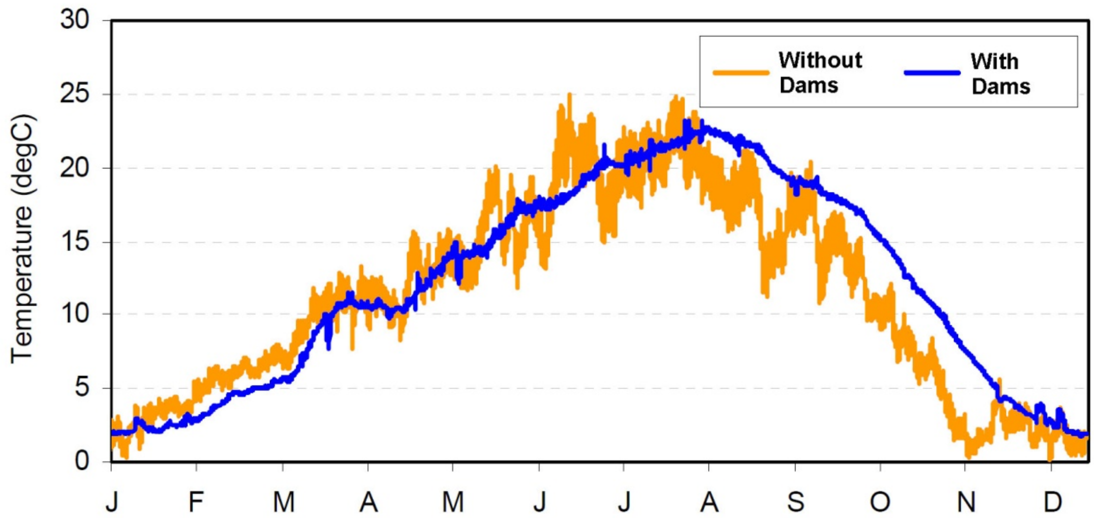
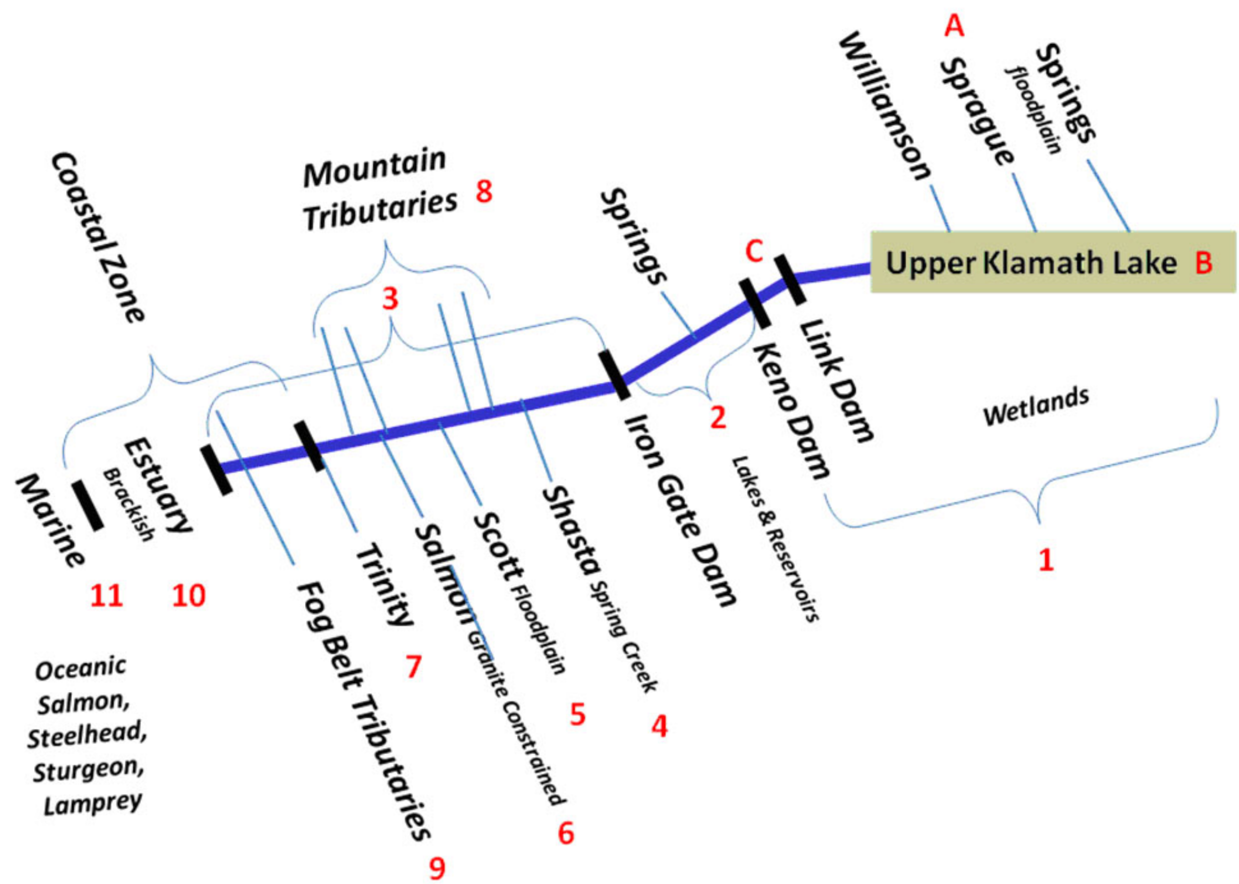


Figure 7-4. Hourly modeled water temperature in the mainstem Klamath River below Iron Gate Dam with and without dams for the year 2000 (adapted from NCRWQCB 2010).



7-5. Ecological domains (numbered) of the Klamath Ecosystem.

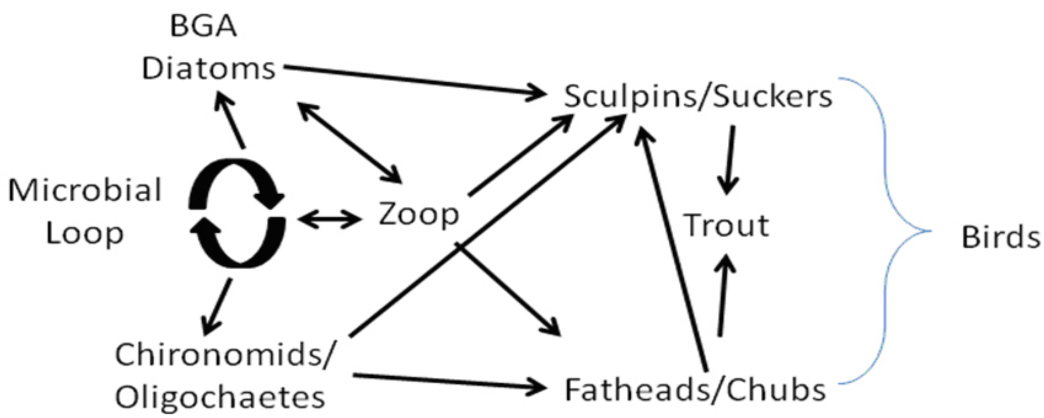


Figure 7-6. Food web of the pelagic or open water areas of Upper Klamath Lake.

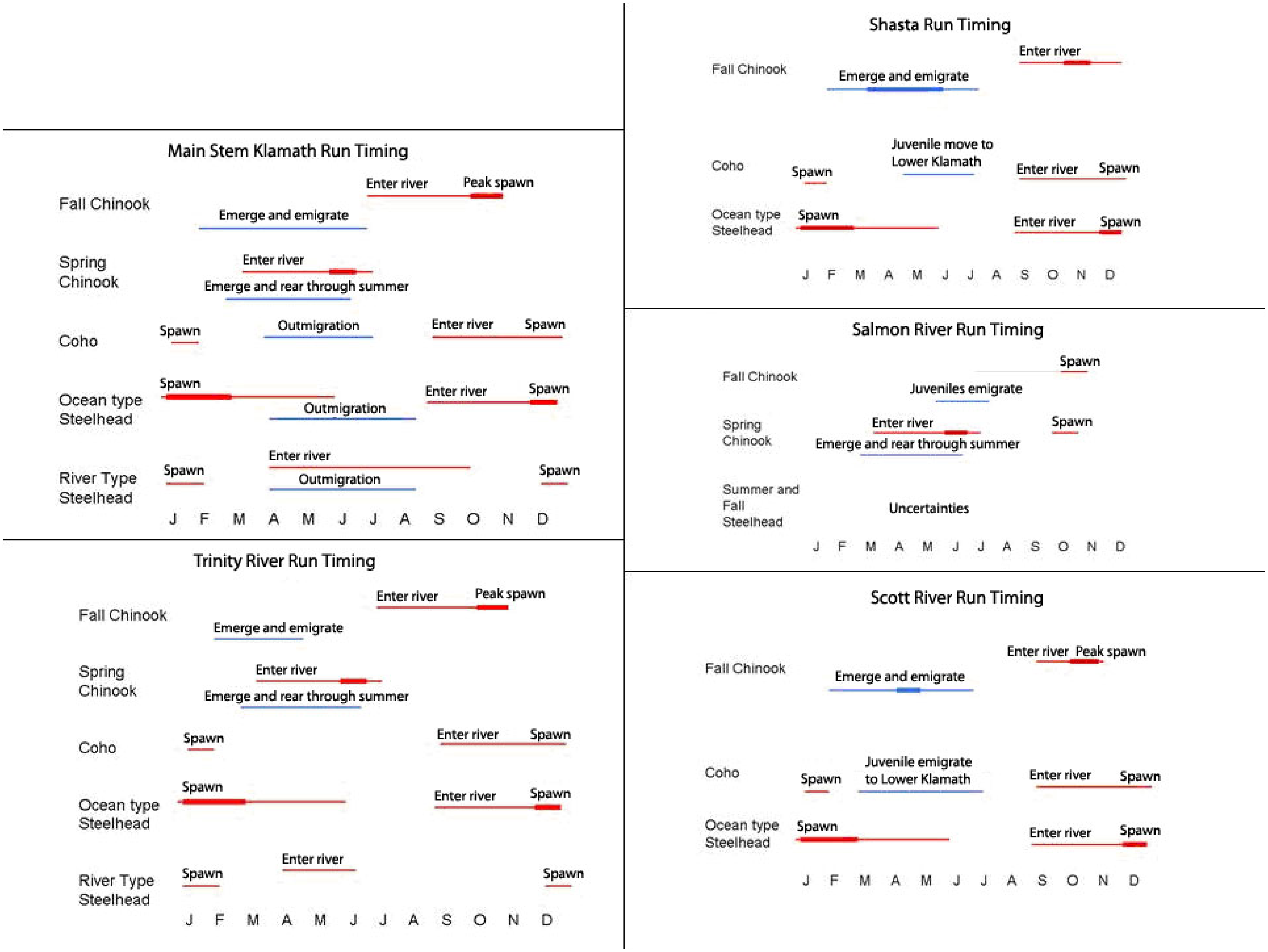


Figure 7-7. Comparative timing of life history stages for salmon and steelhead in the key domains of the Klamath River.

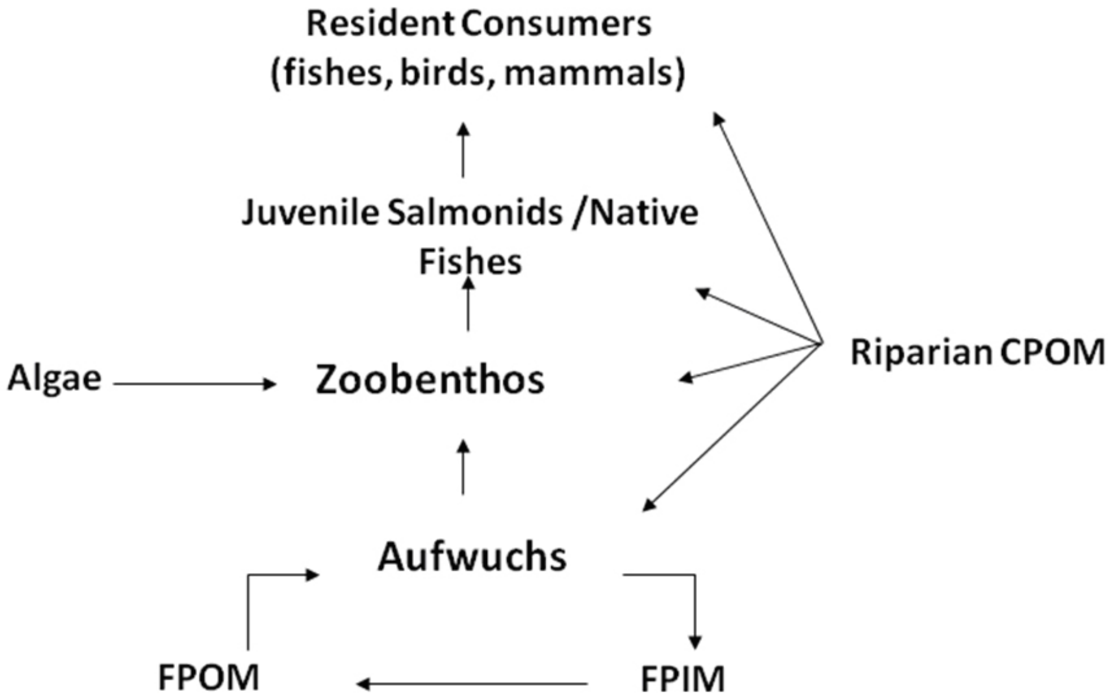


Figure 7-8. Generalized food web model for the Klamath River and tributaries. Riparian course particulate organic matter (CPOM) inputs will vary depending on ecological domain and we expect a strong interaction between fine particulate organic matter (FPOM) and fine particulate inorganic matter (FPIM) and production of biofilms (aufuchs) that drive the food web.

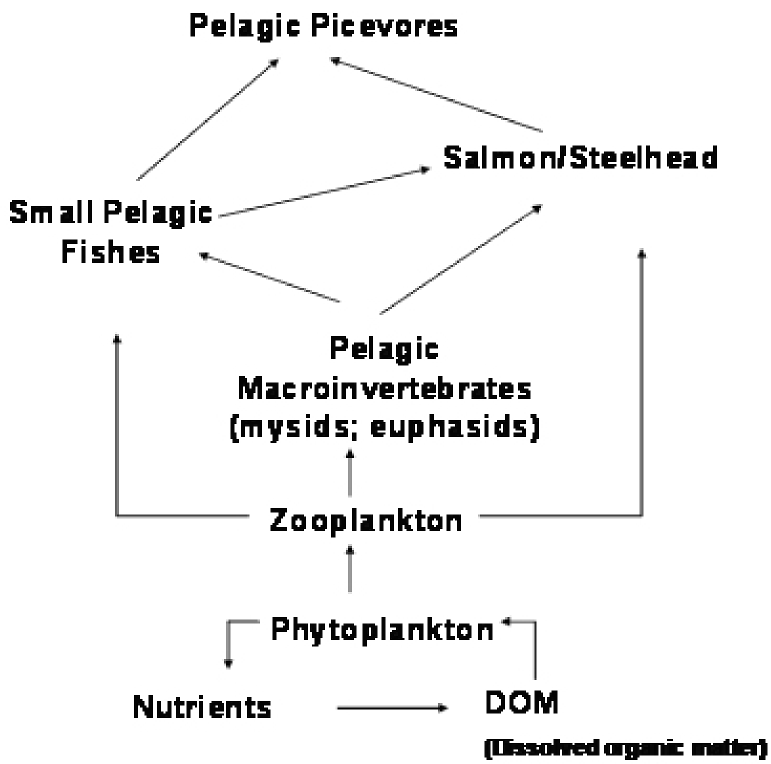


Figure 7-9. Generalized model of ocean food web involving Klamath salmon and steelhead stocks.

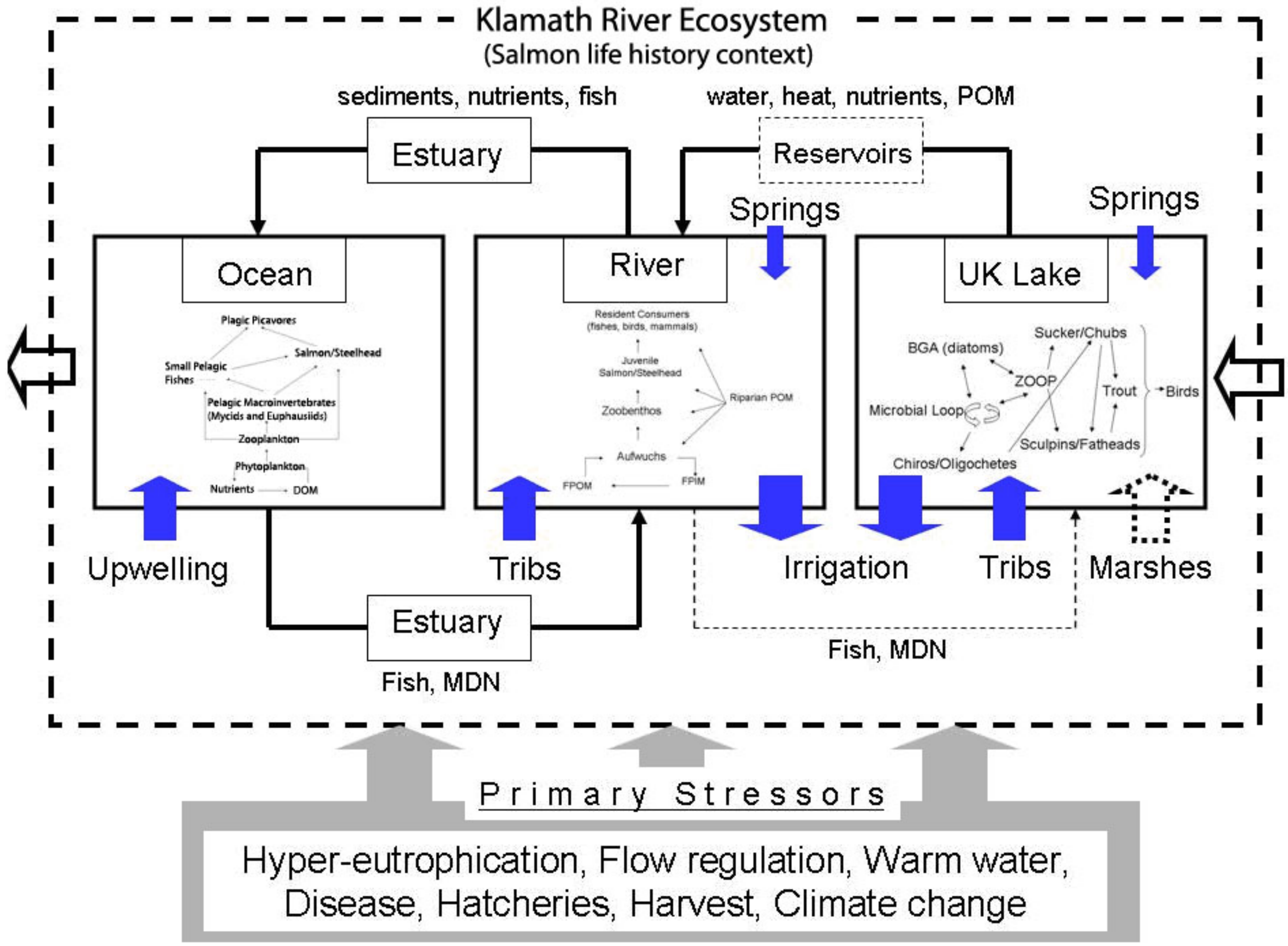


Figure 7-10. Conceptual diagram of the primary components of the Klamath Basin Ecosystem. (Upper Klamath Lake, the River system and a portion of the Pacific Ocean used by Klamath salmon stocks).

The interactive attributes and primary human-mediated stressors (listed in priority order) of the Klamath River Ecosystem are presented in context of anadromous fish conservation. The ecosystem is open to energy and materials fluxes (denoted by arrows entering and leaving the system) and bounded (bold broken line) by the watershed and the portion of the ocean used by salmon. The estuary may actually be a primary component but processes are poorly documented. The primary components are characterized by food webs that control fish production. Water, timber, hydropower, ag products and other ecosystem goods are exported whereas water, airborne pollutants, non-native biota, energy, fertilizers and many other materials are imported. Internal and external policies, laws, economies also influence energy and materials fluxes in and out of the ecosystem and between the primary components within the ecosystem.

Table 7-1. Human-caused stressors influencing the ecological domains (see fig. 7-2) of the Klamath Ecosystem where X refers to known impact and O refers to probable impact. Numbers in parentheses refer to ecological domains identified in figure 7-5. Blue Creek, one of the Fog Belt tributatries, is presented separately because of its special importance (see text).

	Upper Tributaries (1A)	Upper Klamath Lake (1B)	Link Dam - Keno Dam (1C)	Hydro Reach (2)	Shasta River (4)	Scott River (5)
High Temperature	O	X	X	X	X	X
Flow Impairment		X	X	X	X	X
Low D.O.		X	X	X	X	
Nutrient Cycling		X	X	X	X	
Toxins			X	X		
Lack of Connectivity			X	X	O	X
GW Springs Present[1]			O	X	X	
Cold-Water Refuges[1]	X	X	O	X	X	
Non-native Species	X	X		X	X	
Dewatering		X		X	X	X
High pH		X		X		
Migration Barriers	X	X	X	X	X	
Low Flow Blockages	X	NA	O	X	X	X
Low Flow				X	X	X
Fine Sediments		X				X
Loss of Riparian Cover	X			X	X	X
Spawning Gravel Loss				X	X	X
Channel Alteration	X		X	X	X	X
continued						

Table 7-1. (Concluded). Blue Creek, one of the Fog Belt tributatries, is presented separately because of its special importance (see text).

	Salmon River (6)	Mountain Tributaries (8)	Fog Belt Tributaries (9)	Blue Creek[1]	Main Klamath River (3)	Trinity River (7)	Estuary (10)
High Temperature	X	O	O	O	X		X
Flow Impairment	O	O	O		X	X	
Low D.O.							
Nutrient Cycling							X
Toxins		X					
Lack of Connectivity		O	X		O		
GW Springs Present	O		O		X		
Cold Water Refuges	X	X	O	X	X		
Non-native Species							X
Dewatering	O	O			X	X	
High pH							
Migration Barriers	O	O	O	O	O	X	
Low Flow Blockages		O	O	O			
Low Flow		O	X		X		
Fine Sediment	X	X	X			X	X
Loss of Riparian Cover		X	X			X	X
Spawning Gravel Loss	X			O	X	X	
Channel Alteration						X	
Riparian Wetland Loss			O			X	X

[1] Stressors for groundwater springs and cold-water refuges are negative when springs or refuges are divered or covered, otherwise they are positive.

Chapter 8. Synthesis of Information Needs and Science Priorities

Walter Duffy[1] and Lyman Thorsteinson[2]

Here we synthesize information presented during panel discussions and breakout sessions, each intended to identify science needs in the Klamath Basin. The Klamath Basin Science Conference opened with four panel discussions to elicit the perspectives of tribal representatives, county governments, State and Federal managers, and non-governmental organizations on science needs within the Basin. A fifth panel discussion specifically addressed the Department of the Interior Secretarial Determination Process. Breakout sessions were structured to solicit the perspectives of conference attendees on science needs to better understand two broad topics—watershed processes and freshwater and marine habitats and biological communities. In our synthesis, we summarize information provided by the Secretarial Determination panel and integrate information conveyed during other panels and breakout sessions into six categories. These categories are (1) the process and scale of science, (2) climate science, (3) watershed processes and restoration, (4) fisheries ecology, (5) monitoring, and (6) governance of the restoration process. We also summarize observations of science managers and close with brief conclusions.

The Secretarial Determination

The Klamath Hydroelectric Settlement Agreement calls on the Secretary of the Interior to undertake a thorough scientific review of existing science, data, and other information so as to be fully informed of the potential costs, benefits, and liabilities associated with removing four Klamath River dams. The Secretary must then determine whether removal of the dams (1) will advance restoration of the salmonid fisheries of the Klamath Basin, and (2) is in the public interest.

The Secretarial Determination process will attempt to answer two high-priority questions:

1. Would implementation of the Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement improve the status of fish populations?
    a. Are implementation of Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement in the public interest? In this context, public interest will consider (a) economic interests, (b) impacts to local communities and tribes, and (c) national scale interests.
2. Can dam removal and restoration be achieved within the cost estimate of $450 million?
    a. What risks and liabilities might result from dam removal? These risks and liabilities include (a) the risks of flooding, and (b) long-term, downstream risks such as contaminant releases.

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[1] U.S. Geological Survey, Cooperative Fisheries Research Unit, Humboldt State University.
[2] U.S. Geological Survey, Western Fisheries Research Center.

The information needed to address these questions will be assembled by a team of Federal and State experts using a process that considers two alternatives. One alternative will be an "action" alternative under which dams are removed and the other a "no action" alternative under which dams are not removed. The science information gathered by these experts will consist of existing science, such as information available in Federal Energy Regulatory Commission filings by the dam operators for dam relicensing, and data available from agencies and tribes. Where needed, additional studies will be undertaken to fill essential data gaps.

The "no dam removal" alternative will assume that management of the Klamath River would change little. Current regulatory requirements and structures would remain in place and water management would remain as it is today. Ecological restoration would continue, but at a slower pace than envisioned under the Klamath Basin Restoration Agreement. Lastly, the feasibility of a trap-and-haul program to allow anadromous fish access above dams would be evaluated.

The "dam removal" alternative will assume that management of the Klamath River would change and be consistent with changes described in the Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement. Under this alternative, the experts would undertake analyses to consider human impacts on a variety of natural and societal elements during the coming 50 years. The societal elements considered will be fisheries, agriculture, hydropower, employment, real estate values, tax bases, and cultural and tribal elements.

Estimating the response of fisheries: The evaluation of biological changes possible with dam removal will focus on species having commercial, cultural, recreational, or aesthetic value, as well as their habitats. These species include fall and spring Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), shortnose sucker (*Chasmistes brevirostris*) and Lost River sucker (*Deltistes luxatus*), steelhead (*O. mykiss*), lamprey (*Lampetra* spp.), green sturgeon (*Acipsenser medirostris*), eulachon (*Thaleichthys pacificus*) and other species having high recreational or cultural value. Biological evaluations are being guided by population viability criteria and will consider how population abundance, diversity, and distribution might change during the coming 50-year period with dam removal. This 50-year period is being separated into an interim period ending in 2020 when dam removal is projected to occur and a 40-year period following dam removal.

Chinook salmon offer a unique opportunity to assess a biological response to dam removal since more data are available for fall Chinook salmon than for any other species in the Klamath River. Chinook salmon also have cultural, economic, and recreational values. For these reasons, the potential population response of fall Chinook salmon will be modeled over a 50-year period.

Additional biological challenges are being considered in these analyses. These challenges include the implications of diseases and water quality on fish populations during the 50-year period as well as the response to restoration by marine groundfish and Dungeness crab (*Metacarcinus magister*) in the Pacific Ocean.

Estimating costs of dam removal: Under the KBRA, removal of all four dams is anticipated to occur simultaneously, presenting a logistical as well as an economic challenge. Cost analyses will consider a range of fish passage alternatives from removing only dams for fish passage to removal of all structures, including embankments, concrete, spillways, equipment, and canals. Costs included in these analyses include the physical removal of dams as well as activities associated with dam removal, such as restoration of reservoir habitats, fish passage facilities, and infrastructure improvements. Cost analyses will also include a dam safety evaluation of Keno Dam, which may be transferred to the Department of the Interior.

Evaluating hydrology under dam removal: The future hydrology of the Klamath River from Keno Dam to the Pacific Ocean will be analyzed to forecast conditions that are likely during the coming 50-year period. Analyses will be conducted using hydrologic models that include all dam removal scenarios considered. Hydrologic models will consider recent hydrology of the Basin, current conditions, and likely future hydrology with potential climate change influences on precipitation and temperature.

Evaluating potential sediment impacts from dam removal: Sediment impacts on the Klamath Basin are being evaluated with and without dam removal. Without dam removal, it is anticipated that the Klamath River from below Keno Dam to below Iron Gate dam will continue to be sediment starved (see Chapter 7). Lack of sediment load in this river reach will continue to impact channel morphology negatively.

With dam removal, there will be changes in the Klamath River over short- and long-term periods. Turbidity will increase in the short term during reservoir drawdown. Suspended sediment will also increase in the short term, but increased suspended sediment is anticipated to last less than one year. Long-term changes anticipated are a resupply of sediment to the Klamath River that will contribute to restoration of natural river channel morphology in the reach from below Keno Dam to below Iron Gate Dam.

Risks associated with sediment release during dam removal are being analyzed. Modeling is being undertaken to evaluate the risk of flooding from sediment aggradation, the effects of a burst re-supply of sediment, and potential impacts to groundwater and surface water supplies.

Evaluating potential water quality impacts from dam removal: Possible short-term water quality impacts associated with dam removal are being evaluated, as are long-term changes that may be realized after dam removal. In the short term, studies are planned to evaluate nutrient and contaminant concentration in reservoir sediments, the potential for bioaccumulation of contaminants in reservoir sediments, and concentrations of algal toxins in reservoir water.

In the long term, Upper Klamath Lake has been identified as being central to Klamath River water quality. A question central to Klamath River water quality is, if external nutrient loading can be reduced, what is the time scale in which a measurable change in loading from the lake to the river could be anticipated – years, decades? In addition to investigating approaches to answer this question, studies are planned to evaluate long-term water quality responses to dam removal. Planned studies include investigations of periphyton growth and scour with a natural flow regime in the river, nutrient cycling, and dissolved oxygen, pH, and organic matter responses to dam removal.

Lastly, the Secretarial determination process will be broader in scope than either the National Environmental Policy Act (NEPA) or the California Environmental Quality Act (CEQA). It will try to better estimate risks and liabilities of the two alternatives. It will also incorporate information beyond a normal Environmental Impact Statement (EIS) document. This scientific evaluation will be published as the “Secretarial Determination Overview Report,” and will inform the Environmental Impact Statement/Environmental Impact Report in compliance with NEPA and CEQA.

Synthesis of Science Needs in the Klamath Basin

The process and scale of science needs

Implementing key elements of a science process was identified by multiple conference participants as critical to the success of Klamath Basin restoration. Chief among the elements discussed was the need to establish an independent science body to guide science in the Klamath Basin. The role of this independent body could be to guide a logical progression of the collection of science information and oversee research awards, direct peer review so as to insure scientific rigor, and communicate science to stakeholders.

The need for sound science that is transparent was a common theme during conference discussions. Sound science was articulated as embodying several elements. First and foremost, it must be objective and not influenced by advocacy. Second, it should be guided by hypotheses describing the expected outcome of phenomena. Third, science in the Klamath Basin should be informed by conceptual models of ecological processes within the ecosystem, how key ecological processes function, and how each affects other processes as well as how species and habitats respond to these ecological processes. Finally, science in the Klamath Basin should be transparent and communicated to the public in language understandable by all.

Science in the Klamath Basin should strive to provide an understanding of how climatic and ecological processes, habitats, and species function at multiple scales within the entire basin. This goal can only be achieved if science integrates multiple disciplines, is comprehensive and is organized hierarchically. Hierarchical scales should include: (1) a regional scale for capturing Pacific Ocean and climate processes, (2) a basin or watershed scale for ecological process within the Klamath River Basin, (3) a subbasin or reach scale for understanding ecological flow and flux of materials and energy, and (4) a localized scale for understanding mechanisms requiring restricted spatial coverage. If approached this way, science can further our understanding of the response of biological communities to physical processes and interactions among species within biological communities, as well as the ecology of single species.

Climate Science

Climate currently has, and will continue to have, an overarching influence on ecological processes and biological communities within the Klamath Basin ecosystem. Because of its influence, climate and how it may change with time must be better understood and considered in every aspect of Klamath Basin restoration.

Conference attendees discussed climate change in the context of the uncertainty it poses in understanding how ecological processes may change in the Klamath Basin. There is a need to document important ecological processes in the Klamath Basin and to understand how these processes may be affected by climate change, as well as by changes brought about through restoration actions.

Uncertainty in the magnitude of future climate change and in the spatial variation in change could hamper restoration. There is a need to understand how climate change at the regional scale may influence the Pacific Decadal Oscillation, ocean upwelling and upwelling intensity, ocean acidification, and ocean water temperature that together influence ocean productivity. Changes in ocean chemistry are causing many concerns in regards to physiological and subsequent population and ecosystem impacts on commercially important fish and shellfish species. Research is needed to understand and quantify species-specific physiological responses of all life stages of commercially important fish and shellfish species to ocean acidification and to forecast population dynamics, distribution and abundance, productivity, and ecosystem impacts of these physiological responses.

At the basin scale, there is a need to understand how climate change may vary between the upper and lower Klamath subbasins, and within discreet watersheds. Rising air temperatures may increase the importance of the “fog zone” or marine layer and shift the migration timing of both juvenile and adult salmon and stimulate earlier maturation, while having a positive effect on warm water fish species. Better forecasts of potential future climatic variation within the Basin are needed to inform decision making on practical management questions such as how water quality and quantity may change and affect fish and their habitats and resources in the future. Improved forecasts and scenario evaluations are needed now to develop the tools and strategies to mitigate the effects of climate change.

Watershed Processes and Restoration

Conference participants indicated that watershed restoration in the Klamath Basin should strive to restore natural ecological processes that will, in the future, move the ecosystem toward a more sustainable state. Restoring ecological processes requires that the watershed restoration program be strategic rather than opportunistic. The strategy should be stakeholder-driven and identify the chronology and scope of restoration measures likely to result in desired measurable responses and outcomes from restoration actions. Watershed restoration in the Klamath Basin should be guided by a comprehensive assessment of conditions that documents the current amount, distribution, and quality of specific habitats. This assessment should also identify habitat-forming processes that contribute to habitat diversity. Ecological indicators for monitoring of restoration success should be science-based, process-oriented, and sensitive to environmental change and targeted outcomes. The restoration process must be adaptive and therefore based on a strategy that includes regular reviews and mid-course changes if expected goals and outcomes are not being met.

Strategic goals for watershed restoration should be established and agreed upon by a majority of Klamath Basin stakeholders before any projects are initiated. These goals need to be underpinned by natural science and resource management objectives that reflect conceptual ecosystem understanding and address specific ecological processes or habitats. Restoration objectives should include protocols and metrics that are field tested so that long-term monitoring assesses desired end-points and progress toward stated strategic goals.

Watershed restoration in the Klamath Basin should strive to restore ecological processes that will, in the future, move the ecosystem toward a more natural and sustainable state. Determining how to improve water quality in Upper Klamath Lake was identified as the key science need in restoring the Klamath Basin. Nutrient loading to Upper Klamath Lake has resulted in hyper-eutrophic conditions in the lake that contribute to the growth of cyanobacteria and associated cyanotoxins. These cyanotoxins have a negative effect on all biological communities of the ecosystem, including humans. Water discharged from Upper Klamath Lake is of such poor quality that it impairs the quality of water downstream throughout the Klamath River. Some Klamath River tributaries also experience impaired water quality conditions that result from other human-induced alterations and similarly adversely affect species and habitats of concern.

Both internal and external nutrient loading to Upper Klamath Lake must be reduced before water quality can be improved. Reducing external nutrient loading in the Upper Klamath Lake watershed was identified as a high priority for ecological restoration. Reduced external loading could be achieved through a combination of implementing best management practices for agriculture in concert with directed wetland restoration in upper portions of this subbasin. Science is needed to determine the surface area and spatial distribution of wetlands that would need to be restored in order to most effectively reduce external nutrient loading to Upper Klamath Lake.

Reductions in internal nutrient loading to Upper Klamath Lake will also be necessary if water quality is to be improved. Environmental benefits of wetland restoration on external loading may not be realized for a decade or longer, but research on other eutrophic lakes around the world has demonstrated that reductions in internal nutrient loading can be rapid through food web manipulation. Like many eutrophic lakes, the food web of the Upper Klamath Lake has been disrupted by the introduction of exotic planktivorous fishes. In a "top-down" ecosystem model, zooplanktivorous fishes can reduce the seasonal abundance and productivity of zooplankton populations through predation. The effect of this predation pressure is to reduce the ecological efficiencies of grazing by the herbivorous zooplankton communities (i.e., cropping of algae), and thereby creating lake-wide conditions that contribute to the continued development of cyanobacteria. Some species, like detritus feeding fathead minnows, translocate phosphorus from bottom sediments to the water column, as much as 4 to 6 mg/m^2/day in temperate lakes. The combination of these top-down and bottom-up pressures on the ecosystem are believed to facilitate consistently high algal abundance in temperate lakes. The possibility of biomanipulation of the Upper Klamath Lake food web through enhanced piscivory to control zooplanktivorous fish assemblages was offered as an ecosystem-based management experiment that might hold promise for normalizing food web conditions and stabilizing the effects of internal nutrient loading.

Ecological connections were a recurring theme of the conference. These connections extend to management actions and their ecological effects on terrestrial and aquatic systems and their interactions. Currently, dams alter the seasonal warming and cooling of the Klamath River and affect migrating salmon. With respect to water resources, there is much concern about the downstream effects of Upper Klamath Lake water and how this water is managed. How much water is needed to support the ecosystem services of the Klamath Basin? Streamflow criteria for fish are needed in the mainstem river and many tributaries. There is an urgent need to know how water diversions and groundwater pumping in the upper subbasin are affecting water quality in Upper Klamath Lake. Inherent in this is the need for improved quantification of the relationship between groundwater and surface water throughout the Basin. In the upper subbasin, water quality in Upper Klamath Lake may be influenced by lake volume and should be investigated, as water storage will likely be essential for improved forecasts of water availability and restoration planning. Also needed is a drought management plan that addresses irrigation withdrawal efficiencies. Our understanding of the hydrology of the lower subbasins remains poor and should be evaluated.

Conference attendees discussed wildfires as being both natural and unnatural disturbances in the ecosystem. Currently, about 80 percent of National Forest lands in the Klamath Basin have a 0- to 35-year frequency of moderate to severe fires. However, we do not know if these current fire regimes are similar or dissimilar to the historic conditions. Similarly, it is not presently known how water quality throughout the Basin is affected by wildfires, nor do we understand of how fire may influence other ecosystem processes identified for restoration. These uncertainties reflect a need for better scientific tools than are presently available to evaluate ecological interactions. Key questions related to fire issues and restoration effects in the Klamath Basin remain unanswered. How do natural fire regimes influence hydrology and nutrient loading and how may they contribute to the spread of exotic species? How will their intensity, frequency, and impacts be affected by climate change?

Fisheries Ecology

A primary goal of the Klamath Basin Restoration Agreement is "… *to result in effective and durable solutions which: 1) in concert with the removal of four dams, will restore and sustain natural production and provide for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin* …"

Conference attendees and participants recognized that restoring native fish populations to abundances that are "sustainable" presents both challenges and questions. Meeting the goals of fisheries restoration articulated in the Klamath Basin Restoration Agreement will require restoring anadromous fish stocks above current dams, as well as restoring both anadromous and non-anadromous fish stocks throughout the basin. Currently, the amount and type of habitat needed to support restoration of fish populations to sustainable sizes is unknown.

Flow volume in the Klamath River was recognized by conference attendees as important to the restoration of fish stocks. Several concerns were raised over flow allocations under the Klamath Basin Restoration Agreement. These included the need for a scientific review of flow regimes allocated under the agreement and whether or not these flows would best benefit fish, including the migration of salmon smolts. Concern was also expressed over how flows negotiated under the agreement might affect cold-water refuge habitats located around tributary confluences. Additionally, a need was expressed to develop an understanding of how these thermal refugia might be influenced by climate change.

Conference attendees emphasized the need to comprehensively evaluate salmon habitat and respective carrying capacities in the Upper Klamath Basin. This area historically supported spring Chinook, sockeye (*O. nerka*), and coho salmon and steelhead. As part of the reintroduction effort, there will need to be ongoing assessments of run size and escapement and productivity and recruitment of reintroduced and recolonizing salmonids as well as life cycle population modeling of age, growth, and survival. Several pressing questions relate to the quality of Upper Klamath Lake as rearing habitat for juvenile salmon. How will water quality in the lake affect the timing of salmon emigration? Will salmon need to emigrate early or reside in Pelican Bay due to environmental conditions (e.g., overwintering of Age 1 Snake River salmon)? These questions have bearing on brood stock selection in reintroduction planning.

There is uncertainty about the stocks of anadromous fish that should be reintroduced above the dams, what life stage of anadromous fish may be best suited for reintroduction, and whether reintroduction should be passive or active or a combination of the two. The reintroduction and recovery of salmon should involve a strategy that recognizes the diversity of species and life history types that have evolved within the Basin in response to specific environmental conditions. The success of reintroduction will be highly dependent on the selection of brood stock and relative genetic closeness, or fit, to Klamath conditions. If selected correctly the 50-year KBRA period should allow enough generations for salmon recovery. Science will be needed to support the decisions made over these uncertainties as well as to help in defining the trajectory and end points of successful recovery.

Restoration of native Klamath River fish populations to sizes that are sustainable will require a commitment by science agencies and others to provide information that is vital to restoration. Although Klamath River fisheries have received considerable attention for decades, knowledge of key elements of Klamath Basin fisheries remains incomplete. Anadromous fishes, especially salmon and steelhead, are most prominently affected by large-scale influences because of their ocean migrations. How ocean conditions affect Klamath Basin salmon, with respect to growth and survival, remains unresolved with respect to recovery. There is a growing body of evidence that suggests ocean conditions during the first year at-sea for salmon are critical for cohort survival. Large-scale changes in environmental conditions such as El Niño Southern Oscillation and the Pacific Decadal Oscillation affect temperature distributions, biological productivity, and availability of foods. More localized changes within the watershed, such as timing and intensity of spring freshets, and changes in temperatures and flows, may result from climate change and as a consequence could alter the development and hatching of eggs, rate of growth in fry, and timing of emigrational events such as entry to sea. It is thought that these changes would affect various salmonid species differentially in response to the variable freshwater life history strategies that have evolved in Chinook, coho, and steelhead. In nearshore waters extending offshore across the Continental Shelf, changes in the geographic positioning of Central Valley Low and North Pacific High Pressure Systems may affect wind conditions, storm events, intensity of upwelling, and the amount and quality of habitat available for migrant salmon. It was hypothesized that the timing and intensity of upwelling events could be beneficial to early marine survival of sub-yearling Chinook from the Klamath and other basins if upwelling occurs later in summer than it does today. Conversely, these conditions could have an adverse affect on coho salmon and steelhead in response to a hypothesized earlier entry to ocean and mismatch with coastal habitat conditions. Other concerns about climate change and salmon ecology related to acidification effects on coastal food webs and potential widening diminishment of nearshore habitats associated with changes in circulation, temperature, and occurrence of hypoxia in shelf waters.

Salmon ecology in the ocean is still not well understood, even though the first year after ocean entry is a critical part of salmon life history. Conference attendees identified numerous gaps in the data that will be required to restore Klamath River fisheries. Closing these gaps will require the engagement of science.

Completing assessments of fish stocks within the basin is a basic but important fisheries research need to support restoration in the Klamath Basin. These assessments should be completed for species and for different life history types of key species. Assessments should provide information on the current population status, stage specific survival rates, and the movement and distribution of important species. Assessments should identify potential impediments to restoration posed by exotic fishes. An expanded and more coordinated use of Passive Integrated Tagging (PIT) tag technology would aid in understanding fish movement as well as stage-specific survival.

Conference attendees also suggested that a greater reliance on the use of PIT tags will be needed to understand the effects of watershed restoration on salmon colonization and other fish species of management concern within the Klamath Basin. Growth and survival data are needed in a life cycle context for effective fisheries management and conservation. PIT tag technologies are available and could be used to estimate key population parameters about movement behavior, timing of outmigration, and spatial-temporal patterns of habitat use. Examples of other applications include studies about juvenile coho habitats in tributaries and off-channel streams in the fog zone and the importance of cold-water refuges to migrating salmon. The potential partitioning of salmon survival for times prior to ocean entry and upon adult return to the river offers significant promise for quantifying effects of ocean conditions. Are there other bottlenecks to salmon survival within the river below Iron Gate Dam and Keno Reservoir? This technology can help address these and other questions including field experiments designed to evaluate flow/scour effects on the intermediate host for the *Ceratomyxosis shasta* parasite. Web applications can make PIT tag information available to all interested parties. PIT tagging of endangered suckers in the Upper Klamath Basin has strengthened population enumeration procedures including greatly increased confidence in the population estimates.

In concert with assessments, conference attendees suggest that models used to guide harvest regulations in the Klamath River should be improved. These models should incorporate ocean and freshwater population dynamics as well as environmental variables that influence population dynamics. More precise estimates of ocean and freshwater harvest could also improve these models. Furthermore, harvest models and evaluations of harvest should consider the need to recolonize expanded habitat above current dams, which may dictate reduced harvest rates for a period of time.

