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Managing the Columbia River: Instream Flows, Water Withdrawals, and Salmon Survival

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Managing the Columbia River: Instream Flows, Water Withdrawals, and Salmon Survival

Committee on Water Resources Management, Instream Flows, and Salmon Survival in the Columbia River Basin

Water Science and Technology Board

Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

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* This committee was organized, overseen, and supported by the Water Science and Technology Board (lead) and the Board on Environmental Studies and Toxicology. Biographical sketches of committee members are contained in Appendix E and rosters of the two parent boards are contained in Appendix F.

Preface

The Columbia River and its basin have long comprised one of the great natural resources of the United States. The river was an abundant resource for Native Americans that inhabited the region for thousands of years. The river dependably produced vast amounts of salmon to be eaten fresh or dried, which ensured a diet of adequate protein. Subsequently, as the nation developed and expanded westward, President Thomas Jefferson promoted exploration of the recently-acquired lands of the Louisiana Purchase. This led to the 1804-1806 expedition of Lewis and Clark to explore and chronicle the American West and to pursue Jefferson's goal of finding the fabled water route to the Pacific. The journey started on one of the nation's great rivers, the Missouri, and ended on another of the nation's great rivers, the Columbia. Since then, the vast and diverse resources of the Columbia River basin were utilized and contributed to the region's economic and population growth, which gained momentum many years ago and is accelerating today.

Initially, there were efforts to harvest the resources of the Columbia through a fishery industry and through the development of the basin's arid, but fertile, lands. Low-cost hydroelectric power attended and aided this development, which included cities beyond the Columbia basin. The industrial corridor from north of Seattle to south of Portland and beyond will continue to grow, and this human population growth puts ever-increasing social, political, and economic pressures on the resources of the Columbia River. It also increases tensions among the various enterprises that desire a greater portion of the river's largesse.

In the meantime, the salmon populations of the Columbia River have been steadily declining since the first dam was built on the river. In fact, several species of salmon are now listed as endangered under the federal Endangered Species Act. By law, efforts must be made to protect these species from further degradation and to start the process of recovery. The dilemma is how to protect the salmon and the Columbia River's natural resources, and still enable those resources to be used for further enriching the economy of the region. At issue in our study were the implications surrounding the issue of additional water rights permits from the mainstem Columbia River, the applications for which have been on hold for some time. Our committee's charge was to consider the implications for potential additional withdrawals for Columbia River salmon, and to comment upon the body of scientific knowledge used to inform these decisions. Our committee was not charged to review all the ecological issues (of which there are many) across the basin which affect salmon, but rather to conduct a more focused investigation regarding conditions in a stretch of the mainstem Columbia River. Nor was our committee charged with recommending policy decisions, but rather was requested to review the science used by decision makers and to comment on it.

To address these issues, the State of Washington Department of Ecology requested the National Research Council to conduct a study addressing specific issues given in the Statement of Task provided in the body of this report. Our committee avoided the temptation to go beyond the tasks we had been assigned—although each of us, while not encumbered by biases or personal gain from any direction the study might take, nonetheless had personal views, some of them strongly held. All had experience that related to one or more aspects of the issues at hand. We strived to ensure that the many viewpoints expressed by our committee members were heard before we came to a consensus on what should be included in our report. The resulting report represents the collective view of our committee. In some cases, it may differ from what individual members might have written. The composition of the committee was such that most disciplines related to the issues contained in the charge to the committee were represented by experienced and knowledgeable people. I thank each member of the committee who volunteered many, many hours of personal time without any financial compensation. Their reward is the sense of satisfaction in objectively addressing a problem of importance to all of the citizens of the Columbia River basin, the larger Pacific Northwest, and the nation.

We devoted a great deal of time at our meetings listening to interest group representatives, as well as private citizens, in order to learn more about the broad range of interests and concerns regarding the Columbia River and its salmon. Still, the one group central to our task that did not speak was the various species of salmon, whose populations have been in general decline since the introduction of an industrial-based economy. But several people we visited with spoke on behalf of the salmon and of related environmental issues.

Our committee is grateful to the Washington State Department of Ecology for its insight regarding the need for an objective, independent look at the issues related to survival of the various salmon species, and how water management in the Columbia basin might affect the fate of the salmonids. We thank Tom Fitzsimmons, Gerry O'Keefe, and their colleagues at the Department of Ecology, who provided support and assistance before and during our study. We also thank all members of a "Resources Group," which consisted of several experienced, expert scientists from the region. The Department of Ecology invited these experts to provide input to this study. Our committee found the presentations from these experts, which were provided in open public meetings in early 2003, extremely useful and informative.

The committee held four meetings, the first three in the State of Washington and the last at the National Research Council in Washington, D.C. The process involved presentations at the first two meetings from the Department of Ecology and its staff, the Resources Group, and others with specific interests or expertise. All information-gathering meetings were open and publicly announced. We sought to hear from as many groups and individuals as was possible within our time constraints, but all speakers and guests were invited to provide written extensions of their comments at the meeting or subsequent to it. All presentations and written comments were carefully considered by the committee. The committee thanks all individuals who provided oral and/or written information, as that information was very helpful to us.

The committee, and particularly I as committee chair, thank the NRC staff for its dedication and diligent work in making this report highly professional. I particularly thank Jeffrey Jacobs, Senior Staff Officer of NRC's Water Science and Technology Board, who laboriously poured over lengthy and often too verbose input to put together a concise and coherent report. Jeff and the committee were ably assisted by Ellen de Guzman, Research Associate at the Water Science and Technology Board, who handled administrative details for the meetings and ably assisted in all phases of report preparation. Finally, David Policansky,

Associate Director of the NRC's Board on Environmental Studies and Toxicology, provided input and guidance, attending all meetings and contributing to the committee's deliberations. This report is the work of the committee in terms of scientific input, but the final professional product is due to the efforts of the NRC staff.

This report was reviewed in draft form by individuals chosen for diversity of 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 for 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 reviewers for their helpful suggestions, all of which were considered and many of which were wholly or partly added to the final report: Ellis Cowling, North Carolina State University (emeritus); William Kirby, U.S. Geological Survey; Ronald Lacewell, Texas A&M University; Pamela Matson, Stanford University; Willis McConnaha, Mobrand Biometrics; Kathleen Miller, National Center for Atmospheric Research; William Pearcy, Oregon State University; Brian Richter, The Nature Conservancy; Will Stelle, Preston Gates; John Williams, NOAA Fisheries; Robert Wissmar, University of Washington; and Ellen Wohl, Colorado State University. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the conclusions or the recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Robert Beschta, Oregon State University, appointed by the NRC's Division on Earth and Life Studies, and by Stephen Berry of the University of Chicago, appointed by the NRC's Report Review Committee. Appointed by the National Research Council, they were responsible for ensuring that an independent examination of the report was carefully carried out in accordance with NRC institutional procedures and that all review comments were considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

The Department of Ecology faces great challenges in addressing the complex issues of managing Columbia River resources in the State of Washington. It must work with the other basin states, one Canadian province, several Native American tribes, and other interested entities. It will face many political pressures. But we are sure of its sincerity in finding a balance so that no interest is ignored, even if compromise is required by all. We wish the department the best of luck as it faces these challenges.

Ernest T. Smerdon,
Chair

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Executive Summary

BACKGROUND

For thousands of years, North America's Columbia River salmon runs were the most abundant on Earth. The salmon evolved in a setting of many long- and short-term environmental changes and disruptions. With the introduction of an industrial-based economy to the region in the late nineteenth century, the scale and the rate of environmental variability in the basin changed. The creation of impoundments on the Columbia River and its tributaries, dam operations, commercial fishing, logging, diversions for irrigated agriculture, and human population growth have altered the Columbia's pre-settlement flow regime and have reduced the quality of salmon habitat across the river basin. There have been attendant declines—including some extinctions—in the populations of all resident salmon species. Annual salmon and steelhead returns to the Columbia River estuary were estimated to have been as high as 16 million fish per year during the late 1800s. The returns have dwindled over time, dropping to near one million fish per year in the 1990s. These numbers rebounded in the late 1990s and early 2000s, largely because that time frame coincided with a period of favorable ocean conditions for salmon. The majority of returns today consist of hatchery-reared fish. Many of these salmon are currently listed as threatened and endangered pursuant to the federal Endangered Species Act.

The Columbia River makes up part of a large (basin size of roughly 250,000 square miles) ecological system with many features that vary naturally on several different time scales. In addition to natural ecological variability, salmon are affected by human-induced changes such as water diversions and water control structures. Furthermore, Columbia River salmon spend most of their lives in the highly dynamic Pacific Ocean. The combination of these and other factors presents a setting of extraordinary variability and uncertainty for Columbia River salmon. The life cycles of Columbia River salmon (there are several different species and sub-species) have been intensively studied. In fact, Columbia River salmon are among the world's most carefully studied fish species, and this research has yielded an excellent understanding of salmon physiology and migratory behavior.

The Washington State Department of Ecology issues water use permits for the portion of the Columbia River that flows through the State of Washington. Water withdrawal permit decisions must be balanced with the state's obligation to protect and enhance the quality of the natural environment, including salmon habitat. The department considers scientific knowledge of salmon and environmental variables in making permitting decisions. That body of knowledge, as extensive and thorough as it may be, is imperfect and contains some competing theories, models, and perspectives.

This is the context in which the Washington State Department of Ecology requested that the National Research Council (NRC) provide advice regarding salmon and water management decisions. In response to this request, the National Research Council reviewed and evaluated existing scientific data and analyses related to fish species listed under the Endangered Species Act in the Columbia River basin, and reviewed and evaluated environmental parameters critical to the survival and recovery of listed fish species. The cumulative effects and the risks to the survival of listed fish species of potential future water withdrawals of between approximately 250,000 acre-feet and 1,300,000 acre-feet per year were also evaluated. There are currently many pending water withdrawal permit applications along the Columbia River in the State of Washington. The total volume of water represented by these applications falls within this 250,000—1,300,000 acre-feet per year range. In addition, the effects of proposed management criteria, specific diversion quantities, and specific features of potential water management alternatives provided by the State of Washington were to be evaluated. To conduct the study, the NRC appointed the ad hoc *Committee on Water Resources Management, Instream Flows, and Salmon Survival in the Columbia River.* This report's Preface contains additional information about the study process, and Chapter 1 includes verbatim the committee's statement of task.

SALMON AND ENVIRONMENTAL PARAMETERS

There are competing scientific hypotheses and models regarding the effects of environmental forces on Columbia River salmon. River velocity and water temperature are of particular interest to fisheries scientists, water managers, and interest groups, as these factors influence the migratory behavior of salmonids. Several computer models have been used to simulate the effects of river flows (especially water velocity) and temperature on the migratory speed and survival of smolt (young salmon ready to migrate from fresh water to the sea). These models ascribe different levels of importance to river discharge and temperature and their effects on migratory conditions for juvenile salmonids. Selecting the "best" model of salmon-environmental relationships was neither part of this study nor was it critical to its completion. Several scientists presented analyses and models in open public meetings for consideration in this study. These presentations were used as background information for considering the degree to which proposed future water extractions may pose increased risks to the survival of endangered fish species. This information, along with the body of scientific evaluations of Columbia River salmon and their habitat, portrays a complex system of interacting environmental variables that influence the rates of salmon smolt survival on their downstream journey through the Columbia River hydrosystem. **Within the body of scientific literature reviewed as part of this study, the relative importance of various environmental variables on smolt survival is not clearly established. When river flows become critically low or water temperatures excessively high, however, pronounced changes in salmon migratory behavior and lower survival rates are expected.**

COLUMBIA RIVER FLOWS AND WITHDRAWALS

Changes to the Annual Hydrograph

The annual flow patterns of the Columbia River underwent a substantial transformation

during the twentieth century. At the beginning of the twentieth century, the river's flows exhibited great seasonality, with roughly 75 percent of the Columbia's annual flows occurring during summer months (April-September) and roughly 25 percent of annual flows occurring during winter months (October-March). The river's annual discharge is roughly 190 million acre-feet per year. The pattern of annual flows changed in response to the construction of numerous Columbia River mainstem and tributary impoundments, and the subsequent operations of this water control system. The system is known as the Federal Columbia River Power System (FCRPS), and the principal original purposes underlying its construction were to provide hydroelectricity, irrigation, and flood control benefits. Construction of some of the system's large mainstem projects, such as Grand Coulee and Bonneville, began in the 1930s. The post-World War II period saw a burst in project authorization and construction of additional large projects. Other projects were built in connection with the Canada-U.S. Columbia River Treaty signed in 1961. The hydrological implications of the system's construction were tremendous. As the system's water control projects came on line, annual flows of the Columbia became and less and less seasonal, as the differences between summer and winter flows were reduced in order to provide reliable, year-round hydropower generation and distribution. In the late 1970s, the Columbia's annual flows had been modified such that they were divided roughly evenly between summer and winter, as compared to the 75:25 ratio that had existed at the beginning of the twentieth century. In addition to this "flattening" of the annual Columbia River hydrograph, other key impacts of the construction and operations of the hydropower system were a decrease in water velocities, a change in the size and orientation of the Columbia River plume, and major changes to limnology and nutritional pathways in the Columbia River estuary and its food web. All these changes have likely had significant effects on the early ocean survival of juvenile fish leaving the Columbia River. Passage of environmental legislation such as the National Environmental Policy Act (1969) and the Endangered Species Act (1973) resulted in changes in operational patterns and priorities. "Flow targets" were established by federal and state agencies in an effort to sustain and recover salmon habitat and populations that had declined over time. The FCRPS today is operated primarily to provide benefits in terms of flood control, hydropower, and instream flows.

This study's focus was on the implications of potential additional water withdrawals (which would be primarily for irrigated agriculture) from the mainstem Columbia River for salmon survival. The study charge did not call for an examination of the hydrologic impacts of consumptive withdrawals in comparison with other actions, such as the creation of impoundments, dam operations, or changes in land cover.

Prospective Additional Water Withdrawals

Of special interest within this study was the consideration of the effects and risks to salmonid survival of a specific range of possible additional water withdrawals, ranging from 250,000 acre feet per year to 1,300,000 acre-feet per year. The latter figure represents roughly 28 percent of the total volume of water permits that have been issued to present by the State of Washington for surface water withdrawals from the Columbia River and groundwater withdrawals from the zone within one mile of the river. The effects of these proposed withdrawals and their attendant risks for the survival of a specific species will vary considerably depending upon Columbia River flow levels. Despite construction and operations of the

hydropower system, the river still exhibits considerable flow variations on daily, seasonal, and annual time scales. Under current conditions, less than one percent of total annual withdrawals are made during January. By contrast, during July—the month of highest withdrawals—about 18 percent of annual withdrawals from the Columbia River in the State of Washington are made. The seasonality of water withdrawals is of utmost importance when considering how Columbia River water withdrawals affect salmon survival rates.

Many calculations and speculations could be made with regard to the range of prospective additional withdrawals considered in this study. Assuming that the monthly pattern of withdrawals from the mainstem Columbia River continues essentially unchanged, and assuming that the maximum amount of prospective withdrawals in the range considered in this study (maximum of 1,300,000 acre-feet per year) is diverted, additional withdrawals of roughly 2,600 acre-feet in January and roughly 234,000 acre-feet in July would result. The effects of these prospective additional January withdrawals (2,600 acre-feet) would result in withdrawals being less than one percent of mean January Columbia River flow. The effects of these prospective additional withdrawals in July (234,000 acre-feet), when river flows are lower, would increase July withdrawals from their current value of roughly 6.8 percent of mean Columbia River flows to roughly 8.6 percent of mean Columbia River flows. Under *minimum* July flow conditions, the effects would be even greater: the upper end of the proposed range of diversions would increase current July withdrawals from roughly 16.6 percent to roughly 21 percent of Columbia River *minimum* flows. Water temperature is also a concern. Columbia River water temperatures have been increasing for decades, and those temperatures are at their highest during summer months (when demand for extractions is also at or near its peak). Water quality is also an issue, as return flows from irrigated agriculture and urban activities are of degraded quality and could affect fish that are stressed already from high water temperatures and longer travel times.

The scale of the Columbia River basin and current limits of scientific understanding of salmon and their habitat inhibit reliable, precisely quantified predictions of how additional water withdrawals will affect risks to salmon survival. Nevertheless, further reductions in Columbia River flows during low-flow periods will increase those risks, especially since most of those withdrawals would occur during a critical period for those salmon species that are migrating through the mainstem Columbia River. There are differences in the migration patterns and timing of the Columbia River's listed salmon species and sub-species. Accordingly, only those salmon populations that migrate (downstream or upstream) through the Columbia River corridor during critical low-flow periods or years will be exposed to the greater risks entailed by additional withdrawals and reductions in discharge. Examples of these populations include subyearling ocean type Chinook from the Snake and Columbia rivers, adult Snake and Columbia River summer Chinook, adult Snake and Columbia River steelhead, and adult sockeye salmon.

Columbia River salmon today are at a critical point. The basin's salmon populations have been in steady decline over the past century, and scientific evidence demonstrates that environmental and biological thresholds important to salmon—such as water temperature—are being reached, or in some cases exceeded. Salmon are more likely to be imperiled during late summer on the Columbia River, as they experience pronounced changes in migratory behavior and survival rates when river flow becomes critically low or water temperature becomes too high. Further decreases in flows or increases in water temperature are likely to reduce survival rates. Trends such as human population growth in the region and prospective regional climate warming further increase risks regarding salmon survival.

Decisions regarding the issue of additional water withdrawal permits are matters of public policy, but if additional permits are issued, they should include specific conditions that allow withdrawals to be discontinued during critical periods. Allowing for additional withdrawals during the critical periods of high demand, low flows, and comparatively high water temperatures identified in this report would increase risks of survivability to listed salmon stocks and would reduce management flexibility during these periods.

WATER MANAGEMENT INSTITUTIONS

A Joint Forum for Considering Water Withdrawal Applications

The Columbia River basin is a single hydrologic unit extending over seven U.S. states, many Indian reservations, and one Canadian province. Water permitting decisions are made by basin states with few obligations or attempts to make those decisions in a spatially-coordinated manner across the entire basin. This fragmented basis for making water rights permitting decisions represents a barrier to better decision making in this realm. It also inhibits consideration of the cumulative effects of additional small, individual withdrawals. The effects of any one newly authorized individual water withdrawal from the Columbia River on flows and temperature are likely to be minimal. The effects of additional small diversions accumulate, however, and will eventually have serious consequences for salmon, especially when interacting with variables such as climate, ocean conditions, and human population growth. The current "case by case" approach for evaluating the effect of water permits on salmon can be likened to a beaver felling a tree—the effect of any single wood chip removed by the beaver on the health of the tree is slight and indeterminable. Critical thresholds, however, are crossed as the tree is girdled, reducing growth and causing mortality of major branches, or eventually removing enough wood to fell the tree. Every bite has only a small effect in itself, but each one contributes to the tree's eventual felling. Columbia River salmon are being subjected to a similar process. In isolation, small additional water withdrawals each have an imperceptible effect on survival rates of salmon; but the cumulative effects of many small, additional individual water withdrawals throughout the Columbia River basin collectively could push salmon across life-threatening thresholds, particularly in critical periods of high demand and low flows. Decreases in Columbia River flows have been caused by a small number of large diversions along the river—the long-approved large diversions for the Columbia Basin Project clearly dominate historical diversions—along with a large number of small, individual actions. A process in which water rights permitting applications throughout the basin are considered apart from this phenomenon of cumulative effects has contributed to salmon declines and may be contributing to political tensions. Decisions regarding prospective additional diversions should be considered with an understanding of existing and potential future diversions across the entire basin, and should be subjected to professional and public scrutiny, a consideration of risk factors, and system-wide equities. The lack of such a basin-wide framework also tends to discourage efforts at conservation and better management, since such measures employed in one state or other entity will have limited effects if other states and entities do not enact similar measures.

The State of Washington and other basin jurisdictions should convene a joint forum for documenting and discussing the environmental and other consequences of proposed water diversions that exceed a specified threshold. This forum could be convened within the

existing Northwest Power and Conservation Council, which includes broad representation of political entities from across the basin. The council has accomplished good things, and discussions of water permit applications could be integrated into its resource management responsibilities. Limitations of convening this forum within the council include possible administrative and legal complications of extending the council's functions. Convening the forum within a new, simple, framework could offer the advantage of greater flexibility and a clearer focus of responsibilities and obligations.

Better Management of Existing Water Supplies

Water management approaches such as water conservation and associated transfers, conjunctive use of groundwater, water markets, water banks, and environmental water accounts have the potential to support regional economic growth without requiring additional Columbia River water diversions. These approaches can help transfer water between willing buyers and willing sellers and can be useful in helping shift water in response to changing economic conditions and priorities, as well as during periods of shortage. Physically, they may entail transfers of water in conveyance facilities, or the storage of water in a reservoir or groundwater reserve to be used later during a period of high demand. In some cases they may require the construction of conveyance and storage facilities. These approaches can be important in promoting a prosperous Columbia River basin economy that meets human needs while sustaining viable salmon populations and a healthy Columbia River ecosystem. Water supplies procured through these means could augment both water deliveries and instream flows. To be effective, such systems must consider and devise safeguards for preventing undue harm to third parties. They are also likely to require investments in physical infrastructure and in human resources. **The State of Washington and other Columbia River basin entities should continue to explore prospects for water transfers and other market-based programs as alternatives to additional withdrawals.**

MAKING COLUMBIA RIVER MANAGEMENT DECISIONS

Washington State Department of Ecology Water Management Scenarios

The water management scenarios proposed by the Washington State Department of Ecology and that were considered in this study contained many assumptions and actions related to water withdrawal quantities, management actions, and water use fees (key features of the scenarios, and comments that resulted from this study, are listed below; Appendix A lists these scenarios in their entirety). Some of the scenarios promote adaptive management concepts, which is appropriate and encouraging. Several possible management actions did not contain enough specificity to enable detailed evaluation. A pervasive aspect of the scenarios is the lack of comprehensive, basin-wide consideration of water uses and needs as a context for evaluating withdrawal permit applications.

Key features of the scenarios, along with commentary and evaluation, are listed below.

- *Conversion of interruptible to uninterruptible water rights (Scenarios 1-4).*

The needs of some users (especially growers of perennial crops) for uninterruptible withdrawals are understandable. The downside of such a system, however, is that uninterruptible status makes adaptive responses in periods of stress more difficult. Uninterruptible water rights are pre-1980 state law water rights that have priority over mainstem, instream flow rights that were established in 1980. These rights stand in contrast to interruptible water rights, which may be curtailed under certain low-flow conditions to protect mainstem, instream flows.

The conversion of water rights to uninterruptible status will decrease flexibility of the system during critical periods of low flows and comparatively high water temperatures. Conversions to uninterruptible rights, during these critical periods, are not recommended.

- *Criteria for state-of-the-art efficiency (Scenarios 1-4).*

The criteria for assessing the state-of-the-art (water use) efficiency measures are not described. In addition, organizational responsibility for making that evaluation is not specified.

- *Re-evaluation at 10 and 20 years (Scenarios 1-3).*

The idea of re-evaluating the scenarios periodically is excellent and is consistent with adaptive management principles. For this re-evaluation to be meaningful, decisions should be able to be adjusted if evaluation calls for such. No evidence of any such reversibility was provided. In some cases, more frequent re-evaluations may be in order.

- *Monitoring and metering (Scenarios 1-3).*

Monitoring for compliance with standards and water metering are also excellent ideas and could be accomplished as a part of this report's recommended basin-wide joint forum for discussing Columbia River basin water permit applications.

- *Charges for water rights (Scenarios 2-4).*

Charges for water rights appear to be arbitrarily chosen and out of proportion to the probable costs of mitigation and the value of water. For example, Scenario 2 specifies a charge of $10 per acre-foot per year to be used (among other things) to acquire mitigation water in low-water years. Even in high-water years, the economic value of out-of-stream water is greater than $10 per acre-foot per year, and this value increases in low-water years. This scenario seemingly poses selling water rights for $10 per acre-foot per year, when water may later have to be purchased for several times that amount.

- *Water markets.*

Proposals within the scenarios to establish water markets and water banks are appealing, as they offer potential improvements over existing water allocation systems. However, restricting markets to the Columbia River mainstem, and only to the State of Washington, is narrowly construed. For example, the Department of Ecology already allows for 600,000 acre-feet per year to be used by Oregon, but no allowance is made for uses in Idaho, Montana, Canada, or by tribal groups. Efforts toward developing water markets should be complemented with efforts to evaluate third-party effects and to design proposals for compensating users indirectly harmed by water rights transfers.

- *Structural storage measures.*

Structural measures imply that tributaries are to be used for additional storage, but ecological habitat and conditions in tributaries are important for many reasons, including their relationship to Columbia River salmon survival. Tributaries should be considered for protection and for mitigation, as well.

- *Scenario 5.*

This scenario was labeled a "no action" scenario, yet it prescribes new actions in that it allows for additional water withdrawal permits. The notion of consulting with fishery managers is good; however, no mention is made of criteria for the evaluation, how the results of the evaluation might be enforced, who decides how much mitigation is needed, and what—if any—limits on new permits might be enacted.

- *Mitigation.*

"Mitigation" measures are suggested in most of the management scenarios. Although the idea of "mitigating" impacts is attractive, the reality of most mitigation measures is that they are not well coordinated; that is, a management agency may attempt to offset harmful impacts of water withdrawals in one part of a river system with mitigation measures (e.g., ecosystem restoration) elsewhere. The ultimate outcomes of such varying actions, however, are difficult to accurately predict, measure, and compare (if indeed they are ever measured and meaningfully compared, which they often are not), thus making it difficult to determine if "mitigation" was actually achieved.

Science and Decision Making

The management of Columbia River salmon is an exceedingly complex public policy issue. The creation of comprehensive management strategies that enhance viable salmon populations, that calm disputes, and that meet human and economic demands will likely require a flexible and collaborative decision making approach that involves scientists, managers, and decision makers. Science has contributed greatly to the collective knowledge of Columbia River salmon, but "better" or "more" scientific information will not necessarily lead to the resolution of disputes or to better management decisions. **Sound, comprehensive salmon management strategies will depend not only on science, but also on a willingness of elected and duly appointed leaders and managers to take actions in the face of uncertainties**. It will also depend upon scientists and managers working in a process in which managers and elected officials help frame scientific investigations and inquiry. The scientific knowledge of Columbia River salmon is as extensive as for any other fish species in the world. Improvements in salmon habitat and return rates will require a willingness to employ existing scientific knowledge—despite its imperfections—to address some of the factors that scientific research suggests have led to their declines. A process in which scientists monitor outcomes of management actions and provide feedback to stakeholders and decision makers (who then adjust management actions accordingly—generally referred to as "adaptive management") will be instrumental in helping understand how additional scientific research can best support management decisions.

1

Introduction

The Columbia River and its tributaries constitute one of North America's great river systems. The Columbia River Basin extends over an area of 258,000 square miles (Leopold, 1994), covering portions of seven U.S. states and one Canadian province (Figure 1.1). The river stretches 1,214 miles from Canada to the Pacific Ocean (ibid.). One of the Columbia's main tributaries is the Snake River, which drains most of the basin's southeastern reaches and enters the Columbia near the Tri-Cities (Kennewick, Pasco, and Richland) region of central Washington. Other important tributary streams are the Clearwater, Deschutes, Kootenai, Pend Oreille, Salmon, and the Willamette.

COLUMBIA RIVER SALMON

The Columbia River is well-known for its rich variety of salmon species and populations. Columbia River salmon once existed in great abundance and served as the foundation of the diets of the region's Native American tribes for centuries. Lewis and Clark described the abundance of Columbia River salmon during their expedition to the region in 1805-06:

> Captain Clark. . .halted at two large mat-houses. Here, as at the three houses below, the inhabitants were occupied in splitting and drying salmon. The multitudes of this fish are almost inconceivable. The water is so clear that they can readily be seen at the depth of 15 or 20 feet; but at this season they float in such quantities down the stream, and are drifted ashore, that the Indians have only to collect, split, and dry them on the scaffolds (Coues, 1893, p. 641).

The Pacific Northwest and its salmon populations and habitat have undergone many changes in the two hundred years following Lewis and Clark's transcontinental adventure. The region has experienced substantial human population growth, and attendant land use changes have altered vegetation and hydrologic patterns. Hydropower dams on the Columbia mainstem and hundreds of storage, diversion, and smaller-scale hydropower dams on its tributaries have altered the volume and seasonality of river flows. The cumulative effects of these and other changes have contributed to a long-term decline in the number of adult salmon returning to the river to spawn. Historic annual runs of salmon and steelhead, believed to have been at times as great as 16 million fish (NPPC, 1986), declined to about 1 million by the 1990s (http://www.nwppc.org/library/pocketguide/pocketguide.pdf; accessed November 20, 2003), and increased in the late 1990s and early 2000s.

