Free Executive Summary

Hydrology, Ecology, and Fishes of the Klamath River Basin

Committee on Hydrology, Ecology, and Fishes of the Klamath River Basin, National Research Council

ISBN: 978-0-309-11506-3, 240 pages, 6 x 9, paperback (2007)

Summary

The Klamath Basin of northern California and southern Oregon has been the scene of controversies over water allocations in recent years. As often is the case with environmental controversies, a considerable amount of science has been done in the basin. However, the continuing lack of an overall model or vision to provide a framework for identifying science needs has prevented the science from being used effectively enough in decision making and management to resolve the continuing controversies, which has led to the involvement of the National Research Council (NRC). This report, which has as its main focus review of two large efforts to model the hydrology of the basin (the Natural Flow Study by the U.S. Bureau of Reclamation) and the relationship of Klamath River hydrology to habitat for salmon (by Utah State University), also addresses the broader questions of the ecological needs of the anadromous fishes and importance of a broad, comprehensive view of the basin's scientific needs as a guide to scientific activities.

The Klamath basin has been extensively modified by levees, dikes, dams, and the draining of natural water bodies since the Klamath Project was begun in 1905 to improve the region's ability to support agriculture; other changes have occurred as well. All those changes have been accompanied by changes in the biota of the basin. Of particular concern in this report are changes in the distribution and abundance of several species of fishes in the Klamath River and in its tributaries. Those fishes were the subject of earlier NRC reviews prompted by conflicts that arose after management actions were taken to protect the basin's fishes during the very dry year of 2001; one result of those actions was a severe reduction in the water available for agriculture. In addition, in September of 2002, more than 33,000[1] mostly adult fish died in the lower Klamath river, about 95% of which were Chinook salmon, the remainder being mostly steelhead, with less than 1% of the deaths being coho salmon. This mass mortality intensified the controversy over water operations in the Klamath basin.

The management and uses of the natural resources of the basin, including water and fishes, are complex. Many federal, state, county, and other agencies and organizations are involved, and the basin's resources are managed to achieve a variety of divergent purposes.

RECENT EVENTS LEADING TO THIS STUDY

The Endangered Species Act requires that the U.S. Bureau of Reclamation (USBR) make assessments of the effects of the Klamath Project operations on fishes listed as threatened or endangered and consult about those assessments with the U.S. Fish and Wildlife Service (USFWS) for suckers in Klamath Lake and the National Marine Fisheries Service (NMFS) for coho salmon (*Oncorhynchus kisutch*) in the lower Klamath River. The assessments that led to the NRC study initially were conducted in 2001. After consultations, the USFWS endorsed some of the USBR proposals, but concluded that more water than the USBR proposed was needed to maintain Upper Klamath Lake at levels that would

[1]The California Department of Fish and Game, which made this estimate, described it as "conservative."

protect the suckers. The NMFS also agreed with some of the USBR proposals, but concluded that more water was needed to maintain higher minimum flows in the Klamath River below Iron Gate Dam than the USBR had proposed. The "biological opinions" of the USFWS and the NMFS indicated that some of the USBR's proposals would jeopardize the continued existence of the listed species, and therefore the USBR was required to allot more water to the lake and to the river than had been planned, leaving less water than had previously been allocated for agriculture.

Those restrictive allocations, coupled with a very dry year, resulted in hardship for many of the basin's water users, and the controversy surrounding the allocations became intense. As a result of the controversy, the U.S. Department of the Interior asked the NRC to review the scientific bases of the USBR biological assessments and the USFWS and NMFS biological opinions. In response, the NRC established the Committee on Endangered and Threatened Fishes in the Klamath River Basin, which issued an interim report in 2002 focused on the biological assessments and biological opinions and a broader look at strategies for recovery of the endangered and threatened fishes of the basin in 2004.