Disease has emerged as a major threat to Klamath Basin fish stocks and a potential impediment to restoration of these fish populations. Although endemic to the Klamath River, the pathogens *C. shasta* and *Parvicapsula minibicornis* have become a threat to juvenile and adult salmon during the past decade. Understanding the ecology of these pathogens is currently an active area of research. Still, whether these pathogens or the diseases they spread can be controlled or their effects on salmon be mitigated continues to be an important science information need. The population consequences of the diseases spread by these pathogens is currently unknown and must be understood, whether restoration takes place or does not. Finally, there is a need to understand what, if any, role hatcheries play in these diseases and whether hatchery and wild fish are equally susceptible to the diseases.

Wild/hatchery salmon interactions continue to be of major concern throughout the Pacific Northwest. The possible reintroduction of salmon to the Upper Klamath Basin brings renewed debate to concerns about artificial propagation of salmon and potential effects on population fitness (genetic effects), behavioral ecology (competition and survival), and effects of infectious disease on native populations. Genetic effects may result in domestication of wild stocks from straying and intermixing of wild and native stocks during spawning. The reintroduction and recovery of salmon should involve a strategy that recognizes the diversity of species and life history types that have evolved within the Basin in response to specific environmental conditions. The success of reintroduction will be highly dependent on the selection of brood stock and relative genetic closeness, or fit, to Klamath conditions. The question was raised as to whether an active reintroduction or passive colonization (or both) was being planned and what differences might be expected from each scenario.

Other effects of wild/hatchery salmon interactions were discussed by conference participants. The release of large numbers of sub-yearling hatchery fish into Hood River in the Columbia River Basin was described as an example of hatchery stocks increasing competition for food resources. In this case, the Chinook salmon supplementation effort resulted in a swamping effect and reduced overall production in returning wild adults. In the Trinity River, straying of hatchery salmon has resulted in as much as 30 percent of natural reproduction coming from these fish and diminished production of native salmon due to increased mortalities of embryos from superposition. The quantification of straying will be a necessary component of recolonization of salmon in the Upper Klamath Basin.

A number of other important priority objectives for salmon were discussed during the conference. Primary among these objectives were the need to determine population level consequences of infectious diseases and establishing a scientifically based monitoring program that could provide information on spatial distribution, status, and trends of salmon populations. Information on abundance, distribution, and disease would facilitate the development of life-cycle models and geospatial tools for Klamath Basin salmon and contribute to decision support tools. Ideally, these life-cycle models would incorporate information on the genetic structure of Chinook and coho salmon and steelhead in the Basin, which is currently lacking, and improve estimates of ocean harvest. These models would also incorporate information on the estuarine and ocean ecology of salmon, as well as data from monitoring water temperature and chlorophyll and other environmental conditions in the river, estuary, and river plume in the ocean.

Monitoring

Conference attendees repeatedly spoke about the need for an ecosystem monitoring program in the Klamath Basin. The ecological condition of the Klamath Basin is currently not systematically monitored. Existing monitoring programs are not comprehensive, lack coordination, and tend to be geographically constrained. Large-scale connections between physical, biological, and economic conditions in the upper and lower subbasins have not been evaluated. With large-scale restoration and possible reintroduction of salmon into the upper subbasin, there clearly will be a need for a statistically sound, comprehensive monitoring program in the Basin. For this to be successful there will need to be public support and political will for long-term funding as has been the case in South Florida, Chesapeake Bay, and San Francisco Bay restoration programs. The results of long-term monitoring would benefit many users and produce long-term data with which ecosystem status and trends could be evaluated as well as the success of restoration efforts.

A Klamath Basin monitoring program should be organized to address clear objectives. Establishing clear objectives will facilitate identifying metrics to be recorded and developing uniform protocols for recording them. Structured decision making could be a useful tool for agreeing upon program objectives and metrics to be monitored. Irrespective of the process used, metrics selected to be monitored should provide information on ecosystem processes as well as species. In some cases, efficiencies may be realized by expanding existing monitoring efforts, such as adding additional water quality parameters to existing water quality monitoring stations. However, opportunities for efficiency should be secondary to establishing clear monitoring objectives. Lessons learned from restoration efforts elsewhere should be applied to this planning.

The monitoring should include biological, physical, chemical, and socioeconomic metrics. If carefully designed and implemented using uniform protocols, the monitoring should provide valuable information on trends in water quality, fisheries, and the progress of restoration. Progress in restoration should be defined broadly to include the responses of ecosystem processes and fish species. There is a particular need to monitor the status and trends of all fish species and multiple life stages of selected species of importance, as well as trends in fish diseases. Multi-species interactions also should be considered. Finally, an adaptive management process should be initiated at the beginning of the monitoring program that provides a mechanism to communicate results to a science oversight body and to managers.

Governance of the Klamath Basin Restoration Process

In this construct, the restoration process for the Klamath Basin will be guided by science. It should be recognized that ecosystems are dynamic and that there will always be some level of uncertainty associated with the desired outcomes of restoration activities in our planning. What, for example, would be the functional response of the toxin-producing blue green algae *Microcystis* to reduced abundance of *Aphanizomenon* in Upper Klamath Lake? How will climate change affect key geomorphologic, hydrologic, and biologic processes and human use activities in light of restoration activities? (For example, will plant communities in the lower subbasin transition toward an arid subtropical environment, a fog subsidized (moisture-gathering) system, or something else?) Similarly, there are many questions and uncertainties about the possible reintroduction of salmon to the upper subbasin after 100 years of environmental change. Information about the availability of spawning and rearing habitats for each salmon species and how scenarios can be used to evaluate potential climate effects (such as drought years) is needed to guide decision making. These and many other question raised during the conference can be represented by testable hypotheses and, if experiments are undertaken, results expressed as probabilities as a means of addressing uncertainties. U.S. citizens are generally uncomfortable with uncertainty – scientific or otherwise – when it involves large expenditures of public funding. Thus with respect to the Klamath Basin restoration, we must engage in an active scientist-manager-stakeholder partnership.

The Klamath Basin agreements are an integrative force to initiate and sustain the collaboration that will be needed for restoration. Science conferences will be needed, but by themselves, will not support the partnership engagement and commitment needed. The greater Klamath community can learn much about governance of partnerships from other large-scale restoration projects. Already, this community has made significant strides with respect to finding compromise as a way to move forward in a common mission. Implementing restoration and dealing with uncertainties (e.g., scientific and fiscal) in a corporate and adaptive framework will be equally challenging.

A formal governance structure for restoring the Klamath Basin has not been described. However, based on experience elsewhere, some initial considerations for managing the restoration in a partnership model were presented. An initial challenge to a workable partnership will be establishing effective leadership. The leaders should be representative of the entire Klamath stakeholder community and have no agenda other than shared goals established collaboratively. Partnership activities will need to be transparent and administered in isolation from politics. Restoration science will need to be policy relevant and accountable to tribal and public trusts with respect to funding and natural resources. Restoration activities will need to be ecosystem-based and driven by forward-looking science in order to (1) mitigate effects of climate change, (2) balance engineering and ecological perspectives, and (3) forecast realistic natural resource outcomes in a system framework. A common theme expressed was the need for transparency in and communication of science. The diverse communities and interests within the Basin, as well as interests outside the Basin, require a formal process for conducting science that has structure and is transparent and accountable.

A need for an Independent Multidisciplinary Science Advisory Panel similar to those used by the Northwest Power Planning Council (ISAB/ISRP) within the governance structure was also voiced. The membership of this panel should include university scientists as well as other knowledgeable experts. This panel could support the partnership in several key ways by conducting strategic science planning for restoration, reviewing and synthesizing information on topical areas of concern, identifying priority information needs, and providing leadership in review of science proposals as part of a competitive procurement process.

This Science Advisory Panel should also include mechanisms for communicating Basin science so as to inform decision makers and legislators as well as tribal, local, county, State, and Federal governments. Local and county governments within the Basin want to participate in the science process, but often lack the resources to do so. Having the science process guided by an independent science panel is an approach that could ensure shared participation and ensure that science is directed toward important information needs rather than regulatory mandates. However, while there was agreement that science should be guided by questions, Federal regulations such as the Endangered Species Act, Marine Mammal Protection Act, and Magnuson-Stevens Fishery Act cannot be ignored. If successful, the science process would build trust within the Basin as well as informing agencies at multiple organizational levels. Building trust requires stakeholder participation at the very early stages of the science planning process.

Several key actions were identified for initial strategic science planning and research in support of restoration. In the case of the Federal agencies represented on this panel, these shared needs reflect priority needs associated with legal authorities, ongoing projects, and more holistic approaches:

- Develop a comprehensive strategy/blueprint for Klamath Basin restoration including an overall monitoring/research plan to promote efficient use of research resources and information acquisition and capitalize on diverse expertise available.
- Evaluate and predict population, community, and ecosystem level consequences of habitat restoration, especially dam removal, on Basin fish and wildlife resources (emphasis on salmon and aquatic resources).
- Assess ecohydrology of the Klamath Basin, especially temperature and flow relationships to fish distribution, abundance, behavior, and demographics.
- Quantify the relationship between groundwater and surface water interactions for effective management of water resources and aquatic ecosystems in the Klamath Basin.
- Develop an information management system with geospatial analysis and tools for Klamath Basin watershed (Headwaters to Ocean).
- Assess implications of climate change for anadromous fishes in the basin.

Regardless of the governance model followed, the combined needs for coordination, communication, and collaboration will be key action items in any restoration plan. Improved coordination will lead to the stronger integration of resource management and science discussed at this conference. Long-term monitoring of restoration activities will require significant coordination (among Federal, State, and local governments) and adherence to standardized protocols and metrics for comparison of trends (within the Klamath Basin and other basins)[3]. Outreach and communication efforts among the agencies must continue to expand and become more inclusive. A partnership approach to restoration will lend itself to improved communication and better ways of receiving county and tribal inputs and engaging the public. The science and management communities need to promote more interaction with user groups and local communities in needs identification and planning processes. Greater outreach to watershed councils was cited as one way in which agencies could receive assistance in research and monitoring and influence land-use decisions, interact with land owners, and build trust.

Science Managers Panel[4]

A panel of science managers from the U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), U.S. Forest Service (FS), and Oregon State University (OSU) provided their impressions of pressing information needs and science priorities for hydropower and watershed restoration, salmon reintroduction, related management of water resources, and threatened and endangered species, and other topics that were presented at the conference. In preparation for their remarks, they were asked to consider future science directions for the short term; i.e., over the next 5-10 years. Considering the diverse participation of knowledgeable stakeholders at the conference (including citizen groups, non-profit organizations, Tribes, and various government and university officials), the panel’s charge to synthesize, consolidate, and establish management needs and science gaps was no small endeavor. An additional objective was for this panel’s evaluation to serve, in part, as an independent review of conference activities. Many of the science managers comments are stated in the above section and, to avoid redundancy, are not repeated here.

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[3] Monitoring protocols developed through the Pacific Northwest Aquatic Monitoring Program are readily available for application to the Klamath Basin.
[4] Senior science managers included Drs. Frank Shipley (USGS); Churchill Grimes (NOAA); Hao Tran (FS); and William Pearcy (OSU).

Members of the science managers panel noted that the science conference was timely given the pending Klamath Basin hydropower and restoration agreements. The information presented reflected a broad spectrum of environmental topics and issues some, but not all, related to these agreements and the associated Secretarial Determination Process. That process is on fast track for Federal managers to complete a comprehensive information needs assessments by fall 2011. This conference provided an initial forum to begin a public process that was consistent with goals for (1) updating Klamath Basin constituents about recent science activities and findings, (2) bridging upstream and down-river processes, and (3) addressing some of the organizational and science planning priorities identified in reports issued by the National Research Council. The science managers noted a strong sense of common purpose among the conference attendees, and noted that the proposed 50-year performance period for the Klamath Basin Restoration and Klamath Basin Hydropower Agreements secure an essential bond at the policy/science interface early in the planning process. Considering the tumultuous events of the not-so-distant past (e.g., water wars, salmon die-offs, and fishery closures) and current proposals for the dam removal in the Klamath River, this conference provided another forum for voices representing the many viewpoints and interests of the Basin to be heard in ways consistent with ecosystem- and adaptive-based approaches to management and science. A general conclusion was that restoration needs will guide science priorities.

Conclusions

Restoration of the Klamath Basin presents an unprecedented opportunity for all Basin residents to become involved. Restoration will, however, occur during a period of change in human culture, climate, and natural process. These changes could result in novel restoration challenges and outcomes. As it unfolds, the process of restoration may be characterized by risk and uncertainty. Uncertainty may require that agencies, Tribes, and communities function outside of their comfort zones at times. The uncertainty inherent in such a large restoration program reinforces the need for a science process that is technically unassailable, transparent, and clearly communicated to all stakeholders.

Acknowledgments

Our goal was to accurately represent comments and observations made by panel participants and conferenence attendees during the conference. This synthesis is intended to communicate information shared at the conference. Conclusions presented here are intended to faithfully reflect the consensus drawn by conference participants and are not necessarily the official position of the U.S. Geological Survey.

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Appendix 1. Klamath Basin Science Conference Agenda

Agenda
Klamath River Basin Science Conference
Medford, Oregon
February 1–5, 2010

Monday, February 1, 2010

5:00-7:00 pm	**Registration** (Pre-Function Area, Red Lion) **Evening Reception** (Grand Ballroom) (Hors d'oeuvres and No-Host Bar)

Tuesday, February 2, 2010
Day 1 - Setting the Stage

7:00 am-4:00 pm	**Registration** (Lobby, Red Lion) (Continental Breakfast)

Grand Ballroom

8:05-8:15 am	**Welcome** Walt Duffy, U.S. Geological Survey, California Cooperative Fish and Wildlife Research Unit
8:15-8:35 am	**Purpose and Objectives of the Conference** Leslie Dierauf, U.S. Geological Survey, NW Area Regional Executive

Science Needs and Priorities

8:35-9:25 am	**Panel on Tribal Perspectives and Science Needs** Mike Belchik, Yurok Tribe Larry Dunsmoor, The Klamath Tribes Michael Orcutt, Hoopa Valley Tribe Susan Corum, Karuk Tribe Eli Afarian, Quartz Valley Indian Reservation (**Questions and Answers)**
9:25-9:40 am	**Break** (15 minutes)(Snack and Beverage)(Pre-Function Area, Red Lion)
9:40-10:30 am	**Panel on County Perspectives** Jill Duffy, Humboldt County

	Jim Cook, Siskiyou County John Elliott, Klamath County Roger Jaegel, Trinity County Gerry Hemingsen, Del Norte County
	(**Questions and Answers)**
10:30-11:30 am	**Panel on Federal and State Management Perspectives** Mark Stopher, California Department of Fish and Game Robert Hooton, Oregon Department of Fish and Wildlife Kenneth McDermond, U.S. Fish and Wildlife Service Rodney McInnis, NOAA Fisheries Pablo Arroyave, Bureau of Reclamation Patricia Grantham, U.S. Forest Service (**Questions and Answers)**
11:30-12:30 pm	**Panel on Non-Governmental Organization Perspectives** Dave Bitts, Pacific Coast Federation of Fisherman's Association Becky Hyde, Upper Klamath Water Users Association Greg Addington, Klamath Water Users Association Mark Stern, The Nature Conservancy Jack Williams, Trout Unlimited Dean Brockbank, PacifiCorp
	(**Questions and Answers)**
12:30-1:30 pm	**Lunch** (Provided)(Coffee Garden, Red Lion)

Conceptual Foundations Plenary Session

***Convener/Moderator* –** Tommy Williams, NOAA Fisheries

1:30-1:40 pm	**Introduction –** Tommy Williams, NOAA Fisheries
1:40-2:10 pm	**Natural History of Klamath Basin –** Jim O'Connor, U.S. Geological Survey, and Douglas Markle, Oregon State University

2:10-2:40 pm	**Historical Development of the Klamath Basin (1800s To Present Day) –** Mark Clark, Oregon Institute of Technology
2:40-3:10 pm	**Forecast of Future Conditions in the Klamath Basin -** Roger Hamilton, University of Oregon
3:10-3:25 pm	**Break** (15 minutes)(Snack and Beverage)(Pre-Function Area, Red Lion)
3:25-4:10 pm	**A Conceptual Foundation for Ecosystem Restoration -** Jack Stanford, University of Montana
4:10-4:40 pm	**An Integrated Science Framework from South Florida –** Matthew Harwell, U.S. Fish and Wildlife Service
4:40-5:00 pm	**A Call for an Integrated Science Framework in the Klamath Basin –** Jim Sedell, National Fish and Wildlife Foundation
5:00-6:30 pm	**Poster Set-Up** (Grand Ballroom) (Room will be closed from 5:00 to 6:00. Room will open at 6:00 for Presenters to put up posters and will be open to the general session at 6:30.)
6:30-9:00 pm	**Poster Session** (Grand Ballroom) (Hors d'oeuvres and No-Host Bar)

Wednesday, February 3, 2010
Day 2 –Klamath Basin Science Synthesis

7:00 am-4:00 pm	**Registration** (Continental Breakfast)(Pre-Function Area, Red Lion)

Grand Ballroom

Water Resources Plenary Session

***Convener/Moderator* –** William McFarland, U.S. Geological Survey

8:00-8:10 am	**Introduction** – Doug Woodcock, Oregon Water Resources Department

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8:10- 8:35 am	**Hydrology of the Upper Klamath Basin – Present Understanding and Future Directions -** Marshall Gannett, U.S. Geological Survey
8:35 - 9:00 am	**Hydrology of the Lower Klamath Basin – Present Understanding and Future Directions -** Mike Belchik, Yurok Tribe
9:00 - 9:25 am	**Factors Controlling the Aphanizomenon flos-aquae Bloom in Upper Klamath Lake** - Tammy Wood, U.S. Geological Survey
9:25 – 9:50 am	**Overview of Trends in Phytoplankton and Toxic Cyanobacteria in the Klamath River Basin of Oregon and California -** Jake Kann, Aquatic Ecosystem Sciences, LLC
9:50 – 10:15 am	**Klamath River Water Quality Ecological Risk Assessment Conceptual Model: A Proposal for a Comprehensive Assessment Framework -** Clayton Creager, California North Coast Regional Water Quality Control Board, and Steve Kirk, Oregon Department of Environmental Quality
10:15 – 10:35 am	**Break** (20 minutes)(Snack and Beverage)(Pre-Function Area, Red Lion)

Ecological Sciences and Engineering Needs for the Secretarial Determination Process Plenary Session

***Convener/Moderator* –** Dennis Lynch, U.S. Geological Survey

10:35 – 10:50 am	**Overview of the Secretarial Determination Process –** Dennis Lynch, U.S. Geological Survey
10:50 – 11:00 am	**Engineering** – Tom Hepler, Bureau of Reclamation
11:00 - 11:10 am	**Hydrology and Climate Change –** Nancy Parker, Bureau of Reclamation
11:10-11:20 am	**Water Quality and Sediment Quality** – Chauncey Andersen, U.S. Geological Survey or Paul Zedonis, U.S. Fish and Wildlife Service
11:20 – 11:30 am	**Sediment Transport and Geomorphology** –Blair Greimann, Bureau of Reclamation

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11:30 – 11:40 am	**Biology – Anadromous Fishes and Marine Species –** Jim Simondet, NOAA Fisheries
11:40 – 11:50 am	**Biology – Resident Fishes and Terrestrial Species** – John Hamilton, U.S. Fish and Wildlife Service
11:50 – 12:30 pm	**(Questions and Answers)**
12:30 – 1:30 pm	**Lunch** (Provided)(Coffee Garden, Red Lion)

Watershed Processes Plenary Session

***Convener/Moderator* –** Michael Hughes, The Klamath Tribes

1:30 – 1:40 pm	**Introduction –** Michael Hughes, The Klamath Tribes
1:40 – 2:00 pm	**Riparian Areas in Landscapes of Frequent Fires and Associated Patterns of Fire Severity** - Carl Skinner, U.S. Forest Service
2:00 – 2:20 pm	**Hillslope-Channel Coupling in the Lower-Basin Geomorphic Systems: Implications for Sediment Transport and Aquatic Ecology** – Tom Lisle, U.S. Forest Service
2:20 – 2:40 pm	**Fluvial Processes and Landforms in Low-Gradient Upper Basin Riparian Systems –** Patricia F. McDowell, University of Oregon
2:40 – 3:00 pm	**Concurrent Measurement of Geomorphic Hydrologic and Vegetation Characteristics in Riparian Zones: A Needed Synthesis for Integrated Ecological Monitoring** – Chris Massingill, University of Oregon
3:00 – 3:20 pm	**Improving Ecosystem Management and Restoration Through a Comprehensive Regional Bird Monitoring Network in the Klamath Basin –** John Alexander, Klamath Bird Observatory
3:20 – 3:35 pm	**Break** (15 minutes)(Pre-Function Area, Red Lion)

For Room Locations See Supplemental Information Handout

3:35 – 5:05 pm	**Watershed Processes Breakout Session**

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The breakout session will take place after the plenary session and involve as many as 10 to 11 working groups of attendees to discuss specific aspects of the broad science themes of the plenary session. Attendees will have the opportunity to ask questions, make comments, explore, and engage in discussions related to future scientific needs for the Basin.

Each working group will involve a facilitated discussion.

5:05 – 6:30 pm **Poster Set-Up** (Grand Ballroom)
(Room will be closed from 5:05 to 6:05. Room will open at 6:05 for Presenters to put up posters and will be open to the general session at 6:30.)

6:30 – 9:00 pm **Poster Session** (Hors d'oeuvres and No-Host Bar)

Thursday, February 4, 2010
Day 3 – Klamath Basin Science Synthesis and Technical Sessions

7:00 am-4:00 pm **Registration** (Continental Breakfast) (Pre-Function Area, Red Lion)

Grand Ballroom

Freshwater and Marine Habitats and Communities Plenary Session

***Convener/Moderator* –** Pete Adams, NOAA Fisheries

8:00-8:15 am **Introduction -** Churchill Grimes, NOAA Fisheries

8:15-8:55 am **Fishes and Aquatic Communities of the Upper Klamath Basin** -
Scott VanderKooi, U.S. Geological Survey

8:55-9:35 am **Fishes and Aquatic Communities of the Lower Klamath River and its Tributaries -**
Tommy Williams, NOAA Fisheries

9:35-10:15 am **Ecology and Fishes of the Estuary and Nearshore Marine Environments** -

Josh Strange, Yurok Tribe

10:15-10:30 am **Break** (15 minutes)(Snack and Beverage)(Pre-Function Area, Red Lion)
For Room Locations See Supplemental Information Handout

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10:30-12:00 pm **Freshwater and Marine Habitats and Communities Breakout Session**

The breakout session will take place after the plenary session and involve as many as 10 to 11 working groups of attendees to discuss specific aspects of the broad science themes of the plenary session. Attendees will have the opportunity to ask questions, make comments, explore, and engage in discussions related to future scientific needs for the Basin.

Each working group will involve a facilitated discussion.

12:00-1:00 pm **Lunch** (Provided) (Coffee Garden, Red Lion)

For Room Locations and Talks See Revised Concurrent Technical Session Detailed Program

1:00-2:40 pm **Concurrent Technical Sessions** (1 hour, 40 minutes)

2:40-3:10 pm **Break** (30 minutes) (Snack and Beverage)

3:10-4:50 pm **Concurrent Technical Sessions** (1 hour, 40 minutes)

Friday, February 5, 2010
Day 4 – Conference Summary: What have We Learned? What's Missing?

7:00-8:00 am (Continental Breakfast) (Pre-Function Area, Red Lion)

Grand Ballroom

Climate Change Plenary Session

Convener/Moderator **–** David Woodson, U.S. Geological Survey

8:00-10:00 am **Western Climate Change: Observations and Predictions** – Kathie Dello, Oregon State University

Hydrologic Implications of Climate Change for the Klamath River Basin - Lori Flint, U.S. Geological Survey

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Potential Impacts of Climate Change on Klamath Region Ecosystems and Water Resources - Ron Neilson, U.S. Forest Service

Potential Impacts of Climate Change on Infectious Diseases of Fish - Jim Winton, U.S. Geological Survey

(Question and Answers)

10:00-10:15 am **Break** (15 minutes) (Snack and Beverage)(Pre-Function Area, Red Lion)

***Convener/Moderator* –** Debra Curry, U.S. Geological Survey

10:15-11:15 am **Findings from the Breakout Sessions**

Watershed Processes **–** Michael Hughes, The Klamath Tribes

Freshwater and Marine Habitats and Communities - Pete Adams, U.S. Geological Survey

***Convener/Moderator* –** Lyman Thorsteinson, U.S. Geological Survey

11:15-12:15 am **Senior Science Managers Panel:**

Perspectives on Klamath Basin Science Conference

Frank Shipley, U.S. Geological Survey

Usha Varanasi, NOAA Fisheries

Hao Tran, U.S. Forest Service

William Pearcy, Oregon State University

(Questions and Answers)

***Convener/Moderator* –** Debra Curry, U.S. Geological Survey

12:15-12:30 pm **Closing Remarks: Where do We go from Here?**

Leslie Dierauf, U.S. Geological Survey

CONFERENCE ADJOURNS

Appendix 2. Abstracts from Concurrent Technical Sessions

Restoration: Principles, Practices, and Case Studies 1

Habitat Enhancement in the Upper Klamath Basin - Completed Projects and Future Opportunities

Brandt, T., River Design Group, Inc., Corvallis, OR

Since 2001, River Design Group, Inc. (RDG) has collaborated with resource agencies and landowners to enhance habitat in the Sprague River watershed. Sprague River restoration projects, along with tributary stream restoration and fish passage projects, have followed guidance outlined in the *Master Plan for the Restoration of the Sprague and Sycan Rivers near Beatty, Oregon* as well as other planning documents prepared by U.S. Fish and Wildlife Service (USFWS), the National Research Council, and Oregon Department of Environmental Quality. Projects have included historical channel reactivation, large wood placement, floodplain revegetation, off-channel habitat enhancement, and livestock management. These activities are intended to improve habitat conditions for target fish species including federally endangered Lost River sucker *Deltistes luxatus* and the shortnose sucker *Chasmistes brevirostris*, and Federal species of concern Klamath largescale sucker *Catostomus snyderi* and Klamath redband trout *Oncorhynchus mykiss newberrii*.

In 2009, with funding provided by the Natural Resources Conservation Service, USFWS, and the U.S. Bureau of Reclamation, RDG completed the last of three mainstem Sprague River projects recommended in the *Master Plan*. Each of the three projects included reconstructing historical channel alignments that were abandoned due to channel avulsions. Channel avulsions are common features in the Sprague River corridor and are believed to be related to historical grazing practices, beaver loss due to trapping, and accelerated sediment delivery caused by upstream river straightening. The project designs utilized surface models comprised of merged LiDAR and bathymetry data provided by The Klamath Tribes. One-dimensional hydraulic models, calibrated with known stage-discharge data collected at the U.S. Geological Survey Beatty stream gage, were developed to understand existing conditions and evaluate proposed channel hydraulics. Post-project monitoring observations were also applied to improve subsequent projects. The 2009 projects included reactivating 3,700 ft. of historical Sprague River channel, installing over 25 large wood habitat structures, revegetation, and filling the existing channel with excavated soils.

In addition to the restoration opportunities on the Sprague River, Fishhole Creek, the largest tributary to the South Fork Sprague River, offers opportunities for restoring fish passage, geomorphic processes, in-stream and riparian habitat, and channel stability. Successful projects have provided many examples of how restoration can be implemented that benefits both the landowner and ecological habitat restoration. Continuing to engage landowners and offering conservation incentives are recommended pathways for expanding ecosystem restoration in the Sprague River watershed.

The Past, Present, and Future of the Williamson River Delta: Big Changes in the Upper Basin

Stern, M.[1], M. Barry[2], H. Hendrixson[3], and L. Bach[1]

[1]The Nature Conservancy, Portland, OR
[2]U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office, Klamath Falls, OR
[3]The Nature Conservancy, Klamath Falls, OR

One of the largest and most significant restoration projects in the Upper Klamath Basin was recently completed on approximately 5,500 acres of the Williamson River Delta. This $8.7 million project was designed to re-establish the hydrologic connection between Agency Lake, Upper Klamath Lake, the Williamson River and the Williamson River Delta, thereby restoring deltaic wetland ecosystem function to as close to historical condition as feasible for the benefit of two primary objectives: (1) to restore habitat for larval and juvenile Lost River and shortnose suckers, and (2) to improve water quality conditions in Upper Klamath Lake.

In 2006 restoration occurred on the north half of the Delta. Initial steps involved creating a restoration design plan, having construction companies bid on the proposed design, choosing a company to do the earthmoving work, and beginning the process of removing levees, filling toe drains, and recreating historic flow paths through the Delta. Klamath tribal members monitored all ground disturbing activities to insure that cultural resources were not disturbed. In year one 700,000 cubic yards of material was moved on the north and south halves of the Delta, and restoration proceeded ahead of schedule. In 2007 we used explosives to remove two miles of levee, used mechanical means to remove levees along the Williamson River, and lower the perimeter levees between the main levee breaches to below the high water mark. Over one million cubic yards of material was moved in 2007. In 2008, we moved over 800,000 cubic yards of material, sculpting riparian benches and breaching lakeshore levees on the south half of the Delta. Additional earthwork completed in 2009 helped refined previously work to better achieve the desired outcomes.

We developed a monitoring program to assess the results of this restoration on endangered suckers and water quality in the lake; preliminary results reaffirm that suckers are benefitting from the restored habitats. We believe the long-term benefits of this project will aide in the recovery of the two endangered suckers and lessons learned from this project will help inform future restoration of additional lake-fringe wetlands at the north end of Upper Klamath and Agency Lakes.

The was a project of partners, funded and supported by the National Fish and Wildlife Foundation, Natural Resources Conservation Service, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Oregon Watershed Enhancement Board, North American Wetlands Conservation Council, PacifiCorp, Environmental Protection Agency, Ducks Unlimited and the Klamath Tribes.

Monitoring Fishery Effects of Salmonid Habitat Restoration

Thomson, C., NOAA Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA

Considerable resources are devoted to salmonid habitat restoration on the Klamath River. Restoration efforts have typically focused on limiting factors such as water quality and fish passage – with considerable attention now being given to dam removal itself. Monitoring is a critical though often under-funded aspect of restoration. Moreover, even though restoration is often intended to enhance salmon populations and fisheries, monitoring (when it does occur) focuses almost exclusively on population effects – or at least on limiting factors affecting populations. In cases where restoration is intended to enhance fisheries, fishery monitoring is also important and should be conducted with the same rigor as physical or biological monitoring. For instance, fishery monitoring should be conducted pre-restoration and not just "after the fact" to provide an adequate basis for comparison. Given the complex nature of fishery behavior, it is also important that monitoring include collection of economic and other data that allow the effects of restoration to be distinguished from other factors that also influence fishery behavior. Ideally monitoring should provide an opportunity to derive "lessons learned" that can be applied to similar restoration projects on other rivers. This presentation discusses data needs for monitoring fishery effects associated with major salmonid restoration projects, existing gaps in such data, and how those gaps might be filled.

Restoration Prior to Dam Removal: the Key to a Low-impact Dam Removal Strategy?

Ginney, E.M.[1], P. Williams[1], D. Stephens[2], M. Quinn[2], and P. Grant[3]

[1]Philip Williams & Associates, Ltd., Sacramento, CA
[2] H.T. Harvey & Associates, Los Gatos, CA
[3]PanGEO, Inc., Seattle, WA

In early 2009 the California State Coastal Conservancy released a conceptual restoration plan for how a restored Klamath River would look and function after dam removal, prepared by an interdisciplinary team of restoration scientists and engineers. This document included a preliminary plan for what work would be necessary to accomplish successful restoration of the river for the reintroduction of anadromous fish extirpated since dam closure. It involved historical techniques, innovative hydraulic and sediment transport modeling, and site reconnaissance to reconstruct likely geomorphic and ecologic processes and conditions prior to dam closure and assess the likely processes and conditions during and after dam removal. That information was combined with the river restoration planning and implementation experience of the team to develop a comprehensive restoration planning document that includes potential restoration actions and techniques, conceptual restoration plans for each of the three main reservoir areas, including floodplain and in-channel restoration actions, and preliminary cost estimates.

Based on this work and the timeline and details outlined in the recent Klamath Hydroelectric Settlement Agreement, this presentation provides recommendations for immediate (pre-dam removal) restoration actions necessary to achieve successful restoration of the river ecosystem after dam removal. While restoration in the areas submerged by the dams obviously must wait for dam removal, more rapid implementation in non-inundated areas is imperative because of the response time-lag in system conditions relative to the need to provide high-quality habitat in these un-impounded areas immediately after the river is re-opened after dam removal. These actions include measures on the Klamath River in the J.C. Boyle peaking reach, in creeks tributary to the reservoirs, and in key watersheds downstream of Iron Gate Dam. Pre-dam removal action in these areas also supports necessary habitat improvements required to maintain habitat (and aquatic species populations) outside the mainstem of the river. This is important because this habitat and these populations will provide the basis for recovery/repopulation of the mainstem river downstream of Iron Gate after the brief impacts of sediment discharge from dam removal, and will ostensibly be the organisms repopulating the river now inundated by the reservoirs.

Adaptive Management: Lessons from the Everglades, Coastal Louisiana and Missouri River Programs

Padera, C., PBS&J, Jacksonville, FL

The concept of adaptive management (AM) has been around since the 1970s and is being utilized frequently in the planning and implementation of ecosystem restoration and recovery programs. In the most general terms, AM is a structured management approach that links science to decision-making in order to to improve the probability of success. Adaptive management is rooted in sound science and provides a process to address the risk and uncertainty inherent within ecosystem restoration and recovery. Several of the country's largest ecosystem restoration and recovery programs are currently utilizing an AM approach. They include the Louisiana Coastal Area (LCA) Ecosystem Restoration, the Comprehensive Everglades Restoration Plan (CERP), and the Missouri River Recovery Program (MRRP). This presentation will compare and contrast the use of AM by these three programs. The comparison will address such topics as: (1) scale of AM approach; (2) authorities/mandates for use of AM; (3) approach to collaboration and stakeholder engagement; (4) use of scientific information via monitoring, assessment, and field tests; (5) addressing uncertainty and risk using AM; and (6) linking science to decision-making and management actions. Particular attention will be paid to how lessons learned from the application of AM in these ecosystems could be applied to the Klamath River Basin as they pursue protection of threatened and endangered species and address water management issues.

Restoration: Principles, Practices, and Case Studies 2

A 45-Year Retrospective on Restoration Construction Projects on the Trinity River, California

Krause, A.F., Trinity River Restoration Program, Weaverville, CA

Construction projects to facilitate salmon restoration on the Trinity River have changed greatly in form and function since the first restoration efforts began in 1965. These changes have been driven by an evolving understanding of the physical and biological workings of the river, within a backdrop of changing legal mandates and organizational structure.

The early restoration efforts focused on restoring spawning habitat lost due to inundation, in-filling by sand, loss of gravel, and vegetation encroachment. The first restoration effort on the Trinity River was channelization of 4 tributary deltas in 1965 to eliminate delta backwaters (formed by the 1964 storm) that inundated important upstream spawning beds. Fourteen artificial spawning beds were constructed between 1972 and 1976 but had limited success due to continued gravel loss and sand in-filling. From the mid 1970s through the mid 1980s, restoration efforts focused on mechanically removing fine sediment from the mainstem via dredging and ripping the channel bed to loosen the spawning gravels and flush fine sediment. Watershed restoration to reduce fine sediment delivery became a major thrust for restoration activities in the late 1980s and 1990s. During this time period, 18 side channels and 9 "feather edge" pilot projects (with their associated experimental flood flow releases) were constructed in response to a growing recognition of the importance of rearing habitat.

With the signing of the Record of Decision (ROD) in 2000, the Trinity River Restoration Program was restructured with a new focus on encouraging dynamic river processes to restore and maintain adequate salmon habitat. This new approach required revising the operation of Trinity Dam to establish a more natural flood regime, gravel augmentation to replenish the supply lost to the reservoir, mechanical bank rehabilitation construction to destabilize the riparian vegetation on the river banks and create functional floodplains, and continued watershed restoration to minimize fine sediment delivery to the mainstem. Projects since 2004 have evolved to create greater overall diversity by leaving patches of mature vegetation in place, including side channels, islands, and large wood placements, adding micro-topography on floodplain surfaces, and using augmented gravels to both emulate geomorphic features and transport downstream to create new gravel bars. A new vision is emerging on how to design these various features to integrate their function to best support geomorphic processes, riparian regeneration, and salmon recovery.

Restoration Implications of the Holocene History of the Sycan River, Upper Klamath Basin, Oregon

Lind, P.[1], J.E. O'Connor[2], and P. McDowell[1]

[1]University of Oregon, Eugene, OR
[2]U.S. Geological Survey, Portland, OR

Understanding how channels, floodplains and other landforms are created is essential to restoration planning, particularly because the present is not "the key to the past" for many rivers. An example is the Sycan River, which drains 1150 km2 within the Sprague River watershed of upper Klamath Basin. Within a few decades or centuries after the Mount Mazama eruption 7660 cal yr BP, the upper Sycan River was impounded by a short-lived dam, probably formed of pumice dunes near the outlet of Sycan Marsh. This dam, upon failure, transformed the lower Sycan River and, to a lesser extent, the Sprague River downstream of the Sycan River confluence. The massive discharge from the outburst flood scoured the clay-dominated floodplain and buried the Sycan Valley with pumiceous sands up to 3.5 m thick, leaving a broad and sloping planar surface composed of coarse pumice sand. The flood also deposited pumiceous sand along 100 km of the Sprague River downstream of the Sycan River confluence and a flood signal is evident in Upper Klamath Lake. After the outburst flood the lower Sycan River has undergone episodes of channel aggradation and incision, resulting in the sand and silt dominated active floodplain of the modern Sycan River which is inset 1 to 4 m below the high surface of the rapidly abandoned Sycan Outburst Flood deposits. These post-flood episodes of incision and aggradation likely owe to climate shifts as well as the intrinsic dynamics associated with significant post-Mazama sediment transport in the pumice mantled watershed. The geomorphic context provided by studies such as this one has implications for understanding current river processes, information vital for establishing attainable restoration objectives. Study results suggest the high planar surface of the Sycan Outburst Flood never acted as an active floodplain for the Sycan River and restoration efforts to return the river to that surface is not a reasonable restoration objective.

Winter warming has had a strong effect on spring snowpack. Apr 1 SWE/Oct-Mar precipitation ratios decrease over time at lower elevation snowcourse sites, suggesting that more winter precipitation is falling as rain rather than snow. The median difference in Apr 1 SWE between two periods, 1945-1976 and 1977-2007, is only 8 percent at 23 sites >1800m but is 31 percent at 23 sites <1800m. By contrast, the median difference in Oct-Mar precipitation between 1945-1976 and 1977-2007 at the 20 USHCN sites is only 6 percent. Our results suggest that snowpack has declined measurably in the Klamath Basin region in the recent decades, especially at elevations less than 1800m. Our findings are consistent with other studies that conclude snowpack reductions are a response to warmer winter temperatures rather than decreased precipitation.

Valley and Stream Habitat Restoration in the Lower Klamath Subbasin

Fiori, R.[1], S. Beesley[2], and D. Westkamp[2]

[1]Fiori GeoSciences, Klamath, CA
[2]Yurok Tribal Fisheries Program, Klamath, CA

Geomorphic-processed based restoration of coastal valley and stream habitats rely on principles of bio-mimicry and geomorphology, and require collaborative partnerships to affect positive, long-term changes at the landscape scale. In the Lower Klamath Subbasin, the Yurok Tribe's restoration efforts are guided by research and monitoring of trends in geomorphic processes, habitat condition and use by adult and juvenile salmonids. Recent restoration efforts by the Yurok Tribal Fisheries Program have focused on restoring background wood loading levels in tributaries and increasing the amount and quality of off-channel habitats. Results from several mega-wood loading projects that demonstrate the effectiveness of engineered log jams and bioengineering to create in-stream habitat complexity, improve side channel and floodplain connectivity, and to store and build riparian soils will be presented. Projects used a range of construction techniques that included a helicopter, heavy equipment, grip hoists and hand labor. Partnerships that involve landowners, funders and an experienced technical team are important to achieve positive project outcomes. However, streamlining onerous permit requirements and improved access to whole tree materials (trees with rootwads, tops, and branches) is needed to support timely on-the-ground implementation and salmon recovery.

Building on the Baseline Assessment: First Year Restoration Discoveries on Big Springs Creek

Deas, M.[1], A. Nichols[2], C. Jeffres[2], R. Lusardi[2], J. Kiernan[2], J. Mount[2], and A. Willis[1]

[1]Watercourse Engineering, Inc., Davis, CA
[2]Center for Watershed Sciences, University of California, Davis, CA

Big Springs Creek is a spring-fed creek that supplies over half of the Shasta River's annual flow. The steady influx of cold (~12°C) water that is naturally high in nutrients makes this stream a prime rearing site for salmonids including coho salmon. However, decades of land use activities associated with cattle grazing in and around the stream channel has degraded in-stream and riparian habitat. Recent studies have identified Big Springs Creek as a high priority restoration site in the Shasta Basin.

An ongoing monitoring program was implemented in 2008 to develop a baseline assessment of physical and biological conditions and then track the effects of restoration actions. The baseline assessment identified high temperatures and reduced habitat availability and complexity as the primary impairments. During summer months, water temperatures in the creek peaked above 20°C, at times exceeding 25°C, indicating high rates of heating. Available habitat for coho salmon during summer 2008 was limited to a 15 meter reach at the top of the creek below the Big Springs Dam outlet. Data collected during the 2009 field season monitored the effects of initial passive restoration actions (riparian fencing) that commenced in spring 2009. Preliminary results identify rapid geomorphic, hydraulic, and stream temperature responses to passive restoration actions that resulted in the extensive growth of aquatic macrophytes. Ongoing monitoring will examine whether the effects of vegetation growth are permanent or seasonal.

Given the scope of habitat degradation and the limited funds available for immediate action, a hydrodynamic model was developed to help assess restoration alternatives and identify priority actions. Simulations of present temperature conditions represent the geometries, flows, and vegetative growth observed during the 2008 field season. Several passive and active restoration scenarios were designed to estimate the effects of identified restoration actions on water temperatures in Big Springs Creek after 1, 5, and 20 years. Overall, simulations of long-term restoration suggest that much of Big Springs Creek will experience thermal benefit from both passive and active actions taken on the Shasta Big Springs Ranch and surrounding lands owned by The Nature Conservancy. A comparison of the model results with data gathered during the 2009 field season indicates that initial assumptions about the stream's restoration potential were conservative. The benefits of improved conditions in Big Springs Creek will extend into the Shasta River, expanding potential habitat for coho salmon and other salmonid species.

Update and Design Approach on Urban Stream Restoration Projects Along Yreka and Greenhorn Creeks in the Shasta River Watershed of the Klamath Basin

Hesseldenz, T.F., T. Hesseldenz and Associates, Mount Shasta, CA

Yreka and Greenhorn Creeks flow through the City of Yreka in Siskiyou County, California. They are important spawning tributaries for salmon and steelhead trout, but have been degraded by past gold dredging, loss of accessible floodplain, urban runoff, and in the case of Greenhorn Creek, blockage of fish passage to the upper watershed due to a small dam and reservoir. These creeks are also important spawning gravel sources for the Lower Shasta River. Restoration planning began in 2003, involving proposed floodplain widening along a 1-mile portion of Greenhorn Creek, and funded by a grant from the Siskiyou Resource Advisory Committee (RAC). This project was followed by full design of proposed floodplain widening, funded by a grant from the U.S. Fish and Wildlife Service (FWS). Planning for mitigation of urban runoff impacts to both creeks began in 2006, funded by another grant from the Siskiyou RAC. Design for floodplain widening along a 1/2-mile portion of Yreka Creek began in 2007 and construction was completed in 2008, using two California Proposition 40 grants. Greenhorn Creek floodplain widening is scheduled to begin 2010, to be funded in part by FWS. Design is underway for additional floodplain widening along Yreka Creek, funded by a California Proposition 50 grant. Also, a master plan for a 4-mile greenway along Yreka Creek will be updated in 2010 to include floodplain restoration, with funding in hand from FWS and the U.S. Forest Service and proposed additional funding from the Siskiyou RAC. The design approach being taken is to remove tailings and other fill to create wider accessible floodplains next to the creeks, dispose of the spoils nearby but out of the active floodway to minimize hauling costs, re-vegetate widened floodplains, encourage beaver re-colonization, remove invasive exotic plant species, and include stormwater mitigation such as vegetated drainage swales. Widened floodplains will allow fine sediment to settle-out, which will clog porous tailings and restore perennial flows, while also providing topsoil for riparian vegetation. Raising the streams to re-access historic floodplains was deemed to not be feasible due to the urban setting and high collateral ecological impacts. Some of the tailings from floodplain widening may be used for spawning gravel to be injected downstream. Methods of providing anadromous fish passage over or around Greenhorn Dam are also being explored. Restoration design also includes providing ADA-compliant multi-use trails along the creeks for public enjoyment and environmental education.