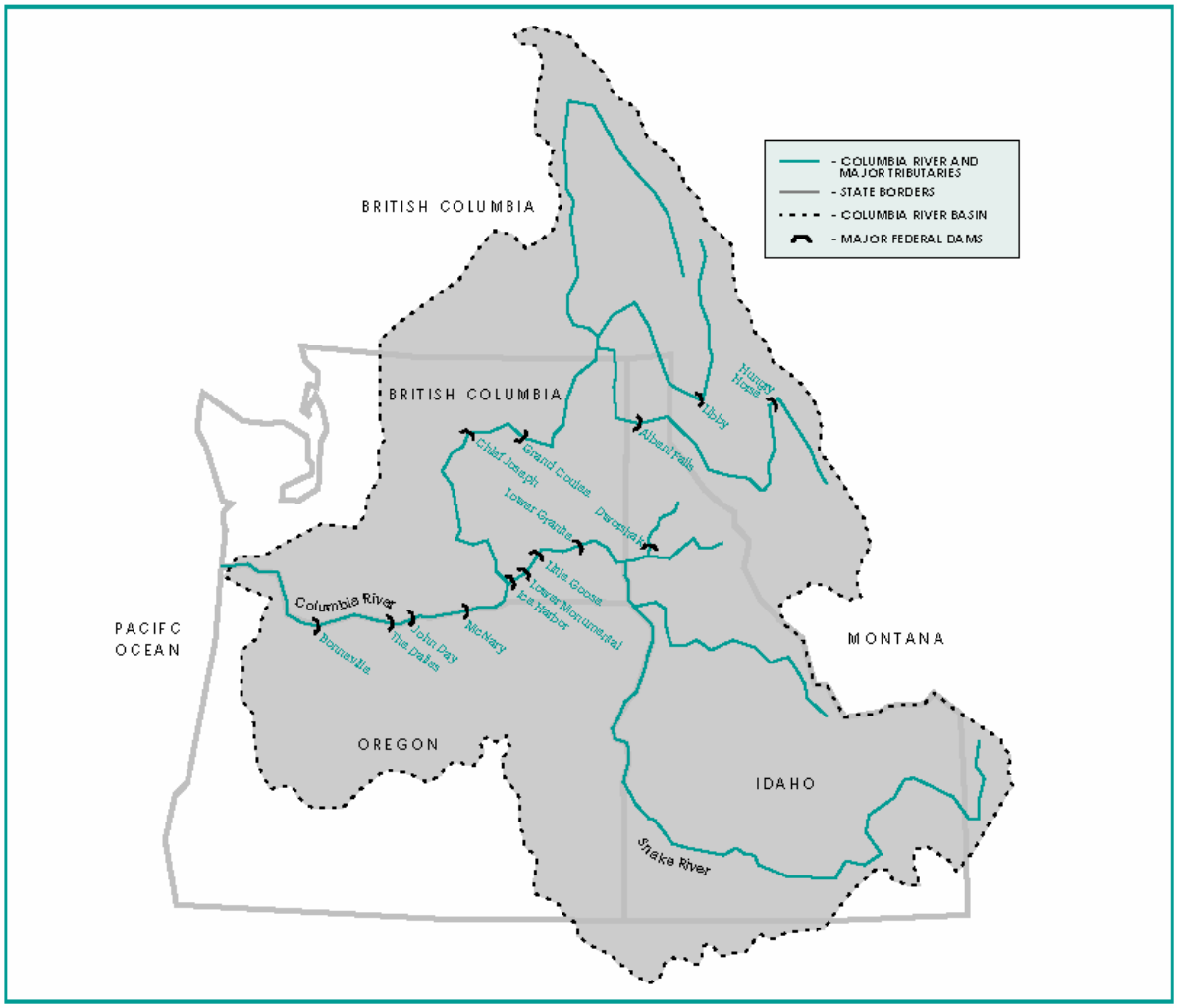


FIGURE 1.1 The Columbia River Basin. SOURCE: Available online at *http://www.bpa.gov/power/pg/fcrps_brochure_17x11.pdf.*

Six species of anadromous salmonids inhabit the Columbia Basin: 1) Chinook salmon (*Oncorhynchus tshawytscha*), 2) coho, or silver, salmon (*O. kisutch*), 3) chum salmon (*O. keta*), 4) sockeye or red salmon (*O. nerka*), 5) pink or humpback salmon (*O. gorbuscha*), and 6) steelhead (*O. mykiss*). Chinook, coho, sockeye, and steelhead that migrate through the middle and upper reaches (above Bonneville Dam) of the Columbia and Snake rivers are all listed as federally endangered species. Salmon and steelhead stocks that are "threatened" or "endangered" (Table 1.1) under the federal Endangered Species Act in the Columbia River domain include:

1. Snake River fall Chinook salmon, threatened (Snake River upstream from Lyons Ferry Hatchery to Hells Canyon Dam, including lower reaches of the Clearwater, Imnaha, Grande Ronde, Salmon, and Tucannon rivers).
2. Snake River spring/summer Chinook salmon, threatened (wild/natural spawners in several subbasins of the Snake and Salmon rivers, including tributaries of the lower Snake River,

TABLE 1.1 Federally Threatened and Endangered Columbia River Salmonid Species

Endangered Species
Steelhead
Upper Columbia River Steelhead
Chinook Salmon
Upper Columbia River Spring Run Chinook
Sockeye
Snake River Sockeye
Threatened Species
Steelhead
Snake River Basin Steelhead
Lower Columbia River Steelhead
Middle Columbia River Steelhead
Upper Willamette River Steelhead
Chinook Salmon
Snake River Spring/Summer Chinook
Snake River Fall Chinook
Upper Willamette Chinook
Lower Columbia River Chinook
Coho Salmon
Lower Columbia River/Southwest Washington Coho (Candidate)
Chum Salmon
Columbia River Chum Salmon

SOURCE: Data from NOAA Fisheries, National Marine Fisheries Service. Available online at *http://www.nmfs.noaa.gov/prot_res/species/ESA_species.html*. Last accessed February 6, 2004.

Grande Ronde and Imnaha rivers, South Fork Salmon River, Middle Fork Salmon River, and the Upper Salmon River).

3. Mid-Columbia River steelhead, threatened (tributaries in the Columbia Plateau region, including Rock Creek, Fifteenmile Creek, and the White Salmon, Klickitat, Yakima Deschutes, John Day, Umatilla, and Walla Walla rivers).

4. Snake River sockeye salmon, endangered (Redfish Lake in the upper Salmon River basin).

5. Upper Columbia River spring Chinook salmon, endangered (tributaries upstream from Rock Island Dam, including the Wenatchee, Entiat, and Methow rivers).

6. Upper Columbia River steelhead, endangered (tributaries upstream from Rock Island Dam, including minor tributaries to the Columbia River and the Wenatchee, Entiat, and Methow rivers).

Other Native and Exotic Species

The Columbia River, like many western U.S. rivers, has far fewer native fish species than similar-sized rivers in the central and eastern U.S. Before the construction of dams, the native fauna was dominated by salmonids (salmon and trout), cyprinids (minnows), and cottids (sculpins), most of which are still present but many in reduced numbers. In addition to salmonids mentioned above, the basin also supports populations of bull trout (*Salvelinus*

confluentus) and coastal cutthroat trout (*O. clarki*). Bull trout are federally listed as threatened and are found throughout the Columbia River basin. They typically reside in upper tributary streams, reservoirs, and lakes and are found occasionally in the mainstem Columbia River. The salmonid complex also included whitefishes and ciscoes. The largest cyprinid in the Columbia River is the northern pikeminnow (formerly known as the northern squawfish). The white sturgeon is usually anadromous (spending part of its life in fresh water and part in salt water) but landlocked populations also inhabit the Columbia River basin (Lee et al., 1980). By the late twentieth century, the white sturgeon population had declined to a point at which they were no longer considered commercially viable in the lower Columbia River (Craig and Hacker, 1940). White sturgeon are currently found in small numbers in distinct landlocked populations. Several species of lamprey also exist in the Columbia River. Counts of lampreys reveal greatly diminished populations (CRITFC, 1996), and there have been some efforts to classify the species as threatened or endangered.

Exotic or nonnative fish species have been widely introduced into the western U.S. and the Columbia River basin is no exception. The striped bass and the American shad, native to the eastern U.S., are nonnative anadromous species that inhabit the Columbia River. Other nonnative freshwater fish in the Columbia River system are largemouth bass, smallmouth bass, various sunfish, crappie, walleye, carp, catfish, bullhead, brown trout, brook trout, and lake trout. Many of these species have thrived in the altered conditions of the Columbia River system; however, some of them may have been more productive in an undammed river. Many prey upon salmon eggs and fry, and some eat salmon juveniles as well, especially the larger individuals (cf. Zimmerman, 1999). Walleye in particular among nonnative species have been implicated in connection with reduced productivity of salmon populations. Smallmouth bass and channel catfish also prey upon salmon, and these predators are more abundant in the upper Columbia and Snake rivers than in the lower Columbia (ibid).

Commercial Fishing

The earliest commercial activity in the Columbia Basin may have been fishing, as Native American tribes caught and traded salmon products. The introduction of commercial fishing, processing, and distribution practices to the region in the late nineteenth century resulted in a burst of economic activity and the generation of a great deal of wealth. The intensity of commercial fishing eventually led to declines in salmonid fish populations in the early- to mid-twentieth century. According to one estimate, total salmon harvest peaked at an average of approximately 34 million pounds/year between 1880-1930, then declined to 24 million pounds/year in the 1940s, dropped to 11 million pounds/year in the 1950s, and was recorded at 1.2 million pounds/year in the early 1980s (Fluharty, 1995). Today, little commercial fishing is allowed or even possible given the small stock sizes in the basin (ibid.). Between 1981 and 1993, total average annual landed value for commercial fisheries in the basin was about $6.8 million (1993 dollars). Roughly half of the commercial value is generated in connection with fishing allowed under the American Indian Treaty fishing, which is based upon the 1974 ruling by a federal judge of parity between tribal and non-tribal fishing (Chapter 5 discusses the *Boldt* decision and other Native American water issues).

In 2000-2003, the commercial value of harvested salmon increased because of large runs of Chinook salmon. However, the listing of several salmon and steelhead stocks in the Columbia as threatened or endangered during the 1980s and 1990s triggered provisions of the federal Endangered Species Act, which in turn limits opportunities for increased salmon harvests from more abundant (non-listed) stocks. Chinook and coho salmon dominate the commercial fishing catch (93 percent), with white sturgeon also being important. Employment in fisheries is today relatively small, and in 1995, the salmon component was negligible because of low stock abundance. Depending upon the assumption of annual income levels, the number of jobs currently dependent on the basin fisheries is estimated to be between 200 and 400 (Fluharty, 1995). Although this is a small percentage of regional employment, commercial fishing has great economic importance in some local areas and communities. The value of commercial fishing has been declining, but fishing remains a major component of the region's recreation and tourism sector. The value of recreational fishing (mostly steelhead) is estimated at approximately $7.7 million (1993 dollars). Recreational fishing is enjoyed throughout the basin, particularly downstream of Bonneville dam. Important localized fisheries occur upstream from Bonneville Dam for fall chinook, and for hatchery spring/summer chinook and steelhead. Catch-and-release fisheries for steelhead in some tributaries are also locally important. Furthermore, non-consumptive fishery-based recreation, such as viewing salmon spawning in rivers and streams, viewing fish at dams, fish ladders, or fish hatcheries, generates an estimated $80 million a year in expenditures (Fluharty, 1995). In some areas, entire communities, resorts, businesses, and individuals greatly depend on services related to recreational fishing.

Salmon Management and Science

Identifying appropriate operational responses to facilitate recovery of salmon populations is a complex scientific and policy task. Dozens of federal, state, and local organizations are responsible for managing the river, its extensive system of dams, and land uses across the watershed. For decades, many scientists and science organizations have investigated the varied aspects of salmon issues. These issues are complicated by the fact that the salmon are anadromous, spending part of their lives in freshwater and part in saltwater. Moreover, the salmon's habitat extends beyond the Columbia River basin. They pass through the Columbia River estuary, spending one to five years (depending on the species) in marine residence, and then return to their natal streams to spawn. Clear understanding of how additional water withdrawals are likely to affect salmon species and their habitat is thus precluded by many factors. In addition to these factors, smolt (young salmon two or three years old that have acquired a silvery color) survival rates are affected by factors beyond streamflow seasonality and discharge, including water temperature, water chemistry, and changes in both land use and the estuarine environment. Existing scientific research and predictive models provide only partial information on these complex relationships and how they might change in the future. Moreover, there are competing models and paradigms with regard to these issues, and not all scientists agree on the fundamental relations among parameters such as flow, temperature, predation, and salmon survival rates.

Several important scientific issues in Columbia River management revolve around the relationships between resident juvenile salmon, smolts, survival rates, and instream flows. These issues are especially important on the middle reach of the Columbia River in central Washington,

where the Washington State Department of Ecology is responsible for the water rights permitting process. Washington State water law is based upon the western U.S. doctrine of prior appropriation, in which water rights are required to make withdrawals. The permitting agency must consider several factors in deciding whether to issue water rights to new, or "junior," appropriators, including possible impacts of additional withdrawals on federally endangered salmon species. Applicants for new water rights would like to receive permits in order to support economic activities and growth; however, additional withdrawals may negatively impact survival rates of salmon smolts.

STUDY BACKGROUND, PROCESS, AND ORGANIZATION

The ambiguities and tensions surrounding Columbia River management and science prompted the Washington State Department of Ecology to request assistance from the National Research Council (NRC). The Department of Ecology contacted the National Research Council in 2002, and later that year, the committee that authored this report was appointed. The NRC's Water Science and Technology Board, working in cooperation with the NRC's Board on Environmental Studies and Toxicology, appointed the *Committee on Water Resources Management, Instream Flows, and Salmon Survival in the Columbia River*, and coordinated the study. The committee conducted its deliberations and its report production in response to the task statement listed in Box 1.1. Consistent with the title of the study committee, and consistent with parts of its statement of task, this report emphasizes the implications of water withdrawals from the mainstem Columbia River in the State of Washington (the "middle reach" of the Columbia) for Columbia River salmon. The proposed water extractions considered in this study have the potential to primarily alter two key physical characteristics in the impounded Columbia River as they affect salmon survival—water temperature and water velocity associated with river flow. These factors are of importance to salmonids migrating through the impounded Columbia. Additionally, one salmon species (ocean type Chinook) spawns and rears in the mainstem Columbia River. Conditions in the Columbia River's tributary streams are also important to salmon survival rates, but given this report's focus on proposed mainstem water withdrawals, environmental conditions in tributary streams are only of peripheral interest in this study. The report also reviews and comments upon several water management scenarios (these scenarios were presented by the State of Washington and are listed in Appendix A).

This committee held four meetings in 2003. Its first two meetings were held in Richland, WA in February and Vancouver, WA in March, which included presentations from scientists from academia and from federal and state agencies, representatives from regional stakeholder groups, basin water managers, and members of the public. At these first two meetings, members of a "Resources Group" (listed in Appendix B), convened by the Department of Ecology to provide scientific input to this study, provided several presentations on key scientific issues. The final two meetings were held in Olympia, WA in July and in Washington, D.C. in November, respectively, during which the committee discussed its statement of task and prepared its report.

In addition to the Resources Group experts, oral and written comments from many interest group representatives and from the public were considered. In listening to and discussing comments from all presenters, it became clear that the issue of water withdrawal and management on the Columbia River is both a scientific and public policy subject of regional as

BOX 1.1
Committee on Water Resources Management, Instream Flows, and Salmon Survival in the Columbia River: Statement of Task

The committee will assess the risks to salmonids at critical stages in their life cycles under a range of different Columbia River system water management scenarios—including diversions for hydropower and other purposes—under both historical and present hydrological conditions.

The study will:

1. Work with a science advisory panel (to be appointed by the Washington Department of Ecology) to gather information necessary to accomplish tasks 3 and 4, from the scientific community with direct experience in the Columbia River Basin, to include holding a workshop in Eastern Washington State.
2. Review and evaluate existing scientific data and analyses related to fish species listed under the Endangered Species Act in the Columbia River basin, as necessary to accomplish tasks 3 and 4.
3. Review and evaluate parameters critical to the survival and recovery of listed fish species as they relate to the hydrology of the Columbia River system in the context of the continued operation of the Federal Columbia River power system and other mainstem power generation facilities. This will include instream flows sufficient for fish and wildlife as well as the potential effects of decreased natural storage capacity on river hydrology.
4. In light of existing withdrawals, describe the risks to salmonid survival of a range of water withdrawals, and the cumulative effects of other factors, during critical times of the salmon life cycle (Note: the State of Washington Department of Ecology suggests an appropriate range of water withdrawals to consider is 250,000 acre-feet to 1,300,000 acre-feet).
5. Evaluate the effects of proposed management criteria, specific diversion quantities, and features of potential water management alternatives (such management information will be provided by the State of Washington).
6. Identify gaps in the knowledge and scientific information that are needed to develop comprehensive strategies for recovering and sustaining listed species and managing water resources to meet human needs.

well as national importance. It was concluded that in order to comprehensively address the committee's task statement, agricultural, biological, economic, energy, environmental, cultural, legal, historical, and political factors all had to be considered. The more important challenge was thus not to decide whether to incorporate this diversity of knowledge into this report, but rather how to integrate it in a balanced manner that provided sound advice for managing water resources and salmon in the Columbia River system.

The challenges of managing Columbia River water and salmon defy simple solutions, and they are not likely to be successfully resolved with information from a single discipline or by the actions of a single group. Decision makers, scientists, policy analysts, and others must cooperate, as must entities across the basin. This report recommends some changes to the water

management processes in the basin. Successful implementation will require both cooperation and compromises. This is not to say that cooperation and compromise on Columbia water management issues has been absent; in fact, the contrary may be closer to the truth. Government scientists have long worked with policy makers and the Columbia has experienced many efforts at cooperative water management. The Columbia River basin may be at a point where novel approaches to cooperation are in order. Humans and society have asked much from the Columbia River, and it has delivered a rich variety of benefits. But after several decades of human and technological interventions on the river and across the basin, the river system has fundamentally changed. In particular, salmon are at a critical point with regard to their long-term survival. If salmon habitat and populations are to be meaningfully protected and restored, people and organizations with stakes in Columbia Basin water may be required to make fundamental adjustments.

This report's organization reflects its interdisciplinary perspectives. Following this introductory chapter, Chapter 2 discusses the basin's broad physical, biological, and social features; Chapter 3 discusses hydrology and water management; Chapter 4 discusses environmental influences on salmon; Chapter 5 discusses laws and institutions; Chapter 6 discusses economics and water management alternatives; Chapter 7 discusses risks and water withdrawals; and Chapter 8 is a brief, concluding epilogue. The target audience for this report is broad and includes science and policy experts, public and private sector officials, and individual citizens and stakeholder groups within the Columbia River basin in the western U.S. and Canada. This group includes Canadian and U.S. governors and legislators, tribal leaders, state-level water managers and staff (which includes the State of Washington Department of Ecology), federal agency staff (Bonneville Power Administration (BPA), the Corps of Engineers, the Northwest Power and Conservation Council (NPCC) and its Independent Science Advisory Board (ISAB), the Columbia Basin Project (CBP), NOAA Fisheries, and the U.S. Fish and Wildlife Service), other operators of dams and water diversion structures, Columbia River basin municipalities, farmers, commercial and recreational fishers, foresters, and tourism, recreational, and environmental organizations. Chapter summaries are listed at the end of each chapter. The reports' principal conclusions and recommendations are printed in bold face in the Executive Summary and in Chapter 8.

2

Development and Changes in the Columbia River Basin

The Columbia River basin consists of several different physiographic regions. There are alpine and sub-alpine environments in its mountainous regions (the Cascades, Rockies, and related sub-chains), an arid and semi-arid Columbia Plateau and other interior areas, and a more humid lower Columbia River valley. This breadth of physical regions is expressed in the basin's diversity of biomes, which include deserts, forests, shrubland, and riparian ecosystems. Much of the basin lies within the rain shadow of the Cascade Mountains and thus experiences an arid to semi-arid climate. Precipitation is strongly seasonal; the majority of precipitation falls during the winter months, much of it as snow. The pre-settlement Columbia River experienced snowmelt-driven peak flows in May and June and low flows in the fall. The Columbia's current flow patterns have been affected by a variety of human activities. Irrigated agriculture has diverted water from the Columbia and its tributaries. Logging has altered vegetative cover and landforms, which has in turn affected surface and groundwater flows. The nation's most extensive hydroelectric power system—the Federal Columbia River Power System (FCRPS)—was constructed on the Columbia River and its tributaries during the twentieth century. The system's numerous dams and storage reservoirs have altered both the volume and seasonal patterns of the Columbia's flows.[1] These changes to Columbia River discharge have affected the assemblage of fishes in the basin. With respect to their impacts on salmonid populations, some adverse changes have diminished in influence over time, while others have increased. Human-induced changes have interacted synergistically with certain natural factors, ameliorating some or exacerbating others. This chapter discusses key environmental and human features in the Columbia River basin and how human activities have impacted the basin's environmental systems. The basin's complex physical character and the changes induced by nineteenth and twentieth century agricultural, forestry, and industrial activities provide the context for considering more detailed aspects of changes to the Columbia River hydrologic regime and its interactions with the life histories of Columbia River salmonids.

SETTLEMENT AND DEVELOPMENT OF THE COLUMBIA BASIN

Most inhabitants in the Pacific Northwest live in the Portland-Seattle urban corridor west of the Cascade Mountains (Portland lies within the Columbia River basin, Seattle does not). Of the roughly 9.5 million people in the four Northwest U.S. states (Idaho, Montana, Oregon, and Washington), about 5 million live in the Columbia River Basin (Volkman, 1997; data from Federal Columbia River System, 2001). Like the rapidly-growing Portland-Seattle corridor, the

[1]The system contains several run-of-the-river reservoirs that have minimal effects on river flows.

basin's interior experienced population growth in many areas since the 1980s, with the largest increases in the urban areas of Bend (Oregon), Boise (Idaho), Richland/Pasco/Kennewick (the "Tri Cities"), Spokane, Wenatchee, and Yakima (these last four urban areas are in Washington State). Beyond these Columbia River basin cities, the rest of the basin is only sparsely populated.

Exploration and Settlement

Humans have inhabited the Pacific Northwest for at least 15,000 years (Jackson and Kimerling, 2003). Its early inhabitants made a transition from hunting large game to a more sedentary lifestyle about 3,500 years ago, and salmon became an important part of their sustenance and their culture. Even then, human activities had impacts on salmon and salmon habitat. Native Americans who lived along and near the river expended considerable efforts in taking salmon from the river, and the populations of some riverside villages swelled during the peak of the salmon runs (White, 1995). Popular sites for catching returning salmon on their upstream journeys were at the Cascades and at Celilo Falls/The Dalles. Native Americans altered the landscape in their quest for salmon, with some consequent effects on the aquatic environment. European settlers introduced a new and more intensive set of harvesting techniques, which resulted in a greater scale and pace of environmental changes and increased pressure on salmon stocks. European settlement in the region, and associated uses in resources and changes in the landscape, varied in timing and in intensity across the Columbia River basin. This progression can generally be classified as: initial European settlement (1810-1930s); mining, livestock, and agriculture (1850s-1910); large-scale timber harvesting (1920-1990s); water diversions and mainstem dams (1900-1968; see Wissmar et al., 1994, for a review of the history of resource use in eastern Oregon and Washington).

The region's best-known and most celebrated exploration was the Lewis and Clark expedition. After traveling up the Missouri River and crossing over the Rocky Mountains, Lewis and Clark and their Corps of Discovery floated down the Columbia River to the Pacific Ocean, spending the winter of 1805-1806 at Fort Clatsop near present-day Astoria, Oregon. Lewis and Clark noted several characteristics of the streamside vegetation in their early nineteenth century exploration of the region, including an increase in riparian forests as one approached the ocean:

> The face of the country on both sides of the river, above and below the falls, is steep, rugged, and rocky, with a very small proportion of herbage, and no timber except a few bushes (p. 669, referring to locations near The Dalles).
>
> Above Crusatte's river (Wind River) the low grounds are about three-quarters of a mile wide, rising gradually to the hills, with the rich soil covered with grass, fern, and other small undergrowth; but below the country rises with a steep ascent, and soon the mountains approach the river with steep rugged sides, covered with a very thick growth of pine, cedar, cottonwood, and oak (p. 679, referring to farther downstream).
>
> At this village the river widens to nearly a mile in extent; the low grounds become wider, and they as well as the mountains on each side are covered with pine, spruce-pine, cottonwood, a species of ash, and some alder. After being so long accustomed to the dreary nakedness of the country above, the change is as grateful to the eye as it is useful in supplying us with fuel. . .the low grounds are extensive and well-supplied with wood. . .the low grounds near the river are

> covered so thickly with rushes, vines, and other small growth that they are almost impassable (Coues, 1893, p. 668-691).

The Columbia's tributaries often had more abundant riparian vegetation than did the mainstem Columbia River:

> A branch of the Wollawollah river. . .Is a bold, deepstream, about ten yards wide, and seems to be navigable for canoes. The hills of this creek are generally abrupt and rocky, but the narrow bottom is very fertile, and both possess 20 times as much timber as the Columbia itself (ibid., p. 978-979).

Other nineteenth century explorers provided additional detail on the pre-development vegetation and agricultural potential, describing the dominance of cottonwood and willow along inundated river banks from an elevation of 5,000 feet down to the river (cf. Cooper, 1860). Although cottonwoods covered the islands and low shores of the lower Columbia River, upstream from The Dalles, willow and small hackberry were the only trees for hundreds of miles. The increasing scarcity of riparian vegetation as one moved eastward along the Columbia River corresponded with increasing aridity, a phenomenon observed by both Lewis and Clark and by railroad explorers and surveyors. Large tributaries of the Columbia River apparently had a similar scarcity of timber. Cooper (1860) described the Yakima River as "wide, open, and destitute of timber, except in the bottom lands, and even there few trees are found for forty miles." The lower part of the Yakima basin was judged to be "less fit for cultivation than higher up, but contains much good grass land" (ibid.). Improvements in soil arability and in streamside timber that correlated with elevation increase were emphasized: "On the immediate banks of the Columbia the country is not promising; but going back a little distance the grazing is very luxuriant and excellent, and the soil rich, particularly in the river valleys" (ibid.).

The basin is also notable for its variety of climatic regions and for sharp changes in climate zones over short distances. These contrasts near the Columbia River upstream and downstream from the Cascade Mountains were noted in the late nineteenth century:

> Even from the Dalles we could perceive a thick fog hanging in the gap, but were quite unprepared to find a heavy rain, which we entered long before reaching the Cascades, and which continued unceasing during the whole day and night following, when we reached Vancouver. Even after entering this rain we could see the bright, unclouded sky of the plains eastward, but I thought the moister and milder air more agreeable than the cold dry climate we had just left. The change in the appearance of the country in the distance of a few miles was almost as great as I have since observed between New York and the isthmus of Panama in January, as we left the ground at the Dalles covered with snow, and entered a region of perpetual spring, with gigantic evergreen forests, tropical looking shrubs, and large ferns, where several spring flowers were still blooming. Even the perpendicular rocks supported a green covering of mosses, etc., over which cascades unbroken for a thousand feet, fell from the mountains directly into the river (ibid.).

Economic Activities and Sectors

Furs and Minerals

The British-controlled fur trade began in the early 1800s in north-central Washington. An active British and American fur trade, with furs being transported from a wide area to the mouth of the Columbia River, continued until mid-century. The decline of beaver and beaver dams reduced water storage in the uplands and reduced the environmental heterogeneity encountered by salmon. Discovery of gold in the 1850s attracted large numbers of miners to Washington and Oregon. For example, 1,200-3,000 miners mined the Similkameen River channel until moving north to the Fraser River in 1860, leaving behind a settlement near Oroville, Washington (Wissmar et al., 1994). The next 40-50 years saw numerous strikes of gold and silver and the appearance of boom towns in Washington. Placer and lode mining, mill wastes, and uncontrolled development degraded many sections of streams including Salmon Creek (Ruby City), which lost its large run of spring Chinook salmon (ibid.).

Ranching and Irrigated Agriculture

Appreciable numbers of domestic stock were present in the basin by the 1860s. In the mid 1800s, settlers arrived via covered wagon and the Oregon Trail. The extension of railroads into the region in the late 1880s supported a subsequent and larger wave of settlers. Numbers of horses and livestock increased rapidly during the same period, as well. Cattle from the Yakima and Willamette Valleys supplied the northern mining camps. Cattle were abundant throughout the Yakima valley by the 1870s. In the summer, cattle and sheep in large numbers were driven into headwater stream valleys. There were also large numbers of sheep in the John Day River basin near Shaniko, Oregon. For example, by 1904, Yakima County had 147,000 sheep, the largest number of any county in Washington (Wissmar et al., 1994). Between the 1850s and 1930s, overgrazing, deliberate burning to stimulate grass production, and wildfires increased soil erosion and sedimentation of streams. Remedies included restrictions on grazing in degraded areas, issuance of fewer grazing allotments, and lower allowable stocking rates.

Agriculture surpassed mining as the basin's principal economic activity in the early twentieth century. Although agricultural expansion was restricted by a lack of reliable water sources in many areas, some rudimentary irrigation canals were constructed as early as the 1850s. This stimulated settlement, and many cattle and sheep ranches sprang up across the basin, especially in the Yakima valley. By 1869, a large irrigation canal watered lands below the confluence of the Naches and Yakima rivers, and many former grazing lands were converted to permanent, higher-value, horticultural crops. Passage of the Reclamation Act in 1902 and the creation of the Reclamation Service (later renamed the Bureau of Reclamation) marked a new era in irrigated agriculture in the western U.S. Today, much of the basin's agricultural production depends heavily on irrigation, and water diverted for agriculture is the largest off-stream water use in the Columbia system; over 6.5 million acres, or 37 percent of total cropland in the area, is irrigated (Census of Agriculture, 1997). Over 93 percent of daily water use in the Columbia River basin (105,301 acre-feet per day) is for agriculture (ibid.). Irrigation typically uses water withdrawn from surface water supplies, while municipal supplies (domestic, commercial, and industrial) are typically from groundwater sources. More than one third (37

percent) of farms in the basin have some irrigated acreage (ibid.). Nearly all the potatoes, sugar beets, hops, fruit, vegetables, and mint produced in the region are from irrigated land, as is a large portion of hay and grain production (NPPC, 1998). Although the basin's economy is diversifying and growing faster than the regional and national averages, employment and per capita income in the area both remain below national averages. Agriculture and related services continue to be major employers in the basin, providing over ten percent of employment. Farm owners, tenants, and ranch families represent 19 percent of households in the basin, compared to 2 percent nationally (Quigley et al., 1997). Within the agricultural sector, the cattle industry represents the largest share of agricultural income, accounting for approximately 29 percent of sales (ibid.).

The Columbia Basin Project is the region's largest irrigation project. Authorized by Congress in 1935, the project was developed in parallel with the construction of Grand Coulee Dam (which impounded Franklin D. Roosevelt Lake). Funds were allocated for the construction of Grand Coulee in 1933, which was constructed to generate hydroelectric power as well as to store irrigation water for the Columbia Basin Project (construction of the Project and Grand Coulee Dam were both assigned to the Bureau of Reclamation). Initial designs of the Project called for the delivery of irrigation water to 1.1 million acres of land. Today, about 671,000 acres are currently irrigated (*http://www.usbr.gov/dataweb/html/columbia.html*; accessed December 5, 2003). The Project stretches northward to the Canada-U.S. border and southward to Pasco, Washington. Crops raised on the Project include grains, alfalfa, hay, beans, fruit, sugar beets, potatoes, and sweet corn (ibid.; Chapter 3 discusses the Columbia Basin Project and its hydrologic features in greater detail).