Since the publication of the NRC reports, two new documents have become available: an estimate of natural or unimpaired flows in the basin as they were before the project was begun (the Natural Flow Study), and a model of the relationship of flows in the Klamath River to habitat in the river available for endangered and threatened fishes there, especially coho salmon (often referred to as "Hardy Phase II," referred to here as "Instream Flow Phase II"). Because those new documents have the potential to change scientific conclusions and management options based on earlier information, the Department of the Interior asked the NRC to evaluate them and their implications for the biota of the basin. In response, the NRC established the Committee on Hydrology, Ecology, and Fishes of the Klamath River Basin, which prepared this report. New developments have occurred since the previous reports were published, so this report is not a revisiting of the issues covered by the earlier ones. This committee endorses the recommendations of the earlier reports for reversing the declines of the listed species, and this report should be considered as building on the previous ones, continuing where they left off.

THE PRESENT STUDY

Statement of Task

A multidisciplinary committee will be established to evaluate new scientific information that has become available since the NRC issued its 2004 report on Endangered and Threatened Fishes in the Klamath River Basin. The new information to be evaluated by the committee will include two new reports on (1) the hydrology of the Klamath Basin and (2) habitat needs for anadromous fish in the Klamath River, including coho salmon. The committee will also identify additional information needed to better understand the basin ecosystem.

To complete its charge, the committee will

1. Review and evaluate the methods and approach used in the Natural Flow Study to create a representative estimate of historical flows and the Hardy Phase II studies, to predict flow needs for coho and other anadromous fishes.
2. Review and evaluate the implications of those studies' conclusions within the historical and current hydrology of the upper basin; for the biology of the listed species; and separately for other anadromous fishes.
3. Identify gaps in the knowledge and in the available scientific information.

To execute its charge, the committee met four times. At the first three meetings, the committee heard presentations from scientists and others, including agency officials familiar with various aspects of the region and the operation of the Klamath Project; the committee also received presentations from the

public. The committee visited a restoration and research project on the upper Shasta River, the Iron Gate Dam and hatchery on the Klamath River, and the monitoring station near the mouth of the Shasta River. Individual members of the committee and staff also visited other parts of the basin, including portions of the Klamath River downstream of Iron Gate Dam, Upper Klamath Lake; the Williamson, Sprague, and Wood rivers; the Link River and Link River Dam; Keno Dam, and J.C. Boyle Dam.

CONCLUSIONS AND RECOMMENDATIONS

We present the committee conclusions on the Natural Flow Study and the Instream Flow Phase II, along with recommendations for their improvement, followed by more general conclusions and recommendations for the conduct of science for management in the Klamath basin. The committee concludes that a more coherent, systematic, and comprehensive analysis of scientific and management needs for the basin should be conducted to identify the most important and urgent science needs to inform management decisions. Only when—and if—that analysis concludes that the Natural Flow Study and the Instream Flow Phase II are important components of such a comprehensive framework should the committee's recommended improvements to them be implemented.

THE NATURAL FLOW STUDY

The U.S. Bureau of Reclamation (USBR) conducted the study *Natural Flow of the Upper Klamath River* to "estimate the effects of agricultural development on natural flows in the Upper Klamath River Basin" using an "estimate of the monthly natural flows in the Upper Klamath River at Keno." Essentially, the USBR study provided flow estimates that would be observed if there *were no agricultural development such as draining of marshes and diversions of flow* in the Upper Klamath Basin (UKB). The products of the study were to be used as inputs for the Instream Flow Study. The study and the committee's evaluation of it are described in detail in Chapter 4.

Committee Evaluation

The Natural Flow Study for the Klamath River has several admirable attributes. The data sets describing stream flow that the Natural Flow Study assembled are extensive and are highly useful. The conceptual model developed to identify the components needed in a natural-flow model appears to be adequate. The simulated data adequately reflect the monthly seasonality of the flow system. Human activities have modified that system over substantial portions of the basin above the Iron Gate Dam gage site, and USBR investigators included many of these modifications in their calculations. Investigators recognized the importance of marsh conversions and agricultural activities in affecting river flows, and included these factors in their calculations. The documentation for the Natural Flow Study is accessible to the reader and provides a straightforward explanation of what the modelers did and how they did it, and provides the complete output of the research. The report also addresses important issues about the natural flow model, including brief accountings of model verification, sensitivity, and uncertainty.