Water Quality Monitoring and Modeling

Water Management and Water Quality Monitoring at BLM Wood River Wetlands 2007-2009

Hamilton, A., E. Duffy, and C. Whiteley, Bureau of Land Management, Klamath Falls Resource Area, Klamath Falls, OR

The Bureau of Land Management manages a 2,800 acre diked, drained, and subsided peat wetland on the north shore of Agency Lake. BLM initiated management directed at wetland restoration and water quality improvement starting in 1995. Previous studies on the wetland estimated nutrient loading from drainage water prior to restoration activities. Between 1996 and 2005, there was little water discharged from the wetland and no monitoring of nutrient discharge from the property. A recent post-restoration study examined standing nutrient loads and characterized seasonal changes in nutrient and water flux from 2003-2005. The unusually high nutrient concentrations observed late in the growing season were attributed to cumulative evapo-concentration due to curtailment of pumping between 1999 and 2005. Pumping was initiated in 2006 in response wetland water quality concerns and to address hydrologic effects on low emergent vegetative cover throughout the wetland. The purpose of this study was to monitor discharge loads and seasonal water quality trends as related to revised water management regimes and to inform adaptive management of nutrient loads and wetland restoration efforts. Monitoring results between 2007 and 2009 show that nutrient concentrations were high in the spring months relative to nearby surface water sources and were similar to concentrations observed during the time that the property was operated as a cattle ranch. Nutrient concentrations and standing loads were much lower in this study compared to the 2003-2005 study and decreased markedly in the summer and fall, and in subsequent years. Annual total phosphorus (TP) loading to Agency Lake decreased by 80 percent and total nitrogen (TN) loading decreased by 59 percent during the study period. Vegetation monitoring indicated that altering the hydrology of the wetland was successful in establishing emergent vegetation cover in areas previously dominated by mudflats and submergent vegetation. Intra and inter annual differences in physical and chemical water quality are presented and compared to data from previous studies on the Wood River Wetlands and to nearby managed wetlands. Inferences are made regarding the affects the recent water management changes in the observed physical and chemical water quality trends within the wetlands.

Modeling Hydrodynamics, Temperature, and Water Quality in Klamath River, from Link River Dam to Keno Dam, Oregon

Sullivan, A.B.[1], M.L. Deas[2], S.A. Rounds[1], J. Asbill[3], and M. Johnston[1]

[1]U.S. Geological Survey, Portland, OR
[2]Watercourse Engineering, Davis, CA
[3]U.S. Bureau of Reclamation, Klamath Falls, OR

The U.S. Geological Survey, Watercourse Engineering, Inc., and the Bureau of Reclamation are working together to build an improved hydrodynamic and water-quality model of the Link River Dam to Keno Dam reach of the Klamath River. Two seasons of extensive data collection and experimental work in 2007 and 2008 were used to improve the current understanding of instream processes in this system and form the basis of this new modeling effort. The model is built with CE-QUAL-W2, a two-dimensional, laterally averaged model that can simulate hydrodynamics and many water quality constituents including temperature, oxygen, nutrients, and algae. Models are first being built and

calibrated for the years 2007 and 2008, which have the most extensive datasets. Models also will be built for 2006 and 2009 to examine a wider range of hydrologic conditions and explore the ramifications of developing models with less extensive datasets. Preliminary model results will be compared to data collected from the reach and visualized graphically and with computer animations.

Multi-year Nutrient Budget Dynamics for Iron Gate and Copco Reservoirs, California

Asarian, E.[1], J. Kann[2] and W. Walker[3]

[1]Riverbend Sciences, Eureka, CA
[2]Aquatic Ecosystem Sciences LLC, Ashland, OR
[3]William W. Walker Environmental Engineer, Concord, MA

Daily hydrologic and biweekly nutrient data were collected and/or assembled for inflow, outflow, and in-reservoir stations for a Karuk Tribe water quality study of Copco and Iron Gate Reservoirs conducted between May 2005 to December 2007. Mass-balance nutrient budgets were constructed to assess seasonal and annual loading and retention dynamics of nitrogen and phosphorus. Methodological improvements included (1) flow- and season-based multiple regression models to estimate daily nutrient concentrations, (2) uncertainty estimates for nutrient concentrations and loads, and (3) adjusting inflow concentrations to account for hydropower peaking above Copco.

The combined retention for Iron Gate and Copco Reservoirs was 9±4 percent of the total phosphorus (TP) inflow over the entire study. Much of the observed retention occurred during winter and spring high flow periods when the percent of TP comprised of particulate P was high. In contrast, during the main reservoir phytoplankton growing season (May 18–September 30) the total combined TP retention was -8 percent, while for the period encompassing turnover (May 18–December 11) it was 0 percent. Likely drivers for relatively low to negative retention during the growing season are a high percent of dissolved P in the incoming TP load, which is less likely to settle than particulate phosphorus, and internal loading during anaerobic conditions in the stratified period. Flow-weighted average TP concentrations showed similar patterns to TP retention, with outflow TP concentrations ranging from 73 percent to 104 percent of inflow concentrations across the various summary periods.

Over the entire study period, the combined reservoir retention was 13±3 percent of total nitrogen (TN) inflow. The main reservoir phytoplankton growing season combined TN retention was 23 percent, while for the period encompassing turnover it was 15 percent. Higher percent retention during summer months may reflect settling of inflow organic matter and in-reservoir algal material, and/or denitrification. Flow-weighted average TN concentrations showed similar patterns to TN retention, with outflow TN concentrations ranging from 68 percent to 97 percent of inflow concentrations across the various summary periods.

Although variation in relative TN and TP retention occurred among years for the various summary periods, inter-annual differences were less than ~10 percent of inflow, and uncertainty analysis indicates that among-year values were not significantly different.

Overall net retention accounted for a relatively low (11 percent for TP, and 12 percent for TN) percentage of inflow on an annual basis, but were generally within the range predicted using models developed from a broad range of lakes and reservoirs that incorporate inflow loading and other hydraulic characteristics.

Scott River Water Balance Model (Understanding Water Quality and Quantity)

Yokel, D. and E. Yokel, Siskiyou Resource Conservation District, Etna, CA

The Siskiyou RCD, Scott River Watershed Council, and local landowners have been working since the late 1990s to develop a Water Balance Model for the Scott River Watershed. It is acknowledged that a better understanding of the hydrology of the watershed is key to developing more effective restoration and water management plans in the Scott River Watershed. Local monitoring of water quality began in the mid-1990s, and has expanded in the past 10 years to include expanded monitoring of water quantity. Pairing of water quality and quantity data will ultimately lead to the development of a comprehensive Scott River Water Balance Model.

One objective of the Water Balance Model has been to develop run-off forecasting abilities to predict in the winter or early spring the potential run-off for the Scott River and tributaries. WaterCourse Engineers Inc., has been very involved in analyzing available hydrologic data and reccommending additional monitoring locations. WCE has developed a preliminary Water Balance Model, Runoff forecast model, and Water Year Types for the Scott River. Since 2007 the RCD and local community has worked closely with U.C Davis and the North Coast Regional Water Quality Control Board to develop a Groundwater Study Plan. This GW Study Plan will identify and collect baseline data useful to develop, evaluate, and assess the design and implementation of water projects and water management alternatives with respect to protecting the needs of anadromous fish, agriculture, and other beneficial uses. The GW study plan will also evaluate the effects of groundwater on health of riparian vegetation, and evaluate cumulative effects of groundwater and surface water use in the Scott River System flows and temperature. In addition, U.C. Davis has been working with the local community to develop a preliminary Groundwater Model for the Scott River Watershed. Ultimately these models will be incorporated, providing a tool to guide local water users and land managers in making the most effective decisions to restore the Scott River Watershed.

This presentation will summarize what has been completed to date, and identify the next steps in the implementation of the Scott River Water Balance Model.

Method Development to Modeling the Shading Provided to the Klamath River and its Tributaries by Vegetation and Geomorphology

Forney, W., Western Geographic Science Center, U.S. Geological Survey, Menlo Park, CA

As part of the USGS's River Ecosystems and Science (REMS) project to advance the science of instream flows, a subtask exists to develop research approaches relevant to characterizing the thermal regulation of water and the dynamics of cold water refugia. High temperatures have been shown to have physiological impacts on the performance of anadromous fish species. Various drivers of the presence, variability, and quality of thermal refugia such as hypoheric flows, deep pools and bathymetric factors, thermal stratification of reservoirs, and other broader climatic considerations are being addressed elsewhere in the overall REMS project. This research, however, focuses on developing a conceptual model and methodological techniques to quantify the reduction in insolation load to the Klamath River and select tributaries below Iron Gate Dam provided by riparian and floodplain vegetation, the morphology of the river and its watersheds. Related to multiple scales, initial field-research and GIS/imagery observations resulted in the following postulates: (1) on a vegetation scale, primary seasonal changes will be a result of evergreen conifers that provide shade throughout the year, and deciduous vegetation that provide the majority of shading after it has leafed out; and although generally taller, conifers are often found further from the primary channel, thereby reducing the shading provided, which is exacerbated during the summer months when the zenith angle of the sun is smaller; (2) on a geomorphic channel scale, steep banks can provide local pockets of shading; and (3) on a regional and watershed scale, the orientation of the ridgelines and canyon walls with respect to the azimuth of the sun will be a main driver of shading. Using GIS and remote sensing software packages in concert with the consideration of various sources of newly-collected satellite imagery (i.e., IKONOS and Quickbird), existing ancillary datasets (i.e., 10 m. DEMs, USFS's Land cover mapping and monitoring program vegetation, USGS's National Hydrography Dataset), and selective ground truthing and equipment specifications (i.e., GPS vegetation, pyranometers), conceptual design and preliminary model investigations suggest the potential for further development of a location-specific metric of seasonal shading potential within a riverine system as a result of watershed features.

Integrated Modeling

Overview of SALMOD, a Fish Production Model, in the Secretarial Decision

Campbell, S.G., U.S. Geological Survey, Fort Collins Science Center, Fort Collins, CO

USGS Ft. Collins Science Center scientists have developed a decision support system model (SIAM) for the Klamath River over the past 10–12 years. The model contains 3 major components: a water balance model, a water quality model, and a fish production model. All of these components are coupled in a Windows interface that allows resource managers to "game" with the model to determine the effects of differing water temperatures and flow conditions on production of fall Chinook salmon. The model has been used for a variety of resource management issues including the FERC relicensing and Settlement Negotiations processes. The upcoming Secretarial Decision to either remove or retain four hydropower dams along the Klamath River is another opportunity to apply SIAM, specifically the fish production module – SALMOD – to support this process. SALMOD will provide fish production (number of out-migrating fall Chinook salmon) for the mainstem Klamath River from Keno downstream to the Pacific Ocean. SALMOD will be part of several models that will represent the full-life cycle; i.e., both fresh and salt water phases of this anadromous species. The effort is an intense collaboration among Department of Interior agencies, the National Oceanic and Atmospheric Administration, the Tribes, State agencies, universities, and consultants to provide the best available science for the Secretarial Decision.

Conceptual Design and Approach for Modeling Fall-run Chinook Production Post Dam Removal

Hendrix, N.[1], S. Lindley[2], J. Hamilton[3], J. Simondet[4], and C. Huntington[5]

[1]R2 Resource Consultants, Inc., Redmond, WA
[2]National Marine Fisheries Service, NOAA, Santa Cruz, CA
[3]U.S. Fish and Wildlife Service, Yreka, CA
[4]National Marine Fisheries Service, Arcata, CA
[5]Clearwater BioStudies, Inc., Canby, OR

As part of the Secretarial Determination, a population dynamics model capable of forecasting annual abundances of fall-run Chinook with uncertainty over a 50 year time frame was requested. In addition, the model should be capable of comparing a status-quo scenario and dams out scenario. The first step in this process was to construct a conceptual model. The conceptual model should have several qualities to be useful: (1) capture the biological processes of interest; (2) capture existing hypotheses about environmental or anthropogenic factors thought to affect the population dynamics; (3) identify sources of data for those factors; (4) identify the pathways for management actions; and (5) if using statistical methods, identify sources of data that can be used as indices of abundance. The conceptual model was presented to stakeholders and has resulted in a conceptual model composed of several components including: an adult migration model, an upper basin production model, an outmigrant mortality model (SALMOD), a retrospective ocean survival model, and a harvest model. Using the conceptual model as a blueprint, a life-stage model (e.g., Leslie-matrix type model) with transition among stages described by stage-specific Beverton-Holt functions is being constructed. The Beverton-Holt function is parameterized with two coefficients, the carrying capacity and the productivity. Each of these two coefficients can be further modeled as a function of environmental driver variables. For example, productivity in the rearing stage may be a function of instream temperature. The conceptual models and progress on translating the conceptual models into a quantitative model capable of meeting the objective of forecasting fall run abundances with uncertainty will be presented.

Evaluating Economic Effects on Fisheries Associated with Klamath Dam Removal

Thomson, C., NOAA Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA

According to the Klamath Hydroelectric Settlement Agreement, the Secretary of the Interior will determine whether removal of four dams on the Klamath River "(1) will advance restoration of the salmonid fisheries of the Klamath Basin, and (2) is in the public interest, which includes but is not limited to consideration of potential impacts on affected local communities and Tribes." Among the myriad analyses being prepared to inform the Secretarial Determination are a number of economic studies that focus on the range of human uses and values potentially affected by dam removal. This presentation focuses specifically on the economic analysis as it relates to fishery effects. Topics to be discussed include data requirements, modeling issues and the need for interdisciplinary collaboration.

Effects of Flow Augmentation and Meteorological Conditions on Coho Salmon Production in the Klamath River Basin

Courter, I.[1], S. Cramer[1], K. Jones[1], M. Teply[1], and M. Deas[2]

[1]Cramer Fish Sciences, Gresham, OR
[2]Watercourse Engineering, Inc., Davis, CA

It has been hypothesized that water project operations in the Klamath River basin are a major driver of anadromous fish production. Moreover, fisheries interests have been strong advocates for mainstem flow augmentation to increase abundance of threatened coho salmon. For this reason there was a sincere desire to understand effects of flow and temperature conditions on coho salmon production. Due to the paucity of data in the Basin, a simulation approach was required. We sought to quantify the effects of flow alterations at Iron Gate Dam on coho production in the Lower Klamath River through population life-cycle modeling. For comparison, we also quantified water year-type (wet, moderate, and dry) effects on coho. The functional relationships between environmental conditions and coho survival were incorporated into a detailed population model, which was used in conjunction with a hydrodynamic model and water operations model to predict freshwater production of juvenile coho outmigrants. Results suggest that changes in IGD discharge have a limited effect on coho salmon production relative to effects of meteorological conditions. The influence of IGD discharge on mainstem flow and temperature conditions diminishes rapidly downstream due to flow accretion from tributary sources. Furthermore, the majority of juvenile coho production occurs in tributary habitats where temperatures are cooler and velocities more suited for rearing. Proposed changes in river management for fisheries restoration purposes should be viewed within a complete life-cycle context. The effect of river discharge should be quantified in a spatially and temporally explicit manner to properly predict the expected magnitude of fisheries benefit associated with a change in water project operations.

Bioenergetics of Juvenile Chinook and Coho Salmon at Klamath River Tributary Mouths

Duffy, W., M. Metheney, B. Youmans, W. Willey, and S. Zipper, U. S. Geological Survey, California Cooperative Fish and Wildlife Research Unit, Humboldt State University, Arcata, CA

Juvenile Chinook and coho salmon occupy cool water associated with Klamath River tributary confluences during mid- to late-summer each year. These areas of cool water influx have been identified as refuges, suggesting these habitats provide refuge from seasonal warm water temperatures in the Klamath River that may be harmful to juvenile salmon. We used bioenergetics modeling to investigate the physiological response of juvenile Chinook and coho salmon to thermal conditions at several Klamath River tributary mouths. Our bioenergetics model for juvenile Chinook salmon was developed from laboratory experiments on Klamath River Chinook salmon, while our model for juvenile coho salmon was developed using laboratory data from coastal populations in Oregon. Modeling investigations focused on generating hypotheses of how juvenile Chinook and coho salmon might benefit physiologically from using tributary mouth habitats or from migrating between tributary mouth and river habitats. Results from these investigations will be used to inform a continuing U. S. Geological Survey effort to model at differing spatial scales within the Klamath River Ecosystem.

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Algae: The Forgotten Half of the Klamath River Phytoplankton

Raymond, R., E&S Environmental Chemistry, Inc., Corvallis, OR

Although cyanobacteria in the Klamath Hydroelectric Project have received considerable attention, they comprise only 52 percent of the phytoplankton biomass in the Klamath Hydroelectric Project. Diatoms account for 44 percent of the total biomass, and have a significant effect on the biology and nutrient dynamics of the system. Seasonal patterns of diatom growth influence nutrient concentration in the Klamath reservoirs which, in turn, may influence the growth of cyanobacteria. Phytoplankton data collected from the Klamath River and reservoirs in the vicinity of the Klamath Hydroelectric project from 2000–2009 illustrate the distinct spatial, seasonal, and interannual distribution of phytoplankton species. Correlation of phytoplankton growth patterns with changes in nutrient availability may provide some insight into the factors influencing cyanobacterial growth in Copco and Iron Gate reservoirs.

Genetic Analysis of the Population Turnover in the 2007 Copco Reservoir *Microcystis* Bloom that Resulted in Predominantly Non-toxigenic Variants Late in the Season

Bozarth, C.S.[1], A. Schwartz[1], J. Shepardson[1], F. Colwell[1,2], and T.W. Dreher[1]

[1]Department of Microbiology, Oregon State University, Corvallis, OR
[2]College of Atmospheric and Oceanic Sciences, Oregon State University, Corvallis, OR

Toxic *Microcystis* blooms associated with very high levels of the liver toxin microcystin have occurred in Copco Reservoir on the Klamath River during the last several summers. We have characterized the genetic diversity of *Microcystis* present throughout the 2007 bloom season (June through October) in surface samples taken near the Copco dam. We have determined the DNA sequences of two target loci, *cpcBA* (phycocyanin B/A intergenic region) and ITS (16S/23S ribosomal RNA gene internal transcribed spacer) by constructing clone libraries of PCR products produced with cyanobacterial-specific primer pairs. Based on information from both target loci, distinct sub-populations of *Microcystis* variants (strains) could be distinguished. Distinct strains were present at the early and late ends of the bloom season, with other strains making appearances during the transition period in August. Quantitative PCR was used to quantify the relative gene copy number of *cpcBA* and *mcyB*, one of the genes needed for toxin production, in the Copco Reservoir and UKL samples. We observed a high proportion of toxigenic strains early in the bloom (90 percent in July), declining to very low levels (<2 percent) in September and October. A single sampling (21 August) from the water column of Upper Klamath Lake, which suffers blooms that are dominated by *Aphanizomenon*, indicated that its minority *Microcystis* population was genetically related to the early season highly toxigenic population in Copco Reservoir. The August UKL sample indicated the presence of >90 percent toxigenic *Microcystis*. These studies illustrate the extensive *Microcystis* population changes that can occur within a bloom season. We have also identified *Microcystis* strains whose presence can be monitored with specific genetic techniques to better understand bloom development or to follow remediation efforts.

Nutrient Limitation of Phytoplankton and *Microcystis* Blooms in Copco and Iron Gate Reservoirs

Moisander, P.H.[1], M. Ochiai[1], and A. Lincoff[2]

[1]Ocean Sciences Department, University of California Santa Cruz, Santa Cruz, CA
[2]U.S. Environmental Protection Agency, Region 9, Richmond, CA 94804

Large toxin-producing blooms of *Microcystis* are present in the summertime in the Klamath River reservoirs Copco and Iron Gate. Nutrient limitations were investigated in 2007 and 2008 using *in situ* nutrient enrichment experiments, following responses in phytoplankton biomass, abundances of *Microcystis* (using quantitative PCR targeting the phycocyanin intergenic spacer *cpcBA*), and microcystin concentration, to additions of dissolved inorganic nitrogen (DIN) and phosphorus (P), and different forms of N (NH_4^+, NO_3^-, and urea).

The total phytoplankton biomass increased with additions of N both before the onset and during the summertime *Microcystis* blooms, while increases in microcystin concentration were detected in response to additions of either N or P. The data suggest primary N limitation and frequently a secondary P limitation for phytoplankton and *Microcystis* growth prevails in the reservoirs during the summer

season. Our data suggest vertical migration of *Microcystis* is a mechanism for nutrient access in the reservoirs during summertime oxygen stratification.

Microcystin Analyses in the Klamath River by ELISA

Lincoff, A., U.S. Environmental Protection Agency, Region 9 Laboratory, Richmond, CA

Since 2007, the USEPA Region 9 Laboratory has analyzed 1,350 surface water samples from the Klamath River for the algae toxin microcystin. The results are used by public health authorities to determine whether the river and reservoirs are safe for recreational use. Analyses are performed using Enzyme-Linked Immunosorbant Assay (ELISA) kits manufactured by Envirologix. This assay was designed as a screening method for drinking water. Our experience indicates that ELISA is also an inexpensive and reliable method for screening surface water samples for recreational use. Modifications to the drinking water method include freezing and sonication for cell lysis, high sample dilutions, and additional Quality Control measures to ensure that data are of known quality.

Evaluation and Comparison of Five Commercial Microcystin Enzyme-Linked Immunosorbent Assays to Liquid Chromatography Tandem Mass Spectrometry Used for Risk Assessment of Inland Waters

Loftin, K.A., M.T. Meyer, and J.L. Graham, U.S. Geological Survey, Kansas Water Science Center, Lawrence, KS

Enzyme-linked immunosorbent assays (ELISAs) are currently (2009) the most common technique used to measure microcystins, a class of cyanotoxins, for risk assessments of inland freshwaters to protect public health. Substantial variation in microcystin results can be observed when comparing multiple ELISA methods and between ELISA and liquid chromatography tandem mass spectrometry (LC/MS/MS) results because of differences in cross-reactivity of microcystin congeners for each respective ELISA and sample congener composition. Inland water samples were analyzed by five commercial microcystin ELISAs and a multi-cyanotoxin LC/MS/MS method. A four parameter calibration curve fit generally provided the greatest precision and accuracy for each ELISA. Four of the five ELISAs exhibited adequate precision for replicate measures of a 0.75 µg/L microcystin-LR standard and for environmental samples. LC/MS/MS data corrected for cross-reactivity showed a better correlation with the respective ELISA results in three of the remaining four ELISAs with adequate precision than uncorrected LC/MS/MS data. When results from four of the five ELISAs and LC/MS/MS techniques were categorized based on World Health Organization microcystin-LR recreational guidelines, agreement between techniques was observed in most samples. However, detection frequencies and concentrations are not equivalent between each ELISA in most cases.

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Cyanotoxins in Waters of the Klamath Basin: Historical Perspective and Current Risks

Carmichael, W.W., Department of Biological Sciences, Wright State University, Dayton, OH

Increasingly, harmful algal blooms (HABs) are being reported worldwide due to several factors, especially – human development, increasing eutrophication and climate change. HAB organism types include: PSP (paralytic shellfish poisoning), DSP (diarrhetic shellfish poisoning), NSP (neurotoxic shellfish poisoning), ASP (amnesic shellfish poisoning) and CTP (cyanobacteria toxin poisoning). All but CTP organisms are mainly a marine occurrence. CTPs occur in freshwater lakes, ponds, rivers and reservoirs throughout the world. Organisms responsible include an estimated 40 genera but the main ones are *Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Lyngbya*, *Microcystis*, *Nostoc* and *Oscillatoria* (Planktothrix). Cyanobacteria toxins (cyanotoxins) include cytotoxins and biotoxins with biotoxins being responsible for acute lethal, acute, chronic and sub-chronic poisonings of wild/domestic animals and humans. The biotoxins include the neurotoxins; anatoxin-a, anatoxin-a(s) and saxitoxins, the hepatotoxins; microcystins, nodularins and cylindrospermopsin plus the recently discovered neurodegenerative amino acid, β-methyl amino alanine.

The first report of cyanotoxins being produced by Klamath Lake cyanobacteria is from the late 1960s when *Aphanizomenon flos-aquae* was reported to produce a neurotoxic factor. Later work was unable to confirm this report but other species of *Aphanizomenon*, from other geographic locations, are now known to produce paralytic shellfish toxins - the Saxitoxins and cylindrospermopsin. Tests, over the past 25 years have failed to show the presence of anatoxin, cylindrospermopsins or saxitoxins from Klamath Lake cyanobacteria. The only confirmed cyanotoxin in Klamath Lake and Klamath River cyanobacteria is the microcystin group of related heptapeptide liver toxins. The microcystins have become a regular occurrence and environmental risk from cyanobacteria in the Klamath basin. To date the only cyanobacteria confirmed to be a producer of microcystins, in the Klamath Basin, is the colonial waterbloom forming species *Microcystis aeruginosa*. While the presence of *Aphanizomenon flos-aquae* is linked to natural eutrophication in the Klamath Basin, *M. aeruginosa* has been present in Klamath Basin phytoplankton since at least the early 1980s and should be considered an indicator of increased cultural eutrophication. *Microcystis aeruginosa* production of microcysins should be considered the primary risk factor from cyanotoxins in the Klamath Basin-especially Klamath Lake and the Klamath River.

An evaluation of risk assessment of microcystins (i.e., microcystin-LR) in the 1990s by the World Health Organization indicate that a level of 1 µg L-1 should be considered a guideline value for maximum allowable concentration (MAC) based upon an adult consumption of 2 L day-1. Other MACs for the neurotoxins and cylindrospermopsin will not be set until more basic toxicology and epidemiology are available. In addition the State of Oregon has set a regulatory level of 1 µg g-1 for microcystins in human food supplements produced from Aphanizomenon flos-aquae, in Klamath Lake, and Brazil has set a regulatory level of 1 µg g-1 for microcystins in drinking water supplies. Health authorities from several countries are also evaluating the risks of cynotoxins and are adopting guideline or regulatory levels for microcystins in drinking and recreational waters, and algae food products. The USEPA has listed microcystins, cylindrospermopsin and anatoxin-a as highest priority cyanotoxins, and saxitoxin(s) and anatoxin-a(s) as medium to high priority. Research is needed to assess the frequency and concentrations with which these cyanotoxins occur in recreational and finished drinking waters. Health research is needed to obtain cyanotoxin dose-response data for establishing Reference Doses (ingested compounds), Reference Concentrations (inhaled compounds) and cancer assessments. Risk management research is needed to assess the efficacy and sustainability of ecological and chemical approaches to freshwater harmful algae bloom control. As part of this need a National Freshwater Harmful Algal Bloom Research Plan (FHABRP) is being developed along with legislation in the form of a Freshwater Harmful Algal Bloom Research & Control Act of 2009 (FHAB Act). Information and discussion of this act is available at: http://www.FreshwaterHABlegislation.com/.

Preliminary Assessment of Cyanotoxin Occurrence in the United States

Loftin, K.A., J.L. Graham, M.T. Meyer, and A.C. Ziegler, U.S. Geological Survey, Kansas Water Science Center, Lawrence, KS

Public scrutiny of potential cyanotoxin exposure in lakes and reservoirs used for drinking water supplies and recreation in the United States has increased over the last decade. Media reports of cyanobacterial blooms and human and animal poisonings to cyanotoxin exposure have occurred in at least 32 U.S. States. In August 2006, the U.S. Geological Survey conducted a bloom-targeted cyanotoxin reconnaissance in 23 midwestern U.S. lakes and reservoirs in 4 States. Samples were analyzed by liquid chromatography tandem mass spectrometry (LC/MS/MS) and by enzyme-linked immunosorbent assays (ELISAs) for microcystins, nodularins, cylindrospermopsins; anatoxin-a and lyngbyatoxin-a (LC/MS/MS only), and saxitoxins (ELISA only). Microcystins were detected in all water samples for this study where total concentrations ranged from less than 0.025 μg/L to greater than 17,000 μg/L. The 2nd most frequently detected cyanotoxin was anatoxin-a, being detected in about 30 percent of the samples with a maximum concentration of 13 μg/L. In 2007, the U.S. Geological Survey analyzed about 1200 lake and reservoir water samples collected between May and October for microcystins by ELISA with confirmation of a subset of samples by LC/MS/MS in the U.S. Environmental Protection Agency's National Lake Assessment. In contrast to the 2006 Midwestern Lake reconnaissance, water samples for this study were collected from the photic zone at the deepest part of each water body. Preliminary results from this study show that microcystins were present in 32 percent of the samples (n=1238) with an average detection concentration of 1.0 μg/L. The results of these two studies demonstrate the wide range in concentrations and the co-occurrence of multiple toxin classes and variants in US lakes and reservoirs. Furthermore, these studies demonstrate the utility of using LC/MS/MS and ELISA to provide multiple lines of evidence to confirm total cyanotoxin exposure.

Multi-year Trends in *Microcystis aeruginosa* and Associated Microcystin Toxin in the Klamath River System: Implications for Public Health Guidelines

Kann, J.[1] and S. Corum[2]

[1]Aquatic Ecosystem Sciences LLC, Ashland, OR
[2]Karuk Tribe of California, Department of Natural Resources, Happy Camp, CA

Copco and Iron Gate Reservoirs located on the Klamath River in Northern California have experienced consistently large toxigenic blooms of *Microcystis aeruginosa* (MSAE) over the past five years, exceeding World Health Organization (WHO) Moderate Probability of Adverse Health Effect Levels for both cell density and toxin by 10 to over 1000 times during July–October. Although both cell density and toxin data indicated that MSAE cells and microcystin were either not detectable or detected at very low levels in the Klamath River directly above the reservoirs, levels of both parameters increased directly below the reservoirs in all years, including accumulation in slow velocity river-edge areas. From a public health perspective these data illustrate that low MSAE or toxin values in open-water (collected in mixed areas of higher velocity) Klamath River samples often translates to values exceeding public health thresholds in river-edge areas.

The four year monitoring program has allowed for the determination of inter-annual and seasonal bloom dynamics, relationships between MSAE cell density and microcystin toxin, as well as between chlorophyll a and microcystin. For example, the State of California (SWRCB/OEHHA) public health guidance level of 8 µg/L microcystin had 15 percent and 20 percent exceedance probabilities when MSAE cell density was 20,000 cells/ml, and ~25 percent and ~40 percent probabilities when MSAE cell density was 40,000 cells/ml for the Jun–Sept and Jun–Aug models, respectively.

Further evaluation of WHO low probability of adverse health effect guideline values of 20,000 cells/ml MSAE and 4 µg/L microcystin as utilized by the California North Coast Regional Water Quality Control Board for Total Maximum Daily Load calculations, showed that at an MSAE cell density level of 20,000 cells/ml that there were ~35 percent and 50 percent probabilities of exceeding 4 µg/L microcystin for the Jun–Sept and Jun–Aug models, respectively. The greater frequency of exceedance observed for the Jun–Aug models reflect both higher absolute microcystin values and higher microcystin toxin to MSAE cell density ratios occurring during that time, and thus provide a more conservative indication of risk with respect to public health.

Agreeing with WHO guidelines relating values of 10 µg/L or greater of chlorophyll to a moderate probability of acute health effects, ~30 percent and ~25 percent probabilities of exceeding 20,000 cells/ml MSAE and 4 µg/L microcystin were observed at a chlorophyll a level of 10 µg/L in this study. By demonstrating increasing trends in response variables with either increasing CHL or MSAE cell density, the above relationships provide a robust basis for evaluation of public health guidance values for toxic cyanobacteria in the Klamath River system.

Microcystis Blooms in the San Francisco Estuary: Monitoring their Toxicity and Potential Adverse Impacts to Fish Health

Teh, S., Aquatic Toxicology and Health Program, Department of Anatomy, Physiology, and Cell Biology, School of Veterinary Medicine, University of California-Davis, Davis, CA

Toxic cyanobacteria are viewed as one of several environmental problems and health hazards for aquatic animals and human beings worldwide. Effective forecasting of algal bloom toxicity requires knowledge on the presence of toxin producing genotypes and the combined effects of environmental conditions that may induce toxin production to lethal levels. In addition, critical food web components such as zooplanktons and pelagic planktivores may be exposed to cyanotoxins directly by consuming cyanobacteria during harmful algal blooms or indirectly by preying on organisms that have previously ingested or exposed to toxic cyanobacteria. This presentation will discuss the potential relationships between *Microcystis* toxicity, trophic transfer and pelagic fish health in the San Francisco Estuary. Of particular concern is the potential role of *Microcystis* toxins as one of several stressors affecting fish populations that are currently experiencing unprecedented decline in the estuary.

Microcystin Bioaccumulation in Klamath River Fish and Freshwater Mussel Tissue: Implications for Public Health

Kann, J.[1], S. Corum[2], and K. Fetcho[3]

[1]Aquatic Ecosystem Sciences LLC, Ashland, OR
[2]Karuk Tribe of California, Department of Natural Resources, Happy Camp, CA
[3]Yurok Tribe Environmental Program, Klamath, CA

Klamath River fish and freshwater mussel tissues (FWM) were evaluated for cyanotoxins by the California Department of Fish and Game Water Pollution Control Laboratory in 2007 and 2009 (FWM only). In 2007, analyses were performed on composite (consisting of 6 yearling fall Chinook) liver, stomach, and fillet samples from the Iron Gate Hatchery, composite and individual freshwater mussel samples (*Gonidea angulata*) from the Klamath River in the Seiad Valley area, as well as yellow perch (both individual fillets and liver composites) collected from Copco and Iron Gate Reservoirs. In 2009, freshwater mussels were evaluated by both the Karuk and Yurok Tribes in locations extending from below Iron Gate Reservoir to the lower river. A variety of known microcystin (MCYST) congeners were analyzed, including MCYST-RR, -LR, -YR, -LA, -LW, -LF, -LY and the demethylated analogues of –RR, and –LR. In addition, in 2009 anatoxin-a, domoic acid, and okadaic acid were also evaluated.

Results for tissue concentration of various MCYST congeners showed some level of bioaccumulation in the majority (85 percent) of samples tested in 2007, although there was some indication of depuration in November 2007 FWM samples taken after bloom decline. However, unlike 2007, late season FWM samples in 2009 continued to show relatively high levels of MCYST bioaccumulation. Differential uptake of the MCYST congeners occurred both between organisms (fish *vs*. freshwater mussels) and between fish liver vs. fish fillets, with only IG Hatchery liver composite samples showing detectable MCYST, while FWM's showed elevated concentrations of MCYST-RR, MCYST-LR MCYST-LR-DM, and MCYST-LA, with MCYST-LR and –LA being the most dominant congeners. Yellow perch fillets were dominated by the demethylated version of MCYST-LR. In contrast, yellow perch livers showed concentrations of both demethylated –LR and –RR, as well as MCYST-LA. FWM samples in 2009 often showed relatively high levels of MCYST bioaccumulation (typically the –LA variant) even when ambient river concentrations were low or below detection.

Comprehensive literature reviews of cyanobacterial toxin accumulation indicate that concentrations of various MCYST congeners in Klamath River fish and FWM tissue exceeded various tolerable daily intake values relevant to public health protection. For example in 2007, MCYST in FWM exceeded the Lifetime TDI guideline for children by 8 to 663x, the Seasonal TDI by 0.8 to 66x, and the Acute TDI by 0.1 to 10.6x. For yellow perch filets, 66 percent of the samples were greater than 10x (up to 100x) the Lifetime TDI and 1-10x greater than the seasonal TDI, with several samples exceeding the Acute TDI. These trends will be discussed relative to public health protection and State of California guideline values for MCYST in tissue.

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Fall Chinook Salmon Escapement and Run Characteristics for the Mainstream Klamath River, 2001–2008

Gough, S.A.[1], and S.C. Williamson[2]

[1]U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, CA
[2]U.S. Geological Survey, Fort Collins Science Center, Fort Collins, CO

The U.S. Fish and Wildlife, in collaboration with tribal and State partners, initiated monitoring of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) escapement in the mainstem Klamath River in 1993 using redd survey methods. To improve the accuracy of escapement estimates generated using redd survey data, we conducted carcass surveys of fall-run Chinook salmon within weekly time strata on the Klamath River below Iron Gate Dam during spawning seasons of 2001 through 2008. Carcass survey data were used to estimate escapement using postmortem tag/postmortem recovery methods and to characterize the age and sex composition and spawning success of the run. Unstratified Petersen, stratified Petersen, and Schaefer tag recovery methods were employed to estimate escapement. Our analyses indicate that the unstratified Petersen estimator contains decreased reliance on potential sources of bias compared to the other estimators used. In comparison to redd counts from concurrent redd surveys between Iron Gate Dam and the Shasta River confluence, unstratified Petersen carcass tag recovery methods yielded 3.2 to 4.7 successfully spawned females per observed redd. Redd surveys are still used to estimate escapement between the Shasta River and Indian Creek confluences, where the number of carcasses each year is too sparse for a sufficient carcass-based estimate. According to Kimura-adjusted scale readings and subsequent expansions, jacks (age two fish) represented only 0.1 percent to 3.9 percent of the carcasses sampled each season in 2001, 2003 through 2005, and 2007 but 9.4 percent, 15.8 percent, and 17.1 percent in 2002, 2006, and 2008, respectively. Extremely low jack numbers in 2005 boded poor returns in 2006 and 2007 of age 3 and age 4 adults, respectively. Despite low adult estimates in 2006 and 2008, jack estimates were highest, portending good returns of 3 year old spawners in 2007 and 2009 and of 4 year old spawners in 2008 and 2010. Pre-spawn mortalities of females ranged from an unusually high 22.1 percent in 2005 to a low of 2.7 percent in 2007. Estimated annual egg deposition by adult females in the study area, calculated from the unstratified Petersen estimates, ranged from 21.1 and 24.5 million (in 2002 and 2003) down to 6.7 and 5.7 million (in 2005 and 2006).

Klamath Basin Lampreys: Critical Uncertainties for Restoration and Management

Goodman, D.H., U.S. Fish and Wildlife Service, Arcata Field Office, Arcata, CA

The Klamath Basin is home to the highest diversity of lamprey species in the world. These species have a variety of life history strategies from the large anadromous and predatory Pacific lamprey (*Entosphenus tridentatus*) to the small non-predatory Klamath brook lamprey (*Entosphenus lethophagus*). Included in the Klamath Basin lamprey fauna are several endemic species including the smallest extant lamprey, the Miller Lake lamprey (*Entosphenus minimus*). The lampreys of the Klamath Basin also have cultural significance to the Tribes of the Klamath Basin with many of the Lower Basin Tribes actively harvesting Pacific lampreys as part of a subsistence fishery. Despite the importance of the lamprey fauna in the Klamath Basin, little is known about these fishes. Although population monitoring information for any lamprey species on the Pacific coast is sparse, data indicates that populations are at depressed levels and declining. Furthermore, much of the information needed to

properly manage and restore these unique species has not been developed. The most studied of the lampreys that occur within the Klamath Basin is the Pacific lamprey. Although the Pacific lamprey is anadromous and sympatric to many Pacific Coast salmonids, current studies demonstrate that their biology and management needs differ dramatically. Some specific examples include differences in genetic population structure, habitat use, passage needs, bioaccumulation of toxins and more. These differences highlight the need to address the major knowledge gaps and consider lampreys during Klamath Basin restoration planning and implementation.

Population Genetics of Klamath Basin *Oncorhynchus mykiss*

Pearse, D.[1], J.C. Garza[1], and M. Peterson[2]

[1]NOAA, Southwest Fisheries Science Center, La Jolla, CA
[2]Department of Fisheries Biology, Humboldt State University, Arcata, CA

In the Klamath Basin, the salmonid fish species *Oncorhynchus mykiss* is present throughout the lower Klamath-Trinity River system as anadromous summer- and winter-run steelhead as well as freshwater resident rainbow trout, all of which are forms of the coastal subspecies *O. m. irideus*. In addition, redband trout (*O. m. newberrii*) occur in the upper Klamath Basin. However, compared with the Columbia River to the north, relatively little is known about the relationships among *O. mykiss* populations within the Klamath River. Although steelhead and other anadromous salmonids historically migrated into the upper Klamath Basin and associated tributaries, the construction of Copco Dam #1 in 1918 and Iron Gate Dam in 1962 stopped all upstream migration of fishes past these barriers. We have conducted population genetic analyses of *O. mykiss* samples collected throughout the Klamath watershed using data from 18 variable microsatellite loci. Samples included steelhead, rainbow and redband trout, presumably representative of ancestral coastal and inland lineages, as well as samples of *O. mykiss* from neighboring inland basins. In addition, the Klamath samples were compared with data from *O. mykiss* populations in other coastal California river systems. Results demonstrate the presence of distinct inland and coastal genetic lineages, as well as divergent lineages represented by samples from the inland lake basins.

Status of Coho Salmon in the Scott and Shasta River Watersheds

Knechtle, M., California Department of Fish and Game, Yreka, CA

The California Department of Fish and Game has operated video fish counting facilities to enumerate coho salmon (*Oncorhynchus kisutch*) on the Shasta River and Scott River watersheds since 2001 and 2007 respectively. The purpose of these counting facilities is to enumerate abundance and describe the run characteristics of adult coho salmon. Video fish counting operations are initiated each season in the early fall and continue through early January unless high in-stream flows force earlier removal. The total number of coho salmon that entered the Scott River during 2007, 2008 and 2009 was 1,622, 62 and 21 respectively. The total number of coho salmon that entered the Shasta River from 2001 to 2009 has ranged from 9 to 373. The hatchery component of coho salmon in the Scott River is thought to be extremely low, as very few marked fish have ever been recovered in the watershed. The proportion of hatchery origin coho salmon returning to the Shasta River in 2008 and 2009 was estimated to be 73 percent and 20 percent respectively. On the Scott River only one data point is available for each cohort, preventing any trend analysis, although it is clear that one of the three brood years is sustaining itself while the remaining two are critically low. All three cohorts on the Shasta River have declined (14 percent-95 percent) over the course of the last two generations. Recent counts on two of the three Shasta River cohorts are critically low (<31 individuals). Both the Scott River and Shasta River coho salmon populations are identified in the Southern Oregon Northern California Coho (SONCC) recovery plan as independent core populations, which indicates their high level of importance to the long term success of the ESU. Current data collected from the Shasta River and Scott River counting facilities indicates that both of these important populations are at critically low abundance levels and are facing an extremely high risk of extinction.

The Potential for Integrating Fish Tagging Studies Throughout the Klamath River Basin

Janney, E.C., D.A. Hewitt, B. S. Hayes, and A.C. Harris, U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR

Management and recovery of imperiled fish populations depend on understanding key life history parameters and their roles in regulating population dynamics. Capture-recapture studies offer a reliable way to estimate these parameters including survival, recruitment, population growth rate, movement, and habitat use. Capture-recapture data can be incorporated into a robust modeling framework to evaluate the effects of water management strategies and other environmental factors on fish populations. Severe water quality problems in the Klamath River Basin have led to fisheries concerns in the region and a non-binding conditional agreement to remove four dams separating the upper and lower basins. State, Federal, and tribal natural resource agencies throughout the Klamath River watershed are currently using passive integrated transponder (PIT) tags to study various endangered and sport fish populations. Unfortunately, the potential of these studies has often been hampered by low probabilities of re-encountering tagged fish. To ameliorate this problem, researchers have begun using remote underwater PIT tag detection systems to improve data collection efforts. Recent technological advances have improved the feasibility of tagging studies and allow for numerous study design possibilities. These advancements will allow researchers to conduct larger scale studies and ask bigger and better questions that address more complex hypotheses. In order to achieve the full potential of the various tagging studies in the basin, substantial thought should be given to study design, and collaboration among agencies will be required. To facilitate future collaboration, the USGS Klamath Falls Field Station is creating a centralized tagging database for the entire Klamath Basin that will allow storage and retrieval of data. This basinwide database will simplify and facilitate data-sharing and collaboration among agencies.