Forestry and Logging

Road construction facilitated logging and recreation in less accessible, higher-terrain areas. Greater access to riparian areas increased recreational activity, resulting in impacts to soil and vegetation near streams. Prior to road expansion, timber harvest and transport by water and horse was largely limited to lower valley bottoms and adjacent slopes, with the timber used locally. Logging by truck in the Little Naches watershed began in 1931. Private land outside of the Forest Reserve was completely logged by 1944. In 1975, the first timber clear-cuts appeared, and by 1992, 35 percent of the harvestable area of the watershed had been harvested. Timber harvesting and road construction in the upper Grand Ronde River basin have increased since the 1950s. Similarly, timber harvest is a dominant land use in the Blue Mountains (Ochoco, Umatilla, and Malheur national forests); the Blue Mountain Forest Reserve was established in 1906, and by the 1920s timber harvest was significant. Timber harvests across the basin steadily increased until about 1950, held constant through much of the 1990s, and have since decreased. Harvesting and grazing over the past century have reduced the tree canopy over many streams in the Columbia River watershed (e.g., in the John Day River basin, the entire canopy of many river sections has been removed). Environmental impacts of these actions include increased stream temperature, a reduction in areas of cold-water refugia for fish, and a reduction in ecologically-beneficial inputs of coarse woody debris to the channel.

Many watersheds across the Columbia River basin are recovering from twentieth century logging practices, such as splash dams, that had deleterious effects on streams. Changes in logging practices since the 1960s and 1970s, such as the addition of buffer areas, have helped

reduce logging's impacts (e.g, soil erosion, slope failure). Similar trends are associated with the Columbia basin mining industry—many streams are still "recovering" from nineteenth and twentieth century activities. Impacts on the Columbia basin landscape from grazing and irrigated agriculture practices continue in much the same mode as they did through the twentieth century. Human population growth and its attendant effects, such as the paving of watersheds and pressures for additional water withdrawals for human activities, will be a major factor affecting Columbia River basin landscape and hydrologic dynamics in the twenty-first century.

Human Population Projections

Human population in this region may reach 40 to 100 million by the end of the twenty-first-century. Estimates of population growth for the interior Columbia Basin to 2040 range from 0.3 percent per year (based on birth and death rates in the 1980s), to 1.6 percent per year (including immigration; McCool and Haynes, 1996). Nearly all of the basin's economic activities have affected Columbia River salmon and salmon habitat. The fact that so many human actions have affected salmon habitat in so many different ways confounds scientific investigations of the relative impacts of a given activity(ies). Yet, the fact that the region's human population seems highly likely to continue growing (with substantial growth in some regions in or near the basin, such as the Portland-Seattle corridor and environs likely under current population and immigration policies) suggests that pressures for water and related services (e.g., hydroelectricity) will likewise continue to grow, which will exert more pressure for additional diversions of water from the Columbia River mainstem and tributaries. As a previous National Research Council committee that reviewed Columbia River salmon management stated, "As long as human populations and economic activities continue to increase, so will the challenge of successfully solving the salmon problem" (NRC, 1996).

FEDERAL COLUMBIA RIVER HYDROPOWER SYSTEM

The Federal Columbia River Power System (FCRPS) was constructed and is managed and operated by three federal agencies: the Bonneville Power Administration (BPA), the Bureau of Reclamation, and the Corps of Engineers. The system consists of 31 dams on the Columbia River and its tributaries and the related power generation and transmission infrastructure. It provides about 60 percent of the region's hydroelectricity generating capacity (USACE, BPA, and Bureau of Reclamation, undated). The system has a firm capacity of 8,550 megawatts and generates an estimated net present value of benefits from $3 billion to $25 billion annually (BPA, 1998). This power system provides the Pacific Northwest with the lowest power rates in the nation and has been an important factor in attracting industries such as aluminum smelting and aircraft manufacturing. In addition to the economic and social changes that resulted from the project's construction and operations, it also fundamentally restructured the Columbia's hydrologic character and its related ecological resources. The system's dams and reservoirs impound roughly 55 million acre-feet of water (ibid.), an amount equal to roughly one-fourth of the Columbia's annual average discharge of 198 million acre-feet (*http://www.nwppc.org/library/pocketguide/pocketguide.pdf*; accessed November 21, 2003).

Plans for construction of the system were under way in the early twentieth century. In the mid-1920s, Congress requested the Corps of Engineers to conduct a survey of the basin's potential for the construction of dams and related works to promote hydroelectricity production, irrigation, flood control, and navigation. In 1931 the Corps issued a comprehensive study of the Columbia and its prospects for multipurpose development (the document was part of the Corps' "308 reports," so named after the U.S. House Document authorizing them and which were conducted for several major U.S. river basins). The Corps of Engineers 308 report called for 10 dams on the Columbia, and the report shaped the river's development for the next 40 years (USACE, BPA, and Bureau of Reclamation, undated).

The early 1930s were a period of technological optimism, with a strong faith in the ability of multipurpose river basin development to deliver substantial social and economic benefits. The federal Tennessee Valley Authority was established in 1933, and presidential candidate Franklin Roosevelt promised hydroelectric development of the Columbia River while campaigning in Portland, Oregon in 1932. Many saw electrification of the Columbia as central to the region's development and as an antidote to the Great Depression's economic woes. Construction began on both Bonneville and Grand Coulee dams in 1933. In 1937 the Bonneville Project Act was signed, which created the Bonneville Power Authority (BPA) to market power from the two dams. The agency was mandated to construct and operate transmission facilities and market hydroelectricity, while responsibility for dam operations remained with the Corps and the U.S. Bureau of Reclamation. In 1939, BPA first transmitted energy from Bonneville Dam to Cascade Locks, Oregon, then later to Portland. Grand Coulee Dam first provided power to the BPA system in 1941. The Bonneville Power Administration and the Federal Columbia River Power System have since played crucial roles in the region's economic development. The large supply of low-cost power provided by the FCRPS enticed many industries to locate in the region, most notably aluminum smelting and aircraft production. Boeing Aircraft Works in Seattle ramped up production in the World War II era, and other wartime industries followed. BPA and the FCRPS were vital to World War II industrial production, as BPA also marketed power to the Hanford Reservation for plutonium production. BPA marketed power produced from the Hanford Generating Plant, which was part of the Washington Public Power Supply System (WPPSS). The BPA has also been an important participant within the processes of the Northwest Power and Conservation Council (known until 2003 as the Northwest Power Planning Council, or NWPPC).

The Northwest Power Planning Council was created in connection with passage of the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (P.L. 96-501). The council was formed with representatives from the states of Idaho, Montana, Oregon, and Washington. The act directed the council to draft a plan for meeting the region's electrical needs at the lowest cost. The council was also charged to develop a fish and wildlife program (in addition to a power plan) that directs the Bonneville Power Administration to fund projects to enhance fish and wildlife resources (at between $100-$150 million per year; see *http://www.nwcouncil.org*; last accessed March 3, 2004). The BPA was given responsibility to meet electrical demand while managing the system to meet the act's purposes relating to fish, system efficiency, and experimental projects (Available online at: *http://www.nwppc.org/library/2003/2003-2.pdf*; last accessed December 5, 2003). The act's emphasis on equitable treatment of fish and wildlife drove efforts to rebalance FCRPS operations during the 1980s and 1990s. Key guidance in operating the system to provide instream flows and help protect endangered fish species has been provided in Biological Opinions (BiOps) issued by NOAA

Fisheries (formerly the National Marine Fisheries Service, or NMFS). These documents are issued in response to Biological Assessments submitted by federal action agencies pursuant to the federal Endangered Species Act.

Beyond system operations, the construction of the hydropower system itself also had notable environmental consequences. The reservoirs inundated and eliminated almost all mainstem spawning areas, with the exception of the Hanford reach (a stretch of river downstream of the federal Hanford Nuclear facility in central Washington). The Grand Coulee (Columbia River) and Hells Canyon dams (three dams on the Snake River) blocked large amounts of habitat that were once highly productive salmon habitat in the Columbia basin. The tributary habitat that today produces spring Chinook and steelhead is the fringe habitat that remains (Dauble et al., 2003). The dams also inundated vast acreages of wildlife habitat.

SUMMARY

Human activities have long had significant impacts on Columbia River salmon and aquatic habitat. Activities of Native Americans impacted the salmon, as tribal actions altered the landscape and affected aquatic environment. But the introduction of industrial-based economic activities to the Columbia River basin, and the consequent settlement and human population growth, resulted in widespread and substantial changes in land uses and basin hydrology. The basin has been developed and altered by additional settlement and population growth, extractive activities (e.g., mining and trapping), agriculture and ranching, large-scale timber harvesting, water diversions, and mainstem dams and reservoirs. The basin's economy has historically depended heavily on the Columbia River, first through the harvest of salmon, then later through the construction of dams and related infrastructure to promote irrigated agriculture and hydroelectric power development, to provide flood control, and to support navigation. The Columbia River has clearly yielded a wealth of benefits to the region and its inhabitants. But the impacts of these various activities have had substantial effects on salmon in the Columbia River basin. As a result of these activities, several of the basin's anadromous salmon are listed as threatened and endangered under the federal Endangered Species Act. Over the years, regional and federal water and fisheries management organizations have enacted several strategies designed to mitigate environmental impacts on the salmon. As this chapter has discussed, these impacts have derived from several different activities. Strategies aimed at replacing natural ecosystem processes that have been lost or compromised cover a wide spectrum of practices, including fish ladders, the transporting of salmon around dams, and dam operations (NRC, 1996; the next chapter discusses "flow targets," or instream flows designed to meet the needs of salmon). Other strategies could include changes in human uses of tributary riparian systems, changes in logging practices and policies, hatchery management practices, or changes in ocean salmon harvest policies. The point is that salmon have been affected by a wide variety of human activities, and that policies designed for protecting or enhancing salmon populations may need to assume a similar breadth. The potential additional water withdrawals from the Columbia River considered in this study thus make up only a portion of a large, complex mosaic of human activities that affect salmon.

The human population in the interior Columbia Basin in the U.S. is about 5 million and projected to grow annually by 0.3 to 1.6 percent per year. Human population growth has implications for salmon survival, not only because of urbanization's direct effects on land use

and hydrology (e.g., changing of timing of runoff patterns, decreasing of surface waters percolating to groundwater), but also because additional people will generate additional demands for Columbia River water and related resources. The region has changed dramatically over the past one hundred fifty years, and given human population growth projections, even more rapid future changes are likely. As discussed in this chapter, construction of the Federal Columbia River Power System resulted in marked and lasting changes to the basin's physical and economic systems. The following chapter reviews the details regarding the construction of the system for Columbia River basin hydrology, as well as other important hydrological changes wrought by decades of human activities in the region.

3

Hydrology and Water Management

Columbia River water flows have generated enormous social and economic benefits. These uses include hydropower generation, flood control, instream flows for fish and habitat, irrigation, navigation, and water for municipalities and industries. A vast number of jurisdictions and individuals use Columbia River water, including seven U.S. states, the Canadian province of British Columbia, and several Indian reservations (Figure 3.1). The geographical focus in this study, however, is on the mainstem Columbia River in the State of Washington.

As explained in Chapter 2, there are many large dams (storage and run-of-the-river) and reservoirs along the river that compose the Federal Columbia River Power System. The Columbia River dams in Washington State are owned and operated by federal entities and by state public utility districts. Their daily operations are designed to meet the needs of many sectors, the most important being flood control, hydroelectric power generation, and instream flows. Like most regions of the western U.S., irrigated agriculture is the largest consumptive water user in the region. Irrigated agriculture along the Columbia River in the State of Washington consists of one very large withdrawal—the Columbia River Basin Project—and a large number of small (relative to the Columbia's flows) withdrawals by individual irrigators. These structures and uses have affected stream flows, water quality, and water temperature. This chapter examines twentieth century changes in Columbia Basin hydrology and the annual hydrograph, the current and prospective future picture of water withdrawals (this study's primary focus), water quality, and changes in water temperature and related, prospective future changes in basin climate.[1]

This study focuses on the implications of water withdrawals from the mainstem Columbia River for salmon survival. An analysis of the relative impacts of mainstem surface and groundwater withdrawals in comparison to the hydrologic impacts of Columbia River dam and reservoir construction and operations was beyond the scope of this study. This report focuses on mainstem water withdrawals because this topic was central to its task statement, not because of the relative influence of withdrawals in comparison to other system objectives and users.

[1] This chapter includes several figures and tables containing hydrologic information. Some of those data are expressed in cubic feet per second (cfs) and some of the data are expressed in acre-feet per year (AF/yr.). This report does not present all hydrologic data in a single unit because both units (cfs and AF/yr) are traditionally and currently used by water managers, farmers, and scientists in different settings in Washington and across the western U.S. Furthermore, cfs represents a rate, while acre-feet represents a volumetric measure. For comparative purposes, however, 1 cubic foot/second of water equates to slightly less than 2 acre-feet/day—or roughly 724 acre-feet/year.

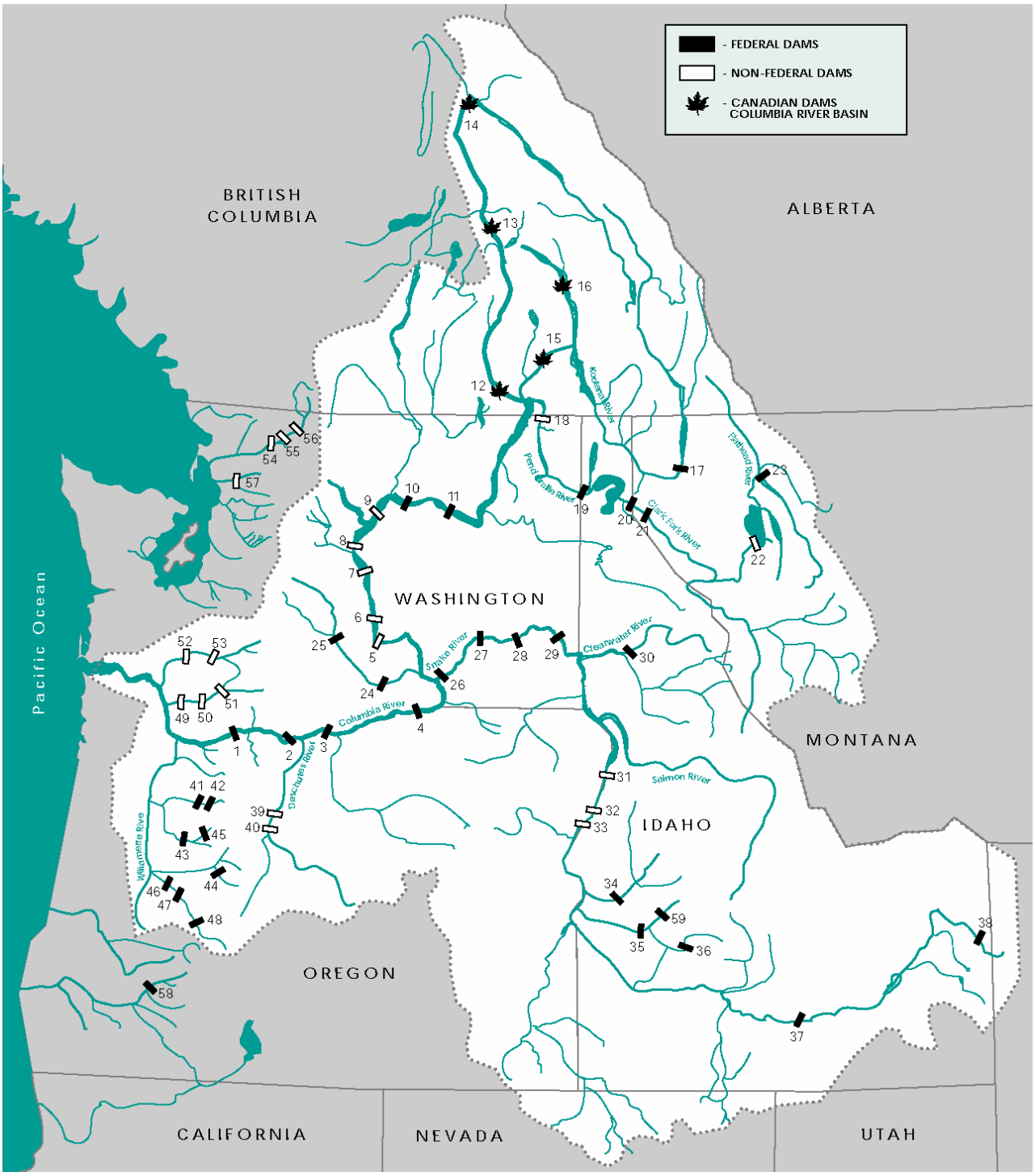
COLUMBIA RIVER FLOWS

Changes to the Hydrograph

The annual Columbia River hydrograph underwent fundamental changes during the twentieth century. These changes were driven primarily by the construction of dozens of dams and reservoirs on the river's mainstem, hundreds of projects on tributary streams (some of these dams, such as those on the Snake River, are also quite large), and this system's operations. Although constructed to serve multiple purposes, the driving force behind Columbia River dam construction was hydroelectric power development, and to a lesser extent, flood control. With its solid rock channel, low levels of silt, and relative steepness, the Columbia River was uniquely suited for large-scale hydropower development.

Construction of the first federal Columbia mainstem projects began in 1933 at Bonneville and Grand Coulee. World War II increased pressure to further tap the river's hydroelectric power production potential, and between 1944 and 1945, Congress authorized several water projects in the basin. In the five years following the war, Chief Joseph Dam, Albeni Falls, Libby, John Day, and The Dalles dams were all authorized (Volkman, 1997). Support for federal dams on the mid-Columbia faded during the 1950s, but licenses were issued to county public utility districts to construct Priest Rapids Dam, Rocky Reach Dam, Wanapum Dam, and Wells Dam, all of which today are operated by public utility districts. Upstream dams that augmented storage and power production capabilities were constructed pursuant to the Columbia River Treaty signed between Canada and U.S. in 1961; these dams included Libby Dam in Montana and Arrow Lakes, Duncan, and Mica dams in Canada. The treaty focused primarily on addressing two main water uses: hydropower and flood control.

The hydrologic implications of the construction of this dam and reservoir system, and the operations of that system, on the Columbia River annual hydrograph were tremendous. Figures 3.2 and 3.3 provide two different portrayals of these changes. Figure 3.2 shows how annual Columbia River hydrologic seasonality has "flattened," as original high seasonal ("summer") flows have decreased and low seasonal ("winter") flows have increased. Figure 3.3 shows how the balance of flows between summer (April-September) and winter have changed since the late 1800s. Through time, this summer-winter division of flows has become closer to a 50:50 balance in response to system construction and operations largely oriented to serve hydroelectric power needs and operations. In addition to the smoothing of the annual Columbia River hydrograph, construction and operations of the dam and reservoir system have had two other major physical impacts: water velocities have decreased, and the size and orientation of the Columbia River plume (a large pulse of fresh water from the Columbia flowing into Pacific) has been greatly altered (Ebbesmeyer and Tangborn, 1992). This is particularly an issue when salmon smolts (young salmon 2-3 years old) are moving downstream. These changes, however, have not eliminated all variability of Columbia River flows, however. Figure 3.4., for example, demonstrates that considerable variability of annual Columbia River discharge exists between years. Flows also continue to vary on other time scales; for example, daily flow patterns below hydropower dams often vary substantially as flows are adjusted to demands in electric power demand. The cumulative impact of all these hydrologic changes has likely had significant effects on the early ocean survival of juvenile fish leaving the Columbia River (Pearcy, 1992). Because of concerns over possible impacts on salmon from the construction and operation of the hydropower system, federal and state management and resources agencies have implemented


- FEDERAL DAMS
- NON-FEDERAL DAMS
- CANADIAN DAMS COLUMBIA RIVER BASIN
BRITISH COLUMBIA
ALBERTA
WASHINGTON
MONTANA
IDAHO
OREGON
CALIFORNIA
NEVADA
UTAH
Pacific Ocean
Columbia River
Snake River
Clearwater River
Salmon River
Kootenay River
Pend Oreille River
Clark Fork River
Flathead River
Deschutes River
Willamette River

Major Northwest Dams

1. **BONNEVILLE** Columbia River, USACE
2. **THE DALLES** Columbia River, USACE
3. **JOHN DAY** Columbia River, USACE
4. **McNARY** Columbia River, USACE
5. **PRIEST RAPIDS** Columbia River, Grant Co. PUD
6. **WANAPUM** Columbia River, Grant Co. PUD
7. **ROCK ISLAND** Columbia River, Chelan Co. PUD
8. **ROCKY BEACH** Columbia River, Chelan Co. PUD
9. **WELLS** Columbia River, Douglas Co. PUD
10. **CHIEF JOSEPH** Columbia River, USACE
11. **GRAND COULEE** Columbia River, USBR
12. **KEENLEYSIDE** Columbia River, BC Hydro
13. **REVELSTOKE** Columbia River, BC Hydro
14. **MICA** Columbia River, BC Hydro
15. **CORRA LINN** Kootenay River, W. Kootenay
16. **DUNCAN** Duncan River, BC Hydro
17. **LIBBY** Kootenai River, USACE
18. **BOUNDARY** Pend Oreille River, SCL
19. **ALBENI FALLS** Pend Oreille River, USACE
20. **CABINET GORGE** Clark Fork River, WWP
21. **NOXON RAPIDS** Clark Fork River, WWP
22. **KERR** Flathead River, MPC
23. **HUNGRY HORSE** Flathead River, USBR
24. **CHANDLER** Yakima River, USBR
25. **ROZA** Yakima River, USBR
26. **ICE HARBOR** Snake River, USACE
27. **LOWER MONUMENTAL** Snake River, USACE
28. **LITTLE GOOSE** Snake River, USACE
29. **LOWER GRANITE** Snake River, USACE
30. **DWORSHAK** N.F. Clearwater River, USACE
31. **HELLS CANYON** Snake River, IP
32. **OXBOW** Snake River, IP
33. **BROWNLEE** Snake River, IP
34. **BLACK CANYON** Payette River, USBR
35. **BOISE RIVER DIVERSION** Boise River, USBR
36. **ANDERSON RANCH** Boise River, USBR
37. **MINIDOKA** Snake River, USBR
38. **PALISADES** Snake River, USBR
39. **PELTON** Deschutes River, PGE
40. **ROUND BUTTE** Deschutes River, PGE
41. **BIG CLIFF** N. Santiam River, USACE
42. **DETROIT** N. Santiam River, USACE
43. **FOSTER** S. Santiam River, USACE
44. **COUGAR** McKenzie River, USACE
45. **GREEN PETER** M. Santiam River, USACE
46. **DEXTER** Willamette River, USACE
47. **LOOKOUT POINT** Willamette River, USACE
48. **HILLS CREEK** Willamette River, USACE
49. **MERWIN** Lewis River, PP&L
50. **YALE** Lewis River, PP&L
51. **SWIFT** Lewis River, PP&L
52. **MAYFIELD** Cowlitz River, TCL
53. **MOSSYROCK** Cowlitz River, TCL
54. **GORGE** Skagit River, SCL
55. **DIABLO** Skagit River, SCL
56. **ROSS** Skagit River, SCL
57. **CULMBACK** Sultan River, Snohomish Co. PUD
58. **LOST CREEK** Rogue River, USACE
59. **LUCKY PEAK** Boise River, USACE
60. **GREEN SPRINGS** Emigrant Creek, USBR

FIGURE 3.1 Columbia River Basin map with major northwest dams. SOURCE: BPA, USBR, and USACE (2001).

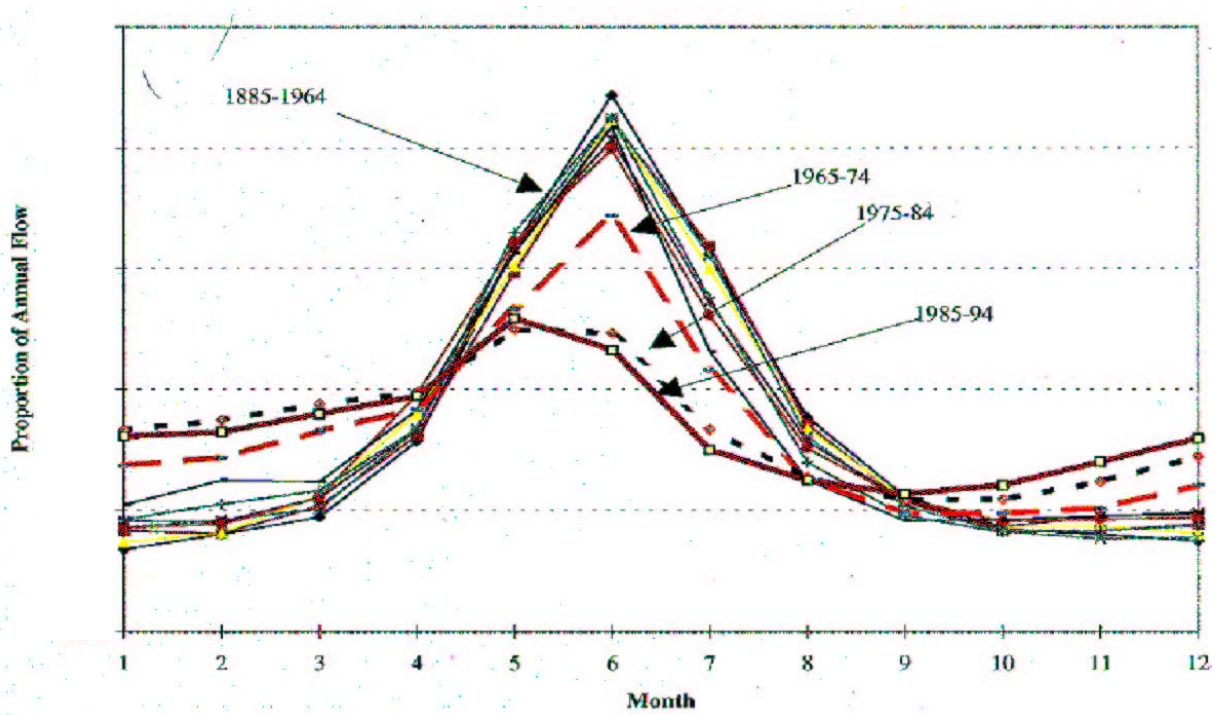


FIGURE 3.2 Annual distribution of monthly flow at The Dalles by 10-year blocks. SOURCE: Volkman (1997).

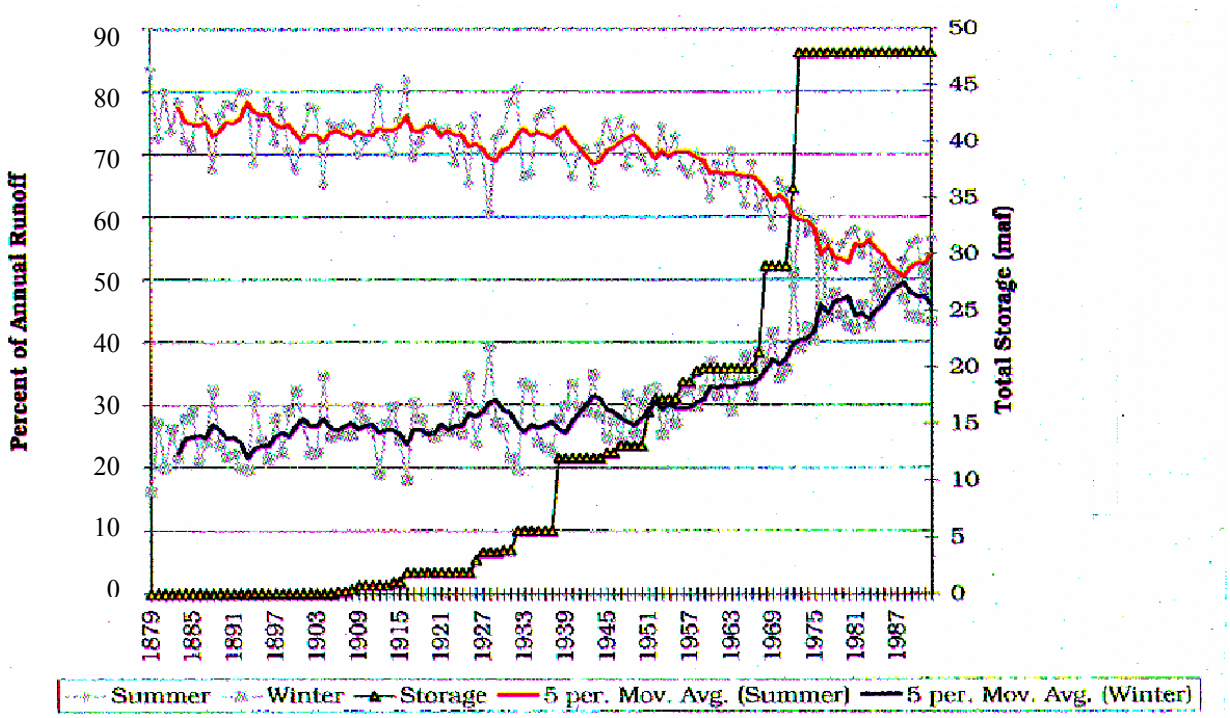


FIGURE 3.3 Change in Columbia River hydrograph at The Dalles, 1879-1992. SOURCE: Volkman (1997).

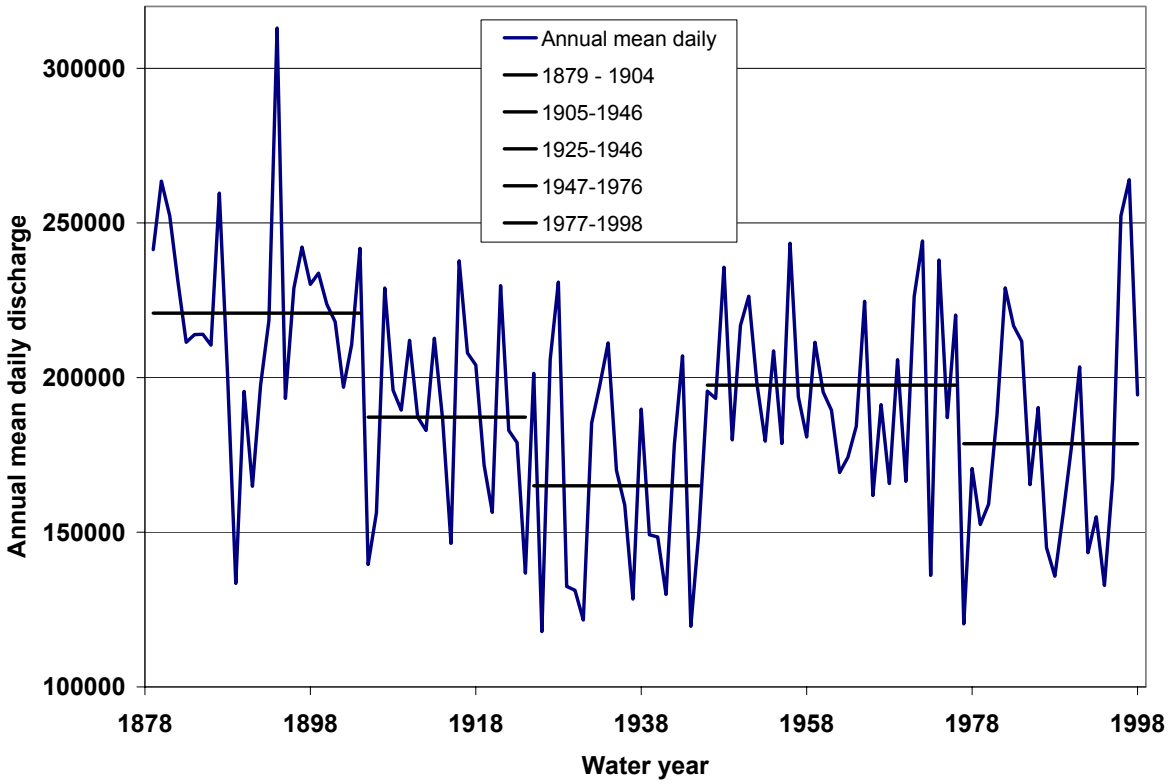


FIGURE 3.4 Columbia River discharge, 1878-2000 at The Dalles, Oregon. SOURCE: USGS (2003).

some changes to system operations to help provide instream flows designed to support and enhance salmon habitat. The flows are referred to as "flow targets" and are discussed in the following section.