The committee concluded, however, that the Natural Flow Study was seriously compromised by several fundamental issues, including its choice of a basic approach for understanding natural flows, choices of the models for calculations, and serious omissions of factors likely to influence river flows at the Iron Gate Dam gage site, as described below:

- The products of the Natural Flow Study, flow values for the Klamath River at the Iron Gate Dam site, were calculated as monthly values. The ecological applications of these calculated flows require

daily values, and as a result, the output of the study would not have satisfied its ultimate use requirements even if the study had been executed without other errors.

- The USBR researchers relied on a "black box"[2] method of accounting for flow using a standard spreadsheet as the foundation. The U.S. Geological Survey's Modular Modeling System (MMS) provides greater flexibility and adaptability, and provides a firmer theoretical foundation than a straightforward accounting system.
- The calculations of the fate of water in the upper basin related to evapotranspiration (ET) were not done according to the best current methods, such as the Food and Agriculture Organization's[3] (FAO's) version of the Modified Blaney-Criddle method. A more serious concern was the model behavior when a sensitivity analysis of its output concerning agricultural land was conducted. The results were not explained, and the apparent anomaly appears to be related to the component of the model that deals with reduction of ET in the Upper Klamath Lake marsh when it is converted to agriculture.
- The USBR attempted to calculate flows at Iron Gate Dam without adequately addressing important controlling factors for those flows, including groundwater.
- More generally, the Natural Flow Study did not fully address the issue of changes in land use and land cover. The inclusions of land-use and land-cover analyses in the study would have increased confidence in the resulting calculations, because if such changes are important they would reflect their influence in the model output; if the changes are unimportant that outcome could be convincingly demonstrated.
- The study failed to adequately model the connection between the Klamath River and Lower Klamath Lake.
- The study did not adhere closely enough to standard scientific and engineering practice in the areas of calibration, testing, quality assurance, and quality control. For example, the natural-flow model cannot be calibrated using standard modeling practices. A reasonable check on the model can be made only by using the data from the earliest available measurements of flows.

The committee concluded that the Natural Flow Study includes calculated flows that are at best first approximations to useful estimates of such flows. The present version of the Natural Flow Study is less than adequate for input to the Instream Flow Phase II and does not provide enough information for detailed management of flows for the benefit of listed and other anadromous fish species in the Klamath River downstream from Iron Gate Dam. However, it does provide some basis for understanding unimpaired flows in the basin and for providing a context for more detailed management decisions. To become useful for more precise decision making in daily or even monthly flow management, the Natural Flow Study should be improved by (1) replacing the Soil Conservation Service (SCS)[4] Modified Blaney-Criddle Method for calculating evapotranspiration (ET) with a more accurate and modern version, such as the Food and Agriculture Organization (FAO) version of the method, using generally available data; (2) including groundwater dynamics in the model in at least a general way; (3) improving the portions of the predictive model relating to land use and land cover so that changes in these variables are represented in a more complete fashion; (4) including the role of the Lost River and Lower Klamath Lake in the complicated high-flow scenarios; (5) replacing the black-box accounting method based on a spread sheet with a more robust physically based model for generating flows, such as the U.S. Geological Survey's Modular Modeling System (MMS), or its new model GSFLOW, which combines the MMS with the groundwater model MODFLOW; (6) including an extensive investigation of high flows along with their geomorphic and ecological implications, and (7) adhering more closely to standard scientific and engineering practice by extensively calibrating and testing the models and their underlying software,

[2]A "black box" method attempts to investigate a complex process—in this case, flows—without making assumptions about the mechanisms or structures that affect the process.
[3]An agency of the United Nations.
[4]An agency of the U.S. Department of Agriculture, now called the Natural Resources Conservation Service.

while addressing issues of quality assurance and quality control. The Natural Flow Study also should be modified to better meet the needs of the Instream Flow Study.