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Chinook and Coho Salmon Outmigrant Trapping in the Mainstem Klamath River

Gough, S.A.[1], T.A. Shaw[1], and S.C. Williamson[2]

[1]U.S. Fish and Wildlife Service, Arcata, CA
[2]U.S. Geological Survey, Fort Collins Science Center, Fort Collins, CO

The U.S. Fish and Wildlife Service (USFWS) has been conducting downstream migrant monitoring for juvenile salmonids in the mainstem Klamath River at Big Bar, 10.0 km upstream of Weitchpec, since 1988. Since 1996, that site has been monitored jointly by the USFWS Arcata Fish and Wildlife Office and the Karuk Tribe of California. Since 2000, USFWS, Karuk Tribe, and USGS Fort Collins Science Center have been using rotary screw traps and frame nets to monitor outmigrants of all fish species at three sites on the mainstem Klamath River between Iron Gate Dam and the Scott River confluence: downstream of the Bogus Creek confluence (2002 to present), near the I-5 bridge river crossing , and just upstream of the Kinsman Creek confluence (2002 to present). After very high disease rates were noted in 2003, we also sampled the mainstem Klamath River at Happy Camp and above Orleans in 2004 (Chamberlain and Williamson 2006). Temporal distribution of outmigration, outmigrant length and weight, and production/successful outmigrant estimates of Chinook salmon, based on mark-recapture trap efficiencies are currently in production using techniques recently developed for the Trinity River Restoration Program. Since 2004 we have recorded external symptoms of infection, which generally are not exhibited until late stages of infection. Gill, belly, anus, eye, and skin conditions, in particular, were examined. QPCR (quantitative real-time polymerase chain reaction) assays and histology analyses (of fish that we provided) conducted by the USFWS California-Nevada Fish Health Center provide more accurate/precise infection rates and relationships to habitat conditions. We intend that these infection rates, by size category and exposure time, observed water temperatures, and locations of disease hotspots, will be included into our young-of-year salmon production model, SALMOD.

Juvenile Coho Salmon Use of Off-Channel Habitats in the Lower Klamath River

Hillemeier, D., Yurok Tribal Fisheries Program, Klamath, CA

The Yurok Tribal Fisheries Program (YTFP) and the Karuk Tribe Department of Natural Resources (KTDNR) initiated a collaborative study in 2006 to better understand juvenile coho salmon habitat use within the Klamath River mainstem corridor, which encompasses the main river channel and its side channels, off-channel habitats and the lower reaches of tributaries near the Klamath floodplain. Fish sampling efforts have included the use of fyke nets, beach seines, and electro-fishing. Fish marking techniques have been used to document fish movement patterns, estimate fish densities, and assess residence time in several off-estuary slough and lower tributary locations. Marking young-of-the year coho salmon with Passive Integrated Transponder (PIT tags) by KTDNR and YTFP throughout mainstem and tributary habitats has enabled tracking movement and growth of these uniquely numbered fish between the time they are marked and subsequent recapture events. Results indicate that fish migrate substantial distances from natal tributaries and mainstem habitats into off-estuary sloughs and off-channel wetlands beginning with the onset of the first fall freshets. Beaver ponds and similar open-water wetlands appear to provide preferred over-wintering habitat in the Lower Klamath for non-natal juvenile coho salmon. Growth rates of coho rearing in these habitats are substantially greater than those of fish sampled over the same time frame in free-flowing tributary habitats; indicating an advantage these still-water habitats, with relatively warm winter water temperatures, offer compared to winter habitat conditions in natal inland streams. PIT-tagged coho from throughout the basin are consistently captured in these types of off-channel habitats, indicating that they play a key role in the growth and survival of coho salmon from throughout the Klamath Basin. Life –stage habitat requirements and spatial distribution of these habitats seem to determine migratory behavior of juvenile coho. Information regarding the importance of off-channel/beaver pond habitats is guiding our restoration efforts in the Lower-Klamath Basin.

Juvenile Coho Life History Tactics Utilizing the Mid-Klamath River Corridor with Linkages Between Inland and Coastal Riverine Habitats

Soto, T., Karuk Tribe, Orleans, CA

The Karuk Tribal Fisheries Program (KTFP) and the Yurok Tribal Fisheries Program (YTFP) initiated a collaborative study in 2006 to better understand juvenile coho salmon habitat use within the Klamath River mainstem corridor. The mainstem corridor encompasses the main river channel and its side channels, off-channel habitats and the lower reaches of tributaries in close proximity to the Klamath floodplain. Sampling efforts include use of beach seines, fyke nets, directional weir traps in combination with marking and tagging fish to determine extent of residence, fitness and distribution in relation to seasonal shifts in habitat characteristics Results indicate that some juvenile coho leave natal areas and re-distribute within the mainstem river corridor with movements closely associated with seasonal changes in water quality and flow patterns. The use of non-natal habitats within the mainstem corridor, including small tributaries and off-channel features, appears to be an important survival mechanism for some juvenile coho in the Mid Klamath region during summer when water temperatures exceed lethal levels, and during winter when high flows occur. The relative importance of an overwintering re-distribution, however, appears to differ between the upper reach of the Mid Klamath region, where winter flows are more stable due to less precipitation compared to the lower part of the region. Flow patterns are much more dynamic downstream of Happy Camp in winter. Findings indicate that recovery actions could be tailored to benefit juvenile coho that utilize the mainstem corridor, thereby improving overall population viability. Strategic habitat restoration within the corridor could benefit all spawning aggregates located upstream.

Factors Affecting Coho Smolt Survival in the Lower Klamath River

Beeman, J.[1], S. Juhnke[1], and N. Hetrick[2]

[1]U.S. Geological Survey, Cook, WA
[2]U.S. Fish and Wildlife Service, Arcata, CA

Coho salmon (*Oncorhynchus kisutch*) populations in the lower Klamath River were listed as threatened under the Federal Endangered Species Act, and the Biological Opinion that followed in 2002 spurred several management actions. One action included implementation of minimum discharges at the lowermost of six dams on the Klamath River. The premise behind this action was that increased discharge during spring would increase survival of coho salmon smolts, thereby aiding recovery. This hypothesis appeared logical, but had not been studied in the Klamath River. A study of the relation between coho smolt survival and environmental factors including river discharge was conducted between 2006 and 2009. Discharge at the dam was not experimentally controlled, however survival rates were evaluated under a wide range of observed flow conditions during the four year study. In each year, apparent survival of radio-tagged fish released near Iron Gate Dam was estimated in seven different river reaches downstream using Cormack-Jolly-Seber mark-recapture models. Estimates of apparent survival through 276 km downstream from the dam ranged from 0.406 (SE = 0.032) to 0.659 (SE = 0.049) among years. The lowest estimates and greatest differences in apparent survival among years were in areas upstream from the Scott River, the first 75 km downstream from the dam. The effects of river discharge, water temperature and several other variables on survival were also evaluated.

Monitoring Adult Spawning Populations of Lost River and Shortnose Suckers to Support Recovery Planning

Hewitt, D.A., E.C. Janney, and B.S. Hayes, U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR

Lost River and shortnose suckers are federally endangered, long-lived catostomids endemic to the Upper Klamath River Basin of southern Oregon and northern California. Since 1995, the U.S. Geological Survey has been monitoring the adult spawning populations of both species in support of recovery planning efforts. The two locations of primary concern for management are Upper Klamath Lake in Oregon and Clear Lake Reservoir in California. A monitoring and research program based on modern capture-recapture methods has produced precise estimates of annual survival for populations of both species in Upper Klamath Lake and shows promise for populations in Clear Lake Reservoir. Results show that survival is typically high, in accordance with life history expectations, but that populations experience substantial mortality in some years. Implementation of remote detection systems for passive integrated transponder (PIT) tags has dramatically increased the amount of information collected. This wealth of data has made it possible to explore more realistic models and hypotheses about factors affecting the conservation and recovery of these species. Of particular interest to recovery planning, the capture-recapture program now produces estimates of recruitment and annual rates of change for the adult spawning populations in Upper Klamath Lake. In this system, both Lost River and shortnose sucker populations are dominated by fish that were spawned in the early 1990s, with little evidence of recruitment in the past decade. Populations have declined by 25–50 percent over the last 6–7 years because mortality has not been counterbalanced by recruitment. The capture-recapture program is complemented by efforts to develop reliable methods for aging these species, as age data can provide a second source of information about recruitment to the adult spawning populations. Our monitoring and research program has provided a solid science foundation that informs managers tasked with recovering these imperiled species.

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Mercury Contamination in Lampreys of the Lower Klamath Basin

Bettaso, J.B., and D.H. Goodman, U.S. Fish and Wildlife Service, Arcata, Field Office, Arcata, CA

Mercury has been linked to a host of lethal and non-lethal impacts to biological organisms. Impacts from mercury include immunosuppression, teratogenic effects and endocrine disruption. Mercury, referred to as Quicksilver by goldminers, was widely used in Northern California during the gold rush. High levels of mercury in the Trinity River led to health advisories for the consumption of fish in Trinity Lake. We investigate presence of mercury in long lived filter feeders in the Klamath Basin, lamprey ammocoetes (*Entosphenus spp.*). In 2007, we sampled freshwater mussels (*Margaritifera falcata*) and lamprey ammocoetes from three paired locations in the Trinity River. In 2008 we sampled lamprey ammocoetes and sediment samples from 31 locations in the Klamath River and its tributaries. In 24 of the 31 (77 percent) batch sample sites collected had Total Mercury (THg) levels above 0.3 ppm, a level of concern set by the EPA for human consumption. At a single site where 31 individual ammocoetes were sampled and tested for THg, 28 of 31 (90 percent) were above 0.3 ppm. Adult lampreys were collected at the mouth of the Klamath with a partnership with the Yurok Tribe and had muscle fillets examined for total mercury, as well as a subset of adult females examined for biodistribution of mercury in muscle fillets, liver, ovaries and muscle biopsies. Adults were tested for

muscle fillets had 23 percent (5 of 21) of the samples above 0.3 ppm. For the smaller portion of adult females tested for several organs, the individual with the highest levels of THg for muscle fillet also had correspondingly high levels in the liver, ovaries and the muscle biopsy. Considerations of future work with mercury levels in these unique species are discussed.

Ceratomyxosis and *Parvicapula minibicornis* Infection of Klamath River Juvenile Salmon

Foott, J.S., U.S. Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, CA

Two myxosporean parasites, *Ceratomyxa shasta* and *Parvicapsula minibicornis*, are quite prevalent in juvenile Chinook salmon that rear or migrate through the Klamath River. Both parasites have a freshwater polychaete alternative host, *Manayunkia speciosa*, that is found at high densities in some reaches of the Klamath River. *Ceratomyxa shasta* infection can result in lethal enteritis while *P. minibicornis* infects the kidney. Prevalence of infection for C. shasta has ranged from 21–49 percent in samples collected above the confluence of the Trinity River with *P. minibicornis* infection > 90 percent. Data on disease progression, species susceptibility, infection characteristics, and potential control measure studies will be discussed. A concerted research effort to understand the ecological factors influencing fish disease in the Klamath River is being conducted by collaboration of Klamath River tribes, Federal and State agencies, and university researchers.

Effects of *Ceratomyxa Shasta* Infections on Klamath River Salmon: What do we Know and Where do we go Next?

Bartholomew, J.L., Oregon State University, Department of Microbiology, Corvallis, OR

Severe infection by the myxozoan parasite *Ceratomyxa shasta* has contributed to the declining numbers of juvenile Klamath River fall Chinook and coho salmon and subsequent impacts on later adult returns. Over the past 7 years, efforts in our laboratory have been directed at understanding the ecology of the parasite in the Klamath River with a goal of reducing disease effects. A monitoring program that utilizes real-time PCR assessment of water samples has provided insights on the temporal and spatial occurrence of the parasite. This monitoring has identified an area of the river below Iron Gate Dam where parasite abundance reaches >10–100 parasites/L. Sentinel studies conducted in this area provide evidence that an exposure dose of 10 parasites/L represents a threshold for mortality in native Chinook and coho salmon. Results of sentinel fish exposures in 2009 show that disease effects this year were severe and also suggest that the infectious zone was expanded in 2009. In contrast to the high mortality in salmon in the lower river as a result of *C. shasta*, exposure of salmon at a location with similar parasite densities in the Williamson River did not result in mortality. Investigation of this anomaly resulted in identification of four parasite genotypes that appear to have specificity for different salmonid species. All of this data is being incorporated into a disease model that will inform efforts directed at reducing parasite numbers and enable us to make predictions on disease effects as either dam removal or fish passage plans progress over the next decade.

Ceratomyxa Shasta Infection in Sentinel Fish Exposed in the Klamath River, 2007–2009

Holt, R.A., R. Adam Ray, and J. Bartholomew, Department of Microbiology, Oregon State University, Corvallis, OR

Sentinel juvenile fish exposures to detect infections of *C. shasta* were conducted for 72 hr at various sites in the Klamath River system during May, June and September 2007–2009. These studies were done to identify those areas of the river where "hot spots" of infection occur, to allow comparisons of infection levels with previous years, and to examine susceptibility of the Klamath fall Chinook and coho juveniles. At most sites, a known susceptible rainbow trout stock, and Iron Gate Hatchery Chinook and coho were exposed, then reared at the Salmon Disease Laboratory, Corvallis, OR and observed for infections of *C. shasta*. The rainbow trout suffered 90–100 percent loss at all sites except at Keno Eddy above J.C. Boyle Dam and above the Klamathon Bridge below Iron Gate Dam. Severe losses of fall Chinook occurred near Beaver Creek and Seiad Valley in May and June. In June 2007, 30–40 percent of the Chinook died but in June 2008 and 2009, losses reached 60–90 percent. Coho were affected at all sites below Iron Gate Dam, but most severely near Beaver Creek and Seiad Valley. Post-exposure holding at a water temperature of 18°C resulted in higher loss of coho when compared to those held at 13°C. Very low loss was observed in Chinook and coho exposed in the lower Williamson River. No mortality occurred in Chinook salmon exposed at Keno Eddy. The sentinel exposures demonstrate that only a 3-day exposure of Chinook and coho in the river reach encompassing Beaver Creek and Seiad Valley resulted in serious mortality. Also, there appears to be a shift downstream of greater infection severity seasonally from spring to summer within this hot zone.

Evaluation of *Ceratomyxa shasta* and *Parvicapsula minibicornis* Infection in Returning Adult Chinook Salmon (*Oncorhynchus tshawytscha*) Throughout the Klamath River Basin

Slezak, R., Humboldt State University and U.S. Fish and Wildlife Service, Arcata, CA

I examined incidence and density of *Ceratomyxa shasta* and *Parvicapsula minibicornis* infection in adult Chinook salmon (*Oncorhynchus tshawytscha*) returning to spawn in the Klamath River Basin. From August 2007 through December 2007, 506 adult salmon were sampled at various locations throughout the basin. Trophozoite and myxospore life stages of the myxozoan parasites *C. shasta* and *P. minibicornis* were identified and quantified using wet mount, histology, and polymerase chain reaction. Chi-square tests were used to correlate any temporal or geographical patterns with incidence and density. Incidence and density for both pathogens peaked on October 25 in samples collected from Iron Gate Hatchery. No clear trends were seen in samples collected from Trinity River Hatchery. Chinook salmon carcasses collected from Bogus Creek, Shasta River, and the mainstem Klamath River were found to have significantly more *C. shasta* myxospores than Chinook salmon artificially spawned at Iron Gate and Trinity River Hatcheries. Further research should focus exclusively on naturally-spawned salmon carcasses to gain a better understanding of the timing and frequency of the myxospore load in the Klamath River Basin.

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Modeling the *Ceratomyxa shasta* Cycle in the Klamath River System

R. Adam Ray, P. Rossignol, and J. Bartholomew, Department of Microbiology, Oregon State University, Corvallis, OR

In the Klamath River (KR) the disease ceratomyxosis is one of the factors impacting the survival of out-migrating juvenile salmon. This disease is caused by the myxozoan parasite *Ceratomyxa shasta*. *Ceratomyxa shasta*, endemic to the Pacific Northwest, requires a salmonid host and a freshwater polychaete host (*Manyunkia speciosa*) to complete its life cycle. Over the past ten years, research in our laboratory has been conducted to determine the distribution and densities of both the parasite and the polychaete host within the Klamath system and also to monitor the severity of disease in juvenile salmon. We have developed a mathematical model that identifies the basic interaction parameters of *C. shasta* and its two hosts. From the parameters in this model a series of equations were developed to describe each stage in the parasites life cycle. These equations were then solved to define the basic reproduction number (R_0) of *C. shasta*. To estimate the value of the basic reproduction number we conducted field experiments to quantify a range of values for select parameters in the model. In the Klamath River, we exposed caged sentinel fish for various lengths of time and measured water velocity to estimate the transmission rate of *C. shasta* and the infectious dose juvenile salmon are exposed to in the river. From these field exposures we identified a non-linear threshold to mortality from *C. shasta* in Chinook salmon. As the number of parasite per fish surpassed 5.5 – 9.9 x 105, the mortality greatly increased. From the basic reproduction number equation we will be able to identify the key parameters that may act as bottlenecks in the transmission cycle. This model also provides a platform to perform computer simulations to determine the relative effectiveness of different management strategies on reducing the in-river parasite burden.

Ceratomyxa Shasta in the Williamson River: Implications for Salmonid Reintroduction and Management in the Upper Klamath Basin

Hurst, C.N., and J.L. Bartholomew, Department of Microbiology, Oregon State University, Corvallis, OR

Ceratomyxa shasta is a myxozoan parasite endemic to the Klamath River basin and is dependent upon both a polychaete worm (*Manayunkia speciosa*) and a salmonid to complete its life cycle. *Ceratomyxa shasta* is established throughout the main-stem Klamath River, with levels highest below Iron Gate Dam and in the lower Williamson River. Questions about how dam removal and the reintroduction of anadromous salmonids into the upper basin will affect disease have necessitated research on parasite density, distribution, host overlap and the parasite genotypes present in the Williamson River. Parasite density was assessed using a *C. shasta* specific quantitative PCR assay from water samples collected throughout the Williamson River and its tributaries. Parasite DNA was sequenced to determine parasite genotype. Polychaete surveys were focused in areas of highest parasite densities to compare polychaete habitat and qualitative polychaete densities between sampling locations. We determined two areas where the highest (>10 parasites/L) parasite densities occur, from the mouth of the Williamson River to below the confluence of Sprague River and above the confluence of Spring Creek. Polychaetes were present in both locations surveyed and were mostly found in slow-flowing, depositional areas. Genetic analysis of parasites from water samples and infected fish in the Williamson River demonstrate parasite genotypes found in the native redband trout differ from those that cause mortality in the stocked susceptible rainbow trout and that the parasite genotype found in Chinook salmon is not present. However, reintroducing anadromous fish could potentially introduce novel genotypes into the upper Klamath basin.

Effects of Elevated Water Temperature on Early Life Stage Development and Survival of Spring-run Chinook Salmon in the Klamath-Trinity Basin

Marine, K., North State Resources, Inc., Redding, CA

Key uncertainties regarding the adequacy of temperature management criteria for protecting spring-run Chinook salmon, a racial component of the Upper Klamath-Trinity rivers Chinook salmon ESU, were identified in the Trinity River Flow Evaluation because of a paucity of data on stock-specific responses to water temperature regimes. Temperature-specific developmental characteristics and mortality of incubating eggs and pre-emergent larvae between 10°C and 16.6°C were evaluated in a blocked experimental design using eggs from 10 one male to one female matings (to control for interfamilial variation) over two study years. Temperature-specific mortality rate exhibited a threshold response as opposed to a continuous function reported for a number of other salmon species. A statistically significant ($P<0.001$) critical water temperature threshold was identified at 14.5°C above which the mortality of incubating embryos and pre-emergent larvae rapidly increases. Temperature-specific embryo development followed a typical van't Hoff rate function. Fry surviving incubation at temperatures above 14.5°C were significantly ($P<0.001$) smaller at emergence than fry incubated at cooler temperatures. Furthermore, latent mortality of post-emergent fry generally increased for eggs incubated at and above 13.3°C compared with eggs incubated at lower temperatures. This latter result suggests that the temperature conditions during egg incubation and its effects on embryonic development persist after fish begin to exogenously feed.

Monitoring the Salmon Parasite *Ceratomyxa shasta* in the Klamath River Through Water Sample Analysis

Hallett, S.[1], G. Buckles[1], S. Corum[2], and J. Bartholomew[1]

[1]Department of Microbiology, Oregon State University, Corvallis, OR
[2]Department of Natural Resources, Karuk Tribe, Orleans, CA

Severe intestinal infection by the myxozoan parasite *Ceratomyxa shasta* has contributed to declining numbers of juvenile Klamath River (KR) fall Chinook and coho salmon and subsequent impacts on later adult returns. The small, spore-forming parasite is found throughout the Pacific Northwest but is most prevalent in the KR. The high prevalence and severity of *C. shasta* infections in KR fish indicates this parasite is a key factor limiting salmon recovery in this system. *Ceratomyxa shasta* has a complex life cycle, involving a polychaete worm host as well as salmon and trout. KR salmon have evolved with *C. shasta* and are relatively resistant to infection compared to salmon from rivers where the parasite is absent, thus the current severity of ceratomyxosis in these fish suggests a shift in the host:parasite balance. In addition to sentinel fish exposures and polychaete sampling, we have been directly sampling KR water to assess the abundance of *C. shasta*. We filter replicate 1L samples and test the concentrated material for parasite DNA using a specific and sensitive molecular assay (quantitative PCR). This approach enables us to readily follow the spatial and temporal abundance of waterborne stages of the parasite. This monitoring began in 2006 and in 2008 we tested over 1000 water samples from five mainstem index sites and four tributaries from March through September. Samples were also taken during sentinel fish exposures to relate parasite dose with fish mortality. We found the geographical and seasonal pattern of abundance of *C. shasta* largely consistent during our monitoring program, although parasite levels fluctuate between years. The parasite increases in abundance in the spring from less than 1 spore/L to peak in June at over 100 spores/L (at Beaver Creek, Rkm 259; 45 Rkm below Iron Gate Dam). Above Beaver Creek, levels are low (around 1 spore/L), and below Beaver Creek abundance decreases westward, likely a combination of dilution from the tributaries and disintegration of the fragile actinospore stage. Only small quantities of parasite (less than 1 spore/L) are detected in the tributaries. Generally, mortalities in sentinel Chinook attributable to *C. shasta* occur once parasite abundance exceeds 10 spores/L. Inconsistencies in dose and mortality (i.e. lower and upper Klamath River) appear to be explained by the presence of two different strains of parasite that differ in host preference. We have now accumulated sufficient data to begin looking for patterns in parasite abundance associated with variables including water flow and temperature.

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Effects of Myxozoa Disease on Population Dynamics of Klamath Fall Chinook Salmon

Fujiwara, M.[1], A. Greenberg[2], and M.S. Mohr[2]

[1]Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX
[2]Fisheries Ecology Division, Southwest Fisheries Science Center, National Marine Fisheries Service, Santa Cruz, CA

Animal populations are frequently infected by pathogens, but it is not always easy to determine their significance on overall population dynamics. One of the difficulties in detecting disease effects in population time-series data originates from the fact that the hosts are also affected by many other environmental factors. In this study, we investigated the effect of *Ceratomyxa shasta* (a myxozoa) disease on the population dynamics of fall-run Chinook salmon spawning within the Klamath River basin (California, USA). We analyzed existing spatially structured abundance data for naturally spawning salmon and survival data on hatchery-released salmon, and examined the effect of *C. shasta* disease. The results from this analysis were supplemented with previous results from a field experimental study monitoring fish survival and a field sampling of *C. shasta* infection rates among migrating juvenile salmon. Based on this synthesis of the results, we conclude that *C. shasta* disease significantly affects the survival of fish that migrate through the location where the pathogen is concentrated, and that this effect is detectable in both survival and spawning-abundance estimates.

Environmental Influences on Endangered Sucker Ecology 1

Lack of Recruitment to Spawning Sucker Populations and Timing of Juvenile Sucker Mortality in Upper Klamath Lake, Oregon

Burdick, S.M.[1], S.P. VanderKooi[1], T.M. Wood[2], B.H. Rosen[3], C.A. Ottinger[4], and K.R. Echols[5]

[1]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[3]U.S. Geological Survey, Florida Integrated Science Center, Orlando, FL
[4]U.S.Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV
[5]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO

Lack of substantial recruitment into adult Lost River and shortnose sucker populations in Upper Klamath Lake, Oregon was one of the major factors leading to the listing of these species under the Endangered Species Act in 1988. There is strong evidence for a lack of substantial recruitment, but less information is available on the timing and causes of juvenile sucker mortality. Length frequency and age data show that the spawning populations of Lost River and shortnose suckers are relatively homogeneous groups spawned in the early 1990s. Estimates of recruitment based on capture-recapture data indicate that few individuals have been added to the spawning populations over the last decade. Regardless of the gear used for capture, catches of age-0 juvenile suckers decline each year in August and age-1 and older suckers are always low. Potential causes of declining catches include emigration from a sampling region and reduced catchability as fish grow. Occupancy models that account for imperfect and changing detection probabilities and sampling across a wide geographic range, however, suggest that mortality is a more likely cause of diminishing catches. The timing of decreasing catches suggests high mortality may occur in July or August in most years. One hypothesis is that a lack of suitable in-lake rearing habitat and periodic poor water quality events reduce survival. Another hypothesis is that toxic cyanobacteria are linked to age-0 sucker mortality through the food chain.

Ecological Strategies Utilized by Cyanobacteria

Rosen, B.H., U.S. Geological Survey, Office of the SE Regional Executive, Orlando, FL

Cyanobacteria, also known as blue-green algae, are the most primitive group of algae. They are simple but remarkably successful organisms. They are most closely related to other bacteria because they are prokaryotic, however, like other algae and higher plants, they have chlorophyll *a*, the primary pigment for photosynthesis. They also have two other important light-harvesting pigments, phycocyanin and phycoerythrin.

Individually, cells are microscopic; however, large clusters of cells are easily visible as surface a scum (a type of algal bloom) on any stable body of water. Distinct colony morphologies include large gelatinous matrices with numerous embedded cells, as found in the genus *Microcystis* and bundles of filaments as found in the genus *Aphanizomenon*. These morphologies reduce the ability of invertebrates to graze on these organisms and also enhance floatation and water column positioning.

Nutrient enrichment often increases the amount of cyanobacteria and they are able to store excess nutrients, termed luxury uptake, and utilize these stored nutrients when environmental supplies become limiting. Polyphosphate bodies are one of the common structures that exemplify this trait.

Several cyanobacteria are capable of producing a heterocyst. This structure is the site of nitrogen fixation; using atmospheric N_2 and converting it into organic compounds. When nitrogen is limiting in an aquatic system, this group of cyanobacteria often dominate because of their ability to perform this metabolic function.

Some kinds of cyanobacteria produce natural toxins. Ingestion of these toxins has caused the poisoning of animals, including domesticated animals, wildlife and fish. Human exposure and toxicity has only recently been documented and awareness at water treatment facilities has increased. The U.S. Environmental Protection Agency has added blue-green algal toxins to its Candidate Contaminate List, which might result in new regulatory measures for surface waters. The toxins are generally of two types: neurotoxins and hepatotoxins. The neurotoxins are normally fast-acting, and animals that ingest a large dose experience paralysis of skeletal and respiratory muscles which results in death. Hepatotoxins affect the liver, disrupting the important proteins that keep the liver functioning. Hepatotoxins generally act slower and a higher dose is needed before death occurs, however, they also may be tumor promoters at low doses.

Seasonal and Spatial Dynamics of Cyanobacteria and Associated Water Quality Variables in Upper Klamath Lake, Oregon

Caldwell Eldridge, S.L.[1], K.E. Kannarr[1], T.M. Wood[2], K.R. Echols[3], B.H. Rosen[4], S.M. Burdick[1], C.A. Ottinger[5], and S.P. VanderKooi[1]

[1]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[3]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO
[4]U.S. Geological Survey, Florida Integrated Science Center, Orlando, FL
[5]U.S. Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV

Massive blooms of phytoplankton, dominated by cyanobacteria, occur annually from June through October in hypereutrophic Upper Klamath Lake, Oregon, due, in part, to hydrologic and land use changes made to the lake and its watershed during the past century. High rates of photosynthesis during bloom growth elevate lake water pH (9.5 and higher), and decomposition during episodes of severe bloom decline increases the concentration of un-ionized ammonia (> 0.5 mg L^{-1}) and dissolved nutrients. This seasonal cycle of phytoplankton growth and decline also causes oxygen concentrations to fluctuate from supersaturation to near anoxia. Preliminary work by the U.S. Geological Survey and others has shown that, in addition to degrading water quality, cyanobacteria in Upper Klamath Lake produce microcystins (hepatotoxins) at concentrations that may be detrimental to the endangered Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers. Data collected in 2009 from samples collected for the analysis of water quality parameters and cyanotoxin concentrations help to relate the spatial and temporal occurrence of microcystins, produced primarily by *Microcystis aeruginosa*, to the seasonal bloom dynamics of the most abundant (in terms of biovolume) cyanobacterium in the lake, *Aphanizomenon flos-aquae*. Peak concentrations of dissolved microcystins observed in lake water samples collected on August 3, 2009, coincided with low levels of chlorophyll *a* (a surrogate measurement of phytoplankton biomass) and elevated concentrations of dissolved nutrients. Given that *A. flos-aquae* composes the majority of chlorophyll *a* measured in lake water samples and that *M. aeruginosa* has been directly linked to microcystin production in Upper Klamath Lake, these observations suggest that microcystins are released during the rapid decline of the *A. flos-aquae* bloom.

Whether populations of *M. aeruginosa*, and therefore, microcystin concentrations, increase as conditions in the lake become less favorable for the *A. flos-aquae* bloom is currently under investigation.

Cyanobacterial Toxins Found in Upper Klamath Lake, Oregon: Implications for Endangered Fish

Echols, K.R.[1], T.M. Wood[2], C.A. Ottinger[3], B.H. Rosen[5], S.M. Burdick[4], and S.P. Vanderkooi[4]

[1]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO
[2] U.S. Geological Survey, WRD District Office, Portland, OR
[3] U.S. Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV
[4] U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[5] U.S. Geological Survey, Office of the SE Regional Executive, Orlando, FL

Upper Klamath Lake is a large hyper-eutrophic lake, found on the east side of the Cascade Mountains in Southern Oregon. Conditions in the lake include high levels of nitrogen and phosphorus nutrients that facilitate large, continuous cycles of cyanobacterial blooms from late spring through the fall. These cyanobacterial blooms include species of algae that are known to produce toxins that adversely affect other aquatic organisms. This study was designed to evaluate the presence of these toxins over three summer seasons (2007–2009) and to determine if there is any risk to the two endangered fish in the system: the Lost River sucker (*Deltistes luxatus*) and the shortnose sucker (*Chasmistes brevirostris*). Juvenile fish of these species are rare and appear to have poor survival in this ecosystem. Water and algae samples were collected monthly in 2007; bi-weekly in 2008 and weekly in 2009 from late June through September. Collected water/algal samples were filtered, extracted and analyzed using an enzyme-linked immunoassay (ELISA) method for quantitation of microcystin toxins, in water and algae. In 2007, high levels of microcystin toxins (up to 17.4 ug/L) were found in algae late in the summer and evidence from fish pathology showed exposure and adverse effects from these toxins. In 2008, lower levels of total microcystin were found in water/algal samples; from a low of 0.17 ug/L to a high concentration of 6.1 ug/L. The high dissolved water concentrations of microcystin in 2009 showed a high of 4.9 ug/L. Published LD50s for fish are around 550 ug/kg for one microcystin toxin variant; so assuming that juvenile fish are consuming 1 percent of their body mass in toxic algae, the average exposure to fish from microcystin was assessed to be approximately 5-fold greater than the published effects levels of microcystins to fish in 2007 and 3-fold greater in 2008. Thus, cyanobacterial toxins may be limiting survival of juvenile endangered Lost River sucker and shortnose sucker in Upper Klamath Lake.

Algal Toxins in Upper Klamath Lake, Oregon: Histopathology of Age-0 Lost River and Shortnose Suckers in 2007 and 2008

Densmore, C.L.[1], C.A. Ottinger[1], K.R. Echols[2], T.M. Wood[3], S.P. VanderKooi[4], B.H. Rosen[5], and S.M. Burdick[4]

[1]U.S. Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV
[2]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO
[3]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[4]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[5]U.S. Geological Survey, Florida Integrated Science Center, Orlando, FL

Recruitment into the adult populations of Upper Klamath Lake Lost River and shortnose suckers has been identified as a limiting factor in the recovery of these endangered species. One hypothesis for this lack of recruitment is based on poor survival of age-0 fish. In 2007 we began a multidisciplinary integrated assessment of factors with potential influence on age-0 sucker survival. This assessment, guided largely by existing data, included a fish health component. In this presentation we will focus on the histopathology data obtained in the assessment. In August 2007 (n = 47) and July – September 2008 (n = 103), age-0 Lost River and shortnose suckers obtained from Upper Klamath Lake were evaluated for histopatholgy. Fish were fixed and processed using standard histologic methods and viewed as whole–fish serial cross-sections. Histopathology data were compared based on capture locality. Age-0 suckers obtained in 2007 exhibited high frequency (45–55 percent) locality-specific occurrence of liver necrosis. Percent occurrence of intestinal (79–80 percent) and kidney (40–42 percent) necrosis was also high in these age-0 suckers. In 2008, age-0 suckers exhibited liver necrosis at locality-specific occurrence frequencies (0–20 percent) that were substantially lower than observed in 2007. The intestinal and kidney lesions observed in 2007 were absent or occurred at a very low frequency in these 2008 age-0 fish. Gill pathology and parasitic infections were also observed in both 2007 and 2008 and will be described.

Environmental Influences on Endangered Sucker Ecology 2

Skin Bacterial Flora of Age-0 Lost River and Shortnose Suckers in 2008: Nature Conservancy Delta Restoration Project and Upper Klamath Lake

Iwanowicz, D.D.[1], C.A. Ottinger[1], K.R. Echols[2], T.Wood[3], S.P. VanderKooi[4], B.H. Rosen[5], and S.M. Burdick[4]

[1]U.S. Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV
[2]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO
[3]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[4]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[5]U.S. Geological Survey, Florida Integrated Science Center, Orlando, FL

In 2007 we began a multidisciplinary integrated assessment of factors with potential influence on age-0 Lost River and shortnose survival in Upper Klamath Lake (UKL). This assessment included a fish health component. In this presentation we will focus on bacterial data obtained in the assessment. In July – September 2008, age-0 Lost River and shortnose suckers obtained from UKL (n = 52) or the newly flooded region of the Nature Conservancy Delta Restoration Project (Tulana Farm; n = 76) were evaluated for skin bacterial flora. Fish mucous samples were examined for bacterial community composition by targeting 16s ribosome DNA using terminal restriction fragment length polymorphism analysis for genus-level identification. Data were compared based on fish capture locality. The bacterial flora on the age-0 suckers exhibited significant changes along a north to south gradient in UKL. Fish sampled from the Tulana Farm region exhibited skin bacterial floras with similarities to those fish obtained from near shore areas in either the northern or central regions of UKL. Although there were similarities, fish from localities in both Tulana Farm and UKL did exhibit unique characteristic in their bacterial flora that permitted accurate assignment of individual fish to a specific locality using discriminate analysis. In addition to data on locality-specific age-0 sucker skin bacterial community composition, we will discuss the impacts these bacteria may have on juvenile sucker health and on delta restoration.

Direct and Indirect Consumption of Cyanobacteria by Juvenile Suckers in Klamath Lake, Oregon

Rosen, B.H.[3], S.M. Burdick[1], S.P. VanderKooi[1], T.M. Wood[2], C.A. Ottinger[4], and K.R. Echols[5]

[1]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[3]U.S. Geological Survey, Office of the SE Regional Executive, Orlando, FL
[4]U.S. Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV
[5]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO

Cyanobacteria and the associated toxin microcystin, have the potential to harm Lost River and shortnose sucker populations in Upper Klamath Lake, Oregon. To understand the potential exposure to cyanobacteria through consumption, the digestive tracts of several young of the year suckers collected in 2008 and 2009 were examined microscopically. Digestive tracts were extracted in the field, preserved in 1 percent glutaraldehyde, and kept cold during transportation and storage prior to examination. The

contents from a 2–4 mm section of the intestine were extruded onto a microscope slide, examined, and photographed at 400x. The majority of intestinal contents were dominated by invertebrate larvae in the chironomid family. Only limited amounts of cyanobacteria were found directly in intestines of the suckers; *Microcystis aeruginosa* colonies were the most commonly found organism. Optical dissection of the chironomid larvae showed that cyanobacteria were being consumed by these invertebrates, which were then consumed by the suckers. This leads to the strong possibility that invertebrate larvae represent an important cyanotoxin exposure route for the young of the year suckers.

Within-year and Among-year Distributions of Benthic Invertebrates in Upper Klamath Lake and the Newly Restored Delta Wetlands

Carter, J.L., and S.V. Fend, U.S. Geological Survey, Menlo Park, CA

Invertebrates represent an integral part of lake and wetland ecosystem function. Benthic invertebrates have been sampled from the Upper Klamath Lake ecosystem since spring 2006. Four research questions have been addressed: (1) are densities sufficiently high to contribute to solute benthic flux via bioturbation, (2) what is the per-invertebrate metabolic contribution to nutrient flux, (3) what is the seasonality of mid-lake and wetland invertebrate densities during the ice-free period, and (4) how does the benthic assemblage change inter-annually in response to wetland restoration? High densities of invertebrates were detected in the benthos. Tubificid worms (63 percent), chironomid midges (21 percent), and leeches (14 percent) dominated the benthos at lake sites, representing almost 98 percent of the individuals present. Weekly collections during summer 2008 at four lake sites revealed mean total invertebrate densities exceeding 10,000 individuals per square meter, strong location and temporal signals among species, and a potential to significantly influence nutrient flux. A sequence of changes in the assemblage structure also has occurred in the newly restored wetland. Given their densities, trophic importance, and potential to influence many lake and wetland processes, considerably more research is necessary on this important component of the Upper Klamath Lake ecosystem.

Larval Lost River Sucker *Deltistes luxatus* and Shortnose Sucker *Chasmistes brevirostris* Response to Wetland Restoration at the Williamson River Delta, Upper Klamath Lake, Oregon

Hendrixson, H., and C. Erdman, The Nature Conservancy, Klamath Falls, OR

The Williamson River Delta restoration project is a large wetland restoration project located at the interface of the Williamson River and Upper Klamath Lake with a primary goal of providing rearing habitat for larval suckers at the mouth of the river. Historically a fully functioning wetland ecosystem, the delta was drained and converted to farmland beginning in the 1940s, thus eliminating access to the deltaic wetlands for passively drifting larvae. Emergent macrophytes typical of wetland systems have been shown to benefit larval suckers by providing protection from non-native species, better feeding and growing opportunities, and shelter from a clockwise, wind-driven gyre in Upper Klamath Lake. In 2007, The Nature Conservancy began the hydrologic reconnection of 5,500 acres of historic deltaic wetlands to Upper Klamath and Agency lakes and the Williamson River by breaching and lowering more than 22 miles of levees. We examined larval sucker habitat use and fish condition (size and gut fullness) at shallow water sites (<1m deep) in both restored and existing lakeshore wetlands to assess the response of larvae to the restoration. Preliminary results from 2009 show that larvae captured in restored areas with emergent vegetation had a size and gut-fullness advantage over fish captured at open water sites. Data collected for several years prior to restoration showed that higher catches of sucker larvae occurred in existing lakeshore wetlands compared to restored wetlands, a trend that was reversed in 2009 when larval suckers were caught more frequently in the newly restored deltaic wetlands. Our results from the initial year of monitoring the fully restored delta suggest that larval suckers are rearing in the shallow water habitat available now for the first time in over 50 years. Increasing larval habitat and high levels of larval survival in restored wetland habitat may help in the long term recovery of both species.

Migrational Movements and Distribution of Spawning Klamath Largescale, Lost River, and Shortnose Suckers in the Sprague River Before and After the Removal of Chiloquin Dam

Ellsworth, C.M., S.P. VanderKooi, and E.C. Janney, U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR

The migratory movements of Klamath largescale suckers (*Catostomus snyderi*), Lost River suckers (*Deltistes luxatus*), and shortnose suckers (*Chasmistes brevirostris*) entering the Sprague River to spawn were restricted by an irrigation dam located near Chiloquin, Oregon. Chiloquin Dam was removed in August 2008 to improve access to upstream spawning habitat and to reduce crowding of spawning fish immediately below the structure. The migratory behaviors and location of spawning areas were determined by tracking radio-tagged individuals before and after the removal of the dam. The spawning distributions of these populations were collected from individuals detected on a series of remote passive integrated transponder (PIT)-tag detection arrays constructed in several reaches above and below the dam. Results suggest adult migrants congregate in discrete reaches of the Williamson River and the Sprague River above and below the former dam site with each species showing some level of temporal and spatial separation in their spawning behavior. Fish passage at the Chiloquin Dam fish ladder prior to dam removal was apparently low. Post-dam removal monitoring has shown an increase in the number of tagged fish migrating past the dam site. Spawning was also observed in the first 2.2 river kilometers above the former dam site the year after removal on what was previously identified as underutilized spawning habitat. Most tagged fish, however, still migrated to spawning areas within a few river kilometers of the former dam site the year after removal. This indicates that although dam removal apparently allowed fish to disperse into underutilized spawning habitat in the lower Sprague River, substantial shifts in migration patterns and spawning distributions at a population level were not observed in the first year after removal.

Riparian Dependent Species 1

Oregon Spotted Frogs (*Rana Pretiosa*) in the Klamath Basin: Status, Threats, and Local Restoration

Pearl, C.A., and M.J. Adams, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR

The Oregon spotted frog (*Rana pretiosa*) is a highly aquatic species that is estimated lost from 70 percent of its historic range in the Pacific Northwest. It is a candidate for Federal Listing and information on the status and threats to the species is needed. The species is presumed extirpated from the Willamette Valley and most of its extant populations are located in the Deschutes and Klamath basins. Genetic data suggest Klamath populations constitute a clade that differs from other parts of the species' range. We present an overview of the status and threats to the species in the Klamath basin and compare this with information from other parts of the species' range. Our recent preliminary results identify factors that suggest that Klamath populations are more at risk than those in the upper Deschutes basin. We discuss information gaps and ongoing work to address these threats.

Comparative Ecology of the Western Pond Turtle (*Actinemys marmorata*) on Two Forks of the Trinity River, Trinity County, California

Ashton, D.T.[1], J.B. Bettaso[2], J.S. Rousseau[1,3], and H.H. Welsh, Jr.[1]

[1]U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA
[2]U.S. Fish and Wildlife Service, Arcata Office, Arcata, CA
[3]Humboldt State University, Arcata, CA

The western pond turtle (*Actinemys marmorata*) is a habitat generalist, occurring in numerous habitats where surface water is available for a significant portion of the year. Despite its ability to survive in a variety of habitat types, this species is declining across much of its range, primarily due to habitat conversion and water resource management. Northern California harbors the majority of remaining robust populations, but even in remote areas, populations can be threatened by land and water use practices. To assess population impacts from damming, flow management, and subsequent river restoration efforts, we studied turtles on two forks of the Trinity River, one dammed and one free-flowing. Here we provide an overview of research conducted from 2005 to 2007, with reference to similar research from the same areas from 1991 to 1994. Where data were comparable across decades, we describe trends. We compare various population parameters between the two forks including demographics, thermoregulatory behaviors, body size and condition, growth rates, and riverine spatial dynamics. While population sizes appear to be relatively stable, several differences are attributable to management of the Mainstem. Most notably, turtles on the dammed Mainstem are considerably smaller than those of the same cohort on the free-flowing South Fork. Implications of smaller body size on population viability are discussed, providing direction for further research.

Thermoregulatory Behavior and Growth Characteristics of Western Pond Turtles (*Actinemys marmorata*) on Regulated and Unregulated Forks of the Trinity River

Ashton, D.T.[1], J.B. Bettaso[2], and H.H. Welsh, Jr.[1]

[1]U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, 1700 Bayview Dr, Arcata, CA 95521
[2]U.S. Fish and Wildlife Service, Arcata Office, 1655 Heindon Rd, Arcata, CA 95521

The western pond turtle (*Actinemys marmorata*) is a California State Species of Special Concern and a Sensitive Species in Oregon. Understanding population specific life-history traits is necessary to make proper management decisions to preserve local populations. We have monitored western pond turtles on the mainstem Trinity River near the Lewiston Dam and on the South Fork Trinity River near Willow Creek, California since 2003. Our objectives were to better assist managers in restoration design and flow management. From 2005 to 2007, we combined the use of radio-telemetry and digital recording thermometers on the external carapace of turtles to study their thermoregulatory behavior in relations to river temperatures. We also conducted mark-recapture studies on both forks to obtain population estimates and estimate demographic parameters such as age structure, sex ratios and growth trajectories. The mainstem Trinity River has a cold thermal regime in the summer due to hypolimnetic releases from the dam, whereas the south Fork has a warm water regime due to solar input. These

differences result in both a change in thermoregulatory behaviors and slower growth in the colder aquatic environment of the mainstem Trinity River.