Biological Flow Targets

Passage of federal environmental legislation in the 1960s and 1970s, such as the Environmental Policy Act (1969) and the Endangered Species Act (1973), led to changes in system operations as some flows were devoted to protect and sustain endangered salmon species and habitat. "Flow targets" were developed by federal and state resources agencies in efforts to ensure adequate instream flows. Key flow targets involving fishery resources include consideration of smolt migration, spawning flows for chum salmon below Bonneville Dam, spawning and incubation flows at Vernita Bar (see Box 3.1), water elevations in storage reservoirs, and minimum instream flows at reservoir outlets. Specifications regarding these flow targets are provided in the 2000 National Marine Fisheries Service Federal Columbia River Power System Biological Opinion (NMFS, 2000). Of all these flow targets, the most critical with respect to this discussion involves smolt migration flows.

BOX 3.1
Vernita Bar Agreement

The Vernita Bar Settlement Agreement, approved in 1988, ensures flows to incubate fall Chinook embryos and fry at Vernita Bar, a large gravel bar and an important spawning area four miles downstream from Priest Rapids Dam. Signatories to the agreement include the Bonneville Power Administration, the National Marine Fisheries Service (since renamed NOAA Fisheries), the Confederated Tribes of the Umatilla Indian Reservation and Colville Indian Reservation, the Yakama Indian Nation, the Washington Department of Fisheries (now Washington Department of Fish and Wildlife), the Oregon Department of Fish and Wildlife, and the Grant, Chelan, and Douglas county public utility districts.

The agreement specifies how the Grant, Chelan, and Douglas public utility districts and Bonneville Power Administration will provide the required flows, and identifies special conditions in the event of inability to perform and adverse water conditions. Flows are regulated to minimize excavation of salmon redds at flows higher than 70 thousand cubic feet per second (kcfs). Grant County Public Utility District is to operate the Priest Rapids Project to the extent feasible to yield river flows during daylight equal to 68 percent of daily mean inflow to Wanapum pool. The agreement does not obligate Bonneville Power Administration to limit fall discharge, but BPA attempts to do so. After the end of salmon spawning season, a field inspection assesses the protection level flow (minimum flow to protect established salmon spawning nests, or redds) by several criteria. Protection of redds is related to flow levels in the guidelines. The protection level even considers details such as weekdays vs. holidays or weekends, and is highly specific. Some flexibility is permitted within the foregoing schedule as long as alternatives provide an equivalent volume. The biological monitoring program tracks temperature data to predict dates of spawning, hatching, emergence of fry, and the end of emergence. At the end of emergence, usually in mid-May, the protection flow level is terminated.

As this report was going to press, an expanded Vernita Bar Agreement was being drafted. The new agreement, tentatively called the “Hanford Reach Fall Chinook Protection Program,” is to be submitted to the Federal Energy Regulatory Commission for consideration in the relicensing process.

The highly managed Columbia River system still exhibits significant variability of discharge on many different time scales. Partly as a result of this variability, migration flow targets are not always met, and it has generally proven difficult to maintain mainstem flows above the target for the entire fish migration period. In years of low to moderate precipitation, decreased flows in the Columbia River exacerbate this phenomenon. Furthermore, because of consumptive use and hydropower demands during low-flow years, tradeoffs between fishery demands often come into play, particularly between biological needs within storage reservoirs, and the associated outlets, and anadromous migration conditions in the mainstem. Competing biological demands for water thus often make it impossible to achieve stated flow targets. Although these target flows have at times not been met, meeting the needs of biological and

ecological objectives has become an objective with operational priority on par with flood control and hydroelectric power generation.

Hydropower Generation and Spill

The Federal Columbia River Power System is operated to furnish electrical power for industrial, urban, and agricultural needs. This results in daily variability in discharge to meet high demand during daylight hours and low demand during nighttime hours. Coordination between release of water from one dam to the next is important because: 1) there are relatively short distances between the dams, 2) most of the dams are run-of-the-river, with little or no storage, and 3) the outflow from one dam is usually the start of the pool behind the next downstream dam. There is also the need to allow some "spill" (the bypassing of water around hydropower generation turbines) of water during downstream migration of salmon smolts to enhance their prospects for survival. The fish spill program is implemented during both the spring and summer smolt migration periods, spanning from April through August. This strategy is designed to intentionally discharge water over spillways at different dams in the FCRPS in accordance with guidelines specified in NOAA Fisheries' 2000 Biological Opinion. These operational features result in sharp changes in diurnal discharge patterns at dams on the Columbia and Snake rivers.

WATER WITHDRAWALS

Existing Water Rights

The Department of Ecology issues water rights permits in Washington State. After water use has commenced, the Department of Ecology visits the site of use and issues a certificate. Washington State law specifies that if the full volume of a water right is not used at its allocated rate over a five-year period, the volume of the water right not used can be taken away. Historical trends indicate that most permit holders do not divert their full allocations during most years.

The Washington State Department of Ecology has to date issued 754 permits for surface water withdrawals from the mainstem Columbia River between the Canadian boundary and Bonneville Dam. The total maximum withdrawal volume of these permits is 4,240,000 acre-feet per year. Withdrawal permits held by the Columbia Basin Project total 3,160,000 acre-feet per year, which represents 74 percent of the water rights issues in this reach of the Columbia River. The Department of Ecology has also issued 110 water rights for groundwater extractions within one mile of the Columbia River, which amount to 440,000 acre-feet per year. Permits in the State of Washington currently issued for Columbia River surface water and groundwater withdrawals within one mile of the river thus amount to about 4,700,000 acre-feet per year. An itemized list of surface-water permits showed that 96 percent of surface water diversions were used for irrigation, with the remaining 4 percent being used by municipalities and other uses (figures based upon data provided by John Covert, Washington State Department of Ecology, 2003).

Table 3.1 illustrates and compares permitted volumes of water withdrawals from the mainstem Columbia River, and from groundwater within one mile of the Columbia River, with regard to maximum, mean, and minimum monthly discharges at John Day Dam[2] (1960-1999 database, USGS, 2001). Columns 1-3 list Columbia River discharge figures at John Day Dam for 1960-1999. Column 4 lists the monthly distribution of water withdrawal permits along the Columbia River in the State of Washington. These monthly values are based on actual monthly withdrawal data at Franklin D. Roosevelt Lake by the Columbia Basin Project (agriculture, 96 percent of the withdrawals) and the City of Pasco (municipalities and industry, the remaining 4 percent). No water use data on groundwater withdrawals were available, so Table 3.1 assumes that 75 percent of groundwater withdrawals were used for irrigation and that 25 percent of groundwater was used for commercial, industrial, municipal, domestic and other uses.

TABLE 3.1 Columbia River Flows at John Day Dam, 1960-1999 and monthly Columbia River withdrawals

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Month	Maximum	Mean	Minimum	Withdrawals	percent of max.	percent of mean	percent of min.
Jan	16,200	9,690	5,430	10.8	0.1	0.1	0.2
Feb	18,200	9,500	5,740	10.0	0.1	0.1	0.2
Mch	20,400	11,100	6,200	110	0.5	1.0	1.8
April	19,800	12,100	5,920	597	3.0	4.9	10.1
May	29,400	17,200	8,110	765	2.6	4.5	9.4
June	34,700	19,000	7,120	792	2.3	4.2	11.1
July	21,400	12,500	5,110	850	4.0	6.8	16.6
Aug	13,400	8,390	5,420	793	5.9	9.5	14.6
Sep	9,260	6,420	4,280	498	5.4	7.8	11.6
Oct	10,400	6,910	5,430	274	2.6	4.0	5.1
Nov	9,280	7,340	5,170	12.3	0.1	0.2	0.2
Dec	15,100	8,870	5,210	11.7	0.1	0.1	0.2

Notes:
Columns 1-3—Maximum, mean, and minimum monthly discharges for Columbia River at John Day Dam. Values in thousands of acre-feet/month.
Column 4—Permitted volumes from mainstem Columbia River surface water withdrawals and groundwater from within one mile of the river, between the Canada-U.S. border and Bonneville Dam. Values in thousands of acre-feet/month.
Columns 5-7—Withdrawals as percentages of monthly Columbia River discharge values at John Day Dam.
SOURCE: USGS, 1996; Washington Department of Ecology, 2003.

[2] John Day Dam was used as a reference site because almost all existing Columbia River consumptive withdrawals are upstream of this dam. Nearly all the pending permits for additional consumptive withdrawals in State of Washington are also upstream of John Day Dam. Columbia River discharge figures at John Day reflect inflows from the Snake River; discharge data in Table 3.1 are thus higher than they would be for stations upstream of the Columbia-Snake confluence.

Consumptive use at the Columbia Basin Project is about 70 percent of the volume of surface water withdrawals (Montgomery Water Group, 1997; see also Appendix C). This 70 percent figure was assumed to apply to other areas of irrigated agriculture along the Columbia River mainstem (keeping in mind as well that the Columbia Basin Project represents the largest irrigated agriculture diversion along the river), with the remaining 30 percent of withdrawals eventually returning to the Columbia River as irrigation return flows and groundwater seepage. With regard to the municipal and industrial (M&I) water reflected in Table 3.1, data indicate that roughly 30 percent of municipal water is returned to the Columbia River through wastewater treatment plants (City of Pasco, written communication, 2003). It was further assumed that an additional 10 percent of M&I withdrawals returned to the Columbia River through groundwater seepage, for a total consumption of 60 percent of municipal and industrial water withdrawals.

Column 5 in Table 3.1 shows that withdrawals of existing water permits under high-flow conditions, as a percentage of total flows, ranged from 0.1 (in December) to 5.9 percent (in August). In contrast, Column 7 shows that withdrawals under minimum flow conditions ranged from 0.2 (in January) to 16.6 percent (July). The critical months of withdrawals under minimum flow conditions are in July and August. These months are periods of high water withdrawals for irrigated agriculture and municipalities. The pronounced seasonality of withdrawals and the sharp differences in the effects of withdrawals according to season are key messages from Table 3.1. These data show that January withdrawals have very little effect on the overall flows of the Columbia, but that during July and August, current withdrawal volumes have noticeable effects on mainstem flows, especially during lower-than-average discharge years.

Columbia Basin Project

The U.S. Bureau of Reclamation's Columbia Basin Project (Figure 3.5) is the largest irrigation project in the Columbia River basin. The centerpiece of the project is the Grand Coulee Dam. Completed in 1941, Grand Coulee is the nation's largest concrete dam. It impounds about 9.4 million acre-feet of water in Franklin D. Roosevelt Lake, which provides water to the East Columbia Basin Irrigation District, the Quincy Columbia Basin Irrigation District, and the South Columbia River Basin Irrigation District (*http://www.usbr.gov/dataweb/html/columbia.html*; accessed February 5, 2004). The most important crops on the project are apples, alfalfa, corn, potatoes, and wheat. The project's network of canals, tunnels, reservoir and pumping plants were intended to deliver water supply to about 1.1 million acres, but today, about 671,000 acres are irrigated (ibid.). Irrigation return flows from the Columbia Basin Project are discharged into the Columbia River through wasteways, creeks, and groundwater seepage.

Withdrawals

Rates and patterns of withdrawals at the Columbia Basin Project vary within and between years. Table 3.2 displays average monthly pumping rates from Franklin D. Roosevelt Lake (from which water is conveyed to the Columbia Basin Project), and shows that irrigation water is generally applied from March through October, with highest usage during June and July. Figure 3.6 shows 1975-2000 annual withdrawals from Franklin Roosevelt Lake to the Columbia Basin Project. Maximum and minimum annual values were 3,090,000 acre-feet and 1,450,000 acre-

FIGURE 3.5 The Columbia Basin Project. SOURCE: Montgomery Water Group, Inc. (1997)

TABLE 3.2 Average monthly volumes (thousands of acre-feet) of water pumped from Franklin D. Roosevelt Lake, 1990.

Month	Mar	April	May	June	July	August	September	October	Annual	Permitted Maximum
Volume	38	387	508	525	539	473	274	141	2,885	3,158
Percent of Total Annual Withdrawal	1.3	13.4	17.6	18.2	18.7	16.4	9.3	4.9		

SOURCE: Bonneville Power Administration (1993).

feet per year, respectively. The low withdrawal in 1980 corresponds to the eruption of Mount Saint Helens. Note that in only one year—1995—did project withdrawals approach the permitted maximum (the U.S. Bureau of Reclamation has water rights for 3,158,000 acre-feet of water per year at Grand Coulee). Expansion of irrigated agriculture on Columbia Basin Project lands would increase withdrawals toward this permitted maximum, which would reduce downstream flows (although roughly 30 percent of the additional withdrawals would return to the Columbia River, a figure that could decrease over time with more efficient irrigation systems). During the time period displayed in Figure 3.6, annual withdrawals averaged close to 80 percent of the permitted level (1990 withdrawals, depicted in Table 3.2, represented an above-average annual withdrawal for the time period in Figure 3.6). If the Columbia Basin Project

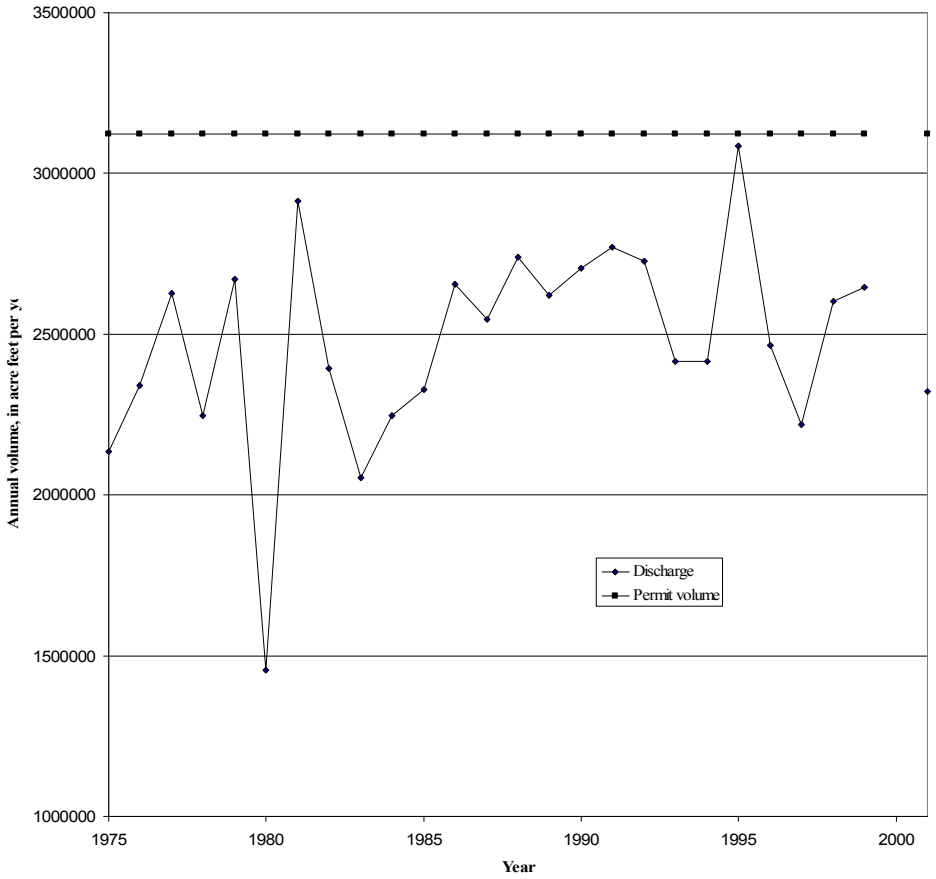


FIGURE 3.6 Annual withdrawals from Columbia River at Grande Coulee Dam by Columbia Basin Project. SOURCE: USGS (2003a).

were to withdraw its full entitlement of water each year, it would roughly result in an average 25 percent increase of water being delivered to the project (an increase in withdrawals of about 600,000 acre-feet per year). As mentioned, the Columbia River Project currently accounts for roughly 74 percent of total water withdrawals from the middle reach of the Columbia River in the State of Washington.

Potential Additional Withdrawals from the Columbia River

One focus within this study was the consideration of the effects and risks to salmonid survival over a specific range of proposed additional water withdrawals (250,000 acre feet per year—1,300,000 acre-feet per year). An additional 1,300,000 acre-feet per year of water withdrawals from the mainstem Columbia River from the Canada-U.S. border to Bonneville Dam would be roughly a 28 percent increase in the volume of water permits that have been issued by the State of Washington for surface water withdrawals from the Columbia River and

groundwater withdrawals from within one mile of the river (current permitted total maximum volume = 4.24 million acre-feet per year). The effects of these proposed additional withdrawals, and their attendant risks, will vary considerably depending upon flow levels in the Columbia River at any given time. Under current withdrawal patterns, the greatest effects of withdrawals on flows are during July and August (particularly during low flow years), as these are the months of highest withdrawals. The seasonality of proposed additional withdrawals was assumed to be similar to existing water uses for irrigation and municipal uses, and is of overriding importance in considering the implications of Columbia River withdrawals for salmon survival. Under current conditions, during January, less than 1 percent of total annual withdrawals are made. About 18 percent of annual total withdrawals are made in July.

Numerous calculations and speculations could be made in regard to the proposed range of withdrawals. Assuming that the seasonal pattern of withdrawals continues essentially unchanged, and assuming that the upper end of the range of proposed additional withdrawals (1,300,000 acre-feet per year) is diverted, this would entail additional withdrawals of roughly 2,600 acre-feet in January and roughly 234,000 acre-feet in July. The effects in January of the upper end of the proposed range of additional diversions (2,600 acre-feet in January) would still result in total withdrawals being less than 1 percent of mean January Columbia River flows. The effects in July of the upper end of the proposed range of diversions (234,000 acre-feet in July), by contrast, would increase July withdrawals from roughly 6.8 percent of mean Columbia River flows to roughly 8.6 percent of mean Columbia River flows at John Day Dam (based on 1960-1999 flows; see Table 3.1). Under *minimum* July flow conditions, the upper end of the proposed range of diversions would increase July withdrawals from roughly 16.6 percent of Columbia River *minimum* flows to roughly 21 percent of Columbia River flows at John Day Dam.

In addition to permit applications for withdrawals currently being considered by the State of Washington, other factors also point to the possibility of further reductions in future Columbia River flows. Regional climate warming could reduce flows in low-flow periods, human population growth is likely to exert pressures for additional withdrawals from the Columbia, and current users (e.g., tribal reservations) may seek to increase current levels of withdrawals. The occasional but virtually certain coincidence of unfavorable ocean conditions with one or all of these trends poses additional and substantial risks to Columbia River salmonid survival or recovery of salmonid populations. Later sections of this report elaborate on the concept of risks and their management in the context of Columbia River flows, withdrawals, and salmon survival rates.

RETURN FLOWS AND WATER QUALITY

In addition to water withdrawals, return flows from irrigation projects like the Columbia Basin Project add to river flows and have implications for Columbia River system water quality and quantity, as well as implications for salmon survival. Complete accounting of surface and subsurface discharges of irrigation return flows from the Columbia Basin Project is not possible because they are not measured. A report from the Montgomery Water Group (1997), however, provides some data from which irrigation return flows can be estimated (the rationale and assumptions made in the mass balance of water in the Columbia Basin Project from 1975 through 1994 are in Appendix C). Irrigation return flows from the Columbia Basin Project consist of canal and lateral operational spills, surface irrigation drainage, and groundwater

outflow. Canal and lateral operational spills are gauged, but surface irrigation and groundwater outflows to the mainstem are unmeasured and were calculated as the closure (balancing) term in the Columbia Basin Project water balance. From 1975-1994, canal and lateral spills averaged 265,000 acre-feet per year and irrigation and groundwater outflow to the river combined to average 540,000 acre-feet per year, for an average total return flow to the Columbia River of 805,000 acre-feet per year. Over this 20-year period of record, 30 percent of the irrigation water for the Columbia Basin Project was thus eventually returned to the river. This also means that 70 percent of the water supply for the Columbia Basin Project was consumed or was evaporated, because change in water storage in the project was assumed to be zero (see Appendix C).

Several water quality parameters are of key concern in the Columbia River system, including water temperature, dissolved oxygen, nutrients, suspended sediments, pesticides, trace metals, and pharmaceuticals (USGS, 1998). The concern with respect to water temperature is illustrated by summer water temperatures in Crab Creek, a small stream near Beverly, WA. Crab Creek conveys irrigation return flows from the Columbia Basin Project. Water temperatures in Crab Creek (Figure 3.7) generally reflect variations in air temperature from July to September. Based on daily water temperature records from 1975 through 2002 at Crab Creek, and at the Columbia River at Grand Coulee Dam and near Vernita (Dept. of Ecology, 2003b), water temperatures in Crab Creek are higher than those in the Columbia River during late winter and spring, and lower than Columbia River water temperatures during fall and early winter.

The U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program for the Central Columbia Plateau for 1992-95 reported that "the health of the aquatic ecosystems is substantially affected by agricultural practices and, in a few streams, by wastewater discharges" (USGS, 1998) in Washington and Idaho. Numerous water quality parameters can be influenced by agricultural practices and wastewater discharge, including nutrients (specifically

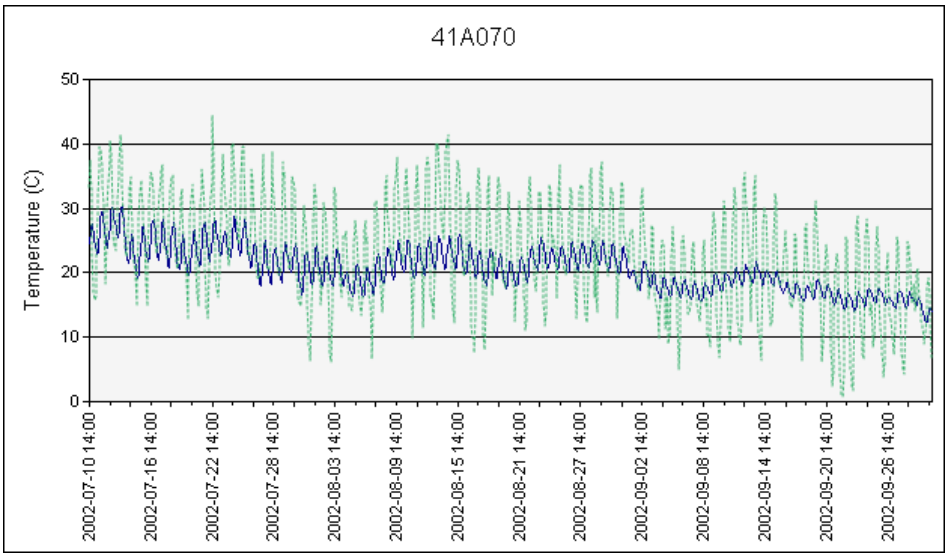


FIGURE 3.7 Water temperatures (bold) in Crab Creek (which conveys return flows from the Columbia Basin Project), and air temperatures, in July, August, and September, 2002. SOURCE: Washington State Dept of Ecology (2003a).

nitrogen and phosphorus), sediment, and organic and trace metal contaminants. For example, the NAWQA study found that nitrate-N concentrations increased from less than 1 mg/L in 1960s to about 3 mg/L in the 1980s (USGS, 1998). Irrigation can also lead to increases in soil erosion, and therefore increased sedimentation in streambeds. In the Columbia Basin Project, however, the conversion of surface furrow irrigation to pressurized irrigation (center pivot and sprinkler) since the 1970s (Montgomery Water Group, 1997) has reduced daily suspended sediment yields (load per acre) from about 0.3 pounds per acre in 1975 to about 0.1 pounds per acre in the 1980s (USGS, 1998). In contrast, agricultural return flows in the Yakima River basin have at times contributed to impaired water quality in the Yakima River (U.S. Bureau of Reclamation, 2002). In addition to the influence of sediment on the quality of stream habitat, sediment yield is an important concern because most organochlorine pesticides, such as DDT, are found in streambed sediments. Long banned from use, DDT levels exceeding general standards for aquatic life protection were nonetheless found in streambed sediments in upper reaches of Crab Creek (USGS, 1998). In the Yakima River basin, DDT and its breakdown products have been found in fish tissue in excess of recommended human health criteria, and concentrations of these pesticides have been correlated with suspended sediment levels (ibid.). Some studies have noted increased cancer risks within certain populations, such as Native Americans, for populations that consume high amounts of Columbia River basin fish (Columbia Basin Bulletin, 2002).

In contrast to surface waters, groundwater in the Columbia Basin Project has elevated nitrate concentrations that exceed drinking water standards in shallow groundwater (observation wells) and smaller background concentrations in deeper wells (USGS, 1998). Pesticide residues were found to be present in high nitrate wells, sometimes exceeding Maximum Contaminant Level (MCL) for drinking waters (USGS, 1998). The USGS has initiated Cycle II studies in its NAWQA program to intensively investigate surface and groundwater qualities in the Central Columbia Plateau and Yakima River Basin (USGS, 2003b).

Beyond immediate human health concerns associated with exposure to pesticides and trace metals through consumption of fish, high concentrations of contaminants and nutrient enrichment in return flows could have long-term implications for the health of salmon populations. For example, in a nationwide reconnaissance of 139 streams conducted in 1999-2000 by the U.S. Geological Survey, a wide range of organic wastewater contaminants, including pharmaceuticals and hormones, were detected in streams downstream of sources of human, industrial, and agricultural wastes (Kolpin et al., 2002). Multiple organic wastewater contaminant detection was common, including many compounds for which aquatic life criteria have not been established. The concern associated with poor water quality of return flows would also exist under a system of water banking that did not result in a net change in water use, but which resulted in greater municipal use that led to contaminated return flows.

The exposure of fish to organic contaminants, particularly treated municipal sewage discharge, has been demonstrated to impact fish health at several levels, ranging from biochemical processes, to organ functions, and to organism fitness (Porter and Janz, 2003). Exposure of adult fish to synthetic hormones and other contaminants with estrogenic properties can significantly impair fertility (Schulz et al., 2003). Exposure to low but detectable levels of organic wastewater contaminants from increasing municipal and agricultural uses of water may thus impact the survival and reproduction of the salmon, especially during low flow summers, when concentrations would be greatest.

WATER TEMPERATURE

There are data for Columbia River water temperatures that date back to 1938 (USACE, 2000). Figure 3.4 shows maximum and average Columbia River August water temperatures at Bonneville Dam. As the figure indicates, the trend lines show clear increases in August water temperatures over time. Water temperature data at Bonneville Dam also reveal that the first and last dates on which water temperatures equal or exceed 20˚ C are occurring earlier in the year later in the year, respectively. Today, average and maximum values of Columbia River water temperatures are well above 20° C. These increasing trends in water temperatures are of great concern with regard to the survival of Columbia River salmon. For example, August temperatures at Bonneville Dam exceed temperatures preferred by cold water fish like salmonids (~10°C—15°C; Kling et al., 2003). More importantly, it means that Columbia River water temperatures are approaching the upper limits of thermal tolerance for cold water fishes (~20°C –24°C; Mohseni et al., 2003) such as salmonids.

These temperature changes appear to have been driven by: 1) construction of the dam and reservoir system (the large surface areas of Columbia River reservoirs and the increased residence time of water in these reservoirs both contribute to higher water temperatures), and 2) increased temperatures of inflows from tributaries from watersheds that have lost riparian cover that provided shade for those streams.

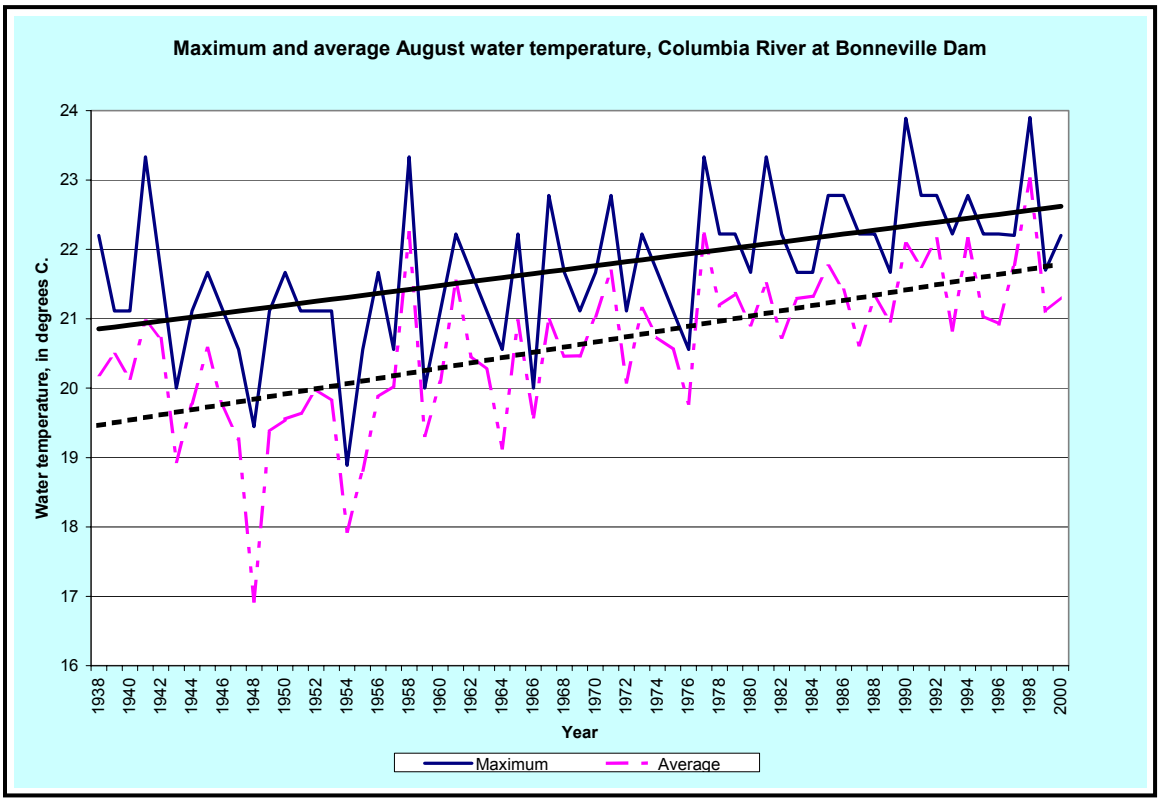


FIGURE 3.8 Maximum and average August water temperatures in the Columbia River at Bonneville Dam (straight lines reflect trends for maximum and average values). SOURCE: USACE data base (2000).