While the Natural Flow Study has advanced our understanding of the basin, its weaknesses also point to next steps that would help development of hydrologic models better-suited and more transparent for the basin's current problems.

INSTREAM FLOW PHASE II

The Instream Flow Phase II for the Klamath River Basin accepted information from the Natural Flow Study discussed above and produced recommendations for instream flows at the U.S. Geological Survey stream gage below Iron Gate Dam. To reach those recommendations the Instream Flow Phase II included an elaborate series of investigations and model-building efforts. The general technical elements of an instream flow study, the procedures followed in this particular case, and the committee's evaluation of those procedures are described in detail in Chapter 5.

Committee Evaluation

Several aspects of the Instream Flow Phase II are praiseworthy. The measurement of stream-bed topography and substrate characteristics in this study represent innovative cutting-edge methods that provided generally useful representations of the river channel. The two-dimensional hydrodynamic model in the Instream Flow Phase II represented the state-of-the-art application of flow models in simulating habitats. The application of two-dimensional approaches represented a willingness on the part of the investigators to engage in a highly complex and ambitious project to deal with the hydraulic and hydrologic aspects of the problem of characterizing fish habitat. The study incorporated distance to escape cover, an important variable that is sometimes ignored in other studies.

As a general perspective, the Instream Flow Phase II followed steps outlined in the Instream Flow Incremental Methodology (IFIM), which has seen wide application in studies of this type. The authors of the Instream Flow Phase II applied the IFIM properly. They also used bioenergetics and a fish-population model to test their results, and they tested model output by comparing observations of fish with predicted fish locations.

Despite these strengths, the committee found important shortcomings in the Instream Flow Phase II and its use of various models and data. Two major shortcomings—use of monthly data and lack of tributary analyses—are so severe that that they should be addressed before decision makers can use the outputs of the study to establish precise flow regimes with confidence. Neither was the fault of the authors of the Instream Flow Phase II; the shortcomings resulted from constraints imposed by the USBR, which indicated that lack of time and resources prevented them from providing additional calculations that would produce daily flows for the ecological modeling. Although monthly flow values can be useful for general river-basin planning, they are not useful for ecological modeling for river habitats, because the monthly average masks important discharge values that may exist only for a few days or even less. In short, planners operate on a monthly basis, but fish live on a daily basis.

The elimination of consideration of tributary processes apparently resulted from an agreement reached by basin managers not to include tributary processes in the habitat studies to simplify the engagement of stakeholders in the process. Since only the main stem of the Klamath River was subject to analysis, stakeholders with interests in tributary locations would not have to deal directly with the study. The Klamath River is not a confined gutter for rainwater, and therefore analyzing the river without considering its tributaries is akin to analyzing a tree by assessing only its trunk but not its branches. In addition, the study did not include important water-quality attributes such as dissolved oxygen levels, nutrient loadings, contaminants, and sediment concentrations, although each has important implications for the vitality of the fish populations of the Klamath River. Second, high flows are especially important

to the physical and biological processes of the Klamath River, and further analysis of their frequency, duration, and timing is essential in understanding the dynamics of the river's hydrologic, geomorphologic, and ecological processes. Reliance on monthly flow data, as outlined above, made analysis of high flows impossible within the scope of the study.

Third, there was a lack of a thorough assessment of the relationship between flow-data time series and the behavior of different species and life stages, and the population dynamics of coho and Chinook salmon. Fourth, the claim that the model outcomes are accurate, as assessed by some empirical tests of fish distributions and by use of the SALMOD model, are not substantiated, which impairs the utility of the Instream Flow Phase II. Statistical measures of the closeness of fit between model predictions and fish occurrence would substantially increase the confidence of users in the outputs of the study.

Finally, there are three major shortcomings in the experimental design of the Instream Flow Phase II: a fundamental beginning assumption about limits on salmon habitat; a lack of thorough assessment of the representativeness of the reaches used for detailed study; and the statistical approach to analyze the calculated set of instream flows, which did not use normalized data and did not have provisions for identifying serial autocorrelations.