Freshwater Mussel Abundance, Distribution, and Habitat Preference in Two Northern California Rivers Within Karuk Ancestral Territory

David, A., and E. Davis, Karuk Tribe Department of Natural Resources, Happy Camp, CA

Freshwater mussels (Bivalvia: Unionoida) are an integral component of freshwater ecosystems. Historically, they formed an important part of the diets and material culture of indigenous peoples in North America, including the Karuk Tribe and other Klamath Basin indigenous groups. West of the Rockies, mussels are not well-understood, but because of their sensitivity to anthropogenic changes, legacy as an indigenous cultural resource, and importance as bioindicators of water quality and freshwater ecosystem health, it is imperative to advance our understanding of this taxon. This study, a collaborative effort between the Karuk Tribe and Whitman College, is the first systematic survey to examine freshwater mussel abundance, diversity, distribution, and habitat preference in the Klamath and Salmon rivers of Northern California. In 2007 and 2009, eighty sites on the mid-Klamath between the Klamath-Trinity confluence and Irongate Dam, and 15 sites on the lower Salmon were snorkel-surveyed to assess abundance, diversity, distribution, and habitat preference of mussels. In 2009, 15 sites on the mid-Klamath were surveyed for mussel population age structure to determine mussel recruitment success and population health. Historical and contemporary use of mussels by local Karuk tribal members were assessed via interviews. Three mussel genera (*Margaritifera*, *Gonidea*, and *Anodonta*) were recorded, with *Gonidea* abundant and well-distributed within the Klamath, *Margaritifera* present in low numbers, and *Anodonta* present at 2 upriver sites. In the Salmon, only *Margaritifera* were found. Mussels were situated in microhabitats that minimized shear stress and provided protection from bed scour during high flows. Mussels were located on sand, gravel, and bedrock substrates significantly more often than on other substrates. Preliminary interviews indicated that mussels remained a significant portion of Karuk traditional diet until the mid-20th century and continue to function as a ceremonial food today. Preliminary data from population age structure surveys indicate that *Gonidea* populations are successfully recruiting. Continued study of Klamath mussel habitat and ecology will be essential to their conservation. Funding for the 2009 research was provided through the U.S. Fish and Wildlife Service Tribal Wildlife Grant Program.

Riparian Dependent Species 2

Ecology and Conservation of Western Pond Turtles in the Klamath Basin: What are the Challenges Ahead?

Bury, R.B., U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR

The Western Pond Turtle is a species of concern in OR and CA, and was earlier proposed for Federal listing. Yet, we have scant information on the species in the Klamath Lake basin or along the Klamath River. Fortunately, there are on-going studies at a few sites in the Trinity River basin: (1) Bureau of Reclamation/U.S. Fish and Wildlife Service efforts along the river since mid-1990s and (2) Hayfork Creek, a tributary, where I have studied the turtle since 1968. These data sets provide unprecedented opportunities to design effective studies that compare trends in numbers, growth rates, and habits of turtles throughout the Klamath Basin, including responses to proposed dam removal on the Klamath River. My preliminary data reveal recaptures of turtles marked 40–41 yrs ago. Although few reach such age, some are 55+ yrs or older. Our preliminary work indicates marked differences in population features within the Klamath system: Hayfork turtles are the slowest-growing anywhere whereas recent preliminary surveys indicate that turtles in the Klamath Lake basin are among the fastest growing (2nd only to turtles in the Central Valley). Now, we could establish an effective network of permanent sampling sites to track changes in turtle numbers over time, including an effort to locate and archive all existing data sets. We need more work on understanding their population features, particularly their fecundity and survivorship. The ecology of small-sized or juvenile turtles remains almost unknown. Because habitat loss and alteration remain the principal threats to the long-term survival of turtles, management agencies may find these data useful for determining if specific areas should be considered for protection. Turtles receive widespread public support and are charismatic, which assists in efforts to protect them.

Breeding Distribution and Phenology of the Foothill Yellow-legged Frog (*Rana boylii*) in Regulated and Unregulated Tributaries of the Trinity River Basin

Ashton, D.T.[1], J.B. Bettaso[2], and H.H. Welsh, Jr.[1]

[1]U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA
[2]U.S. Fish and Wildlife Service, Arcata Office, Arcata, CA

The foothill yellow-legged frog (*Rana boylii*) is adapted for life in dynamic river systems and is the only western ranid that is an obligate breeder in lotic habitats. Stabilized flows resulting from damming of the Mainstem Trinity River have resulted in a suite of structural habitat changes that have degraded oviposition and rearing conditions for this species. These changes combined with unnatural timing of flows have led to severe population declines of this frog below the dam. Annual float surveys of twenty miles of the mainstem river below the dam have been conducted since 2004 to determine numbers of egg masses and the distribution of breeding sites. Comparable surveys have been conducted on the undammed South Fork and North Fork rivers. Over the past five years the mainstem breeding population has been two to three orders of magnitude lower than the undammed South Fork and one to three orders of magnitude lower than the North Fork. In 2008 and 2009 surveys were conducted to monitor the fate of egg masses in relation to managed changes in flow on the mainstem river. The desiccation rate of the annual egg mass cohort was 68 percent in 2008 and 30 percent in 2009. Beginning in 2006 we examined the timing of oviposition and larval development rates at sites in several tributaries to better elucidate the impacts of flow regimes and temperature impacts on key aspects of larval ecology. We compared timing of oviposition, rates of development, and time and size at metamorphosis between the Mainstem and six tributaries of the Trinity River. Differences are described relative to thermal regime and flow characteristics.

What are the Challenges for Amphibians and Reptiles in the Klamath River Watershed: Biogeographic Barriers, Endemism, and Conservation Status

Bury, R.B., U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR

Assessing and monitoring populations of amphibians and reptiles throughout the Klamath River watershed will assist management agencies entrusted with their protection. This basin and adjacent areas in the Klamath-Siskiyou Ecoregion (KSE) is an ancient landscape with markedly rugged topography and abrupt climate breaks. The KSE has the highest species richness of herpetofauna (amphibians and reptiles) in the Pacific Northwest due, in large part, to the overlap of two Biotas: Arcto-Tertiary (Northern, forest-dependent amphibians) and Madro-Tertiary (Southern, hot-adapted reptiles). Mountain slopes along the Klamath River are home to 3 endemic species of woodland salamanders plus up to least 3 more undescribed species. Field surveys now indicate that several species terminate their geographic ranges at the Siskiyou Mountains along the OR-CA border. These features run east-to-west, creating the "Great Wall of the Siskiyous" blocking N-S movements of the herpetofaunas along the Coast Range and Cascade Mountains. Also, species of concern such as Western Pond Turtles and Foothill Yellow-legged Frogs frequent the region's flowing waters. We know little how these species will respond to conversion of reservoirs to free-flowing rivers. Invasive species (e.g., bullfrogs) are invading standing waters and slow sections of rivers. These increasingly complex relationships merit greater study. We barely understand the local distribution of the herpetofauna let alone possible causative factors for occurrence. Biologists and managers could work together and incorporate educational efforts to create a regional "task force" to study and manage populations of amphibians and reptiles in the Klamath River watershed.

Environmental Assessment and Monitoring 1

Vegetation and Fluvial Geomorphology of the Riparian Greenline in the Sprague River Basin

Hughes, M.L., and C.A. Leeseberg, Klamath Tribes Research Station, Chiloquin, OR

Like many regions in the western U.S., valley-floor environments of the semi-arid Sprague River basin of southern Oregon are heavily irrigated and widely grazed by cattle. These and other land uses have diminished water quality in channel systems throughout much of the basin. To better understand these impacts and to set a baseline for ongoing and future restoration efforts, the Klamath Tribes have begun a long-term, basinwide biogeomorphic riparian monitoring program. Because if its widespread application, determining the composition of the lowest line of perennial vegetation above baseflow, or the "greenline," has been included. The goal of this paper is to summarize results of 38 greenline surveys conducted at 19 sites in 2008–9 and to explore geomorphic hypotheses that may explain vegetation patterns evident in the surveys. Spikerush (*Eleocharis ssp.*) and reed-canary grass (*Phalaris arudinacea*) were the most commonly occurring vegetation in the greenline across all sites. Because these species are aggressive colonizers, they indicate widespread availability of fresh alluvium in greenline zone. This availability may be associated with chronic channel-bank disturbance. Sedges dominated portions of the greenline at most of the sites, but occurred in less abundance. Because many of these sedges are late successional or early-to-late transitional species, their relative scarcity further supports the hypothesis that geomorphic environments remains chronically disturbed and dynamic. Grazing is common, but variable in intensity, at nearly all of the study sites, likely contributing to the persistence of channel-bank disturbance at some sites. Among meandering channels, the richness of dominant species (i.e., "intracommunity diversity") was higher on the outer bends than on the inner bends of meanders at 10 of 12 sites. The variability of geomorphic surfaces (abandoned or incised floodplain, incipient floodplain, failed bank, bar, accreted toe material, etc.) incorporated into the greenline by the spatially discontinuous processes of channel-bank failure appears to increase the types of habitats surveyed on the outer bends of meanders, and therefore their combined floral biodiversity. In contrast, the spatial continuity of bar accretion on the inner meander bends appears to result in a more uniform geomorphic setting with fewer dominant species in the greenline. Despite widespread recognition that geomorphic processes influence riparian vegetation, factors such as the type and severity of bank erosion, the location of the survey with respect to meander geometry, and the type of geomorphic surface underlying greenline observations are not explicitly included in published guidance for biogeomorphic monitoring of the riparian greenline. Inclusion of such factors the greenline methodology improve the design, communication, and application of interdisciplinary research aimed at developing a better understanding of interactions between fluvial processes and riparian vegetation.

Long-term Ecological Effects of Debris Flows and Debris Floods on Tributary Streams in the Klamath Mountains

Cover, M.R.[1], J. de la Fuente[2], and V.H. Resh[3]

[1]Department of Biological Sciences, California State University, Stanislaus, Turlock, CA
[2]U.S. Forest Service, Klamath National Forest, Yreka, CA
[3]University of California, Berkeley, CA

Debris flows and debris floods are catastrophic disturbances in steep, mountainous landscapes, but little is known about their long-term effects on stream ecosystems. In 10 basins (10–20 km^2) in the Klamath Mountains that are tributaries to the Klamath River and Scott River, we used a space-for-time substitution to infer the long-term (10–100 y) ecological effects of debris flows on the structure of stream ecosystems. Debris flows mobilized sediment and wood and removed riparian vegetation in large portions (often >50 percent) of the channel networks of many study basins. Streams that had recent (1997) debris flows had riparian zones dominated by young, even-aged stands of white alder (*Alnus rhombifolia*). Although these young forests provided substantial canopy cover, canopy cover was reduced following the flood of December 31, 2005, resulting in increased stream temperatures and primary productivity. Debris flows resulted in reduced levels of large woody debris and benthic organic matter that persisted for at least 40 years. The composition of benthic macroinvertebrate assemblages reflected these ecological changes. For example, detritivorous stoneflies were virtually absent in recent debris flow streams. Although rainbow trout (*Oncorhynchus mykiss*) were abundant in most of the streams that had recent debris flows, populations of other vertebrates, such as Coastal giant salamander (*Dicamptodon tenebrosus*) and coastal tailed frog (*Ascaphus truei*), were virtually absent. Stream temperatures at the mouths of streams that had recent debris flows were substantially higher than temperatures in other streams, indicating that debris flows can have long-term impacts on the quality of cold-water refugia in the mainstem of the Klamath River. Our findings suggest that debris flows have substantial long-term effects on the structure of stream ecosystems and cause local extirpations of aquatic species. Environmental management of aquatic habitats in major tributaries, as well as in the Klamath River, needs to reflect the history and long-term impacts of debris flows and debris floods.

Applications of Environmental Monitoring in the Scott Valley

Yokel, E.[1], D. Quigley-Yokel[1], and R. Hines[2]

[1]Siskiyou Resource Conservation District, Etna, CA
[2]Department of Land, Air, and Water Resources, University of California, Davis, CA

The Siskiyou RCD and cooperators have been performing biological and stream condition monitoring and water quality and quantity monitoring in the Scott River for over a decade. This monitoring data has been used to develop watershed plans, prioritize and implement restoration and protection projects, develop a better understanding of watershed process and assess the effectiveness of resource protection and conservation programs. Three examples of monitoring programs will be

discussed and connected to the applications in watershed management and planning: coho salmon adult and juvenile direct observation surveys, water temperature monitoring and water quantity monitoring. Direct observation of juvenile and adult coho salmon over all brood years has identified stream reaches, meso habitat types and micro habitat types that are utilized by higher densities of coho salmon. This information is important for the prioritization of locations for stream and riparian protection and enhancement. Additionally, these surveys document existing structures utilized by coho salmon allowing for the replication of natural designs in reaches needed enhanced carrying capacity. Stream temperature has been collected for over a decade throughout the Scott River's tributaries and mainstem. In 2008, U. C. Davis, University of Nevada – Reno and the Siskiyou RCD performed a distributed temperature (DTS) survey on a valley reach of the Scott River. This effort combined biological monitoring with water quality and quantity monitoring to increase our understanding of stream processes and groundwater-surface water interactions. The U.S. Geological Survey, California Department of Water Resources and the Siskiyou Resource Conservation District have been collecting stream discharge data in the Scott River. The existing stream discharge data has been used to help develop the Scott River Water Balance and monitor the water supply and effectiveness of the Scott River Water Trust activities in the summer and fall. In October 2009, continuous stream discharge monitoring in the mainstem Scott River discharge was utilized to monitor the forbearance of water by the Scott Valley Irrigation District to increase the flows and allow for the migration of adult Chinook salmon to the Scott Valley.

Feasibility Assessment of Constructed Treatment Wetlands in the Vicinity of the Klamath Hydroelectric Project

Lyon, S.[1], A. Horne[2], J. Jordahl[1], H. Emond[1], and K. Carlson[1]

[1]CH2M Hill, Portland, OR
[2]Alex Horne Associates, El Cerrito, CA

In 2008, we conducted a feasibility assessment on behalf of PacifiCorp to determine the potential for constructed treatment wetlands to provide improved water quality in the vicinity of the Klamath Hydroelectric Project. The Project's reservoirs receive large inflowing loads of nutrients and organic matter from upstream sources (notably Upper Klamath Lake), which fuel summertime blooms of cyanobacteria in the reservoirs. Treatment wetlands can act as filters removing particulate material, as sinks accumulating nutrients, or as transformers converting nutrients to different forms. As a team of scientists and engineers with expertise in constructed wetlands and water quality, we conducted a joint field survey to identify candidate treatment sites in the Klamath River upstream of Copco reservoir. Conceptual layouts for constructed treatment wetlands were developed for these sites, along with calculated estimates of potential treatment effectiveness (e.g., nutrient reductions). The sites are generally low-lying and directly adjacent to the river, and would be amenable to wetland construction. However, a major constraint identified in this assessment is that the potential sites for constructed wetlands on PacifiCorp-owned lands in the Project area could receive and treat only a minor fraction of the total flow of the Klamath River, and would be unlikely to provide a demonstrable river nutrient and organic matter load reduction. Instead, to achieve such a reduction, it would be necessary to develop more and larger wetland sites that would collectively or in the aggregate treat a substantial portion of the river flow. This would by necessity involve constructed treatment wetlands on lands elsewhere above the Project area in proximity to the river system. The need to "scale-up" the overall size of constructed wetlands to achieve demonstrable and meaningful water quality benefits points to the need for a basinwide effort that would require multiple stakeholder participation.

Using Spatial Techniques to Aid Ecological Inventory and Monitoring at Regional Scales

Groshong, L., D. Sarr, and S. Mohren, Klamath Inventory & Monitoring Network, National Park Service and Southern Oregon University, Ashland, OR

The Klamath Inventory & Monitoring Network is one of 32 networks set up by the National Park Service to conduct natural resource inventories and to monitor key ecological indicators (vital signs) across the nation. The Klamath Network is composed of six park units in northern California and southern Oregon: Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National and State Parks, and Whiskeytown National Recreation Area. Doing inventory and monitoring projects at this large scale requires careful planning and innovative strategies that may help inform similar efforts in the Klamath Basin. Use of a variety of spatial (GIS) techniques helps delineate sampling frames and target populations and generates probabilistic sampling designs. The appropriate spatial sampling design depends upon our goals and objectives, resource limitations, statistical power considerations, spatial characteristics of the population being sampled, and practical concerns related to ease of access and safety.

GIS is heavily used in all aspects of planning, implementation and data analysis associated with each inventory or monitoring project. Models to estimate travel times to survey locations help crews avoid obstacles and steep slopes and take into account the frequent need to locate sites at least 100m off of a road or trail to avoid anthropogenic disturbance signals. Map atlases have been developed so field crews can quickly create maps specific to their needs. Additionally, extensive use of GPS units with ArcPad allows for quick data entry, better quality data collection, and faster accessibility to data for reports and presentations. These “raw data” are then processed and analyzed, often within the GIS environment, to create maps, run analyses and write reports. Additionally, new GIS technologies such as a program called eCognition are applied to assist in object-oriented image analysis, which facilitates habitat classification and sampling frame delineation. This talk will discuss completed and ongoing natural resource inventories and monitoring research and what methodologies the Network applies to adequately survey such a large region.

Environmental Assessment and Monitoring 2

Where in Upper Klamath Lake are the Largest Concentrations of Phosphorus, Organic Carbon and Metals Found in Bottom Sediment?

Simon, N.S., S.Y. Ingle, D. Webster, and A. Abdul-Ali, U.S. Geological Survey, Reston, VA

The largest source of phosphorus to the water column in Upper Klamath Lake (UKL) is phosphorus from bottom sediments. There have been less than a half-dozen studies of UKL sediment in which cores were analyzed for phosphorus concentrations. Sampling locations selected for previous studies have been in southern, western and northwestern areas of the lake. For this study, sediment cores were collected in October, 2006, at 21 sites distributed throughout the lake that conform to a circulation pattern proposed by U.S. Geological Survey scientists.

Cores were sectioned at 1-cm intervals to a depth of 5-cm. Sediment was separated into $< 63\mu$ and $> 63\mu$ particle-size fractions and chemical analyses were carried out on both fractions. Percent organic carbon was larger in the $> 63\mu$ particle-size fraction than in the $< 63\mu$ particle-size fraction.

Concentrations of analytes in whole samples were calculated using the proportional contribution of each particle size fraction. Data from these cores were used to produce contour maps for total concentrations of Al, Ca, Fe, Ti, organic N, and organic C in UKL surface sediments. Concentration data for metals indicate that inflowing waters in the northern portion of the lake are the primary sources of metals to the lake. Phosphorus analyses provided data for the construction of contour maps which indicate the distribution of total P determined by dissolution of sediment samples, and geochemical forms of P determined by sequential extraction. Total phosphorus concentrations were found to be largest along the northern portion of the lake and at sites also near marshes on the southeastern lake shore. There was no significant correlation between total phosphorus and total iron concentrations in these sediment samples. Acid-soluble phosphorus concentrations were related to the distribution of metals in the lake. The largest fraction of phosphorus in these sediments was residual phosphorus. The concentration of residual phosphorus is calculated as the difference between the concentration of total phosphorus and the sum of the concentrations of inorganic phosphorus (determined by sequential extraction). Residual phosphorus can contain organic phosphorus, phosphate bound to clays, and/or refractory phosphorus minerals. Preliminary data indicate that a portion of the residual phosphorus is sorbed onto clays (smectite) in the sediments. ^{31}P NMR analyses indicate that most of the phosphorus in the clays is present as orthophosphate with a smaller fraction present as organic phosphorus. It is unclear whether the phosphorus adsorbed by these clays is refractory or bioavailable.

Building a Foundation for Coordinated Water Quality Monitoring in the Klamath River Basin

Royer, C.F., A.P. Stubblefield, S. Steinberg, T. Uyeki, and S. Eliason, Humboldt State University, Forestry and Wildland Resources, Arcata, CA

The 303(d) listing and the subsequent Total Maximum Daily Load (TMDL) development and implementation for improving water quality in the Klamath Basin has been a challenge due to the lack of coordinated water quality monitoring within the Basin. Although a multitude of State, Federal, tribal, and non-profit organizations collect water quality data within the Basin, progress toward obtaining a Basin-wide picture of water quality has been hampered by duplication of effort, sampling gaps, and lack of data sharing. In 2006, the California Water Resources Control Board, with funding from the U.S. Environmental Protection Agency and the California Nonpoint Source Pollution Control Program, engaged the Klamath Watershed Institute (KWI) at Humboldt State University to facilitate the development of a coordinated monitoring plan with the participation of the Klamath Basin Monitoring Program (KBMP), formerly the Klamath Basin Water Quality Monitoring Coordination Group, an existing network of monitoring organizations. Other project goals were to build a data sharing web portal to inform monitoring and management decisions, and to establish a communications plan to promote dissemination of information. KWI also worked with the KBMP on their group's organizational development, including drafting a mission and vision, and developing mechanisms for long-term sustainability of the organization and the monitoring plan. Presenters share products of this collaborative effort, including the KBMP Draft Klamath Basin Water Quality Monitoring Plan, technical and political challenges to developing collaborative data sharing agreements.

Benthic Sources of Dissolved Nutrients and Trace Metals in Upper Klamath Lake and Associated Wetlands after Designed Levy Breaches

Kuwabara, J.S., and B.R. Topping, U.S. Geological Survey, Menlo Park, CA

In October 2007, a series of planned explosions hydrologically reconnected levied agricultural lands to adjacent Upper Klamath and Agency Lakes. Because the intended wetland restoration involved areas used for agriculture for decades, there was interest in the chemical and biological effects of this hydrologic reconfiguration. With support from the Bureau of Reclamation, benthic-flux studies of Upper Klamath Lake were extended to include these newly restored wetlands, as well as established wetlands that had not been levied. Previous studies have established that benthic flux of biologically reactive solutes represent important solute-transport processes for Upper Klamath Lake. Porewater profilers were deployed in triplicate, immediately after the levy breach then in subsequent years prior to and at the latter stages of the annual *Aphanizomenon flos-aquae* bloom to quantify the benthic flux of dissolved (0.2-micron filtered) macronutrients (soluble reactive phosphorus, nitrogen species and silica) and trace elements (iron, manganese, copper and others) at three sites within Upper Klamath Lake and four sites in the proximal wetlands. Through these flux measurements, we describe time scales of chemical transition associated with this major change in land-use.

Well Designed Performance Measures are Essential for Planning, Operation and Validation of Landscape Scale Restoration Programs

Redwine, J., and T. St.Clair, PBS&J, Jacksonville, FL

The Klamath River Restoration Program is one of an ever increasing number of ecosystem scale restoration programs. These projects are likely to be a central organizing feature in determining how the United States re-engineers its infrastructure in the coming decades. Quantitative determinations of how a landscape scale watershed can be expected to perform following engineered modifications are essential for planning, actual operation, and subsequent validation of the effects of an engineered solution. The term “Performance Measures” has been used by scientists working with the Comprehensive Everglades Restoration Program (CERP) to describe topic-specific, information filters that quantitatively describe the simulated ecological effects of engineered projects and altered water management on the ecosystem. The process of development, use, and refinement of performance measures in the Everglades restoration program has been complex and has resulted in multi-agency agreement that ideal performance measures are based on objective facts determined through scientific experiment and which can be validated with rigorous monitoring. When performance measures have been developed in this way, they are also useful for guiding operation of the system, since they can be developed to capture the key causes that lead to negative environmental impacts, and they provide the necessary context for systematic uncertainty reduction. This presentation will provide a brief analysis of the key uncertainties associated with the Klamath Restoration program compared to a similar analysis of uncertainties facing the Everglades Restoration program, followed by a brief description of an Active Adaptive Management approach formulated to address a few of the key uncertainties in the Everglades Restoration program. While developing and utilizing performance measures is intellectually challenging, these tools are essential for crafting credible restoration programs which will affect the lives of millions of people.

Seasonal Water Quality Patterns Downstream of a Hypereutrophic Lake: Summary of 2007–2009 Multi-probe Monitoring in the Lake Ewauna Reach of the Klamath River

Asbill, J.[1], A.B. Sullivan[2], M.L. Deas[3], S.A. Rounds[2], M. Johnston[2], A. Tower[1], G. Schanzenbacher[1], M. Krizter[1], and J. Ross[1]

[1]U.S. Bureau of Reclamation, Klamath Falls, OR
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[3]Watercourse Engineering, Inc., Davis, CA

The 21-mile reach of the Klamath River from Link River to Keno Dam exhibits poor water quality on a seasonal basis, manifested as high concentrations of algae and ammonia, elevated pH, and hypoxic to anoxic dissolved-oxygen conditions. The hypoxic to anoxic conditions are caused by an extremely high organic load from Upper Klamath Lake. The heavy organic load imposes a high biochemical oxygen demand (BOD) on the Lake Ewauna reach of the Klamath River. The high BOD in combination with sediment oxygen demand can deplete nearly all oxygen in the water column for several river miles, which typically lead to annual fish die-off events. Recent monitoring efforts with multi-probe instrumentation in the Lake Ewauna reach of the Klamath River for temperature, pH, specific conductance and dissolved-oxygen show that for the three years of the study, all twelve monitoring locations during the winter and spring had dissolved-oxygen concentrations near saturation, but during the summer and fall, all of the monitoring locations except Link River, had dissolved-oxygen concentrations less than 4 mg/L. The monitoring efforts also show that for the three years of the study, all monitoring locations during the summer and fall had temperatures that exceeded 22°C.

Trinity River

Hatchery Impacts on the Genetic Structure of Native Stocks in the Klamath Trinity Basin

Kinziger, A.P., Associate Professor and Curator of Fishes Department of Fisheries Biology, Humboldt State University, Arcata, CA

Understanding the impact of hatchery origin fish on wild stock is of critical importance for salmonid restoration because recent research suggests hatchery fish may depress the fitness of wild fish. We evaluated the genetic contribution of hatchery fish to native stocks by constructing a genetic baseline data set for Chinook salmon from the Klamath Trinity basin composed of 12 populations and 29 microsatellite loci. We found that Klamath Trinity Chinook salmon exhibit substantial levels of genetic structuring despite the large amount of out of basin transplantation that has historically occurred in the basin. It appears that both Trinity River Hatchery and Iron Gate Hatchery serve has source of migrants that genetically homogenize wild and hatchery populations. The degree of homogenization appears to be related to geographic distance, with geographically proximate populations more likely become homogenized than distance populations. The Salmon River, which is geographically sandwiched between Iron Gate and Trinity River hatcheries, appears to be genetic mixture of these hatchery populations but does contain a small degree of genetic uniqueness.

Using Integrated Hatchery Practices to Improve Genetic Fitness of Naturally and Hatchery Produced Coho Salmon in the Trinity River, California

Naman, S.W.[1], and W. Sinnen[2]

[1]National Marine Fisheries Service, Seattle, WA
[2]California Department of Fish and Game, Arcata, CA

In recent years there have been large adult returns of hatchery fish to the Trinity River. The average hatchery coho salmon adult and jack return from 1997 to 2008 was 16,469, roughly three times the Trinity River Hatchery coho salmon mitigation goal. The average percentage of hatchery coho salmon in the total return during the same period was 89 percent. The substantial numbers of adult hatchery fish, the majority of which were not harvested by Tribes and could not legally be harvested by recreational or commercial anglers, prompted concern from several stakeholders on the effects of hatchery stocks on naturally produced stocks. The Trinity River Hatchery Technical Action Group was formed to make technical recommendations to a policy group. We used information from historical run sizes, spawner-recruit relationships, smolt-to-adult returns, and "All H Analyzer" modeling to examine current production relative to mitigation goals and objectives. Spawner-recruit relationships indicated that in years of large hatchery returns, carrying capacity of the river may have been exceeded, possibly triggering density dependent mechanisms leading to reduced productivity. Using the smolt-to-adult returns rates from 1997 to 2008, we calculated hypothetical adult returns based on three different theoretical juvenile release levels. We also modeled likely outcomes of changes such as decreased juvenile production and increased natural origin broodstock. Based on the information, we formulated a variety of recommendations to the policy group such as a reduction in juvenile coho salmon production and trapping of surplus hatchery adults.

Legacy Effects of Trinity River Gold Mining

Kraus, A.F., Trinity River Restoration Program, Weaverville, CA

This presentation explores the history and legacy effects of hydraulic and dredger gold mining on the Trinity River. Gold was discovered in 1848 at Reading Bar near Douglas City, the second find of the California Gold Rush. From 1849 through 1862, large placer mining works were erected at major bars along the river. These works included wing dams, water wheels, and several dams that fully spanned and diverted the Trinity River. Intensive hydraulic placer mining of the valley walls and surrounding mountains started in the early 1860s and lasted until 1950. Ninety years of intensive hydraulic mining literally washed away mountains, contributing vast amounts of sediment to the mainstem. This is three times as long as the well known hydraulic mining in the Sierra Nevada mountains that was effectively banned by the 1884 Sawyer Decision (which did not apply to the Trinity River). Topographic surveys of the Trinity River from the 1930s and 40s show evidence of several sediment waves resulting from the hydraulic mining.

Dredger mining of the mainstem channel and floodplains began in the early 1900s and lasted through the 1950s. The dredges worked their way back and forth from valley wall to valley wall, digging down to bedrock looking for gold. The larger dredges could chew through 6 acres of floodplain a week, processing over 50,000 cubic yards of material. The result was a straightened river inside a floodplain with an inverted sediment profile and full of large tailings piles. The combination of dredger

mining, the large floods of 1955 and 1964, and reduced flows due to water diversions to the Central Valley has created terraces.

A New Model for Introducing Environmental Challenges into the Public School Curriculum: Learning and Applying Core Science to Save Salmon

Jensen, J. EdD[1] and L. Svanevik, PhD[2]

[1]Educational Solutions (ES), Klamath Falls, OR
[2]Oregon Institute of Technology (OIT), Klamath Falls, OR

Educational Solutions is a Klamath Falls-based non-profit that has successfully completed a 2008-2009 project Klamath Watershed project involving 315 students from nine Oregon and California high schools. Students learned about stakeholders' perspectives, causes of water shortage, evaluation of water quality, and factors influencing fish mortality. The focus was finding solutions to watershed problems. Average student improvement, based upon pre- and post-test evaluations, was 91 percent. In addition, 57 percent of the students qualified for one unit of biology credit for OIT.

Participating teachers requested that additional projects directly address State standards mandated by the No Child Left Behind Act. To this end, ES is developing a new educational model, reverse-engineered from State standards, to help students understand and solve important environmental problems. This project focuses on salmon because of the range of habitat and the problems that returning salmon will face in the Klamath Basin when mid-basin dams are removed.

ES has been encouraged by the Oregon Department of Education to submit a proposal for a Title IIB grant to test the model. We have also been encouraged by the willingness of scientists from the Hatfield Marine Science Center, Oregon State University's Salmon Disease Laboratory, and the United States Geological Survey to work with us to facilitate our model. This presentation will demonstrate how to relate State standards to important research related to salmon restoration.

Adaptive Environmental Assessment and Management in the TRRP: Progress, Challenges and Opportunities

Marmorek, D.R., D. Pickard, M. Porter, K. Wieckowski, ESSA Technologies, Vancouver, B.C., Canada

Adaptive Environmental Assessment and Management (AEAM) is a rigorous approach to environmental management designed to explicitly address and reduce uncertainty regarding the most effective on-the ground actions for achieving management goals and objectives. But it isn't easy, particularly at watershed scales. This presentation reflects some insights we've gained over the last 30 years of tackling AEAM challenges, including the last five years of working intensively with TRRP and external scientists on the Integrated Assessment Plan and other work products. We briefly describe 'ideal AEAM', and provide examples of rigorous adaptive management designs for ecosystem rehabilitation and species recovery in Western North America. We emphasize the need for strong contrasts, replication and randomization of actions, coupled with rigorous monitoring and evaluation (M&E) that provides clear signals for revising hypotheses and management actions. We then examine various spatial and time scales of AEAM in the TRRP, from annual decisions on flow and sediment augmentation, to periodic adjustments in rehab site designs, to multi-decadal evaluations of the effectiveness of habitat restoration in meeting Program goals.

At each scale, we highlight progress made over the last few years (e.g., improved sampling designs and monitoring protocols) and outline remaining challenges (e.g., tightening up domain-specific management targets, formulating if…then decision rules, resolving tradeoffs among competing ecosystem objectives). We conclude by highlighting various opportunities for improving the implementation of AEAM in the TRRP.

Physical Hydrology and Climate

Simulation of Regional Groundwater Flow to Inform Resource Management in the Upper Klamath Basin, Oregon and California

Gannett, M.W.[1], and B.J. Wagner[2]

[1]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[2]U.S. Geological Survey, National Research Program, Menlo Park, CA

The upper Klamath Basin encompasses approximately 21,000 km^2, spanning the Oregon California border east of the Cascade Range. Average precipitation ranges from 166 cm/yr in the Cascade Range to 28 cm/yr in interior lowlands. Because of the semiarid conditions in the interior parts of the basin, cultivated lands (approximately 200,000 ha) are irrigated, primarily from surface water. During the past decade, however, there has been increasing competition for limited surface water due to the habitat requirements of threatened and endangered fishes. As a result, there has been considerable interest in using groundwater to supplement surface-water sources. While groundwater use has the potential to augment water supplies, it also has the potential to negatively affect streamflow. The importance of groundwater to the flow and temperature of streams is generally recognized, but without the ability to quantitatively evaluate the connection, clear management strategies have remained elusive.

A regional groundwater flow model has been developed to fill this need. The model encompasses the entire upper Klamath Basin and simulates groundwater interaction with major streams, lakes, and wetlands. Groundwater discharge to agricultural drains in the 77,000 ha Bureau of Reclamation Klamath Project area is also simulated. The model was calibrated using 5,562 head observations at 662 wells and 643 groundwater discharge observations for 10 spring complexes, stream reaches, or drainages. Preliminary results show that the distribution of the effects of pumping primarily depends on well location and depth. In some areas, much of the water pumped from wells is reflected as diminished discharge to streams. In agricultural areas with shallow groundwater, in contrast, much of the pumping is reflected as diminished discharge to agricultural drains. The regional groundwater model will provide useful insights into the spatial and temporal distribution of the effects of groundwater pumping, but the model alone can not identify the best management strategy. Groundwater management in the upper Klamath Basin will require controlling the timing and location of effects of pumping on streams and exploiting aquifer storage properties to balance the pumping and recharge at a variety of time scales. This presents a complex problem with many interdependent variables. Optimization techniques are being employed to identify the best management strategy given certain objectives, constraints, and decision variables, and to help identify ways in which the strategy must adapt to varying climate conditions.

Use of a Simulation-optimization Model to Evaluate Alternative Groundwater Management Strategies for the Upper Klamath Basin, Oregon and California

Wagner, B.J.[1], and M.W. Gannett[2]

[1]U.S. Geological Survey, Menlo Park, CA
[2]U.S. Geological Survey, Portland, OR

Demand for groundwater in the upper Klamath Basin has increased in recent years due to drought and changes in surface-water management aimed at improving habitat for fish listed under the Endangered Species Act. Water and environmental managers in the basin need methods to determine groundwater withdrawal strategies that provide additional water supply while avoiding detrimental impacts of pumping on stream flows and groundwater levels. Here we present a decision model for the upper Klamath Basin that combines groundwater simulation with optimization. The simulation–optimization management model evaluates a complex array of water management options to identify strategies that best meet the resource allocation objectives of the basin.

The upper Klamath Basin has a groundwater flow system that discharges to streams throughout the basin and provides the majority of late-summer stream flows needed to support critical wildlife habitat. The effects of groundwater pumping on stream discharge have not been directly measured, and there is uncertainty regarding the timing, distribution, and magnitude of the effects of sustained groundwater development on surface water resources. A numerical groundwater simulation model for the upper Klamath Basin has been developed to provide insight into these questions. The model can be used to explore the response of the groundwater/surface water system to pumping. When linked with techniques of optimization, the simulation model can identify groundwater management practices that support the complex set of goals and constraints associated with groundwater use in the basin. These include (1) determining groundwater withdrawal patterns that support the spatially and temporally varying water demands for irrigation and wildlife habitat, (2) ensuring that impacts on stream flow resulting from managed pumping are within acceptable limits, (3) ensuring that drawdown due to managed pumping does not exceed that allowed by Oregon water law, and (4) identifying the impact of spatially and temporally varying recharge on groundwater availability, including the necessity, timing, and extent of pumping restrictions during extended drought cycles. Groundwater management alternatives for the basin will be described in terms of trade-offs among groundwater pumping decisions, water demand constraints, stream-flow impact constraints, drawdown constraints, and recharge variability.

Streamflow Response to Climate in the Klamath Basin Region

Mayer, T.[1] and S. Naman[2]

[1]U.S. Fish and Wildlife Service, Portland, OR
[2]National Marine Fisheries Service, Arcata, CA

This study is the second part of our analysis of Klamath Basin hydroclimatology. Here, we examine the response of streamflow in the region to reduced snowpack, as documented in our previous study. We examine streamflow characteristics and trends at 21 predominately unregulated basins in the region with long measurement records (>40 years). The objective of this work is to investigate how elevation and geology interact to control streamflow response to climate.

Precipitation varies across the region from 50 to 200 cm on the west side of the Cascades to 10 to 50 cm on the east side. Consequently, river basins on the wetter, west side are typically more productive (mean annual runoff, normalized to basin area) than streams on the drier east side. The strong precipitation gradient masks the relationship of mean annual runoff and elevation. However, elevation is a strong control of streamflow timing, with higher elevation basins having a later runoff date.

The region transitions from the high relief, impermeable bedrock geology of the west side to the low relief, permeable volcanic geology on the east side. These geologic differences result in a shift from rain-snow stream types on the west side to groundwater-dominated streams on the east side. Rain-snow stream hydrographs are characterized by rapidly rising discharge in the fall, broad peaks throughout the winter, a recession beginning between April and June, and low baseflows in summer and early fall. Groundwater stream hydrographs are characterized by slowly increasing discharge in winter, more muted snowmelt peaks, and high baseflows in summer and fall.

The response of groundwater streams to winter recharge is smoothed and delayed, on a seasonal and annual scale. Groundwater streams tend to be more responsive to dry or wet multi-year cycles rather than a single dry or wet year. Summer and fall flows in these systems, measured in absolute terms or as a percentage of total flow, are about 8 times greater than in rain-snow streams. Groundwater streams sustain a large fraction of the late season flows in many of the major river systems in the region, including the Klamath, the Rogue, and the Umpqua.

While both stream types show declines in total annual flow over the last 4–6 decades, corresponding to reductions in snowpack, groundwater streams show much higher relative and absolute declines in summer and fall. Absolute flow declines in August are about 20 times greater in groundwater streams than in rain-snow streams. The significance of these declines suggests summer and fall flows in these systems are more responsive to snowpack reductions than rain-snow streams. The declines have serious implications for the region because of their importance to water supply, aquatic ecosystems, and mainstem flows.

Watershed Scale Response to Climate Change: Sprague River Basin, Oregon

Risely, J.C.[1], L.E. Hay[2], and S.L. Markstrom[2]

[1]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[2]U.S. Geological Survey, National Research Program, Central Region, Denver, CO

The U.S. Geological Survey Global Change study, “An integrated watershed scale response to climate change in selected basins across the United States,” began in 2008. The long term goal of this study is to provide the foundation for hydrologically based climate-change studies across the nation. Fourteen basins for which the Precipitation Runoff Modeling System (PRMS) had been calibrated and evaluated were selected as study sites. PRMS is a deterministic, distributed-parameter, watershed model developed to evaluate the effects of various combinations of precipitation, temperature, and land use on streamflow and general basin hydrology. PRMS results for the Sprague River basin in Oregon are summarized below.

Six General Circulation Models (GCMs) incorporating three climate change scenarios were used to develop an ensemble of climate change inputs to PRMS. Although, the climate change projections for 2001–2099 showed a wide range of variability between the GCMs, which would indicate a large amount of uncertainty, the central tendency lines showed an overall increase in temperature (2 to 3 degrees Fahrenheit) and a slight increase in precipitation over the 21st century. Using these data as model input, simulated streamflow output from PRMS for the Sprague River indicate increased flooding earlier in the spring and decreased summer baseflow as a consequence of increased and decreased proportions of rainfall and snowfall, respectively. Supplying approximately 25 percent of inflow to the Upper Klamath Lake, the Sprague River basin is vital to environmental and human water needs within the Klamath River basin. As water demands increase, the reliability and timing of flow from the Sprague River becomes increasingly critical in water-management decisions. Potential alterations in flows to the Upper Klamath Lake as a result of climate change could necessitate (1) modifications to the operation of the lake as a storage reservoir and (2) creation of additional storage capacity to meet water demand during the summer.

Bathymetric Mapping with Airborne LiDAR in the Klamath-Trinity Basin

Gaeuman, D., and D.J. Bandrowski, Trinity River Restoration Program, Weaverville, CA

The Trinity River Restoration Program (TRRP) collected airborne bathymetric LiDAR over 40 miles of the Trinity River in April of 2009. The airborne survey was performed by U.S. Geological Survey (USGS) personnel based in Florida using the EAARL (Experimental Advanced Airborne Research LiDAR) system, whereas supporting ground surveys based on both wading and sonar measurements were performed by TRRP and a separate USGS group from Colorado. Immediately after completion of the Trinity mission, both the airborne and ground USGS groups collected similar data from a short reach of the Klamath River. The EAARL system utilizes a green laser to penetrate water, and records full waveform returns that can be used to identify the stream bed with a nominal vertical precision of about ± 20 cm. Waveform data from the Trinity mission were initially processed to xzy coordinates by USGS personnel and delivered to TRRP in September 2009. This initial attempt to process the raw waveform data was largely unsuccessful. Although errors in shallow areas were only slightly larger than expected (RMS ~ 26 cm compared with wading ground-truth measurement), errors in deep water were typically on the order of m. Closer inspection revealed that initial processing had identified false bottoms, commonly at a depth of about 1 m, such that the magnitude of errors in deep water were often approximately H-1 m, where H is the actual water depth. Fortunately, subsequent inspection of the raw waveforms suggests that the raw data do contain sufficient information to correctly identify the stream bed to depths of approximately 3 m. At the time of abstract submission, TRRP is attempting to reprocess the waveform data to extract correct bottom elevations in areas where depths are between about 1 and 3 m, and is acquiring additional sonar surveys to patch in areas with greater depths. Techniques employed by TRRP in this re-processing effort and results will be presented.

Ecohydrology

Klamath River Stream Temperature Modeling and Use of Thermal Refugia by Salmonids

Danner, E.[1], S. Lindley[1], A. Pike[1], and K. Brewitt[2]

[1]National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Santa Cruz, CA
[2]Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA

Late summer and early fall water temperature regimes are critical to the persistence of endangered and threatened salmon on the Klamath River. Water temperatures critically influence fish physiology in numerous ways and understanding water temperature dynamics is a prerequisite to assessing acute and chronic thermal impacts on salmonids. Currently, the temperature dynamics of the Klamath River mainstem are not well understood at the appropriate scales necessary for fisheries management decisions. The presence and duration of cold water refugia may be a key factor for salmonid survival, yet little is known about the spatiotemporal dynamics of these refugia – particularly in relative to the mainstem temperature dynamics. We are addressing these issues through a combination of high-resolution stream temperature and fish mortality models of the Klamath River mainstem, and fish tracking studies to evaluate the associated spatial response of salmonid fishes in and around selected thermal refugia. This model is driven by recently developed NASA satellite derived climate data and will provide hindcasts and forecasts (including various climate change scenarios) of the mainstem at sub-hourly intervals for every 1 km of stream reach. These data will be used as inputs to spatially explicit fish mortality models to evaluate the temperature impacts on salmonids at sub-adult life stages. Finally, we will measure fine-scale spatiotemporal use of the thermal refugia and mainstem by salmonids through radio tracking of individual fish.

Potential Impacts of Climate Change on Aquatic Fauna: Finding a New Paradigm for Wetland and Riparian Systems in the Upper Klamath Basin, OR

Bienz, C., The Nature Conservancy, Klamath Falls, OR

Resiliencies of the Klamath Basin's physical and ecological systems to precipitation and temperatures have provided the framework of our understanding of biotic response to abiotic patterns and processes. Climate change is poised to greatly alter the timing and magnitude of abiotic processes. Understanding which species and which ecological systems will be most vulnerable to climate change and how they will be vulnerable will be critical for setting conservation and management priorities and for developing successful adaptation strategies. One approach is to model climate change projections that have been downscaled from Global Circulation Models for a given watershed, link relevant climate parameters (e.g., temperature and precipitation) to a hydrologic model, and develop future projections for the hydrologic parameters of interest (e.g., streamflow, groundwater recharge, water table elevation). This information was used to design and implement management strategies which took into account how climate change may affect aspects of the freshwater ecosystem and species' responses and the complex socio-political landscapes in which they were implemented. We found the complicated systems of agrarian economics, water use and related infrastructure a constraint in prioritizing freshwater conservation strategies within any particular river basin.