CLIMATE VARIABILITY AND CHANGE

Changes and variability in regional climate across the Columbia River basin influence discharge and water temperatures of the Columbia Basin. For example, winter precipitation amounts and snowpack depths in the basin's higher elevation areas affect seasonal patterns of Columbia River discharge. Climate variability and changes also have important implications for water temperatures in the Columbia River (as was shown in Figure 3.3). The influences of climatic variability on Columbia River flows have been investigated by many scientists (cf., Hamlet and Lettenmaier, 1999; Miles et al., 2000; Mote, 2003; Payne et al., 2004), and there is evidence of a gradual warming of Pacific Northwest climate during the twentieth century. For example, in a report for the U.S. Global Change Research Program, a scientific team that evaluated the potential consequence of climate change for the Pacific Northwest, concluded, "Over the 20th century, annual average temperature in the Northwest rose 1 to 3˚ F (0.6 to 1.7˚ C) over most of the region" (Mote et al., 1999). The Columbia River has been subjected to many changes and human influences during the twentieth century, and care must be taken in ascribing cause-and-effect explanations for climatic and hydrologic trends. Some of the concerns regarding possible future climate warming in the region are related to increasing global mean surface air temperature during the twentieth century (about 0.4˚--0.8˚ C, or 0.7˚--1.5˚ F; NRC, 2001a). Further evidence of possible regional climate changes might be gained by evaluating climate variability in the undammed Fraser River in Canada, which lies just to the north of the Columbia River basin (see Box 3.2). Climate change and possible warming across the Columbia River basin represent additional uncertainties, such as possible upstream development, tribal water rights adjudications, or variations in ocean conditions, that will affect the cumulative future impacts of water management decisions across the basin.

A key concern regarding possible future climate warming across the basin is the effects on the basin's snowpack. Recent research suggests that warmer temperatures across the basin are contributing to declines in total snow accumulations, and that the decline in the Cascade Mountains may be as much as 60 percent (Mote, 2003). The implications are that the melting of snowpack earlier in the spring will increase spring runoff peaks and reduce summer streamflow.

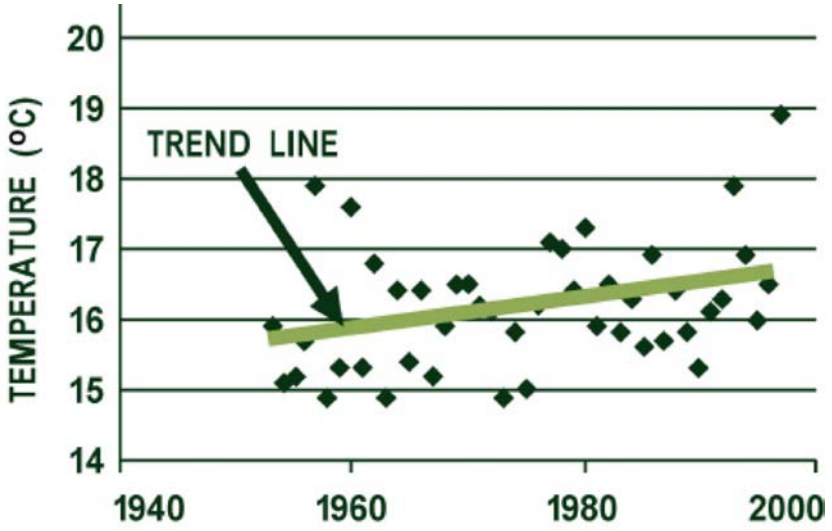
As Daniel Cayan, a climate researcher at the Scripps Institution of Oceanography explained, "It doesn't mean we've lost water . . . It means the water is coming off earlier" (quoted in Service, 2004). The upshot is that winters would be wetter and summer would be drier (ibid.). Not all scientists agree that recent warming across the basin necessarily portends a warmer future, however, as some climate scientists argue that broad trends in temperature and snow accumulation across the basin are due to natural multi-decadal oscillations in climate patters (ibid.)

Many atmospheric scientists are concerned that twentieth century climate warming in the Columbia River basin was a result of global increases in "greenhouse gases" such as carbon dioxide, and there are some concerns that warming will continue during the twenty-first century. Atmospheric and climate scientists have developed General Circulation Models (GCMs) that are used to simulate behavior of the global climate system and to forecast future global and regional changes in climate. Several of these GCMs are used by scientists in North America and Europe, and they are frequently used to forecast regional climatic implications of continued increases in greenhouse gas levels. For example, future Pacific Northwest climate change scenarios from the Intergovernmental Panel on Climate Change and other groups and scientists (Table 3.4) suggest that air temperatures across the region are likely to increase, with less agreement on possible

BOX 3.2
Canada's Fraser River: Comparing the Effects of a Changing Climate

Evaluating the impacts of climate changes and variability is often complicated because the results from other, non-climate variables can intervene and cause similar impacts. For example, water temperatures can be affected by changes in water levels and human activities, such as thermal effects of power plants. In seeking an understanding of how twentieth century climate has affected Columbia River temperatures, a convenient frame of reference exists: Canada's Fraser River. Comparisons between the Fraser and Columbia are useful because the Fraser is relatively close to the Columbia, and its basin is of similar dimensions and has features in common with Columbia (e.g., headwaters along the western flanks of North America's Rocky Mountains). The Fraser also makes for useful comparison because it is undammed, and thus allows for climatic effects on water temperatures in the absence of dams—perhaps the most important human-induced change in Columbia River hydrology—to be considered.

As the figure here illustrates, from 1953 to 1998, mean summer temperature of Fraser River water temperature increased by 1.1 ^{o} C (British Columbia Ministry of Water, Land and Air Protection). Air temperature in the interior of the Fraser River basin also rose by 1.1 ^{o} C in the same period.[3] Fraser River flow has also declined since 1913. Although it is not exactly clear what has caused the increases in Fraser River temperature, the increase did not result from dams and their operations. In considering twentieth century increases in Columbia River water temperatures, data from the Fraser River suggest that the Columbia's temperature increases may not be entirely a result of dams and impoundments, and may be affected by other factors such as increasing air temperatures (i.e., climate change).



Average Fraser River temperature (1953 to 1998)

SOURCE: Pacific Salmon Commission (1941-1998), Environment Canada, analysis by Canadian Institute for Climate Studies. Figure available online at *http://wlapwww.gov.bc.ca/soerpt/pdf/997climate/fraser*.pdf.

TABLE 3.4 Projected Climate Changes over the Columbia River Basin

Area	Winter Temp C	Summer Temp C	Winter Precipitation	Summer Precipitation % Change	Year of Projection	Source
Western North America	+4 to +6	+3 to +5.4	0 to +40 % change	-10 to +10% change	2071-2100 minus 1961-1990	Houghton et al., 2001
Pacific Northwest States	+4.5 to +6	+4 to +4.5	Annual 0 to +50 % change		2090	US National Assessment 2000
Pacific Northwest Regional Climate	Annual +4.8 to +7.3		-1.0 to +10.4 cm	-4.6 to +2.0 cm	2050	Mote et al., 1999
Columbia River Basin	Annual +1.3		+5 % change		2040-2069	Payne et al., 2004

Sources listed in table.

changes in precipitation. In its evaluation of potential climate change impacts on the Pacific Northwest, the U.S. Global Change Research Program also noted that "Regional warming is projected to continue at an increased rate," and also noted less agreement on precipitation forecasts (National Assessment Synthesis Team, 2000). Possible shifts in precipitation patterns and increasing air temperatures have implications for Columbia River hydrology and water management, including water withdrawal permitting decisions. These scenarios represent well-informed speculation on the future, although details across scenarios often show varying results. Nonetheless, the weight of scientific evidence suggests that long-term climate warming of recent decades across the basin is likely to continue. Such long-term temperature increases would represent an increased risk to the survival of Columbia River salmonids, as increasing temperature would represent a threat in terms of further increases in Columbia River water temperatures (which also increased during the latter twentieth century) and reduced flows during low-flow periods. Some observers have noted that the Columbia River water system experiences stresses during low-flow periods under current conditions, and that "the best water management and planning of today will be done by those with an eye towards both natural patterns of climate variability and possible changes in climate" (Miles et al., 2000). Given the increasing water temperatures in the Columbia River, climate warming across the basin during the late twentieth century, and the prospect of possible additional warming across the basin in the twenty-first century, water management agencies would be well-advised to monitor climate data and variability and prepare to adjust operational decisions accordingly as new information becomes available. Appendix D contains additional discussion on climate change and its implications for Columbia River basin hydrology.

SUMMARY

The Columbia River basin experienced a variety of substantial changes to its patterns of water flows and to water quality during the twentieth century. The most dramatic of these

changes was the fundamental alteration of the great river's annual hydrograph. At the start of the century, that hydrograph exhibited a great seasonality between its low flow and high flow periods. With the construction and the operations of the Federal Columbia River Power System, the annual hydrograph was eventually "flattened." By the end of the twentieth century, the differences in flows throughout the year had been greatly reduced, in large part to stabilize flows used to generate hydroelectric power. Considerable inter-annual and diurnal variability in flows remains, however. Other key operational considerations in the system are flood control, instream flows, and irrigation withdrawals.

There are many users of water along the Columbia River in Washington State. As is the case across the West, irrigated agriculture is the largest consumptive user. About 96 percent of withdrawals are utilized by irrigators, the other four percent by municipalities and industries (mainly in the Tri-Cities of Richland, Kennewick, and Pasco). By far the largest irrigator is the federal Columbia Basin Project. The Project diverts an impressive 74 percent of total irrigation water withdrawals from the Columbia River in Washington. The remaining withdrawals are from a large number of small (relative to the Columbia's flows) withdrawals.

The current pattern of withdrawals is such that they have very little effect on Columbia River flows during January, a period of low demand. By contrast, the volumes of withdrawals in July and August—a period of highest demand—have noticeable effects on Columbia River flows. Although hydrologic data on Columbia River withdrawals are imperfect, those data that are available suggest that summer withdrawals in July divert roughly 16.6 percent of Columbia River flows at John Day Dam. The upper end of the range of prospective, additional withdrawals considered in this study would increase that figure, raising it to roughly 21 percent. A key issue in considering the implications of prospective additional water diversions clearly is the seasonality of those diversions.

Other important changes to the river include deteriorating water quality, which has implications for Columbia River salmon, and increasing water temperatures. Water temperatures in the mainstem Columbia increased steadily during the latter part of the twentieth century. Most observers attribute this increase to the construction of dams and impoundments along the Columbia. Other watersheds in the region that have had fewer hydrological alterations—such as Canada's Fraser River—exhibit increases in water temperature in the absence of impoundments (the magnitude of temperature increases there, however, is smaller than in the Columbia). Prospective climate warming across the Columbia basin may thus also be contributing to this trend. Although precise cause-and-effect mechanisms are hard to define clearly, the changes in Columbia River hydrology identified in this chapter have greatly affected the basin's salmon populations. The following chapter examines relations between Columbia River salmon and several environmental changes and variables.

4

Environmental Influences on Salmon

Columbia River basin salmon are among the world's most intensively studied fish species. Quantitative and qualitative data regarding salmon species and their habitat have been gathered and evaluated for many decades. This information has increased understanding of Pacific salmon and their complex life histories. Given their responsibilities to help protect salmon, water management agencies have drawn heavily upon this information and have consulted with fishery science experts in designing strategies for preserving and enhancing salmon habitat and populations. Despite the extent of data and scientific knowledge regarding Pacific salmon, more precise understanding of salmon is inhibited by the complexities of salmon's diverse anadromous (which refers to organisms that spend most of their adult lives in salt water and then migrate to fresh water and lake to reproduce) life histories and the vast scale of the biomes they traverse during their life spans.

In addition to the biological complexities of salmon species, within the impounded Columbia River they have been affected by an array of environmental conditions and changes, such as increasing water temperatures and changes to other water quality parameters, changes to water velocity through reservoirs, habitat degradation, changing turbidity, shifting seasonal patterns and volumes of river flows, passage effects at dams, and changes in predators and predation rates. Scientists and water managers have considered these issues when formulating fish passage strategies such as flow augmentation, construction of smolt (young salmon, generally 2-3 years in age) bypass systems, spill programs, smolt transportation programs, and the construction and upgrade of fish ladders. Collectively, these devices and strategies are designed to work in concert to increase survival rates of salmon migrating through the dammed river and contribute to the productivity of anadromous fish populations. NOAA (National Oceanographic and Atmospheric Administration) Fisheries (formerly the National Marine Fisheries Service, or NMFS), the federal fishery agency responsible for the recovery of anadromous salmonid populations listed pursuant to the Endangered Species Act, embraces these strategies and calls for their continued improvement and use in fostering salmon recovery (cf., NMFS, 2000). Even so, it is not known whether these actions alone can reverse or stall long-term declines in salmon populations. Some passage strategies require refinement to maximize benefits. Much of the research identified in the 2000 Biological Opinion from the National Marine Fisheries Service (ibid.) focuses on improving the implementation of these strategies and gaining a clearer understanding of the outcomes of management actions that are often confounded by environmental complexities. Furthermore, conditions in tributaries and in estuarine and marine habitats have pronounced effects on salmon productivity, as do harvest and hatchery programs. Large salmon returns in 2001-2003, for example, were viewed by many scientists as a function of favorable ocean conditions (e.g., NPCC, 2003), but ecological and

biological complexities inhibit perfect understanding of cause-and-effect in such events. In any event, a 100-year snapshot of Columbia River salmon portrays long-term declines and provides a backdrop against which short-term events should be evaluated. This chapter reviews environmental variables that affect Columbia River salmon and examines competing hypotheses and models constructed to explain the relative importance of these variables.

COLUMBIA RIVER SALMON

Three species of anadromous salmonids commonly migrate through the middle and upper reaches (above Bonneville Dam) of the Columbia and Snake rivers in the State of Washington: Chinook (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), and sockeye (*Oncorhynchus nerka*) all commonly migrate to spawning destinations well upstream from Bonneville Dam. Remnant wild and hatchery populations of coho salmon (*O. kisutch*) are also found in select locales in the upper Columbia basin. All of these species have some population units that are listed as endangered or threatened under the federal Endangered Species Act (see Table 1.1). Additionally, chum salmon (*O. keta*), which are also federally listed, and a vestigial population of pink salmon (*O. gorbuscha*) inhabit waters downstream from Bonneville Dam.

Requirements for each stage of salmon life history can be generalized for all of the anadromous species. Spawning fish, returning from the ocean, require freshwater instream habitat with temperatures that ensure survival until they spawn. Spawning salmon seek species-specific gravels, water depths, and velocities to build redds (nests), in which they deposit their eggs. Egg survival depends upon low sedimentation rates, adequate delivery of dissolved oxygen, and appropriate river temperatures to support egg development. Once the eggs hatch, some of the young fish (fry) maintain locations in the river to develop, while some fry grow while migrating downstream. During the post-fry stage (juvenile), these fish remain in the river from several months to more than two years, depending on the species or life history type. Growth is crucial during this phase, which supports the physiological transformation required for emigrating from fresh water, into brackish water, and then into salt water. This transformation phase is called *smoltification* and during it the fish experience a lengthening, change to a silvery color, and begin to actively migrate out of the river system (as their name suggests, spring migrants smolt during spring months, and summer migrating oceantype Chinook primarily smolt in July and August).

Chinook Salmon

Fishery managers traditionally divide Columbia River Chinook salmon into spring, summer, and fall runs. After spending much of their lives in the Pacific Ocean, spring Chinook salmon adults that spawned in high, cold tributaries in Idaho, Oregon, and Washington return to the Columbia River mouth from February through mid-May. Through olfactory homing instincts, they travel upstream and reach their natal tributary streams in June, move onto spawning sites in August, and largely complete spawning by early September. Summer Chinook salmon, which use the Columbia River upstream from the mouth of the Snake River, enter the Columbia River mostly in May and June and spawn in September and early October in natal streams such as the Wenatchee and Methow rivers. In the Snake River, summer Chinook salmon

make up a later component of the spring Chinook salmon migration, spawning in late August and early September. Fall Chinook salmon enter the Columbia River in July and August and spawn in late October and November in the mainstem Columbia River (a small number also spawn in the Snake River between Lewiston and Hells Canyon Dam). Fall Chinook salmon today make up the largest segment of Chinook salmon runs.

Hatchery and naturally-produced fall Chinook salmon that use the lower Columbia River area are known as "tule" fall Chinook salmon. Relatively dark in color, they arrive in the river in September and October, then spawn in late fall. Fall Chinook salmon that spawn upstream from McNary Dam in both the Snake and Columbia rivers are known as "upriver brights."[1] They enter the Columbia River in August and spawn mostly upstream from McNary Dam. Upstream from Bonneville Dam, the (numerically) most important spawning area—long, damless stretch of river known as "The Hanford Reach"—lies between Priest Rapids Dam and the head of McNary Dam pool.

The shoreline-oriented behavior of subyearling fall Chinook salmon in flowing river segments, and their relatively slow rearing migration in the Snake and Columbia rivers, which occurs in early and mid-summer, makes them potentially vulnerable to high water temperatures. Construction of mainstem hydroelectric projects extended the passage period for subyearling (juvenile fish less than one year old) fall Chinook in the Hanford Reach (Chapman et al., 1994; Park, 1969). Reservoirs like McNary and Lower Granite pools, however, may serve as surrogates for estuarine rearing (Chapman et al., 1994). Fall run Chinook usually migrate to the ocean during their first spring and summer in fresh water. Most yearling spring Chinook salmon migrate in April and May and reach the estuary in early June of their second year in fresh water, thus evading the warmest Columbia River waters of early and mid-summer. Fall run and spring run Chinook are often called ocean- and stream-types, respectively. Returns of spring Chinook and Snake River "summer" Chinook are dominated by hatchery-reared fish. Returns of fall Chinooks (upriver brights) are primarily wild fish.

Steelhead

Columbia River steelhead are categorized according to two broad modes of behavior. *Winter steelhead* remain at sea until late fall or winter, then enter the Columbia River and tributaries as far upstream as 15 Mile Creek at The Dalles, which enters the Bonneville Dam pool. They spawn in late winter and early spring, and fry emerge from redds in late spring to July. Juveniles spend two winters in fresh water before migrating to sea in March to early June. *Summer steelhead*, by contrast, which use some tributaries downstream from Bonneville Dam (e.g., Kalama River) and virtually all suitable streams upstream from Bonneville, enter the Columbia River from May to early September. Adults overwinter in the mainstem of the Columbia and Snake rivers and in large tributaries, and spawn mostly in the period from March to May. Similar to winter steelhead, fry emerge from redds in late spring to mid-summer and spend at least two winters before migrating to sea as smolts. The smolts move seaward in spring. Returns of steelhead at the Columbia River estuary are dominated by hatchery-reared fish.

[1] "Brights" also describes fall Chinook that spawn in the Lewis River, a Cowlitz River tributary, and in the Deschutes River.

Sockeye Salmon

Sockeye salmon require a lake for juvenile rearing. Sockeye were once found in the upper Columbia River lake and tributary systems of the upper Columbia River upstream from Grand Coulee, in Suttle and Wallowa lakes in Oregon, in the chain of Okanogan River lakes and Lake Wenatchee, and in the Stanley Basin lakes of the upper Salmon River in Idaho. Sockeye currently inhabit only Osoyoos Lake in Canada, Lake Wenatchee in Washington, and Redfish Lake in Idaho. Sockeye salmon enter the Columbia River mostly in May and June. They spawn in fall upstream from the two lakes, and fry move downstream soon after emergence from redds, rearing in the lake environment for mostly one but sometimes two years. As smolts, they emigrate in April and May. The bulk of sockeye returns at the Columbia River estuary are wild fish.

Coho Salmon

Coho salmon in the Columbia River mostly spawn (and juveniles rear) in tributaries downstream from The Dalles Dam. Hatchery-produced coho predominate. Wild coho formerly used a number of other tributaries, including some upstream from McNary Dam, like the Yakima, Methow, and Grande Ronde rivers. Most coho smolts move seaward in the spring.

Variations in Migratory Patterns

These different salmon and steelhead species and sub-species migrate downstream and upstream through the Columbia system at different times of year. The greatest risks to the survival of migrating fish occur during periods when Columbia River temperatures are highest and during low-flow periods and in low-flow years. Species and life stages of listed fish of concern in summer months (June-August) include:

1. Subyearling fall Chinook from the Snake River;
2. Late-migrating steelhead (smolts);
3. Snake River adult sockeye salmon (adults);
4. Snake River summer Chinook (adults);
5. Snake and Columbia river steelhead (adults);
6. Snake River fall Chinook (adults); and
7. Bull trout.

This report contains several references to the risks of survival of Columbia River salmonid stocks during critical periods. References to fish in the system during these periods do not apply to all salmon and steelhead species and sub-species, but rather focus on the species listed here that transit the system during these critical periods.

STATUS OF SALMON AND STEELHEAD STOCKS

Historical perspectives of trends in Columbia River salmon abundance are essential to understanding the relative abundance of recent and current salmon runs, as well as long-term fisheries trends. Many sources of data contribute to scientific knowledge of historical changes in the abundance of the Columbia's anadromous salmon and steelhead. Because of their abundance (and their size) in the Columbia, Chinook salmon have long attracted the attention of fisheries scientists and have been carefully monitored and tracked over time. Fish counts at Bonneville, McNary, Priest Rapids, and Lower Granite dams for the period 1977-2002 (Figures 4.1, 4.2, and 4.3, for adult Chinook, adult steelhead, and adult sockeye, respectively) provide an overall picture of recent trends in salmon populations.

Returns of Chinook during 2001-2003 greatly exceeded 1993-2002 average returns (Figure 4.1), and generated a great deal of excitement in the Pacific Northwest. These record returns have generally been attributed to favorable ocean conditions. The Northwest Power and Conservation Council (formerly the Northwest Power Planning Council), for instance, asserted that "Good ocean conditions are creating strong adult returns" and noted that "Ocean conditions will change" (available online at: *http://nwppc.org/news/2003_11/3.pdf*; last accessed December 2, 2003). It is important to note that the 2001-2003 returns of fall Chinook salmon, like in-river runs since the mid-1990s, benefited from increased restrictions on ocean fishing. In addition to recent, comparatively large Chinook runs, steelhead returns also rose sharply relative to figures since the mid-1970s (Figure 4.2). Sockeye also experienced an increase in returns in the late 1990s (Figure 4.3).

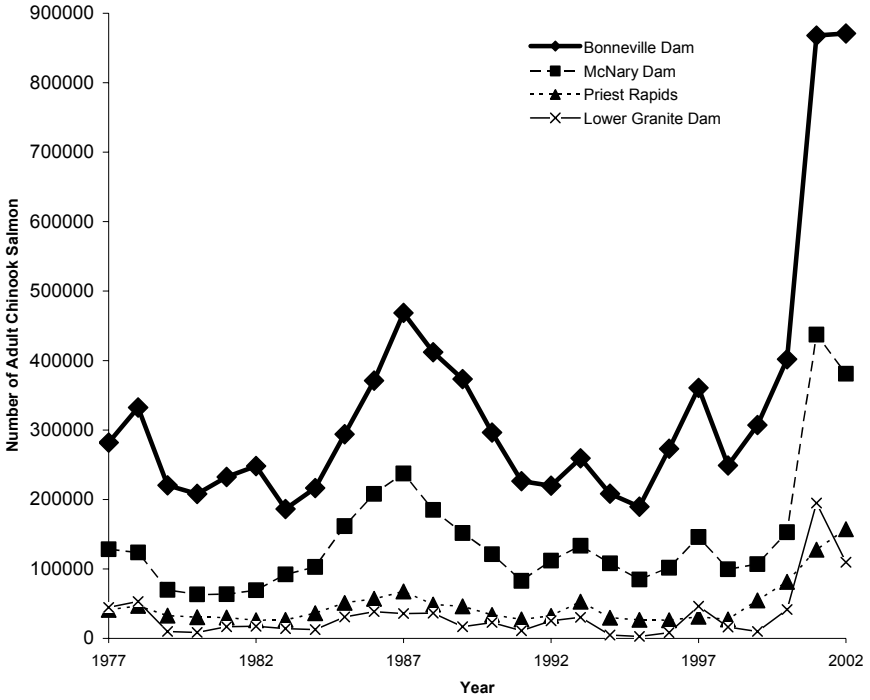


FIGURE 4.1 Counts of adult Chinook salmon at Bonneville, McNary, Priest Rapids, and Lower Granite dams on the Columbia River (1977 – 2002). SOURCE: Fish Passage Center (Available online at *http://www.fpc.org/adult_history/adultsites.html,* last accessed November 17, 2003).

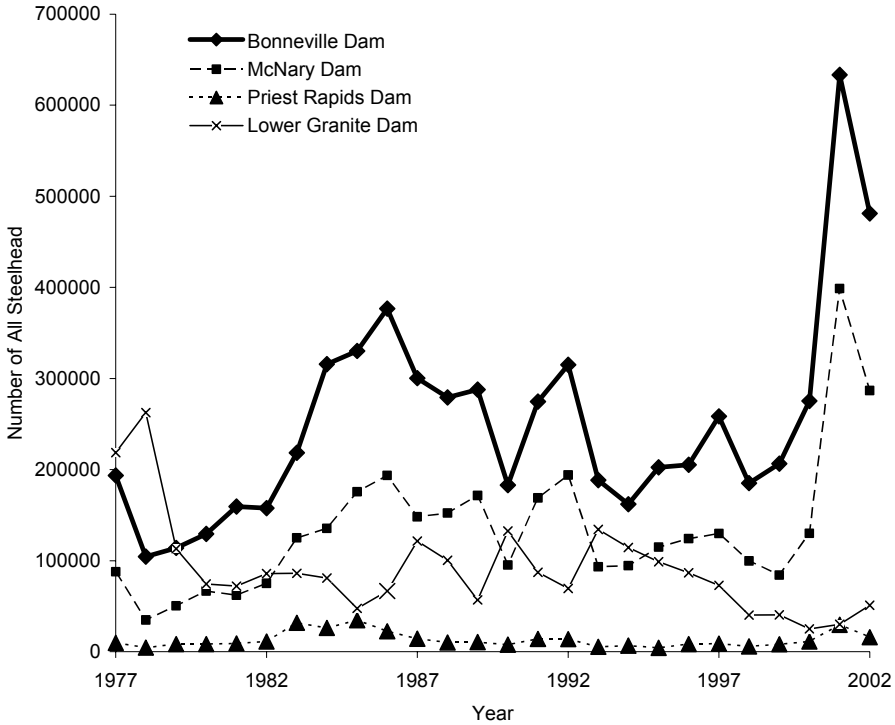


FIGURE 4.2 Counts of all adult steelhead at Bonneville, McNary, Priest Rapids, and Lower Granite dams on the Columbia River (1977 – 2002). SOURCE: Fish Passage Center (available online at *http://www.fpc.org/adult_history/adultsites.html,* last accessed November 17, 2003).

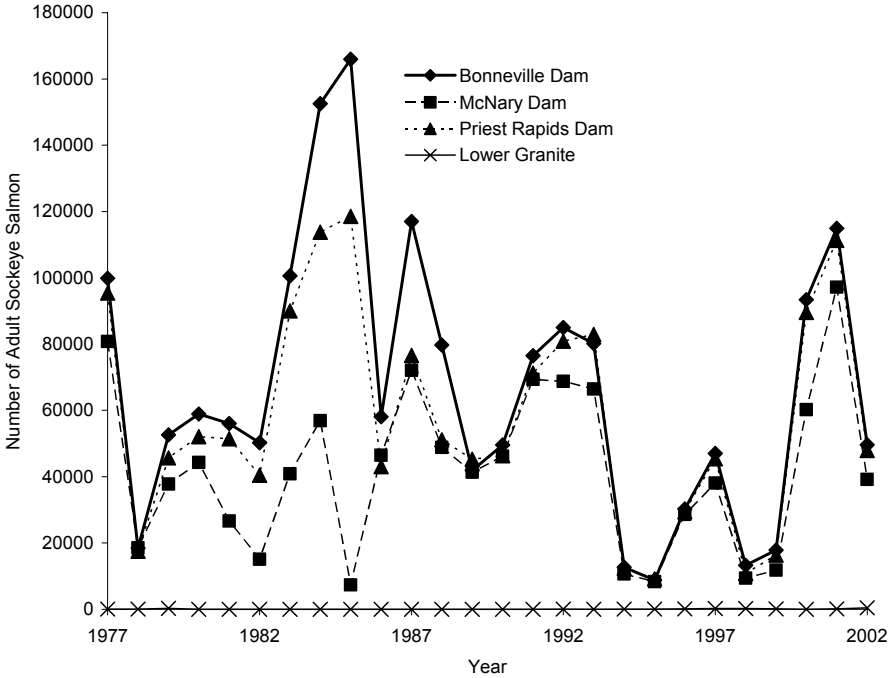


FIGURE 4.3 Counts of adult sockeye salmon at Bonneville, McNary, Priest Rapids, and Lower Granite dams on the Columbia River (1977 – 2002). SOURCE: Fish Passage Center (Available online at: *http://www.fpc.org/adult_history/adultsites.html,* last accessed November 17, 2003).