Despite these limitations, and in the absence of any better information currently available, the committee concludes that the recommended flows resulting from the Instream Flow Phase II probably represent an improvement for the anadromous fishes in the Klamath River over the current flow regime. These are improvements in flow because they include intra- and interannual variations, and likely will enhance Chinook salmon growth and young-of-the-year production. Because the study was based on three species—Chinook salmon, coho salmon, and steelhead—it is not possible to know how well the recommendations apply to any one species or to all the species as a whole. Indeed, most of the information was from Chinook salmon, which suggests that confidence in its applicability to that species would be greater than to other species. To the degree that the studies conclusions are followed, it should be on an interim basis, pending the improvements the committee outlines below and a more comprehensive and integrated assessment of the scientific needs of the basin as a whole.

The study would be improved for greater utility by (1) using daily flows as a basis for calculations; (2) taking into account habitats, water, and sediment contributions from tributaries; (3) specifically testing how representative the selected test reaches are of the entire river; (4) rigorous statistical testing of the model outcomes to support claims of accuracy; (5) including water-quality measures, sediment loadings, and contaminants in the modeling process; (6) including extended analyses of high-flow events; (7) exploring through thorough analysis of the habitat times series the presence or absence of any life-stage habitat limitations for a variety of species and life stages for natural and existing flows; (8) substituting another stochastic approach rather than the Periodic Autoregressive Moving Average model to analyze the statistical nature of the calculated flows; and (9) conduct sensitivity analyses using dynamic fish-population growth and production models to investigate the influence of alternative flow regimes on life cycles and stages of salmon to undertsand the nature of bottlenecks that can potentially constrain population growth, as well as the potential for flow-related improvements. Additional suggestions for improving the model are in Chapter 7.

IMPLICATIONS FOR ANADROMOUS FISHES IN THE KLAMATH RIVER

The Natural Flow Study

The implications of the model investigations are mixed. From a positive perspective, the results define monthly "natural" variation that managers might reasonably expect, absent their own activities. The monthly variation depicted by the model represents a simulated picture of the conditions under which the biological community of the river evolved, and provides a backdrop for assessing the degree to which the present regulated flow regime departs. The flows also provide a general view of the total amounts of

water involved in the river and lake regime, with about 1.4 million acre feet annually flowing out of the lake on the average.

The Natural Flow Study reasonably captures the decadal variations in flows in the system that are likely to have occurred in the absence of upper-basin development and the installation of dams. These variations imply that in the regulated system, some decadal fluctuation in flows is reasonable, and that a completely unchanging regime imposed by engineering structures would not reflect the natural regime.

However, the internal workings of the model in the Natural Flow Study include several computational shortcomings that limit its use. These issues imply that the natural flow model produces results that probably cannot be used as a precise replication of natural flows, and that the individual numbers generated by the study are not firm, irrefutable values. The study's shortcomings imply that managers of the biological resources of the basin may use the results of the model in a general way as a form of guidance for the broad characteristics of the natural flow regime, but they cannot use the exact values produced by the study as a template for developing a flow regime with much confidence. The model is a general representation, and because its output is in monthly time steps, it is not capable of generating the daily time step needed for a completely effective instream flow model to be used in any ecological model downstream. As described in considerations of the Instream Flow Study in Chapter 5, this limitation has a ripple effect that limits the utility of the instream flow recommendations.

Finally, the current model is severely restricted for two general reasons. First, the basin and its biota have changed so much in the past century that the implications for the fishes of restoring "natural flows" are not clear. Second, the model does not treat the tributaries of the Klamath River, although they are and have been an essential part of the environments of the anadromous fishes. Without understanding the ecological and hydrological condition and dynamics in the tributaries, it is not possible to understand the ecological and hydrological condition and dynamics of the river.

A modified version of the Natural Flow Study model, using suggestions made in this report, could have management utility. It could be used as a template for a model of the present-day system. Such a model could be used to simulate "What if?" scenarios, test certain hypotheses, and demonstrate to stakeholders the implications of assorted management decisions and stakeholder choices. Since the Natural Flow Study model is built upon a familiar, user-friendly platform (Excel), a modified model might find wide use among stakeholders.