Application of Hydrological and Ecological Models to Access Effects of Changing Climate and Adaptation Strategies on Pastures and Water Resources in the Wood River Basin

Hagimoto, Y., R.H. Cuenca, and J. Owens, Department of Biological and Ecological Engineering, Oregon State University, Corvallis, OR

It is important to design climate change adaptation strategies after accounting for the effects on water resource availability of various ecosystems in the Klamath Basin. Flood irrigated pasture is the dominant agricultural land uses in the major tributary subbasins (e.g., the Wood River, Williamson River, and Sprague River Subbasins) of the Klamath River. Therefore, understanding potential effects of changing climate and adaptation strategies on productivity and water use efficiency is a key factor for decision makers to predict water resource availability in the Klamath Basin. Our study used the MIKE-SHE hydrologic and the DAISY ecological models to model pasture systems in the Wood River Basin. These models were calibrated with observed vegetation and hydrologic data obtained from fully- and non-irrigated pastures. The models were run with moderately increased temperatures (annual average +1.3°C, summer +1.4°C and winter +1.2°C) and precipitation (+2 percent) projected for the 2020s under the A2 (differentiated world) scenario. In addition, we ran the models with increased legume composition and with sprinkler irrigation systems to access the effects of these practices as potential farm-level adaptation strategies.

Calibration results indicated that nitrogen deficiency and heat stress suppressed productivity of the cool-season grass-dominated pasture systems after July. The results also indicated that converting to non-irrigated pasture could make approximately 500 mm of water during the growing season available for instream flow by suppressing evapotranspiration and by the drainage of water from surface and subsurface layers. (Under irrigation, this drainage of water would only occur at the end of the growing season.) As a result, the non-irrigated pasture would reduce productivity by 15 percent.

Simulation results indicated that the changing climate by 2020s is expected to 1) increase the growing season length by 22 days, 2) increase crop water demand (crop evapotranspiration) by 9.8 percent, and 3) increase total seasonal forage production by 0.3 percent. These changes result in reduction of average daily productivity by 10.4 percent and water use efficiency by 8.7 percent.

As a farm-scale adaptation strategy, introducing 30 percent legume composition would improve pasture productivity by 26 percent mainly by increasing nitrogen availability. Upgrading flood irrigation systems to sprinkler irrigation systems would save approximately 160 mm water during the growing season by the drainage of water from subsurface layers. In conclusion, our study demonstrated usefulness of the combined use of two models by providing key information for decision makers in the Klamath River Basin.

Protecting Groundwater-dependent Ecosystems in the Klamath Basin

Bach, L.[1], A. Aldous[1], J. Brown[2], and A. Wyers[1]

[1]The Nature Conservancy, Portland, OR
[2]The Nature Conservancy, Fall City, WA

In many States within the United States and countries around the world, the value of groundwater for drinking water, irrigation, and industry is reflected in laws and policies that control groundwater availability and quality. However, few or no policies currently exist to protect groundwater for ecosystems. Groundwater-dependent ecosystems (GDEs) include wetlands, lakes, rivers, springs, and species that are supported partially or entirely by groundwater. Effective protection and management of GDEs are hindered by inadequate information on their locations and the condition of their associated groundwater supplies. To address this data gap, we developed a methodology to map GDEs and their threats by 6th-field Hydrologic Unit Code (HUC6), and applied it across Oregon, Washington, and Northern California. Our results demonstrate the importance of groundwater to aquatic ecosystems in the Klamath Basin, where springs and/or groundwater-dependent rivers occur in more than 50 percent of HUC6s, and groundwater-dependent wetlands are found in more than 40 percent of HUC6s in the Basin. Moreover, a number of large spring complexes are known in the Klamath Basin for their important role in sustaining aquatic ecosystems throughout the year. In addition to ecosystems, there are more than 50 obligately groundwater-dependent species that are of conservation concern, including 36 molluscs.

A number of activities pose a threat to GDEs by affecting groundwater quantity and quality. While there are very few data available to understand how these activities are currently affecting GDEs, our mapping work shows where we can expect impacts to occur based on the extent of these activities and their proximity to HUC6s with high densities of GDEs. In our assessment, we identified HUC6s most likely affected by changes in groundwater availability due to groundwater pumping from both irrigation and domestic wells. We also evaluated potential impacts to groundwater quality from industrial contaminants, pesticides, and nutrients.

This initial assessment of GDEs and threats to their groundwater supply highlights the ecological importance of groundwater and the need to incorporate protection of GDEs in water management policy. To address the threats to groundwater quantity, The Nature Conservancy has begun to work with the US Forest Service on a pilot study to develop a method for quantifying environmental water requirements for GDEs. These requirements will describe the amount of water that must remain within the ecosystem for the species and ecosystems to remain viable, and how much can be sustainably abstracted for other uses.

How Much Water Does a Wetland Need? Developing Environmental Water Requirements for Groundwater-dependent Ecosystems in the Upper Klamath Basin

Aldous, A.[1], L. Bach[1], J. Gurrieri[2], and T. Carroll[3]

[1]The Nature Conservancy, Portland, OR
[2]USDA Forest Service, Minerals & Geology Centralized National Operations, Office of Geologic Resources, Hazards, and Surface Management, UT
[3]U.S. Department of Agriculture, Forest Service, Pacific Northwest Regional Office, Portland, OR

Groundwater-dependent ecosystems (GDEs) include lakes, wetlands, rivers, and springs that are found at points of groundwater discharge, as well as subterranean and aquifer ecosystems. A recent Oregon statewide assessment demonstrated a high density of GDEs in the Klamath Basin. They are strongly adapted to relatively stable groundwater supply. Similar to groundwater sources for human consumption, GDEs are threatened by groundwater depletion and contamination. Yet unlike municipal and agricultural groundwater supply systems, little is known about groundwater quality and quantity, and even less is known about thresholds below which a GDE is irreversibly altered.

To address this data gap, we are developing quantitative thresholds for groundwater discharge, termed environmental water requirements, for groundwater-dependent wetlands called fens. This pilot project is being conducted in three fens in the Fremont-Winema National Forest, in the Jack Creek drainage. The fens are in a grazing allotment where water is withdrawn for cattle, thus understanding thresholds for groundwater discharge and withdrawal is critical to manage these ecosystems.

We are using two complementary approaches to set upper limits on water withdrawals. In a “top-down” approach, we are developing numerical hydrologic models to test the sensitivity of water budget parameters to change and to evaluate their effect on groundwater availability. In a “bottom-up” approach, we are developing quantitative relationships between indicator plant species, peat properties, and the timing and depth of water table fluctuations.

For the latter, bottom-up approach, we are monitoring depth to water table, piezometric head at several depths within the peat profile, and total peat depth across the sites. Peat depth ranges from 0.5–2 m, and is closely related to consistent groundwater discharge. We identified a suite of potential indicator species, and we are monitoring their distribution with respect to seasonal depth to water table. We are supplementing our field data collection with data from the published literature on depth to water table requirements of these plants. A combination of botanical, hydrologic, and edaphic data will be used to define the ideal and minimum depths to water table. We will use this information to inform the parameters in the numerical hydrologic model.

Dams, Sediment and Fish

Effects of Dams on the Klamath: Historical Changes, Distinct Sediment Impacts by Reach, and Implications for Restoring Native Fish

Kondolf, G.M.[1], and M. Tompkins[2]

[1]University of California, Berkeley, CA
[2]NewFields River Basin Services, LLC, Berkeley, CA

The six dams on the Klamath River included in the PacifiCorp hydroelectric project have affected sediment transport, and in some cases, flow regime, interacting with natural physiographic differences to create seven flowing river reaches with distinct sediment transport regimes. Based on the most extensive field studies of channel form, bed material, and sediment transport on the river to date, we developed a conceptual model for the Klamath River downstream of Upper Klamath Lake. In upstream to downstream order, these are 1. Link River (steep, sediment starved, fed by outflow from Upper Klamath Lake), 2. Lake Euwana (flat gradient reach above Keno Dam, formerly overflowed into Lower Klamath Lake during floods), 3. Keno-Boyle (steep, bedrock, sediment-starved), 4. Boyle Bypass Reach (steep, sediment starved, dewatered by diversion but still subject to high flows spilled, large sediment source from canal washout), 5. Boyle Full-Flow Reach (steep, low sediment supply, some key tribs, flows vary with generation), 6. Copco 2–Iron Gate (short, steep, sediment-starved bypassed reach, heavily encroached by riparian vegetation), 7. Iron Gate downstream to Cottonwood Ck confluence (sediment-starved, regulated by Iron Gate, moderate gradient reach still accessible to anadromous fish) , 8. Downstream of Cottonwood Creek confluence (geologic change to Klamath Mountains terrane, with flow and sediment supply increasing with each tributary)

The seven reaches vary with respect to sediment availability and transport regimes. In addition, some key historical changes include modifications to the channel to facilitate log transport and elimination of flood overflows into Lower Klamath Lake in the early 20th century, which resulted in higher peak flows through the reaches downstream.

Sediment Transport Dynamics in Dam-influenced Reaches of the Klamath River: Lessons from 10 Years of Study

Tompkins, M.R.[1], G.M. Kondolf[2], and A. Falzone[2]

[1]New Fields River Basin Services, LLC, Berkeley, CA
[2]University of California, Berkeley, CA

The draft Klamath Hydroelectric Settlement Agreement of September 30, 2009, notes that additional studies will be required to support a decision by the Secretary of the Interior as to whether removal of the lower four dams on the Klamath River will advance restoration of the salmonids fisheries of the Klamath Basin. Sediment transport is identified in the draft settlement agreement as one of the key discipline areas requiring study and analysis for the secretarial determination. Significant study and analysis of sediment transport in the dam-influenced reaches has been conducted over the past ten years. However, most of this effort over the past five years has focused on reservoir sediment composition and modeling studies of sediment transport. We conducted studies of reservoir sedimentation, bed material size, bed mobility, sediment transport, and channel form between Klamath Falls, Oregon and Seiad

Valley, California between 2001 and 2005. These studies resulted in the collection of empirical data on channel form, bed material composition, thresholds of bed mobility, and sediment transport downstream of dams. Based on our results from these studies, we identified geomorphically distinct reaches and quantified sediment transport as a basis to evaluate dam effects on downstream channel morphology. Our studies characterized important characteristics of the Klamath River that should be considered in future studies and planning for dam removal. The upper reaches of the Klamath are low-gradient, lake and bedrock-sill-controlled, with small sediment yields but large influxes of natural and anthropogenic nutrients. In addition, the river's gradient and sediment load increase downstream as it passes through the steep Klamath Mountains and Coast Range. Therefore, the impact of the four dams proposed for removal on downstream geomorphic conditions will vary with location in the watershed. Thus, some expectations of downstream dam effects based on observations on other rivers may not be directly applicable to the Klamath dams. Our findings could be used to inform future dam removal approaches for the Klamath River.

Effects of Sediment Release Following Dam Removal on the Aquatic Biota of the Klamath River: Application of Results from a Fine Sediment Transport Model

Bell, E.[1], F. Ligon[1], Y. Cui[2], B. Orr[2], and M. Bowen[3]

[1]Stillwater Sciences, Arcata, CA
[2]Stillwater Sciences, Berkeley, CA
[3]California Coastal Conservancy, Oakland, CA

Four dams on the Klamath River are under consideration for removal: Iron Gate, Copco 1 and 2, and J.C. Boyle. Current dam removal scenarios would result in the transport of 1.3–2.9 million metric tons of fine sediment (sand, silt, and finer) to downstream reaches of the Klamath River. We applied the results of the DREAM 1 sediment transport model to analyze the duration and concentrations of total suspended sediment (TSS) likely to occur downstream during dam removal. To investigate the potential effects of the sediment releases on downstream biota, we evaluated the downstream TSS levels for their potential impacts on selected focal species. Sediment model results indicated that increases in daily average TSS concentrations will fluctuate during dam removal, ranging from approximately 50 ppm (parts per million by mass) to 38,000 ppm, with the duration of peak concentrations ranging from days to weeks depending on location and hydrological conditions in the basin. The worst-case scenario for potential focal species' population responses was analyzed using TSS concentration and duration predictions in conjunction with Newcombe and Jensen's (1996) "severity of ill effects" indices. The focal species, including Chinook salmon (fall and spring) and coho salmon, steelhead (summer and fall/winter), coastal cutthroat trout, Pacific lamprey, and green sturgeon, possess numerous life stages that rely on mainstem habitat on a seasonal basis (winter, spring and/or summer). Effects of predicted exposure to high TSS concentrations range from sublethal avoidance behavior and physiological stress to direct mortality rates of up to 100 percent of fish exposed to TSS, depending on species, exposure duration, and concentration. However, complete mortality is not expected for any species or life stage. The primary mitigating factor is that all species analyzed possess extensive temporal and spatial distribution within the Klamath River basin, a distribution expected to facilitate survival during dam removal, and contribute towards a strong recovery subsequent to dam removal. The combination of tributary use during spawning and rearing, off-channel habitat use for over-wintering, rearing in the lower mainstem or the estuary, and life histories that include mature adults in the ocean, is predicted to buffer short-term (1–2 years) impacts of elevated TSS in the mainstem river. Although focal species' populations are expected to recover in the long term (>2 years), mitigation measures are recommended to support the survival of individuals during dam removal, and to facilitate a stronger population recovery in the short term.

DREAM-1 and Its Application to Klamath River Dam Removal Sediment Transport Simulation

Cui, Y.[1], J. Wooster[1], E. Bell[2], M. Singer[1], B. Orr[1], and M. Bowen[3]

[1]Stillwater Sciences, Berkeley, CA
[2]Stillwater Sciences, Arcata, CA
[3]California Coastal Conservancy, Oakland, CA

DREAM-1 is one of the Dam Removal Express Assessment Models originated from a sediment transport model developed for simulation of sediment pulses in rivers. DREAM-1 and other closely related models have been applied in many sediment transport related projects, and have proven to be successful where data is available to examine model performance. The successful application of these models include: landslide evolution in the Navarro River, California; mining waste disposal in the Ok Tedi and Fly River in Papua New Guinea; Marmot Dam removal in the Sandy River, Oregon; Lake Mills drawdown experiment, Elwha River, Washington; land management in the Waipaoa River, New Zealand; and at least three different sets of flume experiments conducted at different institutions. We have applied DREAM-1 in the Klamath River to predict sediment transport dynamics associated with the proposed removal of Iron Gate, Copco 1, Copco 2, and J.C. Boyle dams under the concurrent drawdown scenario. Using reasonable assumptions with regard to channel geometry to be formed in the former reservoirs following dam removal, DREAM-1 predicted that 1.3–2.9 million metric tons of sediment will be released downstream, resulting in a suspended sediment concentration in excess of 30,000 ppm just downstream of Iron Gate Dam. Predicted suspended sediment concentration peaks in early winter before the arrival of high flow events following the commencement of reservoir drawdown in mid November, disappears with the arrival of high flow events that refills the reservoirs and effectively stops sediment erosion with the rising pool levels in the reservoirs, and reappears in the spring when the incoming flow becomes small enough to allow for a second drawdown of the reservoirs. The predicted suspended sediment concentration in spring is significantly smaller than winter peaks, on the order of a couple thousand ppm just downstream of Iron Gate Dam. Predicted suspended sediment concentration decreases in the downstream direction due to the contribution of flow from tributaries. Downstream of the Trinity River confluence, for example, predicted winter peak TSS is on the order of several thousand ppm compared to over 30,000 ppm just downstream of Iron Gate Dam. Because of the small fraction of sand-sized and coarser particles contained in the reservoir deposits, the model predicts no discernable aggradation over the 190 miles of river downstream of Iron Gate Dam following reservoir drawdown and dam removal. The predicted suspended sediment concentration provided the basis for biological and water quality evaluations.

Evaluating Model Accuracy: Predicted and Observed Sediment Dynamics Following the Chiloquin Dam Removal

Tullos, D.D., C. Walter, and M. Cox, Biological and Ecological Engineering, Oregon State University, Corvallis, OR

Hydrodynamic models are often used to reduce uncertainty regarding the outcomes of dam removal, though the accuracy of these models is not regularly evaluated post-removal. With the goal of improving understanding on the accuracy and limitations of making predictions of sediment dynamics following dam removal, we will compare predicted and observed sediment deposition at three sites downstream of the Chiloquin Dam removal. Results from a 1D hydraulic (HEC-RAS) model, developed to estimate sediment transport rates at the sites, will be compared to cross-sectional and longitudinal profile surveys collected approximately one year following the dam removal. Pre-removal and post-removal bathymetry and grain size distributions document the changes in depth, size, and mass of sand downstream. Modeled estimates of mass and dominant size of sediment remaining and the thickness of sediment in the channel will be reported. Results of field surveys indicate that bathymetric changes over the past year have been minimal in both the reservoir and the downstream reaches, due in part to the low water year and the low volume of sediment stored in the reservoir. Model results generally match observed erosional patterns but predicted greater deposition in pools downstream than was observed. The relationships between the model predictions and observations are reported and potential sources of error and improvement in modeling and field observations will be discussed. Findings will be placed in the context of dam removal in general, and suggestions are made about data needs and potential modeling approaches in future dam removal studies.

Appendix 3. Abstracts from Poster Sessions

Klamath River Nutrient Loading and Retention Dynamics in Free-Flowing Reaches, 2005–2008

Asarian, E.[1], J. Kann[2], and W. Walker[3]

[1]Riverbend Sciences/Kier Associates, Eureka, CA
[2]Aquatic Ecosystem Sciences LLC, Ashland, OR
[3]William W. Walker Environmental Engineer, Concord, MA

Previous analyses evaluated nitrogen loading and retention dynamics for free-flowing Klamath River reaches below Iron Gate Dam using intermittent nitrogen data collected between 1996 and 2004. These analyses showed that the river reaches between Iron Gate Dam and Orleans typically showed positive nitrogen retention (assimilation/denitrification) and that the river reaches below Orleans were more variable, showing both periods of positive and negative retention (release) of nitrogen.

Consistent nutrient data collection efforts by the Karuk and Yurok Tribes (and additional data from PacifiCorp, USGS, and USBR) allowed for detailed multi-year and seasonal nutrient budget and retention dynamics to be evaluated for 2005-2008. In contrast to the previous iteration, dynamics were evaluated not only for total nitrogen (TN), but also for total phosphorus a well as dissolved forms of both nitrogen (i.e., total inorganic nitrogen [TIN], composed of nitrate and ammonia) and phosphorus (soluble reactive phosphorus [SRP]). Free-flowing reaches evaluated included Keno Dam to above Copco (includes the small J.C. Boyle impoundment) and four reaches below Iron Gate Dam: Iron Gate to Seiad, Seiad to Orleans, Orleans to Weitchpec, and Weitchpec to Turwar. Inflow, outflow, tributary, and ungaged accretion loads were calculated for each reach and then retention was determined via mass-balance calculations. Results were summarized for the periods June 1–October 20 (monitoring season) and July 1–September 30 (period of maximum periphyton productivity). Methodological improvements included the use of flow- and season-based multiple regression models to estimate nutrient concentration time-series and assess prediction uncertainty.

Provisional results indicate overall positive TIN and TN retention for middle and upper reaches (Iron Gate to Seiad, and Seiad to Orleans, and Orleans to Weitchpec), and negative for the most downstream reach (Weitchpec to Turwar). In the Keno to Copco reach, TN retention was positive and TIN was not evaluated. Retention was generally positive for TP and SRP in all reaches evaluated. Retention rates for TN were overall higher than for TP on both an absolute (i.e. kg/day/mi) and relative (percent) basis. Similarly, retention rates for TIN were higher than for TN, and SRP higher than for TP. Retention rates for all four parameters were higher in the July-Septembers period than the June–October periods.

Nutrient loading and retention rates from the current study will be compared with 1996–2004 estimates, as well as to impounded reservoir reaches.

Sevenmile Creek Fish Passage

Rotar, M.[1], and D. Ebert[2]

[1]PBS&J, Bozeman, MT
[2]PBS&J, Portland, OR

The purpose of the project was to provide for fish passage around an agricultural diversion structure on Sevenmile Creek, located in the Upper Klamath Basin of southern Oregon. The diversion seasonally blocked up and downstream movement of fish. To provide fish passage, a natural roughened channel was constructed adjacent to the existing channel. Access to existing irrigation ditches on both banks was maintained as part of the project.

The superstructure of the diversion structure itself was removed but sheet pile on the banks and an instream support bar remained to support the banks and bed and prevent migration of the downstream head cut. A rock weir was constructed in the channel immediately upstream of the existing diversion structure to maintain water elevations for continued irrigation. A second rock weir was constructed across the main channel just above where the roughened channel returns to guide migrating fish to the roughened channel and provide additional grade control.

The project facilitates movement of redband trout (*Oncorhynchus mykiss newberrii*) and brown trout (*Salmo trutta*) during irrigation season. It also allows for upstream and downstream movement of the endangered Lost River (*Deltistes luxatus*) and shortnose suckers (*Chasmistes brevirostris*), as well as adult steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*), should they colonize Sevenmile Creek.

According to fish passage criteria established by Oregon Department of Fish & Wildlife, no jumps or steps are allowed in structures designed for passage of suckers. A pool and chute fishway, or denil ladder, was a potential option, however the landowner would not support any fish passage design that required a concrete or steel structure in the creek. Therefore, a roughened by-pass channel was designed, because it had the highest likelihood of success, the highest aesthetic appeal, and can accommodate the inherent variability of flows.

Fish passage criteria that needed to be met included minimum depth (1 ft), maximum flow velocity (4 fps), and maximum bed slope (4 percent). The roughened channel and upstream diversion weir were designed to meet passage criteria between the 10 and 90 percent exceedance flows.

The project was constructed in the early fall of 2008. Depth and velocity measurements taken in the roughened channel immediately following construction confirmed that fish passage design criteria were being met.

Upper Klamath Basin Wetlands: An Assessment

Larson, R., and B.J. Brush, U.S. Fish and Wildlife Service, Klamath Falls, OR

Wetlands are important habitats because of the many goods and services they provide. In the upper Klamath River Basin in southern Oregon and northern California, wetlands are especially critical to migrating birds, and provide habitat for thousands of ducks, geese, swans, and wading and shorebirds each year. Approximately 1 million waterfowl, perhaps as much as 80 percent in the Pacific Flyway, use the basin annually. Additionally 20–30 thousand shorebirds use upper basin wetlands, primarily during their spring and fall migrations. The wetlands also provide habitat for early life stages of endangered Lost River and shortnose suckers and other native fishes, and a wide variety of other native wildlife.

Additionally the wetlands likely provide valuable water quality functions and sequester carbon in the form of peat.

Unfortunately these wetlands have been extensively impacted by agriculture and other development, and wetlands losses have been estimated to be as high as 65 to 90 percent. Because it is unclear exactly what wetlands remain, we undertook an assessment based on data developed by the National Wetland Inventory.

We found that approximately 380,000 acres (1,500 km^2) of wetlands of all types were present in the upper Klamath Basin above river mile 225 as of 1982, the time of the inventory. Palustrine wetlands (primarily marshes locally called "swamps") accounted nearly 90 percent of the total or 337,000 acres (1,300 km^2). Lacustrine wetlands found along lake shores (littoral habitats) accounted for 10 percent of the total or 40,200 acres (160 km^2), and riverine wetlands (and some associated deepwater habitats) accounted for 1 percent or 5,500 acres (20 km^2).

The majority of the wetlands were located in the Lost River subbasin (36 percent of total), followed by Williamson, Sprague, and Upper Klamath Lake subbasins. Wetland losses are unknown, but are likely less than previously thought. Diking and draining and other activities have altered most of the wetlands; however, approximately 150,000 acres (600 km^2) are being managed for wetland values especially for migratory birds, but also for water quality, recreation, and others. Climate change, exotic species, and competition for water pose threats to wetlands; however, on-going efforts to restore wetlands should lessen adverse effects.

A Survey of Vernal-pool Plant Communities in South-central, Oregon with Emphasis on Searching for Two Imperiled Grasses, Slender Orcutt Grass (*Orcuttia tenuis*) and Green's Tuctoria (*Tuctoria greenei*)

Raade, M., L. Schultz, and R. Larson, U.S. Fish and Wildlife Service, Klamath Falls, OR

Vernal pools are seasonal wetlands that harbor a high diversity of plants and invertebrates. They are rich in species diversity and have a high rate of endemism. Because vernal pools are being rapidly lost as a result of agriculture and urbanization, many of the vernal pool species are now federally protected under the Endangered Species Act (ESA). Greene's tuctoria (*Tuctoria greenei*) and slender Orcutt grass (*Orcuttia tenuis*) are small, tufted, annual grasses (family Poaceae) that are primarily found in vernal pools. Both species were listed under the ESA in 1997, and are currently found only in northern California, primarily in the Central Valley region. Recent discoveries of these grasses in Modoc County in Northern California has expanded their range close to the Oregon border, initiating interest in searching for these species in south-central Oregon (Klamath and Lake counties), and in documenting the vernal pool flora. This study was conducted on Bureau of Land Management (BLM) land near Gerber Reservoir known as the "Gerber Block" and in the southwestern part of Fremont National Forest. To aid in locating potential areas to search for vernal pools, GIS-generated maps were developed by U.S. Geological Survey quadrangle, showing an overlay of soil types associated with wetlands (usually identified as poorly drained) and the presence of wetlands as identified by the National Wetlands Inventory. Potential sites were identified and checked for the presence of vernal pools. Plant species were investigated with a focus on searching for *Orcuttia tenuis* and *Tuctoria greenei*. Thirty-four plant species associated with vernal pools were identified and species composition was fairly consistent from site to site and were similar to those in Modoc County where *Orcuttia tenuis* and *Tuctoria greenei* occur. However, these grasses were not observed during this survey. Because this was a preliminary survey, and was done in a dry year, there is a need for continuing plant survey investigations to further understand vernal pool environments and determine if these plants are present in Oregon.

Phosphorus and Nitrogen Legacy in a Restoration Wetland, Upper Klamath Lake, Oregon

Duff, J.H.[1], K.D. Carpenter[2], D.T. Snyder[2], K.K. Lee[2], R.J. Avanzino[1], and F.J. Triska[1]

[1]U.S. Geological Survey, Water Resources Division, Menlo Park, CA
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR

The effects of sediment, groundwater, and surface-water processes on the timing, quantity, and mechanisms of N and P fluxes were investigated in the Wood River Wetland 5–7 years after agricultural practices ceased and seasonal and permanent wetland hydrologies were restored. Nutrient concentrations in standing water largely reflected groundwater in winter, the largest annual water source in the closed-basin wetland. High concentrations of total P (22 mg L^{-1}) and total N (30 mg L^{-1}) accumulated in summer when water temperature, air temperature, and evapotranspiration were highest. High positive benthic fluxes of soluble reactive P and ammonium (NH_4^+-N) were measured in two sections of the study area in June and August, averaging 46 and 24 mg m^{-2} d^{-1}, respectively. Nonetheless, a wetland mass balance simultaneously indicated a net loss of P and N by assimilation, denitrification (1.1–10.1 mg N m^{-2} h^{-1}), or solute repartitioning. High nutrient concentrations pose a risk for water quality management. Shifts in the timing and magnitude of water inflows and outflows may improve biogeochemical function and water quality by optimizing seed germination and aquatic plant distribution, which would be especially important if the Wood River Wetland was reconnected with hyper-eutrophic Agency Lake.

Use of Dual Frequency Identification Sonar (DIDSON) to Estimate Low Abundance Salmonid Escapement in California Watersheds

Pipal, K., M. Jessop, and P. Adams, Fisheries Ecology Division, Southwest Fisheries Science Center, National Marine Fisheries Service, Santa Cruz, CA

Steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) are listed as Threatened or Endangered under the Endangered Species Act throughout most of California. Monitoring these fish presents difficult challenges since their abundances are so low that often a complete census of these populations is needed. Dual frequency identification sonar (DIDSON) is a promising new technology that could potentially be used to monitor adult salmonids runs in California streams and rivers under highly variable environmental conditions. We tested the feasibility of using DIDSON to estimate steelhead escapement in two systems with low abundance in central California: the San Lorenzo River and Scott Creek in Santa Cruz County. DIDSON uses sonar to produce high-quality images in turbid water, which allows for detection and enumeration of fish, as well as estimation of fish size and swimming direction. Each deployment yielded insight into equipment durability, the importance of site selection, data management techniques, and how fish behavior affects data processing. These deployments lead to much improvement in operational techniques. Our 2006 experiment in the San Lorenzo River lasted 8 days and was focused on equipment durability. The DIDSON counts from this site yielded 41 upstream migrants compared to 46 passed at an upstream fish trap. There were some differences in operation time between the two methods which may account for the discrepancy. The Scott Creek (2008) deployment will also span the entire steelhead run season and data validation will be possible using results from a weir located 200 m downstream.

The Salmon Monitoring Advisor: A Hierarchical Web Site to Help Design and Implement Salmon Monitoring Programs

Peterman, R.M.[1], P.B. Adams[2], B. Dorner[1,3], D.L. Drake[4], H.J. Geiger[5], K. Holt[1,6], C. Jordan[7], D.P. Larsen[8], S.A. Leider[9], R.H. Lincoln[10], A.R. Olsen[11], C.K. Parken[12], J.D. Rodgers[13], and S. Walbridge[14]

[1]School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C., Canada
[2]Southwest Fisheries Science Center, National Marine Fisheries Service, Santa Cruz, CA
[3]General Delivery, Lasqueti Island, B.C., Canada
[4]Oregon Department of Environmental Quality, Portland, OR
[5]St. Hubert Research Group, Juneau, AK
[6]Fisheries and Oceans Canada, Pacific Biological Station, B.C., Canada
[7]NOAA Fisheries, c/o U.S. Environmental Protection Agency, Corvallis, OR
[8]Pacific States Marine Fisheries Commission, c/o U.S. Environmental Protection Agency, Corvallis, OR
[9]Governor's Salmon Recovery Office, Olympia, WA
[10]State of the Salmon, Portland, OR
[11]Western Ecology Division, National Health and Environmental Effects Laboratory, U. S. Environmental Protection Agency, Corvallis, OR
[12]Fisheries and Oceans Canada, Pacific Biological Station, B.C., Canada
[13]Oregon Department of Fish and Wildlife, Corvallis, OR
[14]National Center for Ecological Analysis and Synthesis, Santa Barbara, CA

Salmon managers, scientists, and non-governmental organizations face substantial challenges designing cost-effective monitoring programs to assess both status and time trends in abundance, productivity, spatial structure, and diversity of salmon populations. We are currently developing a web-accessible knowledge base called the "Salmon Monitoring Advisor" to help such people choose designs that (1) reliably estimate changes in salmon indicators, and (2) estimate the relative contribution of climate-driven mechanisms to those observed changes (compared to changes caused by other factors). This web site provides a systematic, structured framework to help users develop clear goals and objectives, as well as design and implement salmon monitoring programs that are reliable, informative, and cost-effective. The site is accessible in a hierarchical manner to reflect diverse audiences, including (1) scientists who design monitoring programs and/or analyze the resulting data, (2) technical staff who implement monitoring designs in the field, (3) people involved in providing funding for monitoring programs, and (4) managers and decision makers in government agencies or in local or regional salmon conservation organizations. This web site is named "Salmon Monitoring Advisor" because it provides advice and guidelines to help users work through the essential steps involved in designing monitoring programs to meet stated objectives, and provides pros and cons of different designs, rather than being prescriptive about which design best meets a particular monitoring objective. The web site uses seven sequential steps to guide monitoring design and implementation and provides extensive explanations and real-world examples for each step.

Post-restoration Water Quality Monitoring at the Williamson River Delta, Upper Klamath Lake, OR

Wong, S.[1], and C. Doehring[2]

[1]The Nature Conservancy, Klamath Falls, OR
[2]The Nature Conservancy, Klamath Falls, OR

The Williamson River Delta (the Delta) in southern Oregon was historically a fully functional freshwater marsh ecosystem that provided a substantial nutrient sink for the Williamson River before flowing into Upper Klamath Lake. Beginning in the 1940s, the delta wetlands were drained and converted for agriculture, and the wetlands became hydrologically disconnected from the lake and river. The Nature Conservancy began the large-scale restoration of the Delta in 2007 and has re-flooded approximately 5,500 acres. One of the fundamental goals of the restoration is to help improve water quality in Upper Klamath Lake (a large, shallow hyper-eutrophic lake) by increasing nutrient sequestration in the wetlands, thereby reducing nutrient loads to the lake. Water quality monitoring on the Delta began in 2007 and is currently focused on quantitatively and qualitatively describing the effects of the restoration on nutrient, chlorophyll-*a*, and water chemistry dynamics within and surrounding the Delta. Preliminary results indicate that an initial pulse of phosphorus was released into the water column immediately after re-flooding and that concentrations have subsequently declined in the two years following the restoration. Seasonal trends in dissolved oxygen, pH, and chlorophyll-*a* reflect influences on water chemistry from both wetland processes and inflowing lake and river water. These trends provide important information for evaluating water quality in terms of potential endangered sucker habitat. Initial findings from water quality monitoring on the Delta provide a baseline for assessing how restoration of the Williamson River Delta will affect surface water quality in the longer term, and ultimately help to determine whether restoring wetlands is a practical strategy for improving water quality in Upper Klamath Lake.

Modeling Larval Sucker Transport through the Williamson River Delta, Upper Klamath Lake, Oregon

Hendrixson, H.[1], T. Wood[2], C. Erdman[1], S. Burdick[3], D. Markle[4], and C. Ellsworth[3]

[1]The Nature Conservancy, Klamath Falls, OR
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[3]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[4]Oregon State University, Department of Fisheries and Wildlife, Corvallis, OR

Deltaic marshes at the mouth of the Williamson River at Upper Klamath Lake and Agency Lake probably once served as important nursery habitats for larvae of the endangered Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris*, due to their location downstream of known productive spawning grounds. Beginning in the 1940s, levees were built around the Delta and the wetlands were drained and developed for agricultural uses, and the Williamson River flowed directly into Upper Klamath Lake with no access to its floodplain or deltaic wetlands. Modeling has suggested that without access to the Delta, passively drifting larvae can be transported from the mouth of the Williamson River to the outlet of Upper Klamath Lake in as little as 8 to 10 days. The Nature Conservancy and partners recently breached and lowered over 22 miles of levees and reconnected 5,500 acres of historic floodplain and deltaic wetlands to the adjacent Upper Klamath and Agency Lakes and along 3.5 miles of the lower Williamson River. Prior to and soon after the levee breaches, there was interest in understanding the likely affect of reconnecting the Delta on the travel time of larval suckers

that enter the system from upstream spawning areas. The U.S. Geological Survey developed a calibrated hydrodynamic and heat model for the Upper Klamath and Agency Lake system based on continuous measurements of velocity and temperature. This model was expanded to include the newly inundated portions of the Williamson River Delta. A series of numerical experiments were designed to determine the expected changes in travel time and the drift pathways of larval suckers entering the Delta from the Williamson River. Based on preliminary model runs, it is expected that restoration of the Delta will increase the travel time of sucker larvae from spawning sites in the Williamson River to Upper Klamath Lake and ultimately to the outlet of the lake at the Link River Dam for a given set of meteorological and hydrological conditions. Travel time is also strongly affected by the management of the lake in terms of lake elevation and outflow. To validate the results of numerical experiments we sampled larval sucker density in the Williamson River and Upper Klamath Lake prior to restoration and within and surrounding the Delta after restoration in 2008 and 2009. Samples were collected during the larval sucker migration period at strategically selected locations along modeled flow paths. Here we present the preliminary results of a comparison between sampled and modeled larval sucker densities.

Sprague River Basin Geomorphology Datasets

O'Connor, J., U.S. Geological Survey, Oregon Water Science Center, Portland, OR

The Sprague River basin encompasses about 1,610 square miles (4,170 square kilometers) of south central Oregon and is a principle tributary (via the Williamson River) of upper Klamath Lake. The lower reaches of the North Fork and South Fork Sprague River, the Sycan River, and the 86 miles (139 kilometers) of the mainstem Sprague River meander through broad alluvial valleys historically supporting agricultural crops and livestock grazing. National and regional interest in restoring Klamath Basin ecosystem conditions and processes has motivated several restoration strategies and projects in the Sprague River basin to improve aquatic, riparian, and upland habitat conditions, particularly for endangered fish species. This study, jointly conducted by the U.S. Geological Survey and University of Oregon and in cooperation with the U.S. Fish and Wildlife Service Klamath Basin Ecosystem Restoration Office and the Hatfield Restoration Program, documents historical and current channel and floodplain processes and conditions to assist management and regulatory agencies in evaluating restoration proposals and designing effective restoration and monitoring strategies for the Sprague River and its principle tributaries. The study involves multiple analyses, including assessments of historical channel change, riparian and floodplain vegetation, and surficial geology. To support these analyses, digital floodplain and channel maps were prepared to depict channel and floodplain conditions at different times. The geospatial database of current and historic channel and floodplain conditions will also enable evaluation of long-term trends pertaining to aquatic and riparian habitat conditions.

Klamath River Thermal Refugia as Critical Habitat for Threatened Juvenile Salmonids

Brewitt, K.[1], E. Danner[2] , S. Lindley[2], and A. Pike[2]

[1]Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA
[2]National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Santa Cruz, CA

Late summer and early fall water temperatures on the Klamath River can reach levels that are physiologically stressful to endangered and threatened salmonids. At the limits of their thermal tolerance, salmonids may behaviorally thermoregulate by moving to localized patches of colder water, or thermal refugia. The presence of these refugia may be key to salmonid survival, especially during periods of elevated mainstem temperatures when refugia may be the only usable habitat available, yet their dynamics and importance are not thoroughly understood. While fish obtain thermal benefits by using refugia, trade-offs may include lower food availability and increased risk of disease, and the interplay between these factors influences how much time a fish chooses to spend in the mainstem river versus the refugia. My research focuses on defining the mechanisms driving salmonid thermal refugia use at both landscape and local scales, and the implications refugia use has for salmonid growth and survival. Previous studies have not explored the potential importance of diurnal temperature variations in determining juvenile salmonid survival. The energetic costs of surviving at daily maximum temperatures may make these temperatures critical for determining overall salmonid survival. Knowledge of individual salmonid behavior surrounding refugia is key to understanding how factors such as diurnal temperature variations and heterogeneous food availability impact salmonid growth and survival. To address these issues, I will conduct radio tracking studies to measure fine-scale spatiotemporal use of thermal refugia by individual juvenile salmonids. I will correlate these data with a high-resolution stream temperature model currently being developed by the National Marine Fisheries Service, which tracks Klamath mainstem diurnal temperature fluctuations. Finally, the results of my fieldwork will be integrated into a temperature and food driven bioenergetics model, which will allow me to gain a mechanistic understanding of the relative importance and long-term consequences of the factors affecting salmonid use of thermal refugia.

An Assessment of Using Wild-caught Larval and Juvenile Lost River and Shortnose Suckers for Supplementation Purposes

Russell, K.[1], R. Barnes[2], and R. Larson[3]

[1]U.S. Forest Service, Klamath Falls, OR
[2]Gone Fishing, Klamath Falls, OR
[3]U.S. Fish and Wildlife Service, Klamath Falls, OR

Low adult survival and inadequate recruitment threaten Lost River suckers (*Deltistes luxatus*) and shortnose suckers (*Chasmistes brevirostris*) with extinction. In an effort to determine the feasibility of using wild-caught age 0 suckers for supplementation purposes, we collected larval and juvenile suckers from Upper Klamath Lake (UKL) and adjacent habitats in 2006 and 2007 and reared them.

Substantial numbers of larvae were collected using light traps and small dipnets in conjunction with bright underwater lights at night in Lake Euwauna near the outlet of the Link River in 2006. Additionally, numerous larvae were collected in the Williamson River approximately 1 mile upstream of UKL using dipnets during daylight collection and using dipnets and bright underwater lights during night collection in 2006 and 2007. Larval survival from collection to arrival at the rearing facility was above 95 percent. While pathogen and water quality problems were encountered raising sucker larvae and juveniles in the rearing facility, sucker larvae were successfully reared to sub-adult size in 2 years in small ponds with thermally-heated water, demonstrating that it is feasible to artificially rear wild-caught larvae provided that good water quality, nutritious foods, and adequate pathogen-control protocols are provided.

Juvenile suckers were collected in a screw trap in the Link River during late summer 2006, using fyke nets in the Caladonia Marsh when it was flooded during 2007, and using nets and electroshockers during fall 2007 canal salvage operations. Juvenile survival from collection to arrival at the rearing facility was 99 percent; however, juveniles generally were in poor condition due to high pathogen loads and subsequent survival at the rearing facility was poor even though pathogens control measures were employed.

While collecting juvenile suckers should be more cost effective for providing fish for supplementation activities than collecting larval suckers, poor survival of juveniles at the rearing facility, indicated that it was more effective to collect larval suckers and rear them for supplementation needs. While wild larvae collection appeared to be a potentially effective supplementation technique at 2006 and 2007 sucker population levels, it will become ineffective if adult sucker populations decline substantially from 2006/2007 levels and will be unavailable as a tool for future biologists attempting emergency or “last ditch” recovery efforts.

Potential Areas of Inundation and Stage-Volume and Stage-Area Relations for Diked and Drained Wetlands Adjacent to Upper Klamath and Agency Lakes in the Lower Wood River Valley, Oregon

Haluska, T.L., and D.T. Snyder, U.S. Geological Survey, Oregon Water Science Center, Portland, OR

Former shoreline wetlands that have been cut off by dikes along the northern margins of Upper Klamath and Agency Lakes near the inlet of the Wood River might in the future be reconnected to the lakes by breaching the dikes. Issues of interest associated with restoring wetlands in this way include the area that will be inundated, the volume of water that may be stored, the change in wetland habitat, and the variation in these characteristics as surface-water stage is changed. A recent study conducted by the U.S. Geological Survey in cooperation with the Bureau of Land Management developed GIS maps of inundation and tables for water volume and area for various surface-water stages for wetland parcels extending to the approximate former northern margins of Upper Klamath and Agency Lakes. The analyses utilized detailed land-surface elevation derived from Light Detection and Ranging (LiDAR) data recently collected in the Lower Wood River Valley. Products from this analysis can assist water managers in assessing the effect of breaching dikes, and understanding changes to water storage and ecological habitat with changing surface-water stage in an area with water shortages and endangered or threatened species.

Hydrogeologic Relations in the Williamson River Subbasin of the Upper Klamath Basin, Oregon

Cummings, M.L., Portland State University, Department of Geology, Portland, OR

The hydrogeology of the Williamson River subbasin of the Upper Klamath Basin is controlled by deposition and erosion of volcanic and sedimentary units during the late Miocene to Pleistocene, distribution of pyroclastic deposits from the eruption of Mount Mazama, geomorphic response after the eruption and before widespread vegetation growth, and geomorphic processes acting in the landscape after vegetation became established. In general, Miocene to Pleistocene volcanic and volcaniclastic rocks, particularly pyroclastic flows and hydroclastic deposits, are relatively low permeability. Groundwater migrates along stratigraphic boundaries between these lower permeability units and lava flows. Groundwater discharges to springs and seeps where erosion has cut valleys into these more permeable zones. Pyroclastic flows and pumice deposits from the eruption of Mount Mazama fill topographic lows near the Cascades and mantle the landscape throughout the basin, respectively. Streams along the eastern flank of the Cascade Range have cut steep-walled canyons through the pyroclastic flows and into underlying pumice deposits. Streams lose to the groundwater in these canyons. Pyroclastic flow deposits are relatively lower permeability than pumice deposits and in the vicinity of Klamath Marsh form a confining layer over the pumice. Groundwater discharge from the Cascade Range to Klamath Marsh flows through the pumice deposits. Elsewhere in the basin, pumice deposits store perched groundwater in topographically lower areas in the pre-eruption landscape and locally release water to low-discharge streams. As a result, more water appears to be stored in the landscape now than prior to the eruption. Local erosion of pumice deposits in upland areas and deposition in low-lying areas prior to the time vegetation became widely established modifies pumice stratigraphy and the movement of surface and groundwater. The distribution of some wetlands appears to be influenced by these relations. Infrequent high discharge during spring snowmelt continues to modify the distribution of pumice deposits in uplands areas and to modify the distribution of pumice deposits and alluvial fans building eastward from the Cascade Range. Hydrologic relations in the Williamson River basin are significantly mediated by the physical properties and distribution of pumice.