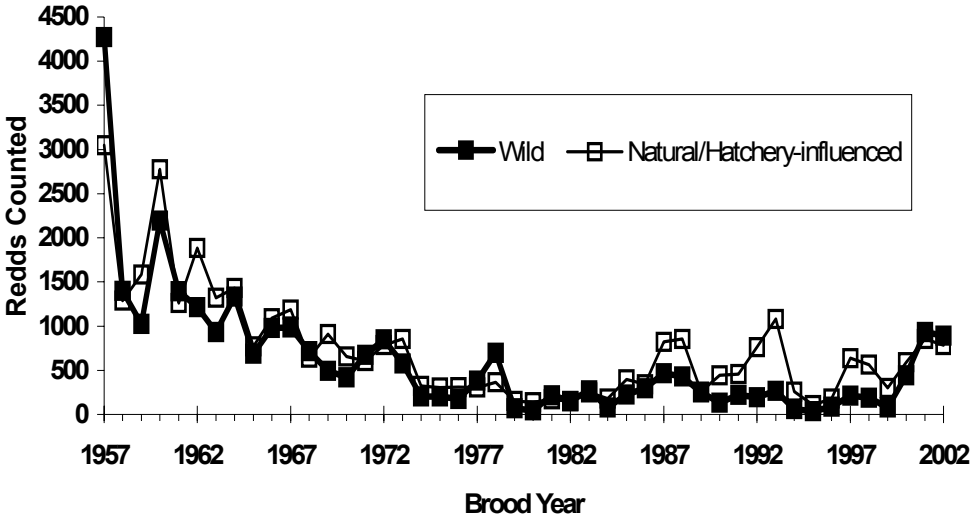


FIGURE 4.4 Number of combined spring and summer Chinook redds (thousands) counted in Salmon River drainage, wild and natural/hatchery-influenced trend areas, 1957-2002. SOURCE: Fish Passage Center (Available online at: *http://www.fpc.org/adult_history/adultsites.html*).

Redd counts from the Salmon River basin of Idaho provide additional information of temporal trends for ESA-listed spring/summer Chinook salmon.[2] Redd counts in 1957, the first year of systematic surveys, were inflated by completion of The Dalles Dam in the lower Columbia River (Figure 4.4). The reservoir behind the dam flooded the Celilo Falls (an important Indian fishing site). This resulted in a reduction of harvests, and Columbia and Snake river escapements of salmon and steelhead thus increased sharply. Later, as Indian fishing shifted to gillnets, fishing and harvest rates increased.

Figures 4.5 and 4.6 present a longer time frame of reference of salmon abundance and its changes, as they show an increase (until the mid-1950s) and subsequent decline in the spring Chinook catch. The harvest rate in the Columbia River between the river mouth and the upper limit of commercial fishing near the site of McNary Dam ranged from 40 percent to 85 percent before the 1960s, declined until 1974, and thereafter averaged less than 10 percent (Chapman et al., 1995). Numerical harvest in the post-Bonneville Dam era peaked in the 1950s, declined to 1974, and then remained negligible. The declines in salmonid stocks, and the variations in declines across stocks, were described as follows:

> The Columbia has numerous kinds and runs of salmon and not all runs have declined at the same pace. There are yearly variations. There are temporary recoveries for some species and runs, but overall the decline has been pervasive and general. The catches on the Columbia are one measure of the decline. From 1880 to 1930 the catch was 33.9 million pounds a year. From 1931 to 1948 it declined to 23.8 million. From 1949 to 1973 the yearly average fell from to 10.9 million pounds. In 1993 the catch was 1.4 million pounds (White, 1995, p. 97).

[2] "Summer Chinook" salmon in Idaho, like spring Chinook salmon, spend one winter in natal tributaries before migrating to sea. They spawn principally in the South Fork Salmon River and upper Salmon River.

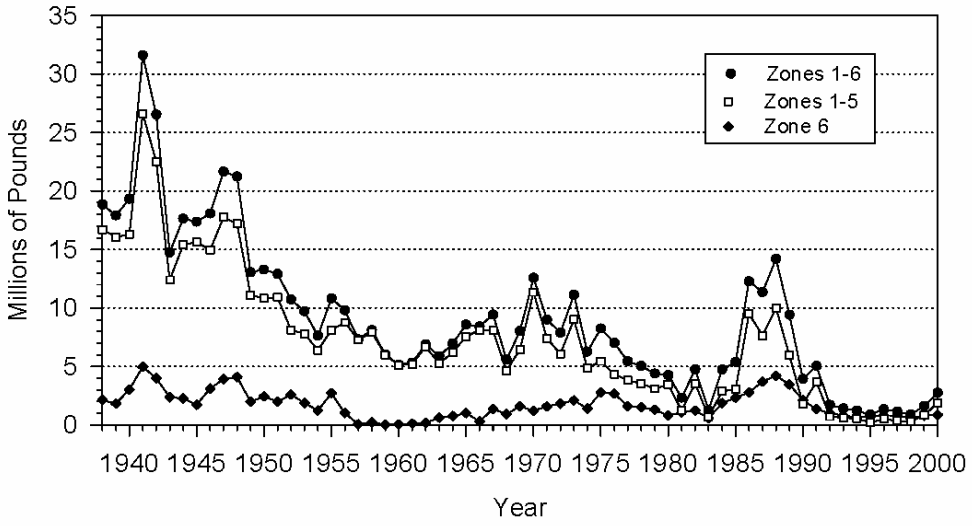


FIGURE 4.5 Commercial landings of salmon and steelhead from the Columbia River in Pounds, 1938-2000. SOURCE: WDFW-ODFW (2002).

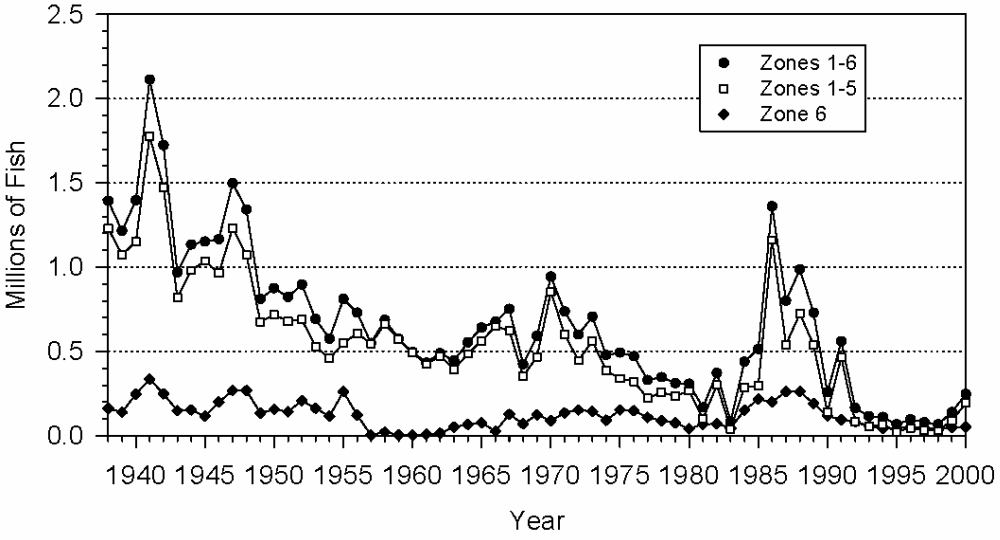


FIGURE 4.6 Commercial landings of salmon and steelhead from the Columbia River in numbers of fish, 1938-2000. SOURCE: WDFW-ODFW (2002).

Populations of the basin's anadromous fish stocks are currently estimated to be generally less than 10 percent of their typical historic levels (Chapman, 1986; Kaczynski and Palmisano, 1993; NPPC, 1986).

In addition to historic declines, another important change is an increasing proportion of hatchery-reared fish in the salmon population. The majority of spring Chinook salmon, summer Chinook salmon, and steelhead counts in recent years showed that most of these fish originated from hatcheries. Only about one-fourth or less of spring/summer Chinook salmon and steelhead that returned to the Snake and upper Columbia rivers in the past two decades have been of wild origin; thus, roughly about 75 percent of spring/summer Chinook salmon that enter the Snake River are produced in hatcheries. The proportion of wild fish within the salmon population is an issue important to long-term survival of the species, as pointed out by a previous National Research Council committee that reviewed Columbia River salmon populations and management: "The long-term survival of salmon depends crucially on a diverse and rich store of genetic variation . . . management must recognize and protect the genetic diversity within each salmon species . . . It is not enough to focus only on the abundance of salmon" (NRC, 1996).

In summary, salmon populations of the Columbia River have decreased dramatically since the 1800s, albeit with annual variations in abundance. Although returns of Chinook salmon and steelhead increased sharply in 2001-2003 relative to 1975-2000 numbers, they remained but a small fraction of former abundance. Furthermore, fish of hatchery origin from a few stocks constituted most of the runs of spring and summer Chinook salmon and summer steelhead. Genetic diversity within these salmon runs has thus declined, which may have reduced the potential for these species to adapt to environmental changes, such as warmer water temperatures (Brannon et al., 2002).

RESEARCH, MODELLING, AND ALTERNATIVE HYPOTHESES

Flow Augmentation

The Federal Columbia River Power System consists of a vast network of storage reservoirs and run-of-river dams, connected in some areas by undammed river segments. Prior to 1983 the water in this system was primarily managed to accommodate and balance a variety of demands, including flood control, hydropower, recreation, irrigation and other extractive demands. In 1983 a new demand was placed on the system, the provision for an allotment of water directed specifically at increasing instream flows during the period smolts migrate seaward. That water allotment was referred to as the Water Budget. Over the last two decades the Water Budget has evolved into a more extensive and complex water management strategy intended to improve instream flows and the survival of smolts as they migrate seaward through the impounded Columbia and Snake rivers (spring migrants smolt during the spring months, and summer migrating ocean type Chinook migrate primarily in July and August). This water management strategy is generally referred to as flow augmentation (NMFS, 2000). Implementation of this strategy has reshaped the pre-1983 annual hydrograph, resulting in more pronounced peaks during the spring and summer smolt migration periods. Not surprisingly, this new demand has impacted other water management needs throughout the system, and called for a new balance among system users. The demand for instream flows is an important priority, and

is a prominent action and feature in the 2000 Biological Opinion of the National Marine Fisheries Service.

Rationale for Flow Augmentation

Flow augmentation is the directed release of water from storage reservoirs to increase instream flows, which are intended to help reestablish suitable migratory conditions for smolts that migrate seaward through the impounded Snake and Columbia rivers; flow augmentation from Dworshak Reservoir is also used to add cold water to the Lower Snake River. Flow augmentation from the Columbia River is provided from large storage reservoirs. These include Grand Coulee Reservoir (Franklin D. Roosevelt Lake) and a complex of storage reservoirs from Canada and Montana. In the Snake River basin, Dworshak reservoir, Brownlee reservoir, and the Hells Canyon Complex—all in Idaho—augment flows (Figure 4.7). The rationale for flow augmentation is founded on two premises:

1. Increased discharge results in higher water velocity through reservoirs that in turn increases the migration speed of smolts in the impoundments of the Lower Snake and Columbia rivers, ultimately resulting in increased smolt survival through this migratory corridor.
2. Increased discharge lowers water temperature, improving migratory and rearing conditions for both juvenile and adult salmonids, particularly during the summer.

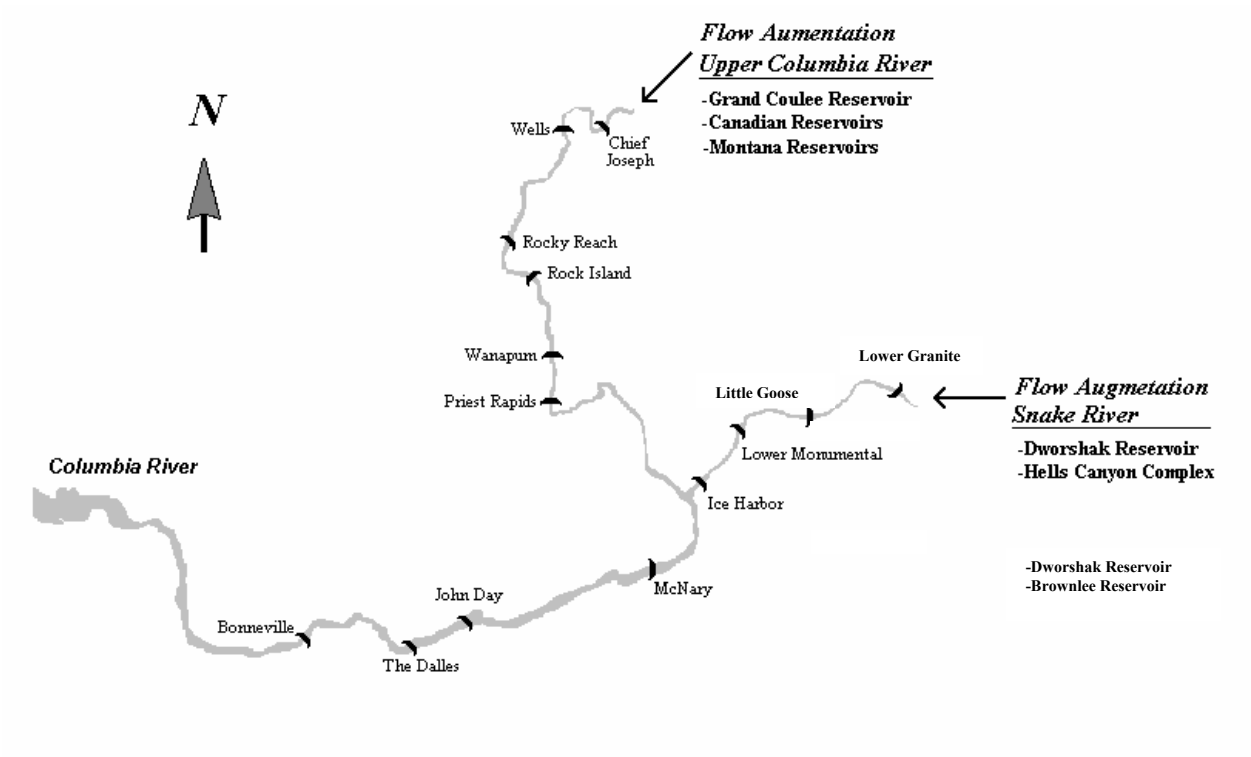


FIGURE 4.7 Dams and impoundments on the Snake and Columbia rivers, through the reaches where anadromous fish passage is accommodated. Sources of flow augmentation water are indicated. SOURCE: Reprinted from Giorgi et al. (2002).

Smolt Survival

Cada et al. (1997) reviewed literature from within and outside of the Columbia River basin, addressing the influence of water velocity on the survival of juvenile salmon and steelhead. Most of the studies reviewed identified a positive relationship between outmigration flows and survival, but they noted substantial uncertainty regarding many of the estimates. In many cases the relationships described did not consider interactions with factors other than water velocity. Other influential factors that were examined in the review included predation, water quality, and physiological state of the smolts at the time of migration. Despite limited data, Cada et al. (1997) felt that a general relationship of increasing smolt survival with increasing flow in the Columbia River basin was reasonable.

Smolt migration speed dictates exposure time to hazards within reservoirs. For example, predatory fish and birds are responsible for a substantial amount of smolt mortality incurred within the impounded Columbia River. Northern pikeminnow, smallmouth bass, channel catfish and walleye prey heavily on smolts. It has been estimated that the predacious northern pike minnow consumed 78 percent of the smolts that were lost to predatory fish in John Day Reservoir from 1983-1986 (Rieman et al., 1991). In the 1990s, a control program (in the form of a bounty fishery) that targets these species was implemented (Young, 1997). Birds also consume large numbers of smolts at various locations throughout the Columbia River. An expanding Caspian tern population and double-creasted cormorants are effective smolt predators in some areas downstream of Bonneville Dam. Gulls can also be effective predators in the tailraces (outflows below dams) of Columbia River dams (Collis et al., 2002). Rugerrone (1986) estimated that gulls foraging in the tailrace of Wanapum Dam consumed 2 percent of the smolts passing the dam in 1982. In an effort to reduce smolt mortality, a variety of actions have been directed at displacing, harassing, or excluding predatory birds from problematic areas.

Historical Background

Shortly after the construction of several Snake River dams, federal biologists documented that dams and associated reservoirs delayed the migration of smolts. For example, Ebel and Raymond (1976) and Bentley and Raymond (1976) estimated that after dam emplacement, travel times of yearling Chinook salmon and steelhead increased at least two-fold over pre-impoundment conditions. The first explicit depiction of a flow-smolt survival relationship was presented by Sims and Ossiander (1981). Building on previous studies (e.g., Raymond, 1979; Sims et al., 1976, 1977, and 1978), Sims and Ossiander (1981) constructed a series of graphs depicting that annual indices of smolt migration speed and survival were positively correlated with annual indices of flow and spill volumes during migratory periods (1973-1979). Although it was not possible to separate reservoir effects (associated with migration speed) from passage effects attending spill passage, this was the first evidence establishing the flow-travel time-survival relationship. Furthermore, these findings were the foundation that led to the development of both the flow augmentation and spill programs in place today. Both spill and migration speed were defined as agents affecting smolt survival. Shortly thereafter, the "Water Budget" was proposed and established in 1983. Under that program, a specific volume of water in Snake River storage reservoirs was dedicated to flush smolts seaward. The Fish Passage Center (previously known as the Water Budget Center) provides fish passage technical advice

regarding spill, flow, and fish facilities operations to fish and wildlife managers was established to track the delivery of water and the response of smolts to the water management action (see *http://www.fpc.org/*; last accessed March 13, 2004). That original water management strategy expanded over the next two decades to the current flow augmentation program described in the 2000 Biological Opinion from the federal National Marine Fisheries Service.

Throughout the 1980s, smolt travel time was consistently monitored. In the early 1990s, studies concluded that variability in smolt travel times was best explained as a function of a combination of flows, water temperatures, and release dates (the latter of which is a surrogate for the level of smolt physiological development; Berggren and Filardo, 1993). It was reported, however, that average river flow explained most of the observed variability in smolt travel time for most stocks investigated (ibid.). These findings reinforced the strategy to provide flushing flows to increase migration rates.

During the same period, federal scientists investigated the migration of ocean-type sub-yearling Chinook salmon through the John Day Pool (Giorgi et al., 1994). Their characterization of migratory behavior in John Day Reservoir differed from that described by Berggren and Filardo (1993). They did not identify a consistent relationship between smolt travel time and any of the three-predictor variables (flow, water temperature, or release date), but rather characterized the migratory patterns as a complicated mix of rearing and migratory behavior, often punctuated by extensive upstream excursions.

Williams and Matthews (1995) questioned the foundation of the Sims and Ossiander (1981) flow-survival relationships by asserting that the 1970s-era data reflected operating conditions that no longer existed in the contemporary hydro-system. They suggested that the high smolt mortality witnessed during low-flow years in that era was in part associated with slow migration, but was exacerbated by sub-optimal turbine and powerhouse operations. Furthermore, they concluded that the Sims and Ossiander (1981) flow-survival relationship does not accurately predict the survival of spring-migrating smolts under contemporary hydrosystem operations and smolt bypass systems in place at dams. The research community generally recognized the need for statistically robust survival estimates acquired in the contemporary setting, since the flow-survival debate was intensifying as more water was being shifted toward flow augmentation. But sampling limitations associated with the need to handle and inspect large numbers of freeze-branded smolts prevented the use of new analytical methods reported by Burnham et al. (1987).

Over recent decades, technological improvements have allowed for more accurate smolt survival estimates. The advent of the passive intergrated transponder (PIT) tag, and associated detection systems that could be retrofitted to existing smolt bypass systems, fostered the transition to a new era and quality of smolt survival and travel time estimates for the Columbia-Snake river system (Prentice et al., 1990). Since 1994, smolt survival estimates have been obtained through segments of the Federal Columbia River Hydro System by the National Marine Fisheries Service/NOAA Fisheries. The bulk of the data for use in flow-survival assessments are from the Lower Snake and, to a lesser extent, portions of the Lower Columbia. There is a paucity of data available for the middle reach of the Columbia River upstream from McNary Dam. Even now, with widespread use of PIT tags, opportunities to provide robust smolt survival estimates through the middle reach of the Columbia River are limited because the required network of PIT detection systems there is lacking.

Contemporary Investigations

Translating river flow, or smolt migration rate, into smolt survival is the critical issue underpinning the rationale for providing flow augmentation and quantifying any associated benefits. This has been the thrust of much research since 1994. During the 1990s, research increasingly focused on identifying a more complex suite of factors that influenced migration speed through the hydrologic system. The collective research indicated that the species responded differently to various factors through different segments of the river. In both the Snake and Columbia rivers, yearling Chinook salmon migration speed was correlated with both flow (water velocity) and the level of smolt development (Beeman et al., 1991; Giorgi et al., 1997; Muir et al., 1994). River discharge (flow) was determined to be the factor that explained the majority of variability in migration speed for steelhead (Buettner and Brimmer, 2000; Giorgi et al., 1997) and for sockeye salmon (Giorgi et al., 1997).

The modern era of smolt survival studies continued in the Snake River and in portions of the lower Columbia River, since an extensive network of PIT detections systems are located there (most flow-survival studies have been conducted in the Snake River, and results from the Snake are generally felt to reflect processes that occur elsewhere in the system). Scientists from NOAA Fisheries generally design and conduct those studies, but the agency relies on the broad-based PIT-tagging program overseen by the Columbia Basin Fish and Wildlife Authority (CBFWA, a coalition of tribes, and state and federal wildlife management agencies) to provide tagged fish for monitoring. Smith et al. (2002) used multiple regression methods to assess the effects of a variety of factors on smolt migration rate and survival for 1995-1999. Using a mixture of PIT-tagged yearling Chinook salmon and steelhead smolts from the Snake Basin, they found that travel time from Lower Granite Dam to McNary Dam was strongly correlated with flow volume, with the physiological development of the smolts a contributing factor, particularly for Chinook salmon. However, they could not identify a substantive or consistent relationship between smolt travel time and smolt survival through that same river segment. It was concluded that survival benefits from increased flow were minimal at best, and that any benefits may be expressed downstream from McNary Dam, beyond their observation zone. These findings were consistent with those expressed in an earlier "White Paper" (NMFS 2000), which assessed flow, migration speed and smolt survival.

Drought conditions in 2001 created one of the lowest run-off years on record for the Columbia River, which presented an opportunity to monitor smolt survival under low-flow conditions. Zabel et al. (2002), consistent with Smith et al. (2002), found no flow-survival relationship for yearling spring and summer Chinook salmon (1993-2001). The Zabel et al. group (2002) found that smolt travel time was correlated to river discharge volume, but no relationship between migration speed and survival was evident. Survival was depressed in 2001 relative to many other recent years; however, low flows were not the only factor implicated in poor survival through the hydro system, as spill was minimal or nonexistent at most dams that smolts encountered. Both conditions likely contributed to poor survival. Furthermore, water temperature has been implicated as a principal factor affecting smolt survival, particularly in low-flow water years, when seasonal water temperature increases earlier and to higher levels (Anderson, 2003).

Zabel et al. (2002) suggested that even in the absence of a flow or migration rate-survival relationship, some other benefits may be provided by the swifter migration made possible by increased flow levels. They speculate that higher flows may improve estuary and Columbia

River plume conditions and associated survival through those zones, but offered no empirical evidence for such. In contrast to yearling Chinook salmon, steelhead survival dramatically decreased in 2001 as compared to other years over the last decade. Three factors were implicated as causing this dramatic increase in mortality of Snake River steelhead. First, spill was negligible at most of the dams the steelhead encountered. This mechanism is distinct from migration speed-related processes. Secondly, of all the salmon species, steelhead migration speed appears to be the most sensitive to flow and associated water velocity (Berggren and Filardo 1993; Giorgi et al., 1997). Lastly, water temperatures warmed sooner in 2001 than in the preceding three years (see *http://www.cbr.washington.edu/dart/dart.html*; last accessed February 28, 2004). This pattern was evident in both the lower Snake and Columbia Rivers. Perhaps importantly, water temperatures exceeded 12.5°C early (by the first week in May at Lower Monumental Dam) in the steelhead migration. This, coupled with slow migration speed, can compromise the migratory process in steelhead, as discussed later in this chapter. Increasing water temperature can disrupt the migratory behavior of steelhead and foster reversion to the fresh water parr (a young salmon during its first two years of life, when it lives in fresh water) state. It is plausible that if migration is slow as witnessed in 2001 (Zabel et al., 2002), then steelhead smolts could have been exposed to seasonally increasing water temperatures that exceeded the threshold to support smoltification and thus they remained in the mainstem.

The Fish Passage Center also monitors smolt migration throughout the system and provides estimates of smolt survival through the hydro system. The Center's characterization of flow–survival dynamics differs from that of NMFS investigators. The Center expressed its conclusions in a paper submitted to the (previous) Northwest Power Planning Council (FPC, 2002), stating that for juvenile steelhead and Chinook salmon spring migrants:

- A water travel time/survival relationship exists for spring migrating Chinook salmon and steelhead of Snake River and Mid-Columbia River origin;
- A water travel time and fish travel time relationship exists for spring migrating Chinook salmon and steelhead;
- It is difficult to define a flow survival relationship because survival is the combined result of many interacting variables and the methodology for estimating survival does not lend itself to identifying each environmental or biotic variable individually.

Snake River Fall Chinook Salmon

For fall Chinook salmon in the Snake River, flow, water temperature, and turbidity are correlated with migration speed and survival (Smith et al., 2003). Over the course of the summer migration period, river discharges decrease, temperatures increase, and turbidities decrease. Thus, predictor variables were typically correlated among themselves. In the middle reach of the Columbia River, the size of sub-yearling Chinook salmon was found to be the best predictor of migration speed between Rock Island and McNary Dams (Giorgi et al., 1997).

John Day Project (McNary tailrace to John Day tailrace)

Smith et al. (2002) also examined survival dynamics of fall Chinook salmon from the

tailrace of McNary Dam to the tailrace of John Day Dam. Fall Chinook salmon were collected, PIT-tagged and released at McNary Dam. The population was primarily composed of mid-Columbia River stocks, such as the wild population from Hanford reach. They found that during the summer (1998-2001) correlations were not significant between annual survival and the average river condition variables measured at McNary Dam, but the correlation with temperature was considerably higher than for flow and turbidity.

Northwest Power and Conservation Council Independent Science Advisory Board

In an effort to bring clarity to this complex and often contradictory mass of information, the (previous) Northwest Power Planning Council called upon its Independent Science Advisory Board (ISAB) to review, update and clarify the effectiveness of flow augmentation. The ISAB challenged the results from the prevailing flow/smolt survival model that has spurred the formulation of smolt-migration water policy over the last two decades, concluding, "The prevailing flow-augmentation paradigm, which asserts that in-river survival will be proportionately enhanced by any amount of added water, is no longer supportable. It does not agree with information now available" (ISAB, 2003). Support for this recent conclusion was based largely on data sets acquired in the lower Snake River from the Lower Granite Project to McNary Dam on the Columbia River. They relied heavily on survival estimates and analyses from NOAA Fisheries to characterize the spring period, and information from the U.S. Fish and Wildlife Service and from the NPPC's Fish Passage Center to describe a survival model for the summer period (the models described in this section are primarily based upon regression analyses. Also see: *http://www.nwcouncil.org/fw/science.htm*; last accessed March 15, 2004, for more information on ISAB models and studies).

Flow/survival. The ISAB suggested a "broken-stick" flow/survival model to describe the NMFS-generated PIT survival data they reviewed (ISAB, 2003). That is, the board identified a "break point" near 100,000 cubic feet per second for yearling Chinook and steelhead in the Snake River during the spring. According to this report, when flows exceed that threshold, no flow-survival relationship is apparent. The value of flow augmentation is thus questionable above those levels. Below that breakpoint, a flow/ survival relationship is evident. However, the report did not derive algorithms to describe the two legs of the generalized model, but rather depicted the model graphically. The intent is apparently not to offer this as a predictive tool, but as a visual framework to introduce the new hypothesis.

Survival dynamics below the breakpoints. With respect to the lower survival rates observed below the break points, the ISAB hypothesized that specific hydropower operations in the form of daily load-following cycles create hydraulic dynamics that affect survival, rather than average daily flow discharged through the complex of reservoirs and dams ("load following" refers to adjustments in power production to meet changes in power demand or "loads"). They noted that the frequency and intensity of load-following substantially increases when river discharge falls below the break points. They suggest that diminishing or eliminating load-following will improve smolt survival more than merely providing higher average daily flows. According to the board's hypothesis, the hydrologic effects of load-following power generation disrupt migration cues, which ultimately results in lower smolt survival during migration.

Fall Chinook salmon summer model. The emphasis within this model is also on the Snake River. In formulating the summer model, weekly survival estimates for ocean-type subyearling Chinook migrating from release sites upstream to the tailrace of Lower Granite Dam, as estimated by the NPPC Fish Passage Center for the years 1999 and 2000, were employed. As was the case for the spring model, the summer model is described only in generic terms, with breakpoints between two legs near 40,000 and 50,000 cfs. The ISAB report offered new hypotheses for describing smolt survival patterns observed in the Snake River. But it cannot be certain that a broken-stick model is relevant in the mainstem Columbia River, as no direct evidence to support such in that river segment was provided. Analyses of flow-travel time relationships have been published and cited by the ISAB for the middle reach of the Columbia River, but no definitive flow-survival analyses were ever published. The paucity of robust, consistent survival indices in the Columbia River thus limits meaningful survival analyses with respect to prevailing environmental conditions.

The ISAB report received immediate attention. The CBFWA staff drafted a 34-page technical memorandum commenting on the ISAB assertions and hypotheses (CBFWA, February 26, 2003), which contained a cover letter stating:

> In conclusion, we believe that the ISAB report supports the biological rationale for the minimum flow objectives contained in the NMFS Biological Opinion. The ISAB report presents additional hypotheses for future study that are of some interest, although there is little data at the present time to support these hypotheses. The ISAB does suggest some operational changes in river operation that may offer benefits when Biological Opinion flow objectives cannot be met, which warrant further study and consideration.

The CBFWA group challenged, however, the ISAB characterization of the flow augmentation, noting:

> We do not agree with the ISAB's characterization of the flow augmentation paradigm, which they state, "asserts that in-river smolt survival will be proportionately enhanced by any amount of added water." Establishing reservoir draft limits and augmenting base flows with additional water are only the tools whereby the objective of providing migration flows is accomplished (ibid.).

The CBFWA questioned whether altering load-following operations can adequately reduce the smolt mortality associated with the descending arm of the ISAB flow-survival model. The technical staff report provided a diverse set of estimates and relationships to support their positions. A well-designed and executed field study might help shed further light on this issue. The ISAB called for such a study, in which smolt survival would be estimated under different load-following treatments, but no formal proposal has apparently been formally submitted to any research planning forum.

Delayed Effects Associated with Migratory Delay

There is another important aspect linked to the migration speed premise. Extended migration travel times may cause delayed effects that could impair survival of smolts in the

Columbia River estuary and after seawater entry. This hypothesis asserts that pre-impoundment timing of seawater entry was synchronized with a "biological window." Extended migration travel times associated with impoundments and reduced velocities have thus disrupted the natural timing of ocean-entry, potentially placing smolts at a disadvantage. This theoretical window has two aspects; the ecological/environmental condition of estuarine and marine waters, and the physiological condition of smolts at seawater entry.