The Instream Flow Study

The basic conclusions of the Instream Flow Study are recommended flows expressed as monthly target values for discharges below Iron Gate Dam on the Klamath River. The most important outcome of the Instream Flow Study was that it indicated that increases in existing flows downstream from Iron Gate Dam probably would benefit fish populations through improved physical habitat associated with more water and through reduced water temperatures. If these conclusions were borne out by studies incorporating experimental flows and monitored responses, managers would be able to have greater confidence that decisions to increase flows would have a beneficial effect on anadromous fishes in the lower river. The authors of the Instream Flow Study mention two caveats, and this committee agrees with them. First, the flow recommendations apply to the needs of the anadromous fishes in the lower Klamath River, and they do not account for competing water demands for other purposes such as agricultural needs or the needs of federally listed fishes in the upper basin. Second, the flow recommendations address the needs of all the anadromous species in the lower Klamath River. They are not targeted for any individual species (listed or otherwise) and it is not possible to evaluate the conclusions separately for individual species.

Despite various concerns about the study, it is extremely unlikely, in the committee's judgment, that following the prescribed flows of the Instream Flow Phase II would have adverse effects on any of the anadromous fish species. Based on general principles and the information developed in that study,

following its prescribed flows probably would have some beneficial effects on the suite of anadromous fishes in the Klamath River considered as a whole, although not necessarily for every species.

DEVELOPING A COMPREHENSIVE SCIENTIFIC FRAMEWORK TO CONNECT SCIENCE AND DECISION MAKING

The committee found that science in the basin was being done by bits and pieces, sometimes addressing important questions, but not linked to other important questions and their studies. The Natural Flow Study and the Instream Flow Phase II were major science and engineering investigations, but the linkage of one to the other was only partially achieved. Other studies in the basin, such as the U.S. Geological Survey's hydrologic studies in the Sprague River Basin, or the extensive research in the Trinity River Basin (which is part of the Klamath River Basin), seem not to have had any influence on each other or on the flow studies examined in this report. The committee found that the most important characteristics of research for complex river-basin management were missing from the Klamath River: the need for a "big picture" perspective based on a conceptual model encompassing the entire basin and its many components. As a result, the integration of individual studies into a coherent whole has not taken place, and it is unlikely to take place under the present scientific and political arrangements.

To address science and management in the basin, the committee first recommends that the agencies, researchers, decision makers, and stakeholders together define basin-wide science needs and priorities. One method of achieving success in this effort would be through the establishment of an independent entity to develop an integrated vision of science needs. The body that defines this vision must be viewed by all parties as truly independent for it to be effective, unlike the Conservation Improvement Program, which, despite good intentions, appears to many people in the region as a creature of the U.S. Bureau of Reclamation, and therefore to be associated with the bureau's official mandates and responsibilities. If the proposed task force reports to the secretary of the interior, rather than to any specific agency, it is more likely to avoid the appearance of being controlled by any particular agency or interest group in the basin, and thus is more likely to be and to appear independent. Leadership of the task force by a senior scientist who reports to the secretary would be a major step toward removing perceived biases in science and its application.

The committee concludes that when the science needs for the basin are better characterized, the individual studies necessary to create a sound science-based body of knowledge for decision makers and managers will be more easily identified. Only if this general vision and process determines that the Natural Flow Study and the Instream Flow Phase II might help satisfy science needs in the basin should investigators seek to address the shortcomings that the committee has identified. The Trinity River Basin experience, despite some difficulties, provides a good example to follow in many aspects of the overall basin-wide effort.

Connecting effective science with successful decision making for delivering water to users, sustaining downstream fisheries, and protecting the populations of protected species has been problematic in the Klamath River Basin. The Natural Flow Study and the Instream Flow Phase II are not likely to contribute effectively to sound decision making until political and scientific arrangements in the Klamath River basin that permit more cooperative and functional decision making can be developed. The employment of sound science will require the following elements:

- A formal science plan for the Klamath River Basin that defines research activities and the interconnections among them, along with how they relate to management and policy.
- An independent science review and management mechanism that is isolated from direct political and economic influence, and that includes a lead scientist or senior scientist position occupied by an authoritative voice for research.
- A whole-basin viewpoint that includes both the Upper and Lower Klamath River Basins with their tributary streams.