Spawning Ecology and Larval Drift of Klamath Largescale, Lost River, and Shortnose Suckers in the Williamson and Sprague Rivers, Oregon

Banks, D.T., C.M. Ellsworth, and T.J. Ciotti, U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR

The U.S. Geological Survey Klamath Falls Field Station has been monitoring the spring spawning migrations of Klamath largescale, Lost River, and shortnose suckers in the Sprague River, Oregon. Information regarding the spawning ecology of these populations was collected before the removal of Chiloquin Dam to provide baseline data about their migrations, distributions, and spawning locations. Larval drift was also monitored to assess the relative contribution of the various spawning areas to larvae found emigrating from the Williamson and Sprague rivers. Spawning distributions and locations were determined by tracking radio-tagged suckers and suckers implanted with passive integrated transponder (PIT) tags. Migratory behavior was observed from March to June with fish congregating in discrete reaches of the Sprague and lower Williamson rivers. Some individuals were found to migrate more than 140 river kilometers upstream from the dam before returning to Upper Klamath Lake. Each species exhibited some level of spatial or temporal separation in their spawning behavior. Klamath largescale suckers migrated into spawning areas earliest, followed by Lost River suckers, then by shortnose suckers. Klamath largescale suckers and some Lost River suckers migrated to spawning areas high in the Sprague River drainage; whereas the majority of shortnose suckers and Lost River suckers migrated to spawning areas low in the Sprague and Williamson rivers. Spatial and temporal patterns were also observed during larval drift and generally mirrored adult migration patterns. This study is ongoing and data will be used to assess the affects of dam removal on the spawning ecology of catostomids in the Williamson and Sprague rivers.

Data Collection to Better Understand Instream Processes in the Klamath River from Link River to Keno Dam, Oregon: Nutrients, Algae, Bacteria, Zooplankton, Oxygen Demand, Stable Isotopes, and Acoustic Doppler Measurements

Sullivan, A.B.[1], M.L. Deas[2], S.A. Rounds[1], J. Asbill[3], R. Wellman[1], D.M. Snyder[1], K. Butler[4], J. Kirshtein[5], S.R. Poulson[6], J. Vaughn[2], and M. Stewart[7]

[1]U.S. Geological Survey, Portland, OR
[2]Watercourse Engineering Inc., Davis, CA
[3]U.S. Bureau of Reclamation, Klamath Falls, OR
[4]U.S. Geological Survey, National Research Program, Boulder, CO
[5]U.S. Geological Survey, National Research Program, Reston, VA
[6]University of Nevada, Reno, NV
[7]U.S. Geological Survey, Oregon Water Science Center, Central Point, OR

The 21-mile reach of the Klamath River from Link River to Keno Dam experiences poor water quality on a seasonal basis, manifested as high concentrations of algae and ammonia, elevated pH, and hypoxic to anoxic dissolved-oxygen conditions. Data from two seasons of sampling and experimental work have yielded insights into the dynamics and variation of water-quality and transport processes and have provided an improved basis for modeling. Weekly water samples, for example, quantified the timing and amount of *Aphanizomenon flos-aquae* that enters Link River from Upper Klamath Lake in summer. Hourly measurements from acoustic Doppler current profilers deployed in Lake Ewauna, just downstream of Link River, showed circulation patterns that are complex, responding to the river's bathymetry and the direction and magnitude of wind as well as inflows from Link River. Moving downstream, the imported algal biomass tended to decrease in concentration due to settling, grazing, and decomposition, whereas concentrations of ammonia tended to increase in summer.

In midsummer, the Klamath River can become hypoxic or anoxic for substantial reaches upstream of Keno Dam. Oxygen-demand experiments showed that decomposition of algal biomass consumes dissolved oxygen quickly, but a significant oxygen demand also is derived from the decomposition of dissolved organic matter. The rates of those oxygen-demanding processes are significant to the river's oxygen budget, and decomposition of dissolved organic matter exported from this reach is likely to be important downstream as well. Stable isotope studies were used to quantify the rate of dissolved oxygen production by algae, another important component of the oxygen budget. These data-collection efforts and experimental studies have resulted in a rich and diverse dataset that has greatly enhanced our understanding of instream processes in this reach of the Klamath River.

Bathymetry and a Model Grid for the Upper Klamath River, from Link River Dam to Keno Dam, Oregon

Sobieszczyk, S., and A.B. Sullivan, U.S. Geological Survey, Oregon Water Science Center, Portland, OR

Poor summer water-quality conditions in portions of the upper Klamath River have resulted in recent efforts to study and model streamflow and water-quality dynamics. Using the two-dimensional, laterally averaged CE-QUAL-W2 model, hydrodynamics and water quality have been simulated for the 21-mile stretch of the river between Link River and Keno Dams, just below Upper Klamath Lake near Klamath Falls, Oregon. In order to effectively model the river at various depths, bathymetric surveys on the river by J.C. Headwaters, Inc. and the Bureau of Reclamation were used to develop the model grid.

The bathymetric data was processed in geographic information systems (GIS) to produce the necessary grid inputs for the CE-QUAL-W2 model. Using GIS tools, the entire river reach was divided into 113 segments, each about 1,010 ft long. Because of the flow component of the model, the orientation of each segment was also derived. Each river segment represented the average volume of 10 equally spaced subsampled cross-sections between segment boundaries. These average segment cross-sections were divided into 1 foot high layers to allow simulation of vertical variation in the river channel. Producing a model grid that represented the river bathymetry was an important step in building a model that could accurately simulate hydrodynamics and water quality.

A Spatial Model for Predicting Unknown Populations of Oregon Spotted Frogs in the Klamath Basin

Groff, L.[1], S. Marks[1], and M. Hayes[2]

[1]Humboldt State University, Department of Biological Sciences, Arcata, CA
[2]Washington Department of Fish and Wildlife, Olympia, WA

The Oregon Spotted Frog (*Rana pretiosa*), endemic to the Pacific Northwest, was once considered widespread in complex warm water wetlands. Over 70 percent of historic populations are thought to be extirpated with range-wide habitat loss exceeding 90 percent. We developed a spatial model to elucidate the probable historic distribution of *Rana pretiosa* toward the southern end of its geographic range using Maxent software and ESRI Geographic Information System technology. This model was generated from two sets of spatial data, a set of occurrence points and a suite of environmental variables. Occurrences include all verifiable populations within the study area. The variable suite, used to characterize habitat associated with known populations, includes landcover, soil hydricity, slope, elevation and selected climatically derived variables. The final output from this model is a predictive map that identifies areas of suitable habitat. Importantly, suitability values from this output are continuous, allowing comparisons to be made between the suitability of different areas. Coupled with the National Wetlands Inventory, we intend to use this model to identify survey-deficient areas for this species, which are anticipated to occur primarily on private lands in the Klamath Basin of Oregon and the Pit River system of California. Most previous surveys of the southern range have focused on public land. Our aim is to survey areas that the model reveals as promising during the 2010 breeding season. Any previously unrecognized populations found, particularly near the species' range limit in California, would be important to its conservation.

Klamath Basin Conceptual Model – Water Quality and Aquatic System Management

Deas, M.L., and J. Vaughn, Watercourse Engineering, Inc., Davis, CA

Flow and water quality conditions in the Klamath River basin vary dramatically along the approximately 250 river miles from Upper Klamath Lake (UKL) to the Estuary at the Pacific Ocean. There are a wide range of natural and anthropogenic influences affecting water quality throughout the system: inflows to the system at Link Dam originate in hypereutrophic UKL; there are four major reservoirs on the mainstem Klamath River, two of which are operated as hydropower peaking facilities; diversions and return flows for agriculture, as well as municipal and industrial use, occur in the reach between Link Dam and Keno Dam; and the river receives considerable inflow from major and minor tributaries (each with unique natural and anthropogenic influences) between Iron Gate Dam and the Estuary.

Not only is the Klamath River System complex, it is also unique because water quality generally improves as water flows from headwaters towards the estuary; in most river systems water quality is highest at the source and degrades as water flows downstream. The water quality of UKL is seasonally impaired and has deteriorated at an accelerated rate over the last century due to anthropogenic activities. UKL is now hypereutrophic. A critical feature of hypereutrophic systems is that the eutrophication processes are typically irreversible. The result is that the quality of the water flowing from UKL is a principal “driver” that dictates seasonal water quality throughout the system. Further, the dynamic nature water quality conditions is an underappreciated factor in understanding and managing water quality in downstream river reaches. The influence of these highly variable seasonally discharges of large quantities of algae, nutrients, and organic matter on downstream river reaches can be dramatic. The characteristics (hydrology, geomorphology, tributary water quality, instream processes, etc.) of the various downstream river reaches affect the fate and transport of these materials. These water quality conditions have direct implications for other processes and functions in the river, including direct aquatic ecosystem affects (elevated pH, elevated temperature, potential ammonia toxicity, depressed dissolved oxygen), as well as indirect effects (primary production, support of fish disease organisms). Consideration and understanding of multiple processes and stressors, and their interactions both locally and at the basin scale, is critical to successful management and restoration of aquatic systems in the basin.

Fairy and Tadpole Shrimp of the Upper Klamath Basin: Hidden Diversity of Vernal Pools

Larson, R., and H. Ray, U.S. Fish and Wildlife Service, Klamath Falls, OR

Vernal pools are temporarily ponded wetlands endemic to regions with wet winters and dry summers, such as California, Australia, Chile, the Middle East, Spain, and Africa. These shallow wetland depressions have seasonally perched water tables above a shallow, impervious substratum. Although surveys of vernal pools have been completed in California, little is known about those in south-central Oregon. Vernal pools constitute distinct habitat sites within semi-arid landscapes and, therefore, play an important ecological role in southern Oregon. Fairy and tadpole shrimp (Branchiopoda) have inhabited temporary freshwater pools for hundreds of millions of years. They have few defense mechanisms and therefore, occupy temporary wetlands where many predators cannot survive. Branchiopod populations inhabiting temporary waters are declining worldwide. However, because of their temporary nature, vernal pools are frequently created and destroyed over time and are difficult to survey.

Raymond W. Coopey described the vernal pool fairy shrimp of southern Oregon in the early 1940’s; however, little has been done to survey them since. The purpose of this poster is to show how diverse the fauna of vernal pools is in our region. In 2009, we began to survey vernal pools in the upper Klamath Basin to document the diversity of fairy and tadpole shrimp. This effort is part of a larger assessment of the flora and fauna of vernal pools in the Klamath and Modoc Plateau ecoregions being undertaken by the Fish and Wildlife Service and Forest Service. Based on this preliminary work, we believe there are substantial numbers (likely in hundreds) of vernal pools in the upper basin. We plan to continue surveys in 2010.

Age-1 Sucker Habitat Use, Distribution, and Apparent Movement in Upper Klamath Lake, Oregon

Bottcher, J. and S. Burdick, U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR

Contrary to other life stages, little is known regarding age-1 Lost River and shortnose sucker habitat use and the influence of poor summer water quality on their distribution, movement, and survival within Upper Klamath Lake. Although significant juvenile sucker mortality occurs at dissolved oxygen (DO) concentrations below 1 mg/L, the effect large diel DO fluctuations have on juvenile sucker distribution is still unclear. Therefore, our goal was to assess seasonal changes in the distribution and abundance of age-1 Lost River and shortnose suckers as they relate to water quality and habitat composition. We collected juvenile suckers in fyke nets between April and September in 2007 and May and September in 2008 and recorded a variety of habitat parameters at each site, including water depth, substrate, and aquatic vegetation composition. We examined water quality from two monitoring stations, which encompass the range of conditions encountered within Upper Klamath Lake. Age-0 juvenile suckers were captured more frequently in relatively shallow water (1–3 m), whereas catches of age-1 suckers peaked in relatively deep water (4–7 m). Deep-water habitats decrease in Upper Klamath Lake as water levels recede throughout the summer. Differences in age-1 sucker catch rates among nearshore and offshore sites were minimal. Spatial-temporal patterns in catch rates of age-1 suckers suggest initial directed movement towards deep water areas along the western shore in late June and early July, followed by emigration away from these areas as DO concentrations dropped below 4 mg/L. From our results, it is unclear why age-1 suckers move to deep water habitats in late spring, but poor water quality events provide a likely explanation for their emigration from these areas in mid-summer. A distributional shift of age-1 suckers after mid-summer declines in water quality, followed by their near-disappearance in late-summer, suggests poor water quality may also affect overall survival.

Effects of a Poor Water Quality Event on the Distribution of Juvenile Suckers within the Williamson River Delta, Upper Klamath Lake, Oregon

Brown, D.T.[1], S.W. Wong[2], S.M. Burdick[1], and H.A. Hendrixson[2]

[1]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[2]The Nature Conservancy in Oregon, Klamath Falls, OR

The earth moving activities to reconnect the Williamson River Delta to Upper Klamath and Agency lakes by The Nature Conservancy in Oregon were completed in November 2008. Delta wetlands were probably used historically as rearing habitat by endangered juvenile Lost River (*Deltises luxatus*) and shortnose (*Chasmistes brevirostris*) suckers given their downstream location from known spawning areas. Prior studies determined that marsh-like habitats, such as those found in deltaic wetlands, are important rearing habitat for larval and juvenile suckers. A poor water quality event in the Williamson River Delta during late-summer 2008 produced conditions similar to those frequently observed during summer months in Upper Klamath Lake. This event provided an opportunity to examine the effects of water quality on spatial and temporal distributions of juvenile sucker catches in a smaller area. We compared water quality data to juvenile sucker catch rates in Agency Lake and within two distinct strata in the Williamson River Delta, deep water wetland and open water. We examined daily maximum pH levels and percentage of the day exceeding a suspected growth limiting stress threshold for dissolved oxygen (DO; 2 mg/L). Our results corroborated previous studies in Upper Klamath Lake that indicated low DO concentrations negatively affect catch rates of juvenile suckers to a greater extent than elevated pH. A decline in juvenile catch rates to zero in the deep water stratum was correlated with the percentage of the day exceeding the DO stress threshold. As catch rates in the deep water strata declined, juvenile sucker catch rates increased from 0.22 to 1.5 fish per net in Agency Lake and from 0.17 to 2.0 fish per net in open water where DO concentrations were rarely below 2 mg/L. As water quality recovered and DO concentrations below 2 mg/L did not occur during a 24 hour period in any strata, Agency Lake catches decreased while catches increased in open water and deep water wetland suggesting a redistribution of suckers to the delta strata. We believe this indicates that the newly reconnected Williamson River Delta provides potentially attractive habitat for juvenile suckers, but extreme water quality events may play an important role in the distribution of juvenile sucker catches.

Hydrologic Monitoring and Trends in the Upper Klamath Basin Over the Last Decade

La Marche, J.L., E.B. Gates, and K.E. Lite Jr., Oregon Water Resources Department, Bend, OR

Over the last decade hydrologic monitoring efforts in the Upper Klamath Basin (UKB) of Oregon have increased in response to the continued strain on surface water and groundwater to meet competing biological and agricultural demands. The Oregon Water Resources Department (OWRD) increased its stream gaging network from three to ten gages, and approximately 80 long-term sites were added to the OWRD and U.S. Geological Survey (USGS) well monitoring network to track both anthropogenic and climate related stresses to the hydrologic system. The expanded monitoring effort accompanied several hydrologic studies to better understand the basin hydrology. A major result of the hydrologic investigations was to quantify groundwater/surface water interactions in the UKB (e.g., Gannett, et. al. 2007). For example, the estimated gross groundwater discharge in UKB is roughly 2,600 cubic feet per second ft^3/s, of which 1,800 ft^3/s occurs into or above Upper Klamath Lake—approximately 70 percent of the lakes' gross annual inflow.

Data collected over the last 10 years demonstrate that dry climate conditions persist in the UKB. Recorded precipitation at Crater Lake reveals below normal precipitation in eight of the last ten years. Although near normal precipitation has occurred in the last few years, this trend has only halted not reversed the decadal decline in summer baseflows and groundwater levels at most monitoring locations above Upper Klamath Lake (UKL). The trends in stream baseflows generally follow groundwater levels observed in nearby wells. Most monitoring locations reflect hydrologic lows similar to the droughts of 1992 and 1994. USGS stream gages operated on the lower Sprague and Williamson Rivers reflect baseflows similar to those encountered during the drought of the late 1930s and early 1940s.

Below UKL, anthropogenic stresses are more prominent than climate influences on streamflow and groundwater. Streamflow below Link River Dam is entirely regulated. Groundwater monitoring shows the added pumping stresses from expanded use since 2001 have locally produced 10 to 15 feet of decline in the Klamath Valley and Tule Lake sub basin. The increased groundwater pumping has also resulted in a greater amount of seasonal fluctuation.

Current-Use Pesticides in the Klamath River Basin

Kuivila, K., and J. Orlando, U.S. Geological Survey, California Water Science Center, Sacramento, CA

Current-use pesticides and their degradates present in the Klamath River ecosystem may pose risks to aquatic organisms through direct exposure in water and sediments, and could affect human health through multiple indirect pathways. A wide variety of pesticides are applied in agriculture and forestry in the Klamath River Basin watershed. These pesticides can be transported off-site and into surface waters via rainfall-runoff, irrigation-return flows, and atmospheric drift. The result is a complex mixture of current-use pesticides and degradates in various environmental compartments (water, sediments, biota, and plants). Inhabitants of the area, particularly the Tribes, are concerned with pesticide residues in their water, food, and plant materials. Mixtures of pesticides in the ecosystem may cause adverse effects on key aquatic species and hinder the reintroduction and recovery of salmonids. Possible removal of dams will allow the transport of sediments and associated pesticides into the downstream ecosystem.

The California Water Science Center has been studying the occurrence, transport, and bioavailability of current-use pesticides in aquatic ecosystems across the Nation for two decades. With our current analytical methods, nearly one hundred pesticides and degradates can be measured in water and sediments. Since moderately-hydrophobic pesticides can bioconcentrate in organisms, methods have been developed to analyze pesticides in crab embryos and fish tissue. In ongoing studies in other locations, pesticide concentrations in water, sediments, and tissue are being measured concurrently with measurements of biological effects on fish and crabs. In addition, methods are being developed to analyze pesticides in plant tissue. This comprehensive analytical approach can be used to characterize the occurrence and fate of current-use pesticides and degradates in the Klamath River ecosystem and observe the effects of changes in the watershed.

Monitoring Groundwater Fluctuations in the Upper Klamath Lake Basin

Polette, D., and M. Gannett, U.S. Geological Survey, Oregon Water Science Center, Portland, OR

The U.S. Geological Survey (USGS) has been mapping water-table elevations and monitoring groundwater fluctuation in the upper Klamath Lake Basin cooperatively with the Oregon Water Resources Department (OWRD) since 1999. This monitoring was born out of an interest to quantitatively characterizing the regional groundwater flow system and to develop a computer model to simulate the regional groundwater flow to help understand the resource and test management scenarios. It continues today as management questions and water-use patterns have evolved.

Monitoring began with the mapping of the hydraulic head distribution in the upper Klamath Basin which relied on water-level measurements from approximately 1,000 field-located water wells in the more populated areas of the basin and the location of springs and gaining reach streams in the less populated areas of the basin.

A subset of just over 100 of the field-located wells was then identified as key wells representing major parts of the system including: recharge areas, discharge areas, different geologic settings, and principal pumping areas. The water-levels in these wells were then monitored to track changes resulting from the effects of pumping, climate, lake-stage variation, and canal operation. The network is reviewed periodically and it's scale, location, and frequency is modified as needed in response to changes in pumping and climate patterns and to accommodate the resulting resource-management questions that arise. Currently, there are 51 USGS sites in the network, seven of which are continuous-recorder sites and the rest are measured quarterly throughout each year.

Monitoring includes the quarterly manual observation of water-levels in most of the wells and the two-hour interval electronic sensing and recording of water-levels in some of the wells where more detail is necessary and/or seasonal access is prohibitive. These data are collected using established USGS water-level measurement protocols for the methods of both manual observation including steel tapes, electric tapes, pressure gages, manometers; and also for the methods of continuous recorder observation including both float and pressure transducer sensor-based systems. This equipment is routinely calibrated to ensure the consistency and the quality of the data. These data are then processed into the USGS's National Water Information System (NWIS) for archiving and are readily available on either the project website, national NWIS website, or the USGS Groundwater Networks website. Data from 20 additional wells monitored quarterly by OWRD in the upper Lost River subbasin have also been entered into NWIS. Not all of the data collected by OWRD in the entire upper Klamath Basin are in NWIS. Intentions are to pursue including additional OWRD data into the USGS system so as complete a picture as possible of the state of the regional groundwater system in the upper Klamath Basin can be obtained from a single source.

Strategic Habitat Conservation: An Integrated, Landscape-level Approach to Conservation Science in the Klamath Basin

Athearn, N., P. Golightly, and M. Cunanan, U.S. Fish and Wildlife Service, Arcata, CA

The Klamath River Basin (Basin) spans 40,790 square kilometers and encompasses a diversity of habitats for sensitive species. This watershed supports a complex ecosystem, including many State or federally listed species which often have conflicting habitat and management needs. Several Federal agencies as well as Tribes, universities, the States of Oregon and California, and other groups have worked to address species conservation and human resource needs in the Basin, and have contributed strongly to our collective understanding of science in the Basin. However, the scope and Basin-wide relevance of these independent efforts could be improved through a synergistic strategy focused on interdisciplinary teamwork and Basin-wide targets. The introduction of the Klamath Basin Restoration Agreement, along with the latest predictions and challenges of climate change, reveal that large-scale habitat changes within the Basin are likely, thus an integrated and strategic approach to conservation and restoration throughout the Basin is more urgent than ever. Strategic Habitat Conservation (SHC) is an approach developed by the U.S. Fish and Wildlife Service (USFWS) and U.S. Geological Survey using principles of conservation biology and landscape ecology to organize conservation strategies on a regional scale. Landscape Conservation Cooperatives, described by USFWS in their Climate Change Strategic and Action Plans, are conservation-science partnerships between agencies, organizations, Native American Tribes, and community members developed to provide and share applied science using SHC as a methodology within a geographic framework. Within the Basin, these strategies are being developed to help us address conservation challenges, many of them unknown, that may result from large-scale restoration efforts and from climate change.

Canal Flow Monitoring and Assessment at Selected Sites in the Upper Klamath Basin

Stewart, M.A.[1], and J.M. Cameron[2]

[1]U.S. Geological Survey, Central Point, OR
[2]U.S. Bureau of Reclamation, Klamath Falls, OR

The use of slope gages has proven to be an inadequate method for delivering accurate discharge values in many of the Klamath Basin’s canal monitoring locations due to low gradients and variable backwater. Acoustic Doppler Velocity Meters (ADVMs) installed in the canals for the Bureau of Reclamation have the capability to provide reliable information on the transport and quantity of flow in the canals. The ADVMs, when calibrated, provided a surrogate for mean channel velocity. The calibrated mean channel velocity multiplied by the channel cross-sectional area can, with ongoing QA/QC, provide an adequate, continuous, real-time record of discharge.

From March 2008 until present, Reclamation and the USGS have cooperated on measuring flow volume and developing QA/QC guidelines for the seven sites listed below. The methods, initial calibrations results, and data summaries for the sites will be presented and discussed. This cooperative work will improve the long term understanding of the quantity and transport of channelized flow in the basin.

Discharge measurement sites:

1. 11509105 North Canal at Highway 97, near Midland
2. 11509340 Klamath Straits Drain near Worden
3. 11509200 ADY Canal at Highway 97, near Worden
4. 11486900 Wilson River/Lost River Diversion entrance
5. 11486400 C canal Below C-G cutoff at Henley at (KID)
6. (Station Number Not assigned) Oregon Drain at State Line Road
7. 11486900 Lost River Diversion near Henley

Yurok Tribal Fisheries Program Green Sturgeon Studies

McCovey, B. Jr., Yurok Tribal Fisheries Program, Klamath River Division, Hoopa, CA

To the Yurok Tribe, green sturgeon are considered sacred and these large fish are an extremely valuable source of food. The Yurok people have lived along the banks of the Klamath River for millennia, subsisting on the Klamath's once abundant runs of anadromous fish. Water quality and water quantity issues have led to the large scale declines Klamath River salmonids and the status of green sturgeon populations are not known. The Yurok Tribe is concerned that declines in green sturgeon numbers may be eminent, and therefore initiated a long term study intended to gather as much information on these revered fish as possible.

From 2002 to 2005 the Yurok Tribal Fisheries Program (YTFP) captured and tagged 56 adult green sturgeon in the Klamath and Trinity Rivers. In 2002 and 2003 we used radio telemetry and focused our study on in-river movements and migrations of green sturgeon. Studies conducted in 2004 and 2005 also examined in-river movements, however in these years we used acoustic telemetry which allowed us to focus our study on where green sturgeon go after emigrating from the Klamath River. Green sturgeon from all four study years were internally tagged with either radio or acoustic transmitters, or both. The acoustic transmitters used in 2004 and 2005 had a life expectancy of up to five years, so it is possible that many are still operational. Since 2002, the YTFP has deployed acoustic monitoring receivers throughout the lower Klamath, Trinity, and Salmon Rivers in order to track the movements of any returning green sturgeon tagged in the Klamath River. Numerous green sturgeon have also been tagged at various locations in California, Oregon, and Washington, and our receivers will detect any of these fish if they enter the Klamath River. In 2006, 2007, and 2008 we deployed a small receiver array in the Pacific Ocean approximately one kilometer off the mouth of the Klamath River. This array has detected numerous green sturgeon from all tagging locations. This poster summarizes some of the major results our green sturgeon study has uncovered.

Yurok Tribal Fisheries Program Pacific Lamprey Studies

McCovey, B. Jr., Yurok Tribal Fisheries Program, Klamath River Division, Hoopa, CA

The Yurok people have called northwestern California home since time immemorial. Yurok territory lies along the banks of the Klamath River and shores of the Pacific Ocean. The abundance of the river and ocean has provided a wealth of subsistence resources to the Yurok people. One of the most important and overlooked subsistence foods to the Yurok is the Pacific Lamprey. The Yurok people capture and consume lamprey in a variety of ways, however there is little scientific knowledge concerning lamprey in the Klamath River. There is no quantitative data on historical abundance or distribution specific to the Klamath River watershed, but anecdotal evidence suggests that Pacific lamprey abundance has been in decline since the late 1980's. Presently few efforts have been made to identify causative factors for this decline. In 2006 and 2007 the Yurok Tribal Fisheries Program conducted a pair of pilot studies that could help to answer some of the critical unknowns related to these revered creatures. This poster summarizes the results of these two pilot studies and illustrates some of the cultural aspects concerning the Pacific lamprey and the Yurok Tribe.

Salmon River TMDL Implementation

Cressey, L., Salmon River Restoration Council, Sawyers Bar, CA

The Salmon River Total Maximum Daily Load (TMDL) for Temperature and Implementation Plan was adopted by the North Coast Regional Water Quality Control Board in 2005. We will look at steps being taken by the Salmon River Restoration Council to implement the TMDL, including riparian assessment/restoration and thermal refugia assessment/restoration.

Modeling Wind on Upper Klamath Lake, Oregon

Buccola, N., and T.M. Wood, U.S. Geological Survey, Oregon Water Science Center, Portland, OR

A hydrodynamic and heat transport model developed by the USGS is being used to determine the travel times and pathways of larval Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers throughout the newly restored Williamson River Delta in Upper Klamath Lake (UKL) through numerical experiments. Larval fish density (concentration) is computed as a function of Williamson River inflow, Link River outflow, lake elevation, and meteorological conditions. Due to the shallow depth of UKL, wind speed and direction are vital forcing factors in determining currents, and thus the spatial distribution of larval suckers within the lake. Measured data from six land-based meteorological stations exists continuously year-round, while the critical mid-lake data from two raft-deployed meteorological stations are available only during late spring and summer months. The critical period for modeling the transport of larval suckers is early spring, a time when data from the rafts is not generally available. A separate wind model is being developed to fill data gaps and create a continuous year-round record of raft data based on statistical relationships to continuous land-based meteorological data. Two model frameworks, Neural Networks and Multivariate Adaptive Regression Splines, are employed and compared with varying degrees of success. The most successful models incorporated time-lagged wind speed, wind direction, and air temperature data as input variables. A similar model is being used to recreate weekly wind conditions at UKL extending back to 2000 to produce a "library" of wind-forcing conditions. This "library" will aid in modeling environmental and reservoir management scenarios, based on the range of forcing conditions that have occurred in the past.

Using Remote PIT Tag Readers to Understand Movements and Habitat Use by Coho Salmon Oncorhynchus kisutch in the Klamath River Corridor

Corum, R.A., Karuk Fisheries, Orleans, CA

Little is known about movements and habitat utilization by juvenile coho salmon *Oncorhynchus Kisutch* in the Klamath River Corridor during their freshwater residence. The Klamath mainstem corridor consists of the mainstem river and associated habitats, as well as the lower reaches of tributary streams. Karuk Fisheries and cooperators have been involved in studies using PIT tags and other marks to understand year-round movement and habitat use by juvenile coho salmon in the Klamath River Corridor since 2006. In October 2008, remote PIT tag detection systems were constructed and deployed at two sites to provide capture points for tagged fish. A multiplexing PIT tag reader and six antennas were deployed at two locations representing different habitats. One habitat was a side-channel pool that was fed by a tributary, and the other was a mainstem backwater at the top of a side-channel. Systems were successful at collecting data on tagged fish around the clock at both sites. Habitat use varied seasonally and by type.

Assessment of Fire Impacted Klamath Tributaries (2007–2008 Fires): Observations and Management Recommendations

Harling, W., and N. Bailey, Mid Klamath Watershed Council, Orleans, CA

During the summer of 2008, the Klamath River experienced one of the longest and largest fire seasons in recorded history. Over 210,000 acres burned in the watershed this year. This is in addition to the 2007 Elk Complex fires near Happy Camp which burned 17,684 acres. Fire intensity mapping of the 2007 and 2008 fires indicate that many of the perennial streams in the wildfire areas were burned hot enough to lose riparian vegetation and destabilize hydrologically connected slopes. These streams are important cold-water contributors to the Klamath system, and are essential to anadromous fishery survival.

Through funding from the Bella Vista Foundation, MKWC (in collaboration with the US Forest Service) assessed and identified restoration actions in several Mid Klamath Tributaries severely impacted by the 2007 and 2008 fires. Objectives were to (1) prevent erosion and sediment delivery in sediment loaded streams, (2) revegetate riparian areas using native species, (3) treat identified barriers to fish passage, (4) monitor survival of plantings and effectiveness of erosion control structures, and (5) explore future opportunities for implementing identified riparian restoration actions following wildfires.

Tributaries addressed by this project provide either spawning (natal), non-natal, or refugial habitat for threatened Coho salmon and other salmonids. Assessments were completed on Bear Creek, Buckhorn Creek, Stanza Creek, Elk Creek, Johnson Creek, Cub Creek, Copper Creek, Burney Valley Creek, and Independence Creek. Implementation of directional felling augmented with manual placement of small woody debris to create erosion control structures occurred on a tributary to Bear Creek.

Endangered Lost River and Shortnose Suckers in Lake Ewauna and use of the Link River Dam Fish Ladder, Oregon

Braham, M., and A. Wilkens, U.S. Bureau of Reclamation, Klamath Basin Area Office, Klamath Falls, OR

Passive Integrated Transponder (PIT) tags were used to investigate endangered adult Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris* use of the Link River fish ladder to return to Upper Klamath Lake, Oregon. Suckers were tagged in Lake Ewauna throughout the late winter and early spring of 2008 and 2009. Trammel nets were set one hour before sunrise and retrieved after four hours of fishing. Using a stratified random sampling technique, in 2008, we found the suckers tended to use the northern end of Lake Ewauna in late March to early May. In 2009, we utilized this information to target our sampling and maximize catches. In 2008, we PIT tagged 126 suckers of which 63 percent were shortnose and 14 percent were Lost River. In 2009 we PIT tagged 519 suckers of which 72 percent were shortnose and 13 percent were Lost River. Eighteen percent of the 2009 tagged suckers were recaptured in 2009 and 11 percent of the 2008 tagged suckers were recaptured in 2009. This study is in collaboration with the U.S. Geological Survey's (USGS) Klamath Falls Field Station. USGS is monitoring sucker movements through the Link River Dam fish ladder using four fixed underwater PIT tag antennas arranged throughout the ladder. In 2009, USGS detected 16 suckers using the fish ladder; 15 were from our 2008 and 2009 Lake Ewauna PIT tagging efforts. Three of the 16 suckers were later detected at other USGS monitoring sites in the upper reaches of Upper Klamath Lake. This study will provide information on the degree of connectivity between Upper Klamath Lake and Lake Ewauna suckers, and lead to refined operational procedures for the Link River Dam fish ladder. Although Lake Ewauna is considered unsuitable for suckers, this study suggests they may be able to survive in numbers.

Salmon River Spring Chinook Status (Modeling for Recovery)

Hotaling, T., and P. Brucker, Salmon River Restoration Council, Sawyers Bar, CA

Among the native aquatic species at risk in the Klamath basin, spring run Chinook salmon are viewed as an emblematic species, particularly by the Native American Tribes, requiring protection and restoration in order to adapt to climate change. The Salmon River spring-run Chinook demonstrate a stream-type life history strategy, where juveniles remain at least a year in freshwater before entering the ocean (Healey 1991), and therefore require coldwater-river conditions like those found in the coldwater system of the Salmon River. This life history requires suitable winter rearing habitats, commonly found in off-channel reaches, wetlands and estuary environments. Cooperative assessment, planning, implementation and monitoring efforts to promote the recovery of the spring-run Chinook in the Salmon River and Klamath Basin have been underway and articulated in the SRRC poster.

Reconnecting historic habitats in the Klamath and its tributaries is necessary for long term persistence of these fish (Moyle 2008). Salmon River spring-run Chinook stocks demonstrate a unique life history, fundamental to the ecosystem of the Klamath basin. It is a population that (1) is substantially reproductively isolated from con-specific populations and (2) represents an important component of the evolutionary legacy of the species. The near extirpation of Spring Chinook in the Klamath River basin indicates potential future problems for other anadromous stocks that rely on freshwater habitats during the juvenile and adult life histories (Moyle 2008). Spring run Chinook are listed by the US Forest Service as a Sensitive Species in the Klamath National Forest.

Spring run Chinook are distinct from fall run Chinook in that adult spring Chinook enter fresh water in spring and early summer, before their gonads are fully developed and hold in cold water areas for 2–4 months before spawning. Because of this unique life history trait spring run Chinook spawn in the upper reaches and tributaries of their native watersheds. Spring Chinook were once found throughout the Klamath Basin. Passage of spring Chinook into their historical range was blocked below Klamath Falls in 1895 by construction of Copco 1 Dam, and on the Shasta River with the construction of Dwinell Dam (Hamilton et al. 2005, Moyle 2008). Historically, they were especially abundant in the major tributary basins of the Klamath and Trinity Rivers, such as the Salmon, Scott, Shasta, South Fork and North Fork Trinity Rivers. Due to a legacy of human impacts (i.e. dams, mining, logging, and overfishing), today, only the Salmon River and its two forks maintain a viable population (Moyle 2008).

Approximately 177 km of habitat is accessible to spring Chinook in the Salmon River (West 1991) but most of it is underutilized or unsuitable. With the imminent removal of 4 Klamath River Dams, and restoration of the upper Klamath River Basin, spring run Chinook may be restored to other parts of their historic range, in the Spraque, Wood, and Williamson Rivers. The Salmon River spring-run Chinook stock are a likely source population for reintroduction in the current PacifiCorp hydro-electric project area and above Upper Klamath Lake.

Salmon River Community Restoration Program 1992-2010

Brucker, P., and T. Hotaling, Salmon River Restoration Council, Sawyers Bar, CA

The Salmon River Restoration Council (SRRC) was formed in 1992 and was provided support by the Klamath Basin Fisheries Task Force between 1993–2006. The SRRC has served as the lead entity in the Salmon River subbasin in the effort to enlist cooperation amongst the stakeholders to create a watershed restoration program, highlighting the anadromous fisheries resources. The SRRC's efforts were spawned by a successful Poaching Prevention Program, which was embraced by the local community starting in 1992, and highlighted the protection of spring-run Chinook and summer steelhead. The SRRC, through its educational approach, has been recognized as reducing the poaching of these species in the Salmon River by over 90 percent.

The SRRC initiated the Community Restoration Program (CRP) in 1993. Through the CRP, the SRRC has planned and sponsored an annual series of ecosystem awareness workshops to increase stakeholder awareness for the Salmon River conditions and needs. These workshops are often accompanied by volunteer workdays, which provide the opportunity for stakeholders to apply learned restoration techniques needed to promote salmonid species recovery. Through the CRP, the SRRC has held over 1,000 scheduled workshops and/or workdays that have involved over 100,000 hours of in-kind contribution, largely from the local community members. Since 1993, the SRRC has administered over $5,000,000 in fisheries/wateshed restoration activities in the Salmon River, with almost $2,000,000 provided by the SRRC as in-kind contribution.

In 1994 the SRRC adopted its first annual Work Plan for the CRP, which created an overview of conditions and needs for anadromous fisheries in the Salmon River and identified projects for the community to address these needs. The annually updated and adopted CRP Plan has helped to guide efforts for the community to help address factors that limit Salmon River salmonids.

In 2002 the SRRC and the US Forest Service completed the Salmon River Subbasin Restoration Strategy (Strategy), which assessed the anadromous fisheries resource conditions for the Salmon River and developed an "Action Matrix" to best address the limiting factors for the existing species. The SRRC and its partners utilize this Strategy, which incorporates the CRP Plan, and tiers to the Klamath and Six Rivers Land and Resource Management Plans, adopted by the U.S. Forest Service in 2005. The

SRRC assisted in the North Coast Regional Quality Control Board's (Board) Total Maximum Daily Load (TMDL) process for water temperature in the Salmon River. This assessment was completed in 2005. The Board adopted the Strategy as the Salmon River TMDL Implementation Plan.

The SRRC and its partners have utilized the Strategy to guide prioritized watershed restoration and fisheries protection in the Salmon River. To address the multiple needs of salmonids, the SRRC has created nine Programs to help focus cooperator attention on specific areas. Each year the Program Coordinators develop annual work plans that are used to coordinate with our cooperators. The Program Areas include: Fisheries Management; Watershed Monitoring; Watershed Education; Roads Management; Fire, Fuels, and Forestry; Invasive Species Control; Riparian Habitat Assessment and Restoration; River-Clean Up; and Maintaining the Watershed Center.

A Review of Assessment/Manual Improvement of Salmonid Fish Passage on Klamath River Tributaries (2006–2008)

Harling, W.[1], T. Soto[2], and C. Wickman[1]

[1]Mid Klamath Watershed Council, Orleans, CA
[2]Karuk Tribe Fisheries Department, Orleans, CA

Thermal refugia are physically and biologically complex environments. Their ultimate size (volume: vertical, lateral, and longitudinal dimensions and characteristics) is generally a function of mainstem and tributary flows and velocity distribution, geomorphology, meteorology, and temperature. These habitats are not stable. Year-to-year variability in hydrological and meteorological conditions can lead to variable channel morphologies, seasonal flow, and temperature response. Because thermal refugia are relatively small in comparison to mainstem regions, changes in flow regime can potentially impact their size. A long-term warming trend has been identified in the Klamath River. Dams and diversions have significantly reduced and degraded habitat. Salmonids disease rates have increased. Coho salmon have been listed as threatened (less than 10 percent historic abundance). Coho are less tolerant of higher temperatures than Chinook or steelhead. Wild Spring Chinook, once the dominant run in the Klamath with annual returns over 800,000, have been reduced to relictual populations in the Salmon River and SF Trinity. Climate change in the southern range of salmon country could further stress threatened Klamath fish populations.

Objectives

- Monitor tributaries in the Mid Klamath, Scott and Salmon River subbasins for blockages to juvenile and adult fish passage from May to November.
- Improve juvenile and adult salmonid fish passage to tributaries in the Middle Klamath, Salmon and Lower Scott River subbasins through manual modification of seasonal barriers (over 200 miles of anadromous habitat).
- Report findings to increase understanding of alluvial fish passage issues in the Middle Klamath, Salmon and lower Scott Rivers.
- Educate local residents on techniques for maintaining fish passage at nearby creeks through involvement in volunteer workdays.

Methods

From May-July, we focus on streams that provide natal and non-natal habitat to juvenile salmonids, in particular threatened coho salmon. From August-November the focus shifts to providing access to adult Fall Chinook, coho, and steelhead. It is critical to maintain connectivity to high quality off-channel pond habitats year-round. Examples of barriers include swimmer's dams, bedrock/boulder cascades, alluvial sills/low flow barriers, culverts/road crossings, and log jams and beaver dams. Monitoring included collaborative biological sampling with Karuk Tribe Fisheries Department, Six Rivers National Forest, and Klamath National Forest. Dive sampling occurred before and after treatments. We also tracked changes in stream gradient, velocity, and pool depth on treated sections. Redd surveys occurred during the fall and winter.

Results and Summary

- Boise Creek: 10 Fall Chinook redds in 2008…no redds since 2006 flood event.
- Sandy Bar Creek: Ongoing PIT Tag study in 2008 showed juvenile coho began moving into off-channel ponds immediately after fishway was constructed at the mouth.
- Portuguese Creek: Fall Chinook juveniles found 0.5 miles up creek after cascade at mouth was treated.
- SF Clear Creek: 1.6 added miles of coho habitat. Estimated 4,000+ juvenile coho counted above the logjam the year after it was removed.

Manual fish passage work on Klamath River tributaries is a viable, low cost method for significantly increasing access to high quality salmonid habitat at critical life history stages. Until larger fixes such as dam removal and restored in-stream flows occur, access to suitable habitat can help maintain viable populations of threatened Klamath salmon. Example of adaptive management based on recent Klamath River thermal refugia studies. Stakeholder involvement is key to the continued success of this work.

Water Supply and Quality Issues Related to Groundwater-Surface Water Interaction in the Upper Lost River Subbasin, Klamath County, Oregon

Grondin, G.H., Groundwater Section, Oregon Water Resources Department, Salem, OR

Most groundwater discharge within the 920-square mile, Upper Lost River subbasin east of Klamath Falls, Oregon occurs at fault related valley springs. These spring complexes are subject to reduced flow due to groundwater development, and under certain conditions, are avenues for groundwater contamination through flow reversals.

The geologic environment is complex. Northwest trending Basin and Range fault-block mountains separate four interconnected valleys. Basalt occurs throughout the subbasin as multiple layers with some sedimentary interbeds. The basalt depositional environments range from subaerial, to some interaction with water, to submerged. Basalt is exposed mostly in the uplands and at mid-valley buttes, and it is buried in the valleys beneath lacustrine, fluvial, and volcaniclastic sediments. The sedimentary unit can contain basalt dikes, sills, and flows. This basin fill can range in thickness from a few feet to hundreds of feet. Some basalt and sedimentary units show evidence of hydrothermal alteration or secondary mineralization that followed deposition.

Groundwater occurs in both the basalt and basin fill sediments. Sufficient hydraulic connection exists between water bearing zones within the basalt units and within the basin fill units to allow lumping each as undifferentiated basalt and undifferentiated sediments. While groundwater in the basalt and the overlying basin fill is generally hydraulically interconnected, the units have very different hydraulic properties. The most productive wells obtain groundwater from basalt.

Groundwater in the basalt generally flows toward the valleys from the surrounding uplands and then flows down valley toward or parallel to the Lost River. Recharge occurs locally in both the uplands and valleys. Most discharge occurs at fault-related valley springs within or near the Lost River, most notably at Bonanza Big Springs adjacent to the Town of Bonanza. Limited groundwater discharge occurs through the basin fill and through stratigraphically controlled springs above the valley floors. Additionally, some groundwater discharge occurs at fault controlled hot springs within the subbasin.

The interconnection between groundwater in basalt and fault-related valley springs in south Langell Valley, Bonanza, and west Poe Valley is highly efficient and problematic. When groundwater use increases, spring levels and flows decrease. Calls for regulation to maintain senior surface water rights have occurred, and new groundwater rights have been denied. Where the springs occur adjacent to or within the Lost River channel, reverse flow through the springs can contaminate local groundwater depending on the stage relationship between groundwater and surface water. In Bonanza, a seasonally impounded river pool inundates Bonanza Big Springs and periodically backflows to groundwater when adverse climate, groundwater use, and river management conditions converge. The backflow has historically caused contamination of nearby domestic wells and interference with surface water rights. Under a 2006 settlement, post 1990 groundwater rights utilizing wells connected to the springs must shut off when groundwater levels are less than 0.5 feet above the river level. The neighboring irrigation district now voluntarily manages the river pool to keep it more than 0.5 feet below the groundwater level.

Two Cyanophages Capable of Lysing Microcystis from Klamath River

Dreher, T.W., N.M. Brown, E. Riscoe, and C.S. Bozarth, Department of Microbiology, Oregon State University, Corvallis, OR

For the last several years, Copco Reservoir has suffered from highly toxic blooms of the cyanobacterium *Microcystis aeruginosa*. With a view to examining the role of virus infection in *Microcystis* population dynamics, we have embarked on a search for cyanophages in this reservoir. We have isolated two Microcystis-infecting cyanophages from water samples taken from Copco Reservoir in September 2008. One virus is able to amplify in and lyse cells of *Microcystis aeruginosa* UTEX LB2386. This virus is a myophage with a double-stranded DNA genome 179 kbp in length. The entire genome has been sequenced, revealing similarities to the photosynthetic phages of marine cyanobacteria. The second virus is able to amplify in and lyse cells of an isolate of toxigenic *Microcystis* cultured from Upper Klamath Lake. The genome of this virus is dsDNA 60.5 kbp in length. Its genome has also been entirely sequenced, identifying it as a siphophage with many previously unrecognized genes. Information on the distribution of these viruses in the Klamath Basin will be presented.