In the late 1990s the concept of Extra Mortality (EM) first arose during the Plan for Analyzing and Testing Hypotheses (PATH) regional modeling process. Briefly, during life cycle model analyses, total mortality exceeded that either estimated or assumed for the various individual life fresh water stages. The theory emerged that some extra or delayed effect associated with certain life stage experiences resulted in the unexplainably poor survival from egg through adult return. Various hypotheses, such as passage through dams and shifts in climate, were offered to explain the key driving mechanisms. Extinction risk analyses conducted in the 2000 NMFS BiOp were particularly sensitive to the existence, magnitude, and persistence of this hypothetical effect.

Recent research offers additional information. Congleton et al. (2002), for example, studied changes in condition of yearling Chinook salmon migrating from Lower Granite Dam to Bonneville Dam (1998-2002). In all years, body lipid and protein masses decreased significantly and with increasing travel time. The relevance of this finding is that it is implied that slower migration forces juveniles to tap caloric reserves beyond normal levels. Such a tax on body reserves could thus compromise smolt performance in sea water. Although survival to returning adult has not yet been demonstrated to be linked to this smolt condition, the potential for decreased performance is implicated.

Transportation of Smolts and Delayed Effects

To avert protracted migration, smolts can be transported from some dams that are equipped with smolt bypass/collector systems and transportation facilities. These sites include three dams on the lower Snake River (Lower Granite, Little Goose and Lower Monumental) and McNary Dam on the Columbia River. Fish can be intercepted at these dams and transported via barge or occasionally truck to release sites downstream from Bonneville Dam. These smolts avoid inriver hazards. Even so, there is ample evidence that delayed effects also attend this passage option (Giorgi et al., 2002). The magnitude and variability of these delayed effects has been identified as another critical uncertainty (NMFS, 2000). If delayed effects are not too severe, transportation could be beneficial. If they are pronounced, the passage strategy can put endangered stocks at risk. NMFS is currently engaged in a multi-year research effort to resolve this issue for key populations in the Snake-Columbia river system.

WATER TEMPERATURE AND FLOW MANAGEMENT

Water temperature is an important factor in life history of Pacific salmon, as it affects the rate of embryo development, juvenile growth rates, metabolic processes, and the timing of life history events such as spawning and migration (Brannon et al., 2002). In cold, high elevation tributaries, newly-emerged salmon fry must grow through the summer to obtain sufficient size to

survive the lengthy downstream migration and in the estuary and nearshore marine environment, then migrate to sea as yearlings. Farther downstream in the mainstem Columbia River, emergent ocean-type fry find more moderate temperatures and sufficient growth opportunities in the first spring and summer of their lives to reach sizes adequate for estuarine and marine survival during their first year or before their first year in sea water. Water temperature regimes have changed in the Columbia River (see Ch. 3), largely because of human activities. Some salmon populations have shown some ability to adapt to altered river thermal regimes. Fall Chinook salmon, for example, recently began spawning in a formerly unused site in a Snake River tributary, the Clearwater River, because water releases from Dworshak Dam[3] warmed the Clearwater River and provided a suitable environment for spawning and incubation. Similarly, releases of relatively warm water by Columbia River storage reservoirs (most importantly Grand Coulee and Chief Joseph), and operation of hydro dams downstream, have increased temperature units[4] in spawning areas between the head of McNary Dam pool and Chief Joseph Dam. Adult sockeye salmon and American shad have gradually shifted the peak of upstream migration forward about 10 days, responding to rising Columbia River water temperature (Quinn and Adams, 1996). More adult summer steelhead have tended to move later, after peak river temperatures (Robards and Quinn, 2002). Although some adult migration and spawning times have adjusted to lower late-spring and summer flows and warmer river temperatures, physiological responses of adult and juvenile salmon and steelhead to temperature very likely have not (Bell, 1973 and 1979; Ordal and Pacha, 1963; Reiser and Bjornn, 1979a, b). High water temperatures delay the upstream migration of adult salmonids (Bjornn and Peery, 1992; Hallock et al., 1970; Major and Mighell, 1966). For example, Chinook salmon slow their movement when water temperatures approach 21° C or above (Bell, 1991; McCullough, 1999), a level already common in the Columbia River in summer (see Fig. 3.4). Steelhead appear to delay migration when water temperatures exceed 21-22°C (Bjornn and Peery, 1992).

Clearly-defined thresholds that affect salmon behavior are difficult to identify. For example, not all Chinook salmon completely stop moving when water temperatures exceed 21° C. Fish counts at Ice Harbor Dam between 1962 and 1992 showed that some fish continued to move when water temperature exceeded 23.3^{o} C (Hillman et al., 2000). Increases in summer water temperatures in the main Columbia River have led to more use of cool tributary refugia (e.g., Deschutes and Wind rivers) by fall Chinook (Goniea, 2002) and steelhead (High, 2002). Higher prespawning mortality and depletion of energy reserves can be expected in adult fish exposed to elevated water temperature during upstream migration (McCullough, 1999; Sauter et al., 2001). There do not appear to be any analyses, however, that support precise and reliable predictions of survival changes as related to water temperature.

Within the Columbia and lower Snake rivers, summer water temperatures now reach levels that impose risks to juvenile salmonids. During the summer, subyearling Chinook salmon rear and migrate downstream when river temperatures exceed 20°C (Giorgi and Schlecte, 1997). Temperature tolerance for juvenile fall Chinook has been reported to range from 5.5 to 20°C (Groves, 1993). The young fish use more energy at high temperature, requiring higher daily rations that may not be available, or consumption of stored energy. Growth tends to decrease as water temperature approaches 19-20°C, which in turn can reduce size of subyearlings at seawater entry. Disease incidence also increases with rising temperatures.

Water temperature is also an important factor affecting predation-related mortality

[3] Dworshak Dam impounds the North Fork Clearwater River just upstream from Orofino, Idaho.
[4] Each 1 ^{o}C for 1 day = 1 TU. Thus, for example, over 24 hours, an incubation temperature of 4 ^{o}C equals 4 TU.

incurred by juvenile salmon. Vigg and Burley (1991) developed a model that suggests that decreasing water temperature from 21.5° C to 17° C could reduce the number of prey consumed by a northern pikeminnow from 7 to 4 per day. This suggests that water temperature regulation measures that reduced Snake River water temperatures could indirectly and locally provide survival benefits to juvenile fall Chinook. High water temperatures during the latter part of the spring migration of smolts pose physiological threats, especially to steelhead. The smoltification process involves a change in physical appearance as parr become more lean and silvery. Physiologically, smolts become more tolerant of salt water. Smoltification continues during the seaward migration (Beeman et al., 1995; Zaugg, 1987); higher temperatures during downstream migration can slowsmoltification sufficiently to prevent fish from reaching the sea.

An appropriate temperature threshold, above which smoltification is inhibited, appears to lie between 12-13°C (Adams et al., 1973; Zaugg et al., 1972; Zaugg and Wagner, 1973). It is not known whether actively migrating steelhead smolts that encounter temperatures greater than 14° C in the lower Columbia River, for example, would revert to parr status (for a more extensive review of temperature effects on smoltification, see *http://www.deq.state.id.us/water/ surface_water/temperature/ContractorReview_EPA_DraftGuidance.pdf;* last accessed January 5, 2004) In 2001, when river flows were low and water temperatures high, survival of steelhead was extraordinarily low, as previously noted. And, as noted earlier, it seems likely that the apparent "mortality" was in part due to reversion of smolts to parr status, hence cessation of seaward movement.

Restoration and Mitigation Measures

Flow Augmentation

Giorgi et al. (2002) reviewed the status of flow augmentation evaluations published to date. They emphasized that establishing general relationships between flows and either migration speed or survival provides a rationale for entertaining flow augmentation as a strategy to improve survival. However, an evaluation of the biological benefits of providing additional water in any particular year has many facets and requires a more focused analysis. Few have been conducted. Even the NMFS 2000 FCRPS BO offered no assessment of benefits or risks associated with flow augmentation, rather it specified volumetric (in millions of acre-feet) standards dedicated to flow augmentation, and prescribed seasonal flow (in thousands of cubic feet per second, or kcfs) targets. However, no quantitative analysis describing the change in water velocity, smolt speed, or survival improvement is presented that can be attributed to the additional water provided by flow augmentation. Some studies that attempted to focus specifically on evaluating the effects of the flow augmentation water delivery are discussed briefly herein.

A study in the later 1990s commented on the effectiveness of flow augmentation in changing water velocity and meeting the flow targets specified in the Biological Opinion (Dreher, 1998). It was found that the volumes of water in storage reservoirs currently earmarked for flow augmentation in the Snake River: 1) provide only small incremental increases in average water velocity through the hydrosystem, and 2) are insufficient to meet flow targets in all years. This analysis, however, was not intended to specifically evaluate flow augmentation strategies and it thus offered no insight with respect to fish responses.

Some salmon populations have adapted to altered thermal regimes. As previously mentioned, fall Chinook salmon recently began spawning in the Clearwater River, a formerly unused spawning site. Water releases from Dworshak Dam warmed the Clearwater River and provided a suitable environment for spawning and incubation. Similarly, releases of relatively warm water from Columbia River storage reservoirs (most importantly Grand Coulee and Chief Joseph), and operations of downstream hydroelectric power dams, have increased temperature units for incubation in spawning areas between the headwaters of McNary Dam and Chief Joseph Dam.

Summer flow augmentation has received increased attention in recent years. Connor et al. (1998) conducted a study that had implications to summer flow augmentation in the Snake River. Using PIT-tagged juvenile fall Chinook that reared upstream from Lower Granite Dam, they regressed tag detection rates at the dam (survival index), against flow and temperature separately. They found that over four years, the detection rate was positively correlated to mean summer flow and negatively correlated with maximum water temperature. They acknowledged that the predictor variables were highly correlated, limiting specific inferences regarding the effects of the individual variables. They also noted water temperatures at Lower Granite Dam dropped approximately 5-6°C during the period of flow augmentation from Dworshak Dam and the Hell's Canyon Complex in 1993 and 1994. They concluded that summer flow augmentation, especially cooler water released from Dworshak Reservoir, could improve survival of juvenile fall Chinook, at least to arrival at Lower Granite Dam. Connor et al. (2003) further analyzed this stock of fall Chinook salmon using PIT tag-based data for the years 1998-2000. Survival decreased as temperatures warmed in decreasing flows over the course of the summer. It was concluded that flow augmentation increased survival of Snake River fall Chinook salmon to the first dam they encounter.

Giorgi and Schlecte (1997) evaluated the effectiveness of flow augmentation in the Snake River for the years 1991-1995. They estimated the volume and temporal distribution of flow augmentation water delivered to the Snake River and evaluated the biological consequences to ESA-listed stocks. They then estimated incremental changes in water velocity and temperature that were attributable to the water delivered as flow augmentation. Using several smolt passage models, the incremental change in smolt migration speed for yearling Chinook salmon, steelhead and fall Chinook salmon that may have resulted from flow augmentation water was estimated. It was concluded that Snake River flow augmentation increased water velocity through Lower Granite Pool an average of 3-13 percent during the spring. The increase was more pronounced during summers, with an increase of 5-38 percent change in water velocity attributable to augmentation water. Correspondingly, the change in smolt travel time predicted by the different passage models varied considerably. For example, decreases in travel time for yearling Chinook ranged from 5 percent to 16 percent over five years, or 0 percent to 5 percent, depending on the passage model applied.

Temperature Manipulation

Several investigations evaluated the effectiveness of Snake River flow augmentation in reducing summer water temperature in the Lower Snake River, specifically focusing on the use of Dworshak Reservoir as a coldwater source for decreasing water temperature in August and

early September (Bennett et al., 1997; Karr et al., 1992; Karr et al., 1998). Karr et al. (1992) first provided results that indicated that strategic releases of outflow from Dworshak Reservoir could reduce water temperature in the Snake, at least to the vicinity of Lower Granite Dam.

Bennett et al. (1997) modeled water temperature and monitored empirical data for 1991-1993. They established that the Corps of Engineers model (COLTEMP) provided reliable predictions of changes in water temperature associated with flow augmentation releases upstream. The reduction in Snake River water temperature associated with coldwater releases from Dworshak Reservoir was greatest at Lower Granite Dam and diminished as water moved downstream to Ice Harbor Dam. Depending on the year and base flow characteristics, the change in temperature at Lower Granite Dam typically ranged from 1-4 °F. However, the model predicted differences as great as 6-8 °F, which extended for a period of several weeks. Here again, prediction depended on base flows and the volume released for flow augmentation. At Ice Harbor Dam the decrease in temperature was typically small, on the order of 1-2 °F. It was also reported that the cold water released upstream tended to sink toward the bottom of the reservoirs and mixed at the dams (Bennett et al., 1997). This suggests that deep cool water may be available as refugia, but that cooling of the entire water column cannot be achieved. Also, the extent of cooling decreases in the lower reaches of the river. Biological information has not yet been integrated with this or similar evaluations.

Benefits and Risks to other Species

Drafting water from storage reservoirs to increase mainstem flows or reduce water temperatures alters conditions within the storage reservoirs and in the tributaries connecting with the Columbia and Snake rivers. These processes in turn have effects on resident and anadromous fish inhabiting those waters. This introduces a broad and complex facet attending flow augmentation. Risks associated with flow augmentation were broached by the Independent Scientific Group's publication "Return to the River," which expressed concerns regarding risks associated with summer flow augmentation, in particular (ISG, 1996):

> Underscoring these substantial uncertainties in flow augmentation rationale is the fact that summer drawdowns in upstream storage reservoirs, for example Hungry Horse Reservoir in Montana, to accomplish summer smolt flushing in the lower Columbia River has direct and potentially negative implications for nutrient mass balance and food web productivity in Flathead Lake, located downstream from Hungry Horse.

The issue involves balancing expected benefits to anadromous fish with ecosystem functions and potential risks to other species. Clearly, a complex array of water management activities has evolved in the Columbia Basin, and arriving at an appropriate balance among competing and complementary strategies is a highly uncertain venture.

Flow Management and the Estuary

The ISAB (1996) stressed the importance of the estuary as a key regulator of overall survival and annual variation in abundance of salmon. The estuary (and nearshore Columbia plume and its interface with sea water) provides a physiological transition zone, potential refuge

from predators (e.g., turbidity), and forage (Simenstad et al., 1982). Rapid growth in this transition zone occurs in an environment where increased size lessens vulnerability to predation. For example, in the lower Sacramento River, the primary floodplain area (typified by the Yolo Bypass) provides better rearing and migration habitat for juvenile Chinook salmon than adjacent river channels (Sommer et al., 2001). Anthropogenic effects on estuarine and plume dynamics derive from in-estuary alterations such as diking and filling and from flow and water quality alterations upstream (e.g., reductions in turbidity; Junge and Oakley, 1966).

The Columbia River estuary has changed greatly since the early 1800s. Total volume has declined by about 12 percent since 1868, and diking and filling have converted 40 percent of the original floodplain to various human developments and uses (Sherwood et al., 1990). The spring freshet has been greatly diminished, thereby reducing organic and sediment inputs. The standing crop of organisms that feed on macrodetritus is only about one-twelfth as great as it once was (Sherwood et al., 1990). The (former) Northwest Power Planning Council's ISAB (1996) assumed that a reduction in the food web supported by phytoplankton macrodetritus has negatively affected salmon. Changes in food web production have resulted in a more favorable environment for herring, smelt, and shad. Estuarine degradation and potential mitigation are further discussed in Bottom et al. (2002), Kukulka and Jay (2003), Jay and Naik (2000). Hatchery-produced salmon and steelhead now pass through the estuary in large quantities, in temporal patterns dissimilar to historical patterns of the passage of wild fish. Effects of these large releases on estuarine ecology are unquantified. Nonetheless, they are likely to negatively affect wild anadromous fish because of the diminished ecological opportunities offered by a reduced estuary with sharply altered hydrograph.

Tributary and Riparian Issues

Potential exists to increase salmon stocks in the Columbia River system by restoring or rehabilitating riparian vegetation destroyed or degraded by overgrazing, timbering, mining, and clearing for agriculture (Maloney et al., 1999;Meehan, 1991). For example, approximately 88 percent of the original, pre-settlement forests occupying the floodplain of the Willamette River (a major tributary of the Columbia) have been removed (NRC, 2002a). A functioning riparian zone, which occurred naturally along tributaries of the Columbia before white settlement, has been shown to benefit salmon spawning and rearing by: 1) shading the stream and maintaining low water temperatures, 2) contributing coarse woody debris to provide cover and in-stream habitat heterogeneity, 3) filtering sediment and pollutants from runoff waters, and 4) producing many forms of organic matter to support stream productivity (Clinton et al., 2002; McIntosh et al., 1994; Naiman et al., 1992). In healthy streams, returning adult salmon themselves contribute to riparian zone and stream productivity, and ultimately to their own welfare, by transporting marine-derived nutrients to their spawning grounds (Schindler et al., 2003).

SUMMARY

Columbia River salmon are anadromous and are affected by environmental conditions and variability not only within the Columbia River basin, but also in the northern Pacific Ocean. Columbia Basin salmon have been in a general state of decline for decades, with these declines

being driven by a variety of environmental changes. There have been departures from this long-term trend, the most recent being an increase in the returns of (mainly hatchery-reared) Chinook salmon in 2002 and 2003. This increase has generally been attributed to favorable ocean conditions. Although a positive development, these increase numbers still fall well short of what was once the premier salmon fishery in the world. Despite these recent increases, there is little disagreement on the long-term declining trends, which have resulted in many wild salmon species being listed as threatened or endangered under the federal Endangered Species Act.

This report reviews the implications for salmon survival of a specific and relatively (compared to the magnitude of Columbia River) small range of proposed water withdrawals that would further reduce flows. Precise and credible forecasts of specific outcomes of these withdrawals (or almost any given range of specific proposed diversions) are beyond current scientific capabilities and knowledge. But as pointed out in Chapter 3, impacts of water withdrawals from the Columbia River on salmon survival rates vary according to seasonality of withdrawals. During periods of high base flows, and assuming that future seasonality of water withdrawals does not change, the upper end of the magnitude of water permit applications being considered in this report (1,300,000 acre-feet) will have only minimal effects during the high-flow season (in May, for example). However, during periods of low flows, the upper range of the prospective withdrawals considered in this report would decrease flows in the Columbia River considerably, especially if these additional withdrawals were diverted during lower-than-average flows during July and August. Moreover, cumulative effects of individual withdrawals eventually result in important thresholds being crossed and with resulting deleterious effects on salmon. Trends such as likely future climate warming across the Columbia River basin, potential additional withdrawals from the Columbia Basin Project, upper basin states, provinces, and tribal reservations, degraded water quality, and periodic poor ocean conditions for salmon, all point to additional risks in managing Columbia River salmon. The coincidence of more than one or all these unfavorable trends could have serious negative consequences for Columbia River salmonids. Given the current setting and likely future trends, additional withdrawals from the Columbia River during periods of low flows will pose substantial additional risks to salmon survival. These risks vary across salmon stocks, with stocks that inhabit the Columbia mainstem during low-flow periods exposed to greater risks. These greater risks to salmon survival should be carefully considered in decisions regarding potential future Columbia River withdrawals during low flows.

Selecting the "best" model of salmon-environmental relationships was neither part of this study nor was it critical to its completion. Analyses and models presented by several expert scientists to the committee during open public meetings were used as background information for considering the degree to which additional water diversions, as well as changes to the river's thermal regime, may pose increased risks to the survival of endangered fish species. This information, along with the large body of scientific evaluations of Columbia River salmon and their habitat, portrays a complex and only partially understood picture of the relative influences of many different environmental variables on salmon survival rates. Efforts to identify whether water velocity, temperature, or some other variable(s), are among the more important factors affecting juvenile salmon survival rates, or identifying critical thresholds associated with these variables, are therefore problematic. **Within the body of scientific literature reviewed as part of this study, the relative importance of various environmental variables on smolt survival is not clearly established. When river flows become critically low or water temperatures excessively high, however, pronounced changes in salmon migratory behavior and lower**

survival rates are expected.

The issue of water use permitting decisions is controversial, as these decisions have important environmental, economic, and social implications. Instituting water use permit and extraction policies that vary according to season and to river flows will require greater flexibility in these institutions than currently exists. This greater flexibility will be necessary, however, if risks to salmon survival are to be better managed and if salmon management is to move toward more adaptive regimes than used in the past. In addition to greater institutional flexibility, additional cooperation across the entire Columbia River basin appears necessary to better manage risks to salmon. For example, if the State of Washington and its water users exercise caution and restraint in considering the issue of additional water withdrawal permits for low flow periods, the benefits of any measures will be decreased or negated if other entities in the basin do not adhere to similar practices. The following chapter reviews past efforts at cooperation across the Columbia River basin, and identifies some of the limits of and lessons from these past efforts and what they bode for future cooperative regimes across the basin.

5

Water Laws and Institutions

INTRODUCTION

In addition to impoundments, dams, diversion structures, and range of environmental variables, Columbia River salmon also encounter a legal, institutional, and decision making framework that affects their migratory and life cycle patterns. This framework reflects the jurisdictional complexity of the Columbia River basin and a patchwork of treaties, legislative enactments, executive directives, and court rulings. The Columbia River is one of North America's most jurisdictionally complex rivers. The Columbia River basin extends into two countries, seven states, and hundreds of other governmental subdivisions. The basin is home is thirteen Indian tribes. Eight federal agencies have water-related resource responsibilities in the basin (Blumm and Swift, 1997). The fish from its waters traverse the international waters of the Pacific Ocean.

This chapter identifies some of the laws and institutions of the law of the Columbia River. This review is not meant to comprehensively review and interpret all laws and policies that govern Columbia River management, but rather is designed to illustrate the many sources of risk that confound decisions in permitting additional water uses in the stretch of the Columbia River that flows within the State of Washington downstream from the Canada-U.S. border. This is consistent with this report's emphasis on the implications of water withdrawals from the mainstem Columbia River in the State of Washington (the "middle reach" of the Columbia). The key themes of this chapter are the prospects of additional diversions upstream of the Columbia middle reach in the State of Washington, and the challenges that additional withdrawals will pose for the existing legal and institutional framework in Washington State and across the river basin.

INTERNATIONAL OBLIGATIONS

Pacific Salmon Treaty

The Pacific Salmon Treaty (16 U.S.C. §§ 3631-3644, Mar. 15, 1985) was concluded in 1984 and ratified by Canada and the U.S. in 1985. The treaty grants each country four commissioners. The U.S. delegation is composed of one commissioner from Alaska, one commissioner representing the states of Oregon and Washington, one commissioner representing the twenty-four tribes, and one nonvoting federal commissioner. Representatives from these governments also serve on several subsidiary panels. The treaty's goal is "coordinated

management of Pacific salmon throughout their range to ensure sustainable fisheries and maximize long-term benefits to the parties" (Waldeck and Buck, 1999). Under the 1999 agreement, the parties agree to an "abundance-based," or supply-side, approach to management and harvest. The 1999 agreement emphasizes the importance of habitat in achieving treaty goals. The parties pledge "[t]o use their best efforts, consistent with applicable law, to: (a) protect and restore habitat so as to promote safe passage of adult and juvenile salmon and achieve high levels of natural production, (b) maintain and, as needed, improve safe passage of salmon to and from their natal streams, and (c) maintain adequate water quality and quantity."[1]

Significance for Columbia River middle reach: The Pacific Salmon Treaty, with its focus on salmon harvest limits, does not impose any direct regulation on water management in the Columbia River's middle reach. However, in its ratification of the treaty, the U.S. foreign policy objective is to sustain the salmon fishery and protect and improve salmon habitat in and passage through inland waters. Increased consumptive diversions in the Columbia River's middle reach, with possible habitat modifications, might produce results contrary to these foreign policy goals.

Columbia River Treaty

The Columbia River Treaty[2] was signed in 1961 by representatives of Canada and the the U.S. and was ratified by the two governments by 1964. The treaty provided for the construction of four upper Columbia River Basin storage dams: Duncan (1967), Keenlyside (1968), Mica (1973), all in Canada, and Libby in Montana (1973). These dams provided flood control and increased hydroelectric power generating potential in both countries. The reservoirs created by these dams largely benefited the U.S., which compensated Canada by agreeing to provide power and flood control.

The sixty-year treaty coordinates binational flood control and electrical energy production in the Columbia River basin. In return for the storage of 15.5 million acre-feet of water, Canada received one-half of the additional power generated at downstream U.S. power plants. As each Canadian dam was completed, its downstream benefits, owned by the Province of British Columbia, were sold to a group of U.S. utilities for a 30-year period. The first 30-year contracts began to expire in 1998. The Province owns the downstream benefits and is now receiving the sales revenues for the remaining 30 years of the Treaty. In 2000-2001, the Province received $632 million as its share of hydropower revenues. Some of this money is assigned to a Canadian Columbia Basin Trust.

The treaty provides for an "entity" from each country. The U.S. Entity refers to the Administrator of the Bonneville Power Administration, Department of Energy, and the Division Engineer, North Pacific Division, Corps of Engineers, who implement the operating arrangements necessary to implement the Columbia River Treaty. For Canada, under a separate British Columbia-Canada agreement, British Columbia Hydro is designated as the Canadian Entity responsible for carrying out that country's obligations under the Treaty, including the construction of the three Canadian dams.

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[1] Att. E, Habitat and Restoration, Annex 4 to Treaty Between the Government of Canada and the Government of the United States of America Concerning Pacific Salmon (www.psc.org/treaty).

[2] Treaty With Canada Relating to Cooperative Development of the Water Resources of the Columbia River Basin, 15 U.S.T. & O.I.A., vol. 2, T.A.A.S. No. 5638. See also Johnson, The Canada-United States Controversy Over the Columbia River, 41 Wash. L. Rev. 676 (1966).

The treaty has important water right features. Canada has certain rights to divert water from the Kootenay River into the headwaters of the Columbia. Between the 20th and 60th years of the treaty, this may be as much as 1.5 million acre-feet per year. For 40 years after the treaty expires, Canada can continue to divert unspecified amounts of water from the Kootenay River into the Columbia, so long as Kootenay River flows at the border are 2500 cubic feet per second or the natural flow. The treaty is not a general apportionment of Columbia River waters. Canada pledges not to divert water in a way that alters the flow of water crossing the boundary, but an exception is made for consumptive uses. Thus, this restraint is designed to prevent transbasin diversions, such as into the Fraser River (Canada's controversial proposed project that resulted in the 1961 treaty).

Significance for the Columbia River middle reach: So long as the level of hydropower production under the treaty is maintained, there should be no significant changes to water availability in the Columbia River's middle reach. Without U.S. consent, Canadian transfers out of the Columbia River basin are prohibited. The water transfer between the Kootenay River (which ultimately flows into the Columbia) into the headwaters of the Columbia generally has water-neutral effects for the Columbia River middle reach. The treaty is not an apportionment of the river between the two countries, however, and other international law principles, such as the Boundary Waters Treaty, must be considered.

Boundary Waters Treaty

The principal water management and sharing mechanism between Canada and the U.S. is the Boundary Waters Treaty.[3] Ratified in 1909, it creates the bilateral International Joint Commission (IJC) to address disputes. Several provisions of the treaty address the apportionment of boundary waters between Canada and the U.S. Under Article I, each country is entitled to "the exclusive jurisdiction and control over the waters" on its side of the border. Several other provisions dampen this exclusive jurisdiction rule. Under Article II, a party injured by an upstream diversion in the other country has the same legal rights as a resident of the upstream nation. Under Article VIII, each nation has "equal and similar rights in the use" of boundary waters. These somewhat contradictory provisions may result in the adoption of an equitable apportionment or an equal division of boundary waters (Tarlock, 2000).

There is a possibility that additional Columbia River water could be developed by Canada, and it is unclear what the legal implications would be for water uses in the Columbia River middle reach. In the case of increased Canadian diversions, a downstream water user in the State of Washington would have the same rights to contest the diversion as a Canadian resident; but application of the equitable apportionment principle usually means (at least in U.S. jurisprudence) that actual water uses within a state must not exceed that state's equitable share of the interjurisdictional water source. As a practical matter, injury to Columbia River middle reach users as the result of increased Canadian diversions would be processed through time-consuming IJC procedures. The U.S. State Department controls how such cases are presented.

Significance for the Columbia River middle reach: With population growth in British Columbia, increased Columbia diversions are likely and these will reduce downstream flows.

[3] Treaty Relating to Boundary Waters and Boundary Questions, 36 Stat. 3488 (1909).

Additionally, Canada likely has an unquantified but, for purposes of prior appropriation in Washington, a senior claim based its equitable interest in the river. Canadian development will thus result in incrementally less water in the river. Additional U.S. water diversions in the Columbia River's middle reach may remain subject to additional Canadian development, the latter of which would be entitled to priority. This does not consider any water-related claims of indigenous people north of the forty-ninth parallel.

INTERSTATE COMPACTS

Attempted Columbia River Basin Compact

From 1950 to 1968, the states of Montana, Idaho, Oregon and Washington attempted the negotiation of a Columbia River Basin Compact (Nevada, Utah and Wyoming were minor participants). Although much of the discussion concerned upper and lower basin allocations of water, the debate really focused on the rivalry between public and private hydropower generation. The movement for public power in the Northwest had resulted in a proposed Columbia Valley Authority for the region in the late 1940s, but private power interests held a political advantage during the Eisenhower Administration. Upper basin states such as Montana, with a history of private power development, supported a compact as a means of promoting private power interests. Although a compact was signed by the compact commissioners and approved by Congress, it ultimately failed when the Oregon and Washington legislatures failed to ratify the document. The central compact feature was a trade of upper basin storage for hydropower. The upper basin states would have allowed the construction of larger reservoirs in exchange for a share of future hydropower production and a guarantee that much of their future consumptive water needs would prevail over lower basin instream uses.

Columbia River Compact

Although the quest to establish a basin-wide water quantification compact was unsuccessful, a compact was reached concerning the commercial fishery. The Columbia River Compact provides authority to adopt seasons and rules for Columbia River commercial fisheries. Compact administration is by the Oregon and Washington agency directors, or their delegates, acting on behalf of the Oregon Fish and Wildlife Commission (OFWC) and the Washington Fish and Wildlife Commission (WFWC). In addition, Columbia River treaty tribes have authority to regulate treaty Indian fisheries. The basic text of the compact is as follows:

> All laws and regulations now existing, or which may be necessary for regulating, protecting or preserving fish in the waters of the Columbia River, over which the States of Oregon and Washington have concurrent jurisdiction, or any other waters within either of said states, which would affect the concurrent jurisdiction, shall be made, changed, altered and amended in whole or in part, only with the mutual consent and approbation of both states. (Oregon Rev. Stat. § 507.010.)