- A data and analysis process that is transparent and that provides all parties with complete and equal access to information, perhaps through an independent science advisory group.
- An adaptive management approach whereby decisions are played out in water management with monitoring and constant assessment and with periodic informed adjustments in management strategies.

The committee recommends that the researchers, decision makers, and stakeholders in the Klamath River Basin emulate their colleagues in the Trinity River Basin in connecting science and decision making, and that the two units coordinate their research and management for the greater good of the entire river basin.

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Committee on Hydrology, Ecology, and Fishes of the Klamath River

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This project was supported by Contract No. 05CS811145 between the National Academy of Sciences and the U.S. Bureau of Reclamation. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the organizations or agencies that provided support for this project.

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The National Academies Press
500 Fifth Street, NW
Box 285
Washington, DC 20055

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Preface

The Klamath River basin is both at the edge and at the center. The basin is a 15,700 square mile watershed at the western rim of North America, where it encompasses a diverse ecosystem, wilderness areas, and irrigated farmlands in southern Oregon and Northern California. The basin is located at the center, however, of the landscape of controversy in American environmental management, and the issues that face Klamath River basin decision makers exemplify in magnified form many of the difficult science and policy challenges that have arisen across the continent. Management of the basin's hydrologic and ecological resources is complicated because decision makers must sort through a myriad of potential strategies for operating a complex system with inter-related rivers, lakes, marshes, dams, and diversions. The river basin boundaries outline an ecosystem that includes economically valuable water resources and ecologically valuable species, including endangered, threatened, and other fishes, which are dependent on the rivers and lakes for their survival. Alterations to the original hydrologic system began in the late 1800s, accelerated in the early 1900s, and continue today. They include water-control works by private land and water owners, by the large and intricate Klamath Irrigation Project of the U.S. Bureau of Reclamation (USBR), and by several hydroelectric dams operated by a private corporation, PacifiCorp.

These hydrologic alterations combined with overfishing, habitat alteration, poor water quality, and nonnative species, have led to a dramatic decline in coho salmon, Lost River suckers, and short-nose suckers and some other fishes of the Klamath River. Salmon, once providing the basis of the third largest salmon fishery among west-coast rivers, are a critical component of the ecosystems and cultural systems of the Klamath region. By the turn of the twentieth century, the inherent difficulties in balancing the benefits of the river's water for fish, agriculture, and hydropower had become further complicated by national resource policies supporting Native American rights, water development, hydropower production, and endangered and threatened species.

Science and engineering have been the handmaidens of water development in the Klamath River basin, and decision makers have called upon science and engineering expertise to aid them in sorting out the choices for future management of the basin's water and water-related resources. Recognizing that the best decisions are likely to benefit from the understanding derived from scientific research and engineering investigations, in 2001 the U.S. Department of Interior and the U.S. Department of Commerce requested that the National Research Council (NRC) form a committee to complete two reports. The first (interim) study, completed in 2002, assessed the strength of scientific support for the 2001 biological assessments and biological opinions on the three endangered or threatened fish species in the Klamath River basin. The second (final) study, completed in 2004, evaluated the 2002 biological assessments and biological opinions, and other matters related to the long-term survival and recovery of the federally listed fish species.

Subsequently, in 2005 the Bureau of Indian Affairs (on behalf of the Native American tribes of the basin) and the USBR (serving many irrigators in the basin) requested that the NRC conduct a more specific evaluation and review two new studies, completed after 2004, which were designed to inform decision makers about the hydrology and fish ecology of the Klamath River basin. In order to define hydrologic conditions that supported the predevelopment fish population, one study used data and modeling approaches to gain a clear understanding of what the natural flows of the river might be without the presence of agriculture and the water control infrastructure. The second study created a model-based linkage between the hydrology and the resulting aquatic ecosystems that support the fish populations in the river. The present report is the outcome of the NRC evaluation and review of those studies.