Variability of Water Quality Dynamics and Cyanotoxins in Upper Klamath Lake, Oregon

Kannarr, K.E.[1], S.L. Caldwell Eldridge[1], T.M. Wood[2], K.R. Echols[3], B.H. Rosen[4], S.M. Burdick[1], C.A. Ottinger[5], and S.P. VanderKooi[1]

[1]U.S. Geological Survey, Klamath Falls Field Station, Klamath Falls, OR
[2]U.S. Geological Survey, Oregon Water Science Center, Portland, OR
[3]U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO
[4]U.S. Geological Survey, Florida Integrated Science Center, Orlando, FL
[5]U.S .Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, Kearneysville, WV

Seasonal phytoplankton blooms in Upper Klamath Lake, Oregon, frequently cause extreme water-quality conditions characterized by high pH, widely fluctuating concentrations of dissolved oxygen, and high levels of un-ionized ammonia, which contribute to the overall decline in populations of endangered Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers. In addition, preliminary work by the U.S. Geological Survey (USGS) and others has shown that cyanobacteria, primarily *Microcystis aeruginosa*, produce microcystins in the lake at concentrations that may be detrimental to the suckers. From June to October, 2009, the USGS collected weekly vertical measurements of *in situ* phycocyanin, dissolved oxygen, temperature, pH, and specific conductance at 5 sites in Upper Klamath Lake. These profile data provide a means to quantify the spatial variability of cyanobacteria throughout the lake and model the behavior of buoyant cells in the water column. The variation in temperature with depth shows that surface cell accumulation depends on the degree of thermal stratification and the depth of the upper mixed layer. Dissolved oxygen profiles show elevated concentrations produced during photosynthesis near the water surface and a high oxygen demand in bottom sediments. Where the lake becomes thermally stratified, these data also show minimum dissolved oxygen concentrations below the surface layer, indicating a sub-surface maximum in gross oxygen demand. In contrast, vertical profile data show that during peak concentrations of dissolved microcystins, the water column was mixed, overall temperature decreased, and concentrations of dissolved oxygen were generally low. Also during this time, levels of chlorophyll *a* (a surrogate measurement of phytoplankton biomass, composed mostly of *Aphanizomenon flos-aquae* in Upper Klamath Lake) were low and dissolved nutrient concentrations were high. Taken together, these observations suggest that microcystins produced by *M. aeruginosa* are released from lysed cells following the rapid decline in the *A. flos-aquae* bloom after extended periods of high productivity near the surface of thermally stratified lake water. Whether populations of *M. aeruginosa* and therefore, microcystin concentrations, increase as conditions become less favorable for the *A. flos-aquae* bloom is currently under investigation.

Aging Western Pond Turtles (*Actinemys marmorata*) Using Annuli Counts: Considering Growth During the Active Season to Accurately Reflect Individual Ages

Ashton, D.T.[1], J.B. Bettaso[2], and H.H. Welsh, Jr.[1]

[1]U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA
[2]U.S. Fish and Wildlife Service, Arcata Office, Arcata, CA

The western pond turtle (*Actinemys marmorata*) is a freshwater turtle of the western United States that shares many life history parameters with other freshwater turtles worldwide; they are long-lived, age at maturity is later in life, and larger females can produce larger clutches. To understand life-history traits accurately, biologists need to consider the timing of their encounters with species exhibiting plasticity in traits such as annual deposition of growth rings. We surveyed two populations on western pond turtles, one on the mainstem Trinity River and one on the South Fork Trinity River over three summers using mark-recapture to estimate population parameters. We photographed most turtles encounter with two to four photos (Carapace, Plastron, Plastron Length, and Age Photo). Our mark-recapture data indicated that some animals caught late in one season would be assigned the same age as if captured early in the following season, and if captured again 30 or more days later in that same field season. We verified our aging records with close scrutiny of photos to determine when turtles started to put on growth for each season. We consistently saw no new growth in earlier captures compared to those captured after the first of July. This is consistent with the hypothesis that as turtles coming out of over-wintering hibernation must allocate resources for replacement and maintenance before allocating energy to growth. We caution biologist working with this species to consider the age of turtles by factoring in when the animal is captured and not assuming that plastron annuli represent the age of the animal for that field season when encountered early in the active season.

Scott River Water Trust: A Cooperative Water Solution

Sommarstrom, S., Scott River Water Trust, Etna, CA

The Scott River and its major tributaries support important runs of Chinook salmon, coho salmon, and steelhead trout. Low water levels in the streams may limit suitable over-summering habitat for juvenile coho and steelhead during the late summer and prevent adult Chinook and coho salmon from getting upriver to prime spawning areas in Scott Valley during the fall months. In 2007, the Scott River Water Trust began to lease water from water users as a means of improving instream flows for fish. Irrigators and stock water users are paid fair compensation for the instream use of their water in priority stream reaches during critical fish periods. Monitoring evaluates the changes in flow and habitat conditions.

Results are presented for the first three years of operation, all of which have been dry or critically dry water year types. Summer leases over the years have added from 279 to 330 acre-feet of water to several priority streams, benefiting 3.7 to 6.1 miles of instream habitat. Fall leases have provided from 280 to 481 acre-feet in the Scott River mainstem, benefiting up to 53 miles of spawning habitat. Another effort of the Water Trust is adding "instream" as a use under the California Water Code (Section 1707) to an individual water right and one of the water rights decrees, in order to develop a more efficient process with the State.

Our organization is the first water trust in California and became a nonprofit in 2009. Water trusts are a popular fish and water conservation tool in the Pacific Northwest. The Scott River Water Trust is adapting their experiences for this part of the Klamath River Basin as well as practicing our own adaptive management. www.scottwatertrust.org

Restoring Habitat Productivity in the Middle Klamath Basin: An Overview

Silveira, J., and G. Curtis, U.S. Fish and Wildlife Service, Yreka, CA

The U.S. Fish and Wildlife Service's Yreka Fish and Wildlife Office has carried out a wide variety of habitat restoration work in the middle Klamath Basin, and has completed more than 200 projects since 1987. Restoration work has been supported by our Partners for Fish and Wildlife, Fisheries, and National Fish Passage Programs. Since 2005 the Yreka office has funded and participated in more than 50 projects, wholly or in part, partnering with agencies, community partners, and private landowners. This work has included projects to restore in-stream and riparian habitats, provide fish passage, create wetlands, improve upland habitats through road decommissioning, and weed control, and increase the resiliency of forested habitats to wildfire by reducing fuels.

Successfully Implementing Habitat Restoration Projects in the Middle Klamath Basin

Mark Cookson, M., S. Hagwood, and D. Johnson, U.S. Fish and Wildlife Service, Yreka, CA

The U.S. Fish and Wildlife Service's Yreka Fish and Wildlife Office has implemented a wide variety of habitat restoration work in the middle Klamath Basin over the past two decades. Project types include riparian plantings, livestock exclusion fencing, fish barrier removal, and fuels reduction. Projects typically address habitat limiting factors that influence species diversity, abundance and productivity. We display and discuss representative projects that demonstrate methods used for restoration, including data on the project footprint, and the benefits to the resources.

Summary of USGS Collected Turbidity and Temperature Data and Sediment Sampling on the Williamson and Sprague Rivers, near Chiloquin, Oregon and on the Sprague River near Beatty, Oregon

Schuster, M.D., and M.A. Stewart, U.S. Geological Survey, Central Point, OR

Klamath Tribes and U.S. Geological Survey (USGS) have cooperated on an ongoing project to collect baseline data that can be used with flow to estimate sediment loads at three monitoring locations: (1) Sprague River near Beatty (USGS Station # 11497500), (2) Sprague River near Chiloquin (USGS Station # 11501000), and (3) Williamson River near Chiloquin (USGS Station # 11502500). Data collected by the USGS includes continuous turbidity and temperature data and suspended sediment samples.

Modeling the Extent Restoration Wetlands around Upper Klamath Lake Release and Sequester Phosphorus

Mulford, E., and Tullos, D., Oregon State University, Corvallis, OR

Each year, the Aphanizomenon algal blooms of the Upper Klamath Lake are one of the factors limiting endangered fish species from flourishing in the lake. Within the lake, phosphorus has been shown to be the limiting growth factor of the algae. Reducing phosphorus loads is viewed as a solution to reducing the blooms. The wetlands around the lake may act as both a source and a sink of phosphorus to the lake, and are important when investigating how to reduce algal blooms. The rate of phosphorus release from wetlands is influenced by both biotic and abiotic mechanisms. It has been determined that all detectable phosphorus is released only during the first 60 days after inundation, with the majority released during the first 48 hours. It is theorized that when natural hydrologic and biochemical functions are resumed, phosphorus sequestration will resume as well.

The point in time when phosphorus sequestration in restoration wetlands resumes was determined through hydrodynamic modeling. The modeling objective was to determine, once phosphorus sequestration begins, the change in phosphorus sequestration over time in the restoration wetlands. Relationships between the carrying capacity of phosphorus storage of the wetlands and the biotic and abiotic variables that may cause phosphorus sequestration were also modeled. The Autobiotic Wetland Phosphorus Model (Kadlec 1996), was used to predict the amount of phosphorus sequestration in Agency Lake Ranch Wetland on an annual basis and the time it takes for the carrying capacity of the wetlands to be reached. The Autobiotic model is a spatially variable, dynamic model that describes the spatial distribution of both biomass and P concentrations in wetlands. From this model, we described phosphorus removal rates of Upper Klamath wetlands in three major removal processes: sorption, biomass expansion and new soil accretion.

Klamath River Estuary Wetlands Restoration Prioritization

Patterson, B., Yurok Tribe Environmental Program, Klamath, CA

The Yurok Tribe Environmental Program (YTEP) has developed wetland mitigation guidance for the Klamath River Estuary. The document titled “Klamath River Estuary Wetlands Restoration Prioritization Plan” guides wetland restoration efforts by identifying the most degraded wetlands and provides a framework for prioritizing wetland restoration based on restoration success potential. The goal of the document is to ensure wetland restoration projects not only have the best chance for success, but are addressing the highest priority aquatic resource needs of the Klamath River Estuary (KRE).

Initiated in 2008, YTEP began assessing the ambient condition of KRE wetlands using the California Rapid Assessment Method (CRAM). CRAM is a recently developed rapid assessment tool which offers standardized procedures for use throughout the State. CRAM assessments are designed to measure the overall condition of a wetland by systematically assessing four attributes: Buffer and Landscape Connectivity, Hydrology, Physical Structure and Biotic Structure. Standardized assessments allow for numerical comparability between sites, leading to identification of the most degraded wetlands, and information regarding anthropogenic stressors causing decline in wetland condition.

YTEP has utilized CRAM attribute data to develop “restoration potential” of each wetland complex assessed. Based on feasibility and restoration project success at the local level, restoration potential is the basis for prioritizing the wetland restoration that should take place. Based on knowledge of the local infrastructure and land use activities, the CRAM attributes Buffer and Landscape Connectivity and Hydrology are much less likely to be restored than are Physical Structure and Biotic Structure. Restoration potential is defined as the numerical difference In CRAM scores between these two groups.

Trends in Temperature, Precipitation, and Snowpack in the Klamath Basin Region

Mayer, T.[1], and S. Naman[2]

[1]U.S. Fish and Wildlife Service, Portland, OR
[2]National Marine Fisheries Service, Arcata, CA

Declining spring snowpack as a result of warmer winter temperatures has been documented in much of the western U.S. Reductions in snowpack and warmer temperatures will have important effects on streamflow and aquatic resources. Here we present the results from one of two studies of Klamath Basin hydroclimatology. In this study, we examine historic changes in winter temperature, winter precipitation, and April 1 snow water equivalent (SWE). We used monthly temperature and precipitation from 20 U.S. Historical Climatology Network (USHCN) climate stations and Apr 1 SWE from 46 snowcourse sites in the region. Our results show that winter temperatures have warmed considerably over the period 1925–2007, especially in the last few decades. The average rate of increase since 1945 at all 20 USHCN stations is 0.2°C/decade, a rate comparable to other studies in the Pacific Northwest. Modern temperatures are higher than during a previous positive phase of the Pacific Decadal Oscillation (PDO) from 1925 to 1944, suggesting that the increase is only partially explained by the changes in the PDO phase after 1977.

Periphyton Assessment of the Lower Klamath River on the Yurok Indian Reservation

Sinnott, S., and K. Fetcho, Yurok Tribe Environmental Program, Klamath, CA

The Yurok Tribe Environmental Program's goal in sampling periphyton on the Lower Klamath River within the boundaries of the Yurok Indian Reservation (YIR) is to understand the extent of nutrient pollution, the prevalence of toxic cyanobacteria in the riverine environment and the potential risk both pose to the food web and human health. In the long-term, this sampling will assist in illustrating pollution variation between water years and provide a basis to judge effectiveness of short-term and long-term management and regulatory actions taken to abate pollution throughout the Klamath River Basin.

This poster presentation will focus on periphyton data gathered at three sites on the YIR: Klamath River at Turwar U.S. Geological Survey Gage (TG), Klamath River upstream of Weitchpec (WE), and Trinity River upstream of Klamath River confluence at Weitchpec (TR) during sampling years 2006–2008. It will discuss the types of periphyton detected at each sampling location, the presence or absence of blue-green algae at each sampling location, and the trends of periphyton metrics at each site throughout each sampling season.

Hydrologic Assessment of Lower Klamath River Tributaries

Gibson, M., and K. Fetcho, Yurok Tribe Environmental Program, Klamath, CA

The Yurok Tribe Environmental Program's goal in operating gaging stations in tributaries to the Lower Klamath is to obtain a continuous record of streamflow, which can be estimated by creating a relationship, or rating curve, between gage height at the gaging station and discharge measurements taken at a range of water levels. In addition, data such as suspended sediment concentration (SSC) and turbidity are also monitored during the winter months, when most sediment transport occurs in watersheds. Watersheds can be impaired by excessive sediment loads, which can lead to changes in channel morphology, habitat degradation, loss of spawning habitat, and may influence salmonid migration. The objectives for conducting this monitoring are (1) establish baseline conditions and long-term trends, (2) provide a basis for comparing inter-annual flow regimes as they relate to fisheries studies, and (3) to monitor long-term progress of restoration projects.

This presentation will focus on Lower Turwar Creek. The Lower Turwar gaging station was installed in October of 2007 to measure height, turbidity, and temperature. YTEP also collects SSC samples before, during and after peak storm events to better understand the relationship between SSC and turbidity. YTEP has another gage on the upper portion of Turwar Creek about 1 mile upstream that has been operational since 2002 with turbidity and a high flow cableway added in 2005. In the Spring YTEP conducts macroinvertabrate sampling as another biological indicator of stream health. It will help us further understand the Turwar watershed and potentially see the result of intensive streambed restoration conducted by Yurok Tribe fisheries program that has been ongoing for almost 3 years. Even in this short period of monitoring YTEP has seen some promising results. The total drainage area of the watershed is 20,380 acres (31.84 mi^2).

Shasta River juvenile coho early life history and survival study

Adams, C., California Department of Fish and Game, Yreka, CA

Passive integrated transponder (PIT) tags were used to gain information regarding the rearing, migration, growth, and survival of juvenile coho salmon (brood year 2007) in the Shasta River in 2008 and 2009. Newly developed and relatively inexpensive remote PIT tag detection systems were installed at key locations to monitor tagged individuals. These efforts revealed migrations to areas of cold spring inflow of the Shasta and its tributaries where coho successfully reared over the summer of 2008. Fall/winter redistribution was documented when tagged individuals were detected at locations throughout the watershed. Survival over three river reaches was estimated using a Cormack Jolly Seber model in program Mark for tagged coho emigrating from mainstem Shasta rearing habitats as smolts in the spring of 2009. Detection probability of several remote detection systems was also estimated using this analytical methodology.

Klamath Hydro Settlement Agreement: 2010 Water Quality Monitoring

Deas, M.[1], R. Carlson[2], C. Creager[3], S. Corum[4], R. Fadness[5], K. Fetcho[6], S. Keydel[7], S. Kirk[8], and L. Prendergast[9]

[1]Watercourse Engineering, Inc., Davis, CA
[2]U.S. Bureau of Reclamation, Klamath Falls, OR
[3]North Coast Regional Water Quality Control Board, Santa Rosa, CA
[4]Karuk Tribe, Orleans, CA
[5]North Coast Regional Water Quality Control Board, Santa Rosa, CA
[6]Yurok Tribe, Klamath, CA
[7]U.S. Environmental Protection Agency, Region IX, San Francisco, CA
[8]Oregon Department of Environmental Quality, Bend, OR
[9]PacifiCorp, Portland, OR

2010 marks the second year of formal monitoring associated with the Klamath Hydro Settlement Agreement (KHSA). Initiated through Interim Measure 12 (Water Quality Monitoring) of the Agreement in Principal, PacifiCorp provides $500,000 per year to fund (1) long-term baseline water quality monitoring to support dam removal, nutrient removal, and permitting studies; and (2) blue-green algae (BGA) and BGA toxin monitoring as necessary to protect public health.

Through a cooperative monitoring program that includes the Yurok Tribe, Karuk Tribe, PacifiCorp, and the U.S. Bureau of Reclamation, water quality monitoring occurs over approximately 250 miles of river and reservoir waters from Link Dam near Klamath Falls to the Klamath River Estuary near Klamath. Annual planning and coordination meetings are organized and administered by the North Coast Regional Water Quality Control Board and Oregon Department of Environmental Quality with support from the U.S. Environmental Protection Agency. Monitoring is coordinated to ensure appropriate quality assurance protocols and standard operating procedures, with transparency a key element of the program.

The program has completed one year of sampling and intends to produce a data summary report for year 2009 baseline monitoring, which will include data presentation, lab cross comparisons among the various sampling parties, and quality assurance information pertinent to the program. Public health monitoring will be reported separately.

Adequacy of Klamath River Fishery Flows under Terms of Klamath Settlement

Franklin, R., Senior Hydrologist, Hoopa Valley Tribal Fisheries Department, Hoopa, CA

To evaluate risks to Trinity River fish populations, water volumes available for fishery flow releases to Klamath River under terms of the proposed Klamath Basin Restoration Agreement (KBRA) were analyzed using criteria adopted from (1) current Federal Endangered Species Act (ESA) requirements for coho salmon, and (2) recommendations for minimum flows (subsistence limits) from Hardy et al. (2006). Hydrologic modeling used in KBRA negotiations, specifically KLAMSIM Run32 – Refuge, was selected to simulate future conditions for Klamath River flows below the location of Iron Gate Dam. Our analysis found violations of the selected criteria were frequent and of large magnitude, especially in years with less than average precipitation. While many violations could likely be avoided though in-season management of water supplies, doing so under the water-allocation terms of KBRA appears to require trade-offs between protection of minimum regulatory and environmental flows, and provision of flows adequate to restore habitats crucial to Chinook fry rearing in mainstem reaches of Klamath River. We conclude that fishery flows resulting from adoption of KBRA are likely inadequate for protection of Trinity River stocks while complying with legal requirements under ESA and at the same time restoring non-Trinity fish populations of the Klamath River.

Harvest and Quality Control of *Aphanizomenon flos-aquae* (Cyanobacteria) by Simplexity Health for Human Dietary Use

Shannon, A.M., and Shaik, R. PhD., Simplexity Health, Klamath Falls, OR

In western cultures, certain cyanobacteria have for about 30 years been an accepted source of microalgal biomass for food. Beginning in the early 1980s, *Aphanizomenon flos-aquae* (AFA) was adopted for similar use. The only known commercial harvesting of AFA is from Upper Klamath Lake, the largest freshwater lake in Oregon. Procedures for removal of detritus and mineral materials, and those for monitoring and reducing the amounts of certain contaminants that can produce cyanotoxins, have become a very important part of Simplexity Health’s harvesting process. Meticulous quality control standards and good manufacturing practices for making nutritional supplements for human consumption are priorities for the company.

Using Archaeological Fish Remains to Determine Species of Anadromous Salmon and Trout in the Upper Klamath Basin before Hydropower Development

Butler, V.L.[1], N. Misarti[2], D.Y. Yang[3], C.F. Speller[3], T.J. Connolly[4], D.L. Jenkins[4], and A.E. Stevenson[5]

[1]Department of Anthropology, Portland State University, Portland, OR
[2]Center for Archaeology, Materials, and Applied Science, Idaho State University, Pocatellow, ID
[3]Department of Archaeology, Simon Fraser University, Burnaby, B.C., Canada
[4]Museum of Natural and Cultural History, University of Oregon, Eugene, OR
[5]Department of Anthropology, Portland State University, Portland, OR

Fish remains from archaeological sites represent an important source of knowledge about pre-development species distribution. The archaeological record of salmonids in the Upper Klamath Basin illustrates this value particularly well, given (a) major habitat destruction occurred prior to any systematic biological surveys, (b) the difficulty in distinguishing salmonid species using historic records, and (c) the magnitude of the issues involved associated with restoration efforts. A pilot study of Upper Klamath archaeological fish remains using mtDNA and stable isotope analysis ($^{13}C/^{12}C$; $^{15}N/^{14}N$) was undertaken to evaluate whether these tools could identify salmonid species and migratory patterns. Seven archaeological salmonid remains from the Beatty Curve site (35KL95) (between 1600 and 120 yrs old) were analyzed. Polymerase Chain Reaction (PCR) analysis focused on short sections --one from Cytochrome B and a section from the D-Loop. Amplified sequences compared to published salmonid species sequences closely match two species: *Oncorhynchus tshawytscha* (Chinook salmon) and *O. mykiss* (steelhead/rainbow trout). Because *O. mykiss* includes both an anadromous and resident freshwater form, to establish whether the archaeological samples represent sea-run fish, we obtained ratios of stable carbon and nitrogen, which are distinctive of adult residence habitat (freshwater vs. marine). All the samples showed a strong marine signal, indicating anadromous life history. Our pilot project demonstrates that at least two species of salmonids, Chinook and steelhead trout, occupied the Upper Klamath prior to major historic habitat losses; and more generally highlights the need to incorporate study of archaeological fish remains in conservation boil and habitat restoration efforts.

Appendix 4. List of Attendees

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Christopher	Adams	California Department of Fish and Game
Pete	Adams	NOAA Fisheries
Greg	Addington	Klamath Water Users Association
Eli	Afarian	Quartz Valley Indian Reservation
Jill	Aho	Herald and News News
Allison	Aldous	The Nature Conservancy
John	Alexander	Klamath Bird Observatory
Justin	Alvarez	Hoopa Tribal Fisheries
Chauncey	Andersen	U.S. Geological Survey
Matthew	Andersen	U.S. Geological Survey
Pablo	Arroyave	Bureau of Reclamation
Eli	Asarian	Kier Associates
Jessica	Asbill	Bureau of Reclamation
Don	Ashton	U.S. Forest Service
Nicole	Athearn	U.S. Fish and Wildlife Service
Leslie	Bach	The Nature Conservancy
David	Banks	U.S. Geological Survey
Terri	Barbur	Syskiyou County
Brian	Barr	National Center for Conservation Science and Policy
Matt	Barry	U.S. Fish and Wildlife Service
Michelle	Barry	Klamath Basin Rangeland Trust
Jerri	Bartholomew	Oregon State University
Daniel	Battaglia	Oregon State University
Matt	Baun	U.S. Fish and Wildlife Service
Caitlin	Bean	California Department of Fish and Game
Ty	Beaver	Herald and News News
Debra	Becker	U.S. Geological Survey
John	Beeman	U.S. Geological Survey
Mike	Belchik	Yurok Tribe
Angie	Bell	Klamath National Forest
Chad	Bell	Humboldt State University
Ethan	Bell	Stillwater Sciences
Grace	Bennett	Siskiyou County
Jamie	Bettaso	U.S. Fish and Wildlife Service
Craig	Bienz	The Nature Conservancy

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Dave	Bitts	Pacific Coast Federation of Fisherman's Association
Mike	Black	Oregon Department of Fish and Wildlife
Greta	Blackwood	U.S. Geological Survey
Joseph	Blanchard	Klamath National Forest
Jeremy	Bloom	TENTHMIL
Dixie	Boley	No Affiliation Provided
Sarah	Borok	California Department of Fish and Game
Jared	Bottcher	U.S. Geological Survey
James	Bowers	U.S. Geological Survey
Crystal	Bowman	Quartz Valley Indian Reservation
Troy	Brandt	River Design Group, Inc.
Missy	Braham	Bureau of Reclamation
Ryan	Braham	U.S. Geological Survey
Troy	Brandt	River Design Group, Inc.
Kim	Brewitt	National Marine Fisheries Service
Dean	Brockbank	PacifiCorp
Daniel	Brown	U.S. Geological Survey
Randy	Brown	U.S. Fish and Wildlife Service
Petey	Brucker	Salmon River Restoration Council
Norman	Buccola	U.S. Geological Survey
Summer	Burdick	U.S. Geological Survey
Bruce	Bury	U.S. Geological Survey
David	Busch	U.S. Geological Survey
Virginia	Buttler	Portland State University
Jason	Cameron	Bureau of Reclamation
Sharon	Campbell	U.S. Geological Survey
Haley	Carlson	AmeriCorps
Ken	Carlson	CH2M Hill
Rick	Carlson	Bureau of Reclamation
Wayne	Carmichael	Wright State University
James	Carter	U.S. Geological Survey
Charlie	Chamberlain	U.S. Fish and Wildlife Service
Ernest	Chen	U.S. Fish and Wildlife Service
Diana	Chesney	California Department of Fish and Game
William	Chesney	California Department of Fish and Game
Damion	Ciotti	U.S. Fish and Wildlife Service
Travis	Ciotti	U.S. Geological Survey
Mark	Clark	Oregon Institute of Technology

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Julianna	Clausen	TENTHMIL
Robert	Coffan	Southern Oregon University
Terrence	Conlon	U.S. Geological Survey
Jim	Cook	Siskiyou County
Mark	Cookson	U.S. Fish and Wildlife Service
Alex	Corum	Karuk Tribe
Susan	Corum	Karuk Tribe
Ric	Costales	Siskiyou County Government
Ian	Courter	Cramer Fish Sciences
Matthew	Cover	California State University, Stanislaus
Matt	Cox	Oregon State University
Clayton	Creager	California North Coast Regional Water Quality Control Board
Sam	Cuenca	U.S. Forest Service
Yantao	Cui	Stillwater Sciences
Michael	Cummings	Portland State University
Michael	Cunanan	U.S. Fish and Wildlife Service
Debra	Curry	U.S. Geological Survey
Gary	Curtis	U.S. Fish and Wildlife Service
Timothy	Dalrymple	U.S. Geological Survey
Michael	Dammarell	Bureau of Indian Affairs
Eric	Danner	National Marine Fisheries Service
Jim	Dastyck	U.S. Fish and Wildlife Service
Aaron	David	Karuk Tribe
Emily	Davis	Karuk Tribe Fisheries Department
Sheri	Davis	Sound Environmental Strategies
Mike	Deas	Watercourse Engineering, Inc.
Kathie	Dello	Oregon Climate Change Research Institute
Michael	Derrig	Bureau of Land Management
Phil	Detrich	U.S. Fish and Wildlife Service
Tara	Dettmar	Watershed Stewards Project
Leslie	Dierauf	U.S. Geological Survey
Eric	Dinger	National Park Service
Carolyn	Doehring	The Nature Conservancy
Amari	Dolan-Caret	U.S. Geological Survey
Cynthia	Donegan	U.S. Fish and Wildlife Service
Scott	Downie	California Department of Fish and Game
Theo	Dreher	Oregon State University

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
John	Duff	U.S. Geological Survey
Jill	Duffy	Humboldt County
Walter	Duffy	U.S. Geological Survey
Mary	Dunning	U.S. Geological Survey
Larry	Dunsmoor	Klamath Tribes
Demian	Ebert	Post, Buckley, Schuh & Jernigan, Inc.
Kathy	Echols	U.S. Geological Survey
Dan Blake	Eldridge	U.S. Geological Survey
Sara	Eldridge	U.S. Geological Survey
John	Elliott	Klamath County Board of Commissioners
Craig	Ellsworth	U.S. Geological Survey
Chanda	Engel	Oregon State University
Scott	English	Northwest Biological Consulting
Charlie	Erdman	The Nature Conservancy
Jim	Eychaner	U.S. Geological Survey
David	Ferguson	Natural Resources Conservation Service, Tulelake
Jon	Ferguson	U.S. Geological Survey
Richard	Ferrero	U.S. Geological Survey
Ken	Fetcho	Yurok Tribe Environmental Program
Rocco	Fiori	GeoSciences
Kris	Fischer	Klamath Tribes
Don	Flickinger	National Marine Fisheries Service
Alan	Flint	U.S. Geological Survey
Lori	Flint	U.S. Geological Survey
Gary	Flosi	California Department of Fish and Game
Suzanne	Fluharty	Yurok Tribe Environmental Program
Scott	Foott	U.S. Fish and Wildlife Service
Richard	Ford	U.S. Forest Service
William	Forney	U.S. Geological Survey
Kaylea	Foster	PacifCorp
Robert	Franklin	Hoopa Tribal Fisheries
Sue	Fry	Bureau of Reclamation
Tracy	Fuentes	U.S. Geological Survey
Greg	Fuhrer	U.S. Geological Survey
Laura	Fujii	U.S. Environmental Protection Agency, Region 9
Masami	Fujiwara	Texas A&M University
Dena	Gadomski	U.S. Geological Survey
David	Gaeuman	Bureau of Reclamation

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Marshall	Gannett	U.S. Geological Survey
Ned	Gates	Oregon Water Resources Department
Dennis	Gathard	Yurok Tribe
Christopher	Gebauer	U.S. Department of Agriculture, Natural Resources Conservation Service
Barbara	Gee	U.S. Geological Survey
N. Stan	Geiger	Aquatic Scientific Resources
Mike	Gentile	U.S. Geological Survey
Micah	Gibson	Yurok Tribe Environmental Program
Sue	Gillespie	The University of Montana
Eric	Ginney	Philip Williams & Associates, Ltd.
Damon	Goodman	U.S. Fish and Wildlife Service
Leslie	Gordon	U.S. Geological Survey
Kyle	Gorman	Oregon Water Resources Department
Steve	Gough	U.S. Fish and Wildlife Service
Rhea	Graham	Bureau of Reclamation
Patricia	Grantham	U.S. Forest Service
Aaron	Greenberg	National Marine Fisheries Service
Blair	Greimann	Bureau of Reclamation
Churchill	Grimes	NOAA Fisheries
Luke	Groff	Humboldt State University
Jerry	Grondin	Oregon Water Resources Department
Lorin	Groshong	Southern Oregon University
Jon	Grunbuam	Klamath National Forest
Yutaka	Hagimoto	Oregon State University
Sheri	Hagwood	U.S. Fish and Wildlife Service
Andrew	Hamilton	Bureau of Land Management
John	Hamilton	U.S. Fish and Wildlife Service
Roger	Hamilton	University of Oregon
Mike	Hamman	Trinity River Restoration Program
Mark	Hampton	California Department of Fish and Game
Cindy	Hansen	U.S. Geological Survey
Will	Harling	Mid-Klamath Watershed Council
Alta	Harris	U.S. Geological Survey
Matthew	Harwell	U.S. Fish and Wildlife Service
Irwin	Haydock	Newport Bay Naturalists/Friends
Brian	Hayes	U.S. Geological Survey
Gerry	Hemmingsen	Del Norte County

First Name	Last Name	Affiliation
Tim	Hemstreet	PacifiCorp
Noble	Hendrix	R2 Resource Consultants Inc.
Heather	Hendrixson	The Nature Conservancy
Tom	Hepler	Bureau of Reclamation
Xana	Hermosillo	Watershed Stewards Project
Thomas	Herrett	U.S. Geological Survey
Thomas	Hesseldenz	Tom Hesseldenz and Associates
Nick	Hetrick	U.S. Fish and Wildlife Service
David	Hewitt	U.S. Geological Survey
Jon	Hicks	Bureau of Reclamation
Dave	Hillemeier	Yurok Tribe
Stephen	Hinkle	U.S. Geological Survey
Chris	Holmquist-Johnson	U.S. Geological Survey
Kirstin	Holsman	NOAA Fisheries
Richard	Holt	Oregon State University
Robert	Hooton	Oregon Department of Fish and Wildlife
Thomas	Hotaling	Salmon River Restoration Council
Bill	House	Salmon River Restoration Council
Michael	Hughes	Klamath Tribes Research Station
Chuck	Huntington	Clearwater Bio Studies, Inc
Charlene	Hurst	Oregon State University
Karen	Hussey	Klamath Bird Observatory / Prescott College
Becky	Hyde	Upper Klamath Water Users Association
Nathan	Jackson	Klamath Watershed Partnership
Roger	Jaegel	Trinity County
Eric	Janney	U.S. Geological Survey
Judith	Jensen	Educational Solutions
David	Johnson	U.S. Fish and Wildlife Service
Grant	Johnson	Karuk Tribe
Mark Alan	Johnson	U.S. Geological Survey
Jennifer	Jones	U.S. Fish and Wildlife Service
Jim	Jordahl	CH2M Hill
Lee	Juillerat	Herald and News
Jacob	Kann	Aquatic Ecosystem Services LCC
Kristofor	Kannarr	U.S. Geologic Survey
Christine	Karas	Bureau of Reclamation
George	Kautsky	Hoopa Valley Tribal Fisheries
Jeffrey	Keay	U.S. Geological Survey

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Tom	Keegan	ECORP Consulting, Inc.
Andrew	Kerslake	U.S. Geological Survey
Susan	Keydel	U.S. Environmental Protection Agency, Region 9
Johnny	Kilroy	TENTHMIL
Andrew	Kinsiger	Humboldt State University
Steve	Kirk	Oregon Department of Environmental Quality
Melissa	Kleeman	No Affiliation Provided
Morgan	Knechtle	California Department of Fish and Game
Kevin	Knutson	U.S. Geological Survey
Justin	Koller	U.S. Geological Survey
George	Kondolf	University of California Berkeley
Steve	Koskello	K&C Environmental Services, Inc.
Andreas	Krause	Bureau of Reclamation
Kathryn	Kuivila	U.S. Geological Survey
James	Kuwabara	U.S. Geological Survey
Irma	Lagomarsino	National Marine Fisheries Service
Jonathan	LaMarche	Oregon Water Resources Department
Ronald	Larson	U.S. Fish and Wildlife Service
Tracy	Le	U.S. Geological Survey
Chris	Leeseberg	Klamath Tribes
Javier	Linares-Casenave	U.S. Fish and Wildlife Service
Andrew	Lincoff	U.S. Environmental Protection Agency, Region 9
Pollyanna	Lind	University of Oregon
Thomas	Lisle	U.S. Forest Service
Ken	Lite	Oregon Water Resources Department
Keith	Loftin	U.S. Geological Survey
Autumn	Lovell	TENTHMIL
Dennis	Lynch	U.S. Geological Survey
Thomas	MacDonald	Desert Springs Trout Farm
Mary Ann	Madej	U.S. Geological Survey
Ian	Madin	DOGAMI
Mark	Magneson	U.S. Fish and Wildlife Service
Greer	Maier	NOAA Fisheries
Jonathon	Mann	HDR Engineering Inc.
Keith	Marine	North State Resources, Inc.
Douglas	Markle	Oregon State University
David	Marmorek	ESSA Technologies Ltd.
Malena	Marvin	Klamath Riverkeeper

Klamath Basin Science Conference

List of Participants

First Name	Last Name	Affiliation
Chris	Massingill	University of Oregon
Sue	Mattenberger	U.S. Fish and Wildlife Service
Stan	Mattingly	Bureau of Reclamation
Dave	Mauser	U.S. Fish and Wildlife Service
Tim	Mayer	U.S. Fish and Wildlife Service
Louisa	McCovey	Hoopa Tribe
Barry	McCovey Jr.	Yurok Tribal Fisheries
Kenneth	McDermond	U.S. Fish and Wildlife Service
Patricia	McDowell	University of Oregon
Bryan	McFadin	Regional Water Quality Control Board
Bill	McFarland	U.S. Geological Survey
Rodney	McInnis	National Marine Fisheries Service
Renita	McNaughtan	Oregon Department of Agriculture
Chris	McWhorter	U.S. Geological Survey
William	Mendenhall	California Department of Water Resources
Jill	Meyer	IM Systems Group
Bill	Meyers	Oregon Department of Environmental Quality
Jennifer	Miller	David Evans and Associates
Sherri	Miller	U.S. Forest Service
Stewart	Mills	TENTHMIL
Jeffrey	Mitchell	Klamath Tribes
Pia	Moisander	University of California Santa Cruz
Kevin	Moore	Bureau of Reclamation
Dale	Morris	Bureau of Indian Affairs
Terry	Morton	Cascade Quality Solutions
Jerry	Mosier	Klamath National Forest
Emily	Mulford	Oregon State University
Steve	Munson	TENTHMIL
Ryan	Murdock	MWH Americas, Inc.
Seth	Naman	NOAA Fisheries
Ron	Neilson	U.S. Forest Service
Jim	Nickles	U.S. Geological Survey
Eric	Nusbaum	Oregon Department of Agriculture
Jim	O'Connor	U.S. Geological Survey
Allison	Oliver	University of California-Davis
Mary	Olswang	California Department of Fish and Game
Kameran	Onley	Post, Buckley, Schuh & Jernigan, Inc.
Michael	Orcutt	Hoopa Valley Tribe

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Christopher	Ottinger	U.S. Geological Survey
Mary	Paasch	MWH Americas, Inc.
Charles	Padera	Post, Buckley, Schuh & Jernigan, Inc.
Robert	Pagliuco	NOAA Restoration Center
David	Palermo	Desert Springs Trout Farm
Nancy	Parker	Bureau of Reclamation
Steven	Parrett	GoldinWater
Allison	Patterson	Oregon State University
Bill	Patterson	Wetland Specialist
William	Pearcy	Oregon State University
Christopher	Pearl	U.S. Geological Survey
Devon	Pearse	NOAA Fisheries
Beth	Pendleton	U.S. Forest Service
Julie	Perrochet	Klamath National Forest
Russell	Perry	U.S. Geological Survey
Shannon	Peterson	Klamath Basin Rangeland Trust
Carrie	Phillips	U.S. Geological Survey
Mark	Pisano	California Department of Fish and Game
Danial James	Polette	U.S. Geological Survey
Joe	Polos	U.S. Fish and Wildlife Service
Victoria	Poole	Poole Productions
Linda	Prendergast	PacifiCorp
Keith	Prince	U.S. Geological Survey
Rebecca	Quinones	Klamath National Forest
Mariah	Raade	U.S. Fish and Wildlife Service
Anders	Rasmussen	HDR Engineering Inc
Josh	Rasmussen	U.S. Fish and Wildlife Service
Adam	Ray	Oregon State University
Heather	Ray	U.S. Fish and Wildlife Service
Richard	Raymond	E&S Environmental Chemistry
Donald	Reck	Bureau of Reclamation
Jed	Redwine	Post, Buckley, Schuh & Jernigan, Inc.
Tim	Reed	U.S. Geological Survey
John	Risley	U.S. Geological Survey
Laura	Robertson	U.S. Geological Survey
Miguel	Rocha	Bureau of Reclamation
Dennis	Rondorf	U.S. Geological Survey
Richard	Roseberg	Oregon State University

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Barry	Rosen	U.S. Geological Survey
Stewart	Rounds	U.S. Geological Survey
Chantell	Royer	Klamath Watershed Institute
Kelly	Russell	U.S. Forest Service
Patrick	Rutten	NOAA Restoration Center
Laurie	Sada	U.S. Fish and Wildlife Service
Robin	Salling	U.S. Geological Survey
Daniel	Sarr	National Park Service, Klamath
David	Schoellhamer	U.S. Geological Survey
Keith	Schultz	Bureau of Reclamation
Linda	Schultz	U.S. Fish and Wildlife Service
Mark	Schuster	U.S. Geological Survey
John	Schuyler	U.S. Forest Service
Andrew	Schwartz	Oregon State University
Megan	Schwartz	ENTRIX
Jim	Sedell	National Fish and Wildlife Foundation
Hank	Seemann	Humboldt County Public Works Department
Rhoda	Sendossi	U.S. Fish and Wildlife Service
Tamara	Seubert	U.S. Geological Survey
Anna	Shannon	Simplexity Health
Frank	Shipley	U.S. Geological Survey
Jennifer	Silveira	U.S. Fish and Wildlife Service
Nancy	Simon	U.S. Geological Survey
Jim	Simondet	National Marine Fisheries Service
Maia	Singer	Stillwater Sciences
Scott	Sinnott	Yurok Tribe Environmental Program
Carl	Skinner	U.S. Forest Service
Ryan	Slezak	U.S. Fish and Wildlife Service
Kathleen	Sloan	Yurok Tribe (Klamath)
Roger	Smith	Oregon Department of Fish and Wildlife
Wes	Smith	National Marine Fisheries Service
Daniel	Snyder	U.S. Geological Survey
Morgan	Snyder	National Fish and Wildlife Foundation
Renee	Snyder	Bureau of Land Management
Jeremy	Sokulsky	Environmental Incentives, LLC
Sari	Sommarstrom	Sari Sommarstrom Associates
Hoda	Sondossi	U.S. Fish and Wildlife Service
Toz	Soto	Karuk Tribe

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Jan	Spitsbergen	Oregon State University
Jack	Stanford	The University of Montana
Mark	Stern	The Nature Conservancy
Alex	Stevenson	Portland State University
Belinda	Stewart	Klamath Water Users Association
Marc	Stewart	U.S. Geological Survey
Mark	Stopher	California Department of Fish and Game
Josh	Strange	Yurok Tribe
Andrew	Stubblefield	Humboldt State University
Annett	Sullivan	U.S. Geological Survey
Ben	Swann	CDM
William	Swanson	MWH Americas, Inc.
Doug	Tedrick	Bureau of Indian Affairs
Swee	Teh	University of California-Davis
Stephanie	Theis	MWH Americas, Inc.
Brian	Thomas	U.S. Forest Service
Cynthia	Thomson	National Marine Fisheries Service
Lyman	Thorsteinson	U.S. Geological Survey
William	Tinniswood	Oregon Department of Fish and Wildlife
Mark	Tompkins	New Fields River Basin Services, LLC
Daniel	Tormey	ENTRIX
Roman	Torres	Klamath National Forest
Hao	Tran	U.S. Forest Service
Desiree	Tullos	Oregon State University
Mike	Turaski	U.S. Army Corps of Engineers
Daniel	Turner	State of Oregon Department of Environmental Quality
Joe	Tyburczy	Congressman Mike Thompson (CA-01)
Torrey	Tyler	Bureau of Reclamation
Marc	Valens	Klamath Riverkeeper
Scott	VanderKooi	U.S. Geological Survey
Stacy	Vynne	University of Oregon
Brian	Wagner	U.S. Geological Survey
Joanne	Wallis	U.S. Geological Survey
Melody	Warner	The Nature Conservancy
William	Warren Olsen	Knife River
Roy	Wellman	HydroTech
Brian	Wells	NOAA Fisheries
Rusty	White	AmeriCorps

Klamath Basin Science Conference
List of Participants

First Name	Last Name	Affiliation
Charles	Wickham	Mid-Klamath Watershed Council
Jack	Williams	Trout Unlimited
John	Williams	U.S. Geological Survey
Thomas	Williams	NOAA Fisheries
Ann	Willis	Watercourse Engineering, Inc.
Brian	Wilson	U.S. Army Corps of Engineers
Margaret	Wilzbach	U.S. Geological Survey
Jim	Winton	U.S. Geological Survey
Rodney	Wittler	Bureau of Reclamation
Siana	Wong	The Nature Conservancy
Tamara	Wood	U.S. Geological Survey
Doug	Woodcock	Oregon Water Resources Department
T.J.	Woodley	Klamath Soil and Water Conservation District
David	Woodson	U.S. Geological Survey
Katrina	Wright	U.S. Fish and Wildlife Service
Jay	Wright	Northcoast Environmental Center
Scott	Wright	U.S. Geological Survey
Danielle	Yokel	Siskiyou RCD
Erich	Yokel	Siskiyou RCD
Ben	Zabinsky	Regional Water Quality Control Board
Paul	Zedonis	U.S. Fish and Wildlife Service

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For more information concerning the research in this report, contact the
Director, Western Fisheries Research Center
U.S. Geological Survey
6505 NE 65th Street
Seattle, Washington 98115
http://wfrc.usgs.gov/

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