The committee is grateful for the support of USBR officials William Rinne, James Hess, and William Shipp, in addition to Pablo Arroyave, of the Bureau of Indian Affairs. Many people with close associations with the Klamath River basin aided the committee in its efforts to understand the Klamath River basin and its resources. The people of Yreka, California, and Klamath Falls, Oregon, made the committee welcome and shared their perspectives during committee visits to those communities. During public sessions associated with those visits, local citizens joined federal, state, and local agency representatives in discussions and presentations for the committee. Jon Hicks and Cindy Williams, of the USBR's Klamath Falls Office, were particularly helpful to the committee in gaining an understanding of the Klamath Project, a key component of the present basin system. During a visit by some committee and staff members to Utah State University in Logan, Dr. Thomas Hardy extended every courtesy, as did Craig Albertson, Elizabeth Cohen, Alan Harrison, Thomas Perry, and Mark Spears during another similar visit to the USBR offices in Denver, Colorado. These researchers repeatedly aided the committee in tracking down information, data, and elusive documents.

The committee also benefited from terrific support from the NRC staff. James Reisa (director of the Board on Environmental Studies and Toxicology) and Stephen Parker (director of the Water Science and Technology Board) provided a supportive institutional home for the committee and its members. David Policansky (scholar and senior program officer of the Board on Environmental Studies and Toxicology) played a pivotal role in the deliberations of the committee and the writing of the report. His wide experience, range of knowledge, and congenial interactions with the committee were important contributions to the result. Suzanne van Drunick (project director and senior program officer) guided the committee with great wisdom and adroit management through its meetings and its report writing, providing organizational skills and knowledge of the Klamath issues that made the report possible. The extensive hydrologic knowledge and sound judgment of Lauren Alexander (senior staff officer of the Water Science and Technology Board) contributed substantially to early stages of development of the committee and its report. The complicated mechanics of arrangements for committee meetings and travel, as well as the smooth production of the meetings was in the capable hands of senior program assistants Liza Hamilton and Jordan Crago. Thank you to all of these talented NRC professionals.

This report is the consensus expression of the committee's conclusions and recommendations, but it is actually the product of hard work and thoughtful review. We express our appreciation to members of the Board on Environmental Studies and Toxicology and the Water Science Board; to the NRC's Report Review Committee, which took on the responsibility of external review oversight; and to the independent scientists and engineers listed below, who reviewed the report. These reviewers provided us with insightful commentary, numerous penetrating questions, and exceptionally helpful suggestions for clarifying and improving our report. We benefited enormously from their help.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report:

Stanley Gregory, Oregon State University
Robert Huggett, Seaford, Virginia
William Lewis, University of Colorado
David Maidment, University of Texas
Jeffrey Mount, University of California at Davis
Patrick O'Brien, ChevronTexaco Energy Technology Company
LeRoy Poff, Colorado State University
Gordon Robilliard, Entrix, Inc.
Kenneth Rykbost, Klamath Falls, Oregon

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by the review coordinator, Paul G. Risser, of Oklahoma State University, and the review monitor, Gordon H. Orians, of the University of Washington (emeritus). Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

To my fellow committee members, I express a special debt of gratitude. They were a committee drawn from different backgrounds and disciplinary cultures, yet they were willing to work together in a harmonious collective effort to address the complexities of science and engineering for the Klamath River system. They put aside their personal biases, worked long hours that sacrificed their own professional time, and traveled great distances to make their contributions to this report. Such unpaid service is remarkable, but the committee received a truly remarkable recompense: the opportunity to contribute the experience and knowledge collected from our careers to support a public vision for the future of the basin and its resources. It is our hope that although the Klamath River basin is at the edge of the continent, it will also be a central example of successful application of science and engineering to American ecosystem restoration and management.

William L. Graf, *Chair*
Committee on Hydrology, Ecology, and Fishes
of the Klamath River Basin

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