When addressing commercial seasons for salmon, steelhead, and sturgeon, the compact considers the effect of the commercial fishery on escapement, treaty rights, and sport fisheries, as

well as the impact on species listed under the Endangered Species Act (ESA). Although the compact does not provide authority to adopt sport fishing seasons or rules, it does address the allocation of limited resources among users.

Significance for the Columbia River middle reach: The treaty is designed to regulate commercial fishing, but the language concerning laws or regulations "necessary for regulating, protecting or preserving fish" has the judicially untested potential of requiring greater collaboration between Washington and Oregon on anadromous fish issues. Water-right permitting decisions, unless they require a new statute or rule, do not appear to be affected by this treaty.

Northwest Power Act and the Northwest Power and Conservation Council

Throughout the twentieth century, growth and demand for electric power, irrigated farmland, and flood control in the Pacific Northwest was met by increasingly large river structures. Until the 1970s, power and other services provided by the system were generally viewed as beneficial and critical to the region's growth. By then, however, the benefits of the system were increasingly challenged, as environmental, economic, and social costs of construction were raising questions. In 1980, Congress passed the Pacific Northwest Electric Power Planning and Conservation Act which authorized the states of Idaho, Montana, Oregon and Washington to create the Northwest Power Planning Council. Renamed the Northwest Power and Conservation Council (NPCC) in 2003, the council consists of eight board members, two each appointed by the governors of each states. The act also directed the council to pay particular attention to information provided by Native American Tribes. The council is responsible for mitigating the impacts of hydroelectric power dams and their operations on all fish and wildlife in the Columbia River basin, including endangered species, through a program of enhancement and protection. The council is intended to be a broker among many contending interests including agencies, tribes, electric utilities, environmental and business interests. The fish and wildlife program of the council directs the expenditure of hundreds of millions of dollars per year of federal Bonneville Power Administration (BPA) revenues intended to mitigate damages to fisheries.

Among the key features of today's Northwest Power and Conservation Council is its authority to guide the actions of federal agencies. The Bonneville Power Administration, for example, is required to ensure that its actions are consistent with NPCC plans and initiatives and other federal agencies are required to consider the council's programs at each stage of the decision-making process. Flows of information for decision-making within the council are complex, as they include large numbers of committees and advisory bodies. The council seeks input from research projects, agency initiatives, and networking workshops. Information is provided from a variety of stakeholder and community sources through public hearings, outreach, and public advisory groups.

In 2000, the Northwest Power Planning Council established a geographically based plan for implementation. The program is to be implemented through sub-basin plans developed locally in more than 50 tributary sub-basins of the Columbia River and amended into the council's program. The efficacy of this grass-roots implementation strategy remains to be seen. The complex organizational arrangements engaging large numbers of professional and public

advisors serves to spread the risks of failure over large numbers of participants as well as co-opt potential critics. In some sense, issues are "domesticated rather than addressed, and hard problems are removed from the day to day decision space" (Rayner et al., 2001). Although problems may not be fully resolved, such strategies allow for additional time and resources in which to search for alternative solutions and in which public tastes and values may undergo changes.

INTERSTATE APPORTIONMENT

Three traditional methods have been used for to resolve interstate water disputes. The interstate compact is the first method for resolving regional, intergovernmental water disputes. Compacts are specifically authorized by the U.S. Constitution and were first used for resolving boundary conflicts. Compacts require congressional authorization, either before or after the agreement is reached; and, once a compact has been approved by Congress, it has the statute of federal law under what is known as the Law of the Union doctrine. The first water quantification compact, allocating water between the upper and lower basins of the Colorado River, was negotiated in 1921. Since the approval of this initial compact by Congress in 1929, over twenty other water compacts have been negotiated throughout the U.S. Since the 1980s, several states and tribes have negotiated congressionally-approved compacts or other agreements determining tribal reserved water rights.

Federal legislation is a second method to resolve intergovernmental natural resource disputes. In interstate conflicts over water, this method, known as a congressional apportionment, has rarely been used: once to allocate water among Colorado River basin states and, implicitly, in water quality disputes in the Great Lakes. Although federal legislation could provide a comprehensive water allocation agreement for the Columbia River basin, members of Congress are rarely able to reach agreement among themselves about divisive regional issues. Many of them also believe these disputes are better left to more local resolution.

A third traditional approach to the resolution of interstate water disputes involves litigation. When water-related disputes are among states, the Constitution provides that the U.S. Supreme Court has original and exclusive jurisdiction to hear these cases. If the dispute involves the interpretation or enforcement of an existing interstate compact, the Court usually will look to that document for the principles necessary to resolve the matter. If no compact exists or an existing compact does not address the dispute, the Court may apply a set of federal common law rules to reach an equitable apportionment of the water resources of the water body. Because these original jurisdiction cases require a factual record, they are usually referred first to a Court-appointed special master who holds hearings and submits a proposed resolution of the case to the Court for its review.

All three of these traditional methods have usually ignored or deferred consideration of tribal interests in the water source. Also, the utility of using these methods to resolve complex water quality disputes or regional endangered species problems generally has not been tested. One exception is the Delaware River Basin Compact, approved in 1961 by Delaware, New Jersey, New York, Pennsylvania, and the United States. This state-federal compact is governed by a commission of the governors from the four states and a federal representative appointed by the president. The compact's most distinctive feature is its requirement that the commission is charged to develop and implement a comprehensive basin plan. The compact also gives the

commission licensing authority by providing that "no project having a substantial effect on the water resources of the basin shall hereafter be undertaken unless it shall have been first submitted to and approved by the Commission." The commission must approve the proposed project if it "would not substantially impair or conflict with the comprehensive plan." The Delaware River Basin Compact is similar to the 1980 Pacific Northwest Electric Power Planning and Conservation Act in that it also created a four-state commission, which also addressed multiple resources and required the development of a regional energy plan (which is presumptively binding on federal agencies). Another federal-state arrangement for coordinating multiple jurisdictions in a U.S. interstate river basin is in the Susquehanna River basin (*http://www.srbc.net/*; accessed February 17, 2004).

More recently, governments sharing regional water bodies have used less formal, more flexible arrangements to address interjurisdictional water issues. These include the Enlibra conflict resolution principles endorsed by the Western Governors Association, statements of guiding management principles such as the Great Lakes Charter, multifaceted state-federal agreements (e.g., California's CalFed Bay-Delta program), and drought or water banks such as those used in Idaho and the lower Colorado River. All of these arrangements may be useful in increasing the flexibility of traditional water management regimes (e.g., the doctrine of prior appropriation) across the Columbia River basin and may be helpful in addressing existing and emerging water allocation issues.

NATIVE AMERICAN WATER AND FISHERIES RIGHTS

Legal Basis

Indian claims to water and fish are usually based on the federal organic document that established a reservation of land for the tribe: a treaty, statute, or presidential executive order. These documents sometimes make explicit statements concerning these resources. They might indicate, for instance, that the tribe has reserved to itself an existing fishery right. These documents are often silent about tribal resources; but the courts have read an "implied" reservation into these agreements or documents, recognizing that neither the tribe nor Congress would have intended a reservation of land without water. Finally, tribes may assert aboriginal rights independent of any document. These claims are based on extended, exclusive occupancy of land before forceful removal (Cohen and Strickland 1982). The Pacific Northwest has produced many judicial opinions that have been hallmarks in the development of Indian law as it pertains to resource management. These cases often involved (and still do) the intersection of fisheries and water resource issues. The foundational legal case in this realm is *United States v. Winans* (198 U.S. 371, 1905), as it serves as the common spring for the law of Indian fisheries and the reserved water rights doctrine (Box 5.1 lists the Columbia River basin tribes).

BOX 5.1
Columbia River Basin Tribal Groups and Reservations

Burns Paiute Tribe (Oregon)—3,000 members; 770 acres of trust land acquired in 1935 to reestablish reservation; 11,000 acres of allotment land owned by tribal members.
Coeur d'Alene Tribe (in Idaho)—1,700 members; 345,000-acre reservation; rights based on treaties as early as 1873.
Confederated Salish and Kootenai Tribes of the Flathead Reservation (Montana)–6,900 members; 1.3 million-acre reservation; assert rights based on 1855 Treaty of Hellgate.
Confederated Tribes of the Colville Reservation (Washington)—8,400 enrolled members; 1.4 million-acre reservation; rights based on 1872 Executive Order and other agreements with U.S. (1892, 1905).
Confederated Tribes of the Umatilla Indian Reservation (Oregon)—2,174 enrolled members; 180,441-acre reservation; rights based on 1855 treaty.
Confederated Tribes of the Warm Springs Indian Reservation (Oregon)—3,916 enrolled members; 650,000-acre reservation; rights based on 1855 treaty and federal court cases.
Kalispel Tribe of Indians (Washington)—280 enrolled members; 4600-acre reservation; rights based on 1914 executive order.
Kootenai Tribe (Idaho)—67 members as of 1974; tribal members accepted 12.5 acres but do not consider it to be a final settlement.
Nez Perce Tribe (Idaho)—3,200 members; 770,453-acre reservation; rights based on treaties of 1855 and 1863, and federal court decisions.
Shoshone-Bannock Tribes of the Fort Hall Reservation (Idaho)—4,291 members; 544,000-acre reservation; rights based on 1867 executive order.
Shoshone-Paiute Tribes of the Duck Valley Reservation (Nevada)—1,818 members; 289,820-acre reservation; rights based on 1863 treaty, 1877 executive order, and other statutory additions to reservation.
Spokane Tribe of Indians (Washington)—100,000 acres held in trust; 57,370 additional acres held as allotments, deeded fee land, other government lands; rights based on 1880 executive order.
Yakama Nation (Washington)—9,092 members; 1.39 million-acre reservation; rights based on 1855 treaty.

United States v. Winans (1905)

This U.S. Supreme Court decision announced reserved right principles (that would be further developed in the *Winters* case in 1908) that held that the tribes' rights of taking fish at all usual and accustomed places in common with the citizens of the Territory of Washington, and the right of erecting temporary buildings for curing them, were reserved to the Yakama Nation in the treaty of 1859. The court ruled that this was not a grant of right , but a reservation of rights already possessed and not granted away. The rights so reserved imposed a servitude on the entire land relinquished to the U.S. under the treaty and which, as was intended to be, was continuing against the U.S. and its grantees as well as against the State and its grantees.

Winters v. United States (1908)

In the 1908 case of *United States v. Winters* (207 U.S. 564 (1908), which arose in the State of Montana, the Supreme Court recognized that the reservation system had been established in an effort to transform tribes into agrarian societies. The court ruled that Congress reserved, by implication, sufficient water to serve the needs of the reservation with a priority extending back to the date the reservation was established. In some cases, these *federally reserved* water rights are claimed as aboriginal, based on historic use, with a priority date of "time immemorial." Since Indian fishing and water right claims are senior to most non-Indian uses, there has been a slow but continuing effort to quantify these treaty or reserved water rights. Quantification can be by litigation, compacts or settlements, or congressional legislation. All tribes with trust-status reservations within the Columbia River and its tributaries potentially have treaty-based or reserved water right claims. Quantification of nonfishing claims has been based on the practicably irrigable acreage (PIA) standard (*see Arizona v. California,* 1963). The Arizona Supreme Court, however, recently utilized a "permanent homeland standard" in the Gila River adjudication that may stimulate further discussion of appropriate quantification methods.

Indian Fisheries Cases in Washington

Under the *Winans* case, tribes may reserve by treaty the right to hunt or fish off-reservation. This legal principle is at the heart of lengthy litigation in state and federal courts in Washington State.

Puyallup Cases

The chronicle of litigation begins in 1968 with *Puyallup Tribe v. Department of Game (Puyallup I)* (391 U.S. 392 (1968), decided by the U.S. Supreme Court. The tribe had entered into a Stephens treaty[4] in 1854 that stated: "The right of taking fish, at all usual and accustomed grounds and stations, is further secured to said Indians, in common with all citizens of the Territory . . . ."[5] Washington State attempted to prohibit tribal members, when fishing off-reservation, from using nets. The Court upheld the state's qualified authority to regulate the tribe's fishing right: "But the manner of fishing, the size of the take, the restriction of commercial fishing, and the like may be regulated by the State in the interests of conservation, provided the regulation meets appropriate standards and does not discriminate against the Indians" (391 U.S. at 398) In a later case, the Court defined "appropriate standards" to mean a reasonable and necessary conservation measure, the applicability of which to Indians "is necessary in the interests of conservation" (Antoine v. Washington, 420 U.S. 194, 207, (1975).

Soon thereafter, Washington allowed tribal members to use nets for salmon but not for steelhead. The tribe argued that this restriction resulted in assigning the entire run to non-Indian sports fishermen. When this restriction was reviewed by the U.S. Supreme Court in *Puyallup II*

[4] The reservations and off-reservation rights of Columbia River basin tribes are established by a series of "Stephens Treaties" named after a former governor of Washington who negotiated with the tribes.
[5] Treaty with the Nisqually and Other Indians, art. III, 10 Stat. 1132, 1133 (1854).

(Department of Game v. Puyallup Tribe, 414 U.S. 44 (1973) Puyallup II), the justices indicated that regulation discriminated against the tribe and violated Puyallup I. The court suggested that some accommodation between Indian and non-Indian uses had to be found; but, if necessary, a nondiscriminatory fishing ban to save steelhead could be applied to Indians. In a third round of litigation, the state allowed the Indians to net steelhead, but limited their share to 45 percent of the natural run. Contemporaneously, many of the Indians' "usual and accustomed" fishing locations were determined to be within reservation boundaries, although still on non-Indian land. The tribe challenged this state limitation as well, particularly as applied to on-reservation locations. In Puyallup Tribe, Inc. v. Department of Game (433 U.S. 165, 1977) (*Puyallup III*), the Supreme Court upheld the state regulation and allowed it to be applied on on-reservation fishing so as to prevent the tribe from taking an unlimited amount of fish to the detriment of non-Indian fishermen.

Boldt Litigation

While the *Puyallup* litigation was pending, the U.S. filed suit in federal district court in 1970 on behalf of seven Washington-based tribes who asserted fishing rights based on the same Stephens treaty language. On February 12, 1974, Judge George Boldt ruled in *United States v. Washington* [384 F. Supp. 312 (W.D. Wash. 1974), aff'd, 520 F.2d 676 (9th Cir. 1975), cert. denied, 423 U.S. 1086 (1976)] that the tribes had a right to fish at their accustomed places and to secure roughly half of the annual catch. More specifically, the district court held that the Indians were entitled to a 45 to 50 percent share of the harvestable fish that would at some point pass through recognized tribal fishing grounds in a defined area of Washington, to be calculated on a river-by-river, run-by-run basis, subject to certain adjustments. With slight modification, the U.S. Court of Appeals for the Ninth Circuit affirmed, and the U.S. Supreme Court declined review. In the same decision, Judge Boldt declined to extend federal recognition or enforce treaty rights for certain landless tribes (the Samish, Snoqualmie, Steilacoom, and Duwamish). Although the district court ordered the state fisheries department to adopt regulations protecting the tribal fishing rights, a state court action resulted in Washington Supreme Court holding that state agencies could not comply with the federal court injunction. The state court ruled that the treaty conferred upon the Indians no greater right than that enjoyed by non-Indians. To rule otherwise, in the court's view, would violate the Equal Protection Clause (Puget Sound Gillnetters Ass'n v. Moos, 565 P.2d 1151, Wash. 1977).

These various federal and state decisions were eventually all reviewed by the U.S. Supreme Court in 1979. In rejecting the ruling of the state supreme court, the Supreme Court vindicated the federal district court's approach. In *Washington v. Washington State Commercial Passenger Fishing Vessel Ass'n, (*443 U.S. 658 (1979) the Supreme Court held that the treaties do not guarantee merely access to the fishing sites and an equal opportunity for Indians and non-Indians to fish, but rather secure to the Indian tribes a right to harvest a share of each run of anadromous fish that passes through tribal fishing areas. Among the more specific holdings:

- A 50 percent share of the harvestable run may be established as the ceiling for the Indian fishery. This share may be reduced when fish are not needed, for instance, when a tribe's population has declined.
- The state has the authority to set the harvestable run for each stream in a manner that

protects the sustainability of each run.

- All fish caught by treaty Indians count against the tribal share, whether caught on- or off-reservation.
- All fish caught by non-Indians count against their share, whether or not caught in state waters.
- Indians are entitled to the exclusive use of all fishing sites within reservation boundaries (Canby, 1981).

Significance for the Columbia River middle reach: The *Boldt* litigation, culminating in the 1979 U.S. Supreme Court decision, recognizes state authority to determine harvestable catch for both Indian and non-Indian fishermen. That authority, however, is tempered by the obligation to manage the resource in a manner that safeguards the sustainability of the resource. In practice, management of the fishery has become more of the collective responsibility of federal, state, and tribal fish managers. Still, the state must be cautious in its water permitting function not to affect the salmon and steelhead resource in such a way that no harvestable catch is available for treaty Indians or to take actions that are detrimental to the sustainability of existing runs.

Water Rights of Indian Reservations

As previously discussed, many of the Stephens treaties reserved tribal rights to fish on the reservations and at off- reservation "usual and accustomed" sites in their treaties, the provision interpreted in the *Puyallup* and *Boldt* litigation. The total land represented by these reservations exceeds 7 million acres (11,000 square miles, about the size of the combined area of Massachusetts and Connecticut). Water rights for some of this tribal land have been adjudicated or settled. Other land may not have been reserved for agricultural purposes or may be of poor quality. If, however, irrigated agriculture was “feasible” on 25 percent of this land, at 4 acre-feet of water/acre, 7 million acre-feet of water could be diverted from the Columbia River system for farming (“feasibility” of irrigation is a technical and economic concept used in defining “practical irrigable acreage;” its calculation depends on site-specific conditions and studies and, depending on assumptions, can vary widely). The following discussion broadly examines some of the larger reservations to gauge how their claims and uses might affect water availability in the Columbia River middle reach.

Yakama Nation/Yakima Indian Reservation (Washington)

The Yakima River flows from the northwest and empties into the Columbia River at Richland, Washington. Water rights established on the Yakima River affect water availability downstream on the Columbia River mainstem. The Yakima River has been the subject of the ongoing Yakima River adjudication, originally filed by the State of Washington in 1977. The water rights of the Yakama have been asserted in the adjudication, and several important decisions have been reached. In November 1990, the Yakima County Superior Court granted a partial summary judgment establishing the quantity and priority of treaty-reserved water rights for irrigation and fishing purposes. The case was appealed to the Washington Supreme Court,

which affirmed the lower court decision in April 1993.

Confederated Tribes of the Colville Reservation (Washington)

Twelve bands or tribes of indigenous people were located on land within the Territory of Washington pursuant to a presidential executive order issued in April 1872. On July 2 of the same year, a second presidential executive order moved the reservation and the residents to its present location on the west side of the Columbia River. Although this location originally totaled almost three million acres, subsequent enactments reduced the acreage to the present size of 1.4 million acres. Tribal members, however, retain hunting and fishing rights on the ceded northern half of the original reservation (Antoine v. Washington, 420 U.S. 194, 1975). Grand Coulee Dam and the lower part of Roosevelt Reservoir are located within the external boundaries of the reservation; the upper lake is within the ceded areas. Tribal membership is approximately 8,700, about half of whom live on or adjacent to the reservation.

The reservation was the location of the *Colville Confederated Tribes v. Walton* (1981) decision, which recognized the ability of non-Indian assignees of Indian allotments to claim a share of a tribal reserved water right. Although the Colville Tribes benefit from the determinations made in the *Boldt* fishing litigation, any other reserved water right claims made by the tribes have not be adjudicated or settled. The tribes have expressed their concern over sedimentation in Lake Roosevelt and the impact this has on tribal water use (Confederated Tribes of the Colville Reservation, 2000).

Significance for the Columbia River middle reach: The Colville Tribes are emphasizing their gaming and forestry operations, but the relatively large size of the reservation provides future agricultural opportunities. Any entitlement to reserved water rights for agricultural or other consumptive uses has not been adjudicated or settled; but if such rights are determined in the future, they would be senior to most downstream state-law diversions and could diminish mainstem flows.

Warm Spring Indian Reservation (Oregon)

Pursuant to the 1855 Treaty with the Tribes of Middle Oregon, the Confederated Tribes of the Warm Springs Indians–comprised of the Wasco, Paiute, and Warm Springs bands—ceded ten million acres of aboriginal territory to the United States. Today, the Warm Springs Nation occupies a reservation of approximately 650,000 acres in north central Oregon, and is inhabited by 3,500 to 4,000 tribal members. The Deschutes River system, tributary to the Columbia, is the principal water source in the area. In an effort to avoid litigation, the Warm Springs Nation approached the State of Oregon in the early 1980s and offered to enter negotiations to determine, quantify, and settle its reserved water rights. After many years of negotiation, the final agreement was signed and executed on November 17, 1997. The agreement was submitted to the Deschutes County Circuit Court in 1999 for incorporation into the Deschutes River Decree, originally issued in 1928. In reaching the settlement, the parties had agreed *not* to use the "practicably irrigable acreage" standard that has been used in other water rights settlements and litigation. Instead, after studying 70 years of flow data from the Deschutes River, the parties felt

that the region supplied enough water to satisfy all current and some future uses. The parties agreed that the amount of water resources used, consumed, and reserved as of September 26, 1996, was sufficient to satisfy their present and future water needs without subjecting other water users to a call by the tribes. The state subordinated its own instream flow right on the Deschutes River to the priorities of the tribal water rights.

Significance for the Columbia River middle reach: Although a reserved water right settlement has been reached for the Warm Springs Nation's claims on the Deschutes River, only the future non-Indian water development is constrained. The tribes are authorized to develop their water entitlement, and to the extent such development is consumptive, it will likely reduce flows in the Columbia River mainstem.

Flathead Indian Reservation (Montana)

The Confederated Salish and Kootenai Tribes share the Flathead Reservation located near Flathead Lake in northwestern Montana. The tribes assert a variety of sovereignty and natural resource rights based on the 1855 Treaty of Hellgate. The Flathead Indian Reservation is a checker-boarded mix of Indian and non-Indian lands. The tribes and non-Indians living in the Flathead Valley have long contested the water supplied by Flathead Indian Irrigation Project. The tribes have prevailed in many lawsuits concerning water including a recent Montana Supreme Court decision preventing the state from issuing additional groundwater permits until the general stream adjudication is complete for the basin. This decision notwithstanding, an increasing number of unpermitted wells have been drilled. Although adjudication claims have been filed for water uses in the area, the adjudication has been stayed pending negotiations between the tribes and the Montana Reserved Water Rights Compact Commission. Those negotiations have barely commenced due in large part to heightened emotions on all sides. If negotiations are unsuccessful, many difficult and potentially volatile years of litigation are anticipated.

Significance for the Columbia River middle reach: The Flathead Tribes have an ambitious economic development program, and their reservation is in one of the fastest growing areas of Montana. Years if not decades will be required before existing water rights are clarified. Water use in the area will increase and thereby reduce flows to the middle and lower basins of the Columbia.

Nez Perce Tribe/Nez Perce Indian Reservation (Idaho)

The Nez Perce Indian Reservation in Idaho has the Clearwater River as its northern border. The reservation is also in the proximity of the Lochsa and Salmon Rivers, as well as the Snake River itself. The tribe, and the U.S. on its behalf, have filed extensive claims in the Snake River. The claims are for sufficient instream flows to support salmon, as well as for water for irrigation and domestic uses. Instream flow claims have been filed in 1134 drainages and virtually extend to all the water in the Snake, Salmon, and Clearwater basins (Shelton, 1997).

The legal basis for the tribe's claim is its 1855 treaty,[6] in which the tribe reserved the exclusive right to fish all streams running through or bordering the reservation and a non-exclusive right to fish in "all usual and accustomed places."

In 1998, non-Indian water users filed a motion for summary judgment in the Snake River adjudication challenging the tribe's off-reservation instream flow water right claims. In 1999, the trial court conducting the adjudication granted the motion for summary judgment and dismissed the tribe's and the U.S. instream flow claim, holding that no implied federal reserved instream flow right exists as a matter of law to support the tribe's fishery right [(Consolidated Subcase No. 03-10022 (Snake River Basin Adjudication Dist. Ct., Idaho, Nov. 10, 1999), appeal filed, Docket No. 26042 (Idaho Nov. 29, 1999)]. The tribe subsequently filed a collateral challenge to the ruling based on an alleged conflict of interest involving the judge, but the action was dismissed as moot after the judge resigned (United States v. State, 51 P.3d 1110 (Idaho 2002). The Idaho Supreme Court still has not reached the merits of the instream flow case although the briefing was completed in February 2003. In the meantime, the major parties to the Snake River adjudication have been involved in mediating the Nez Perce claim. Reportedly, settlement discussions have focused on two major areas: (a) possible reconfiguration of the dam and reservoir system on the lower Snake River and the mainstem of the Columbia; and (b) preservation of fish habitat in the Salmon and Clearwater basins (Shelton, 1997). On May 7, 2003 the Snake River Adjudication Presiding Judge informed the mediating parties that he would order an end to the mediations and advance the remaining Nez Perce claims toward trial (Idaho Statesman, 2003).

Significance for the Columbia River middle reach: The Nez Perce have a senior treaty-based claim on some of the waters of the Snake River system. To the extent they are successful in having their instream flow claims recognized in the Snake River adjudication, Snake River and Clearwater flows at the Washington-Idaho border would likely stabilize or improve. This would likely enhance water availability in the middle reach of the Columbia River.

Fort Hall Settlement (Idaho)

Shoshone and Bannock tribes share the Fort Hall Reservation in southern Idaho. The Fort Hall Indian Reservation was established by an executive order in 1867. The reservation, initially intended to be 1.8 million acres but later reduced to approximately 544,000 acres, is located along the Snake River near Pocatello. The reservation is owned primarily by the tribes collectively (47 percent) and individual Indian allottees (43 percent). In 1985, the state legislature directed the Idaho Department of Water Resources to commence a general stream adjudication in the Snake River basin. The legislature also passed a resolution, at the request of the Shoshone-Bannock Tribes and the Idaho executive branch, authorizing negotiations to settle the tribes' water claims in the Snake River basin. The tribes and the state entered into a memorandum of understanding establishing a process for negotiating a settlement. The tribes obtained a special exemption from the U.S. Department of the Interior allowing them to pursue negotiations independent of the federal government. The U.S. and certain local water users were included in the negotiations later. In 1989, an agreement was reached that sought to protect the rights of water users established under state law. In late 1990, this agreement was ratified

[6] Treaty with the Nez Perce, 12 Stat. 957 (June 11, 1855).

through congressional enactment [Fort Hall Indian Water Rights Act of 1990, Pub. L. No. 101-602, 104 Stat. 3059. See also Committee Report 101-831 to accompany H.R. No. 5308, 101st Cong., 2nd Sess. (1990)].

The settlement, involving a highly developed reach of the Snake River, sets the tribes' entitlement to water from the Snake River Basin at 581,031 acre-feet per year. The water supply is comprised of a combination of natural flow, groundwater, and federal contract storage water. This entitlement is in satisfaction of all claims to water that the tribes may have had under the *Winters* Doctrine. Indian rights in the Fort Hall Indian Irrigation Project were converted to *Winters* rights with a priority of 1867, the date the reservation was established.

Significance for the Columbia River middle reach: The Fort Hall Settlement is one of the few instances in which the Winters rights of an upstream Indian reservation have been determined.

FEDERAL RIGHTS AND OBLIGATIONS

Navigation

The federal government has plenary authority to regulate interstate commerce. Under the U.S. Constitution's interstate commerce clause, Congress may enact statutes regulating interstate commerce. The dormant interstate commerce power is also available to invalidate state statutes and other actions that impermissibly burden interstate commerce. One aspect of the interstate power is federal navigation power that enables the federal government to prevent obstructions that burden river-borne commerce on navigable waterways. The federal navigation power prevents the construction of bridges of other structures that might impede navigation. It also prevents actions that deplete water so that navigation is no longer possible.

Significance for the Columbia River middle reach: Most of the mainstem Columbia River in Washington is navigable and, thus, subject to the restraints imposed by the federal navigation power. The federal government can always insist on a base flow in the river sufficient to allow actual navigation. The exercise of this authority trumps all state actions or diversions under state law that would interfere with this base flow requirement. Because the federal navigation power is constitutionally based, it may even limit federal statutes or federal agency actions that jeopardize navigation flows. Flows necessary for navigation on the mainstem of the Columbia and the Lower Snake rivers may thus be the most legally secure water rights in the system.

Federal Reserved Water Rights (Non-Indian)

Hanford Reach National Monument

Non-Indian federal land can also benefit from federal reserved water rights. On June 9,

2000, President Clinton signed an executive order creating the Hanford Reach National Monument, a 195,000-acre monument along the Columbia in south-central Washington [Proclamation 7319, Establishment of the Hanford Reach National Monument (June 9, 2000)]. The site includes a 51-mile stretch of the Columbia River upstream of Richland. The monument designation was challenged in two separate lawsuits, but the U.S. Court of Appeals, District of Columbia, ruled in October 2002 that the designation had been proper under the 1906 Antiquities Act (16 U.S.C. § 431). The proclamation recognizes the importance of this reach of the river for fishery values. As discussed in a background paper accompanying the proclamation, the "Reach contains islands, riffles, gravel bars, oxbow ponds, and backwater sloughs that support some of the most productive spawning areas in the Northwest, where approximately 80 percent of the upper Columbia Basin's fall Chinook salmon spawn. It also supports healthy runs of naturally-spawning sturgeon and other highly-valued fish species."[7] The proclamation specifically addresses water rights in the Columbia. It "reserves in the portion of the Columbia River within the boundaries of the monument, subject to valid existing rights and as of the date of the proclamation, sufficient water to fulfill the purposes for which the monument is established."[8] It also bans any new agricultural irrigation within the monument boundaries.[9]

Significance for the Columbia River middle reach: The Hanford Reach National Monument withdrawal creates a non-Indian federal reserved water right with a priority date of June 9, 2000. Among the purposes of the withdrawal is the reservation of water necessary to support spawning salmon and other fish species. This reserved right will prevent any new, upstream consumptive diversions that would leave insufficient flows in the river to maintain the fishery protected by the reservation. As such, this reservation could be a significant constraint on new diversions upstream of the Hanford Reach.

Federal Regulatory Water Rights

Endangered Species Act

Mainstem water uses can also be limited by federal regulatory authority, sometimes referred to as "federal regulatory water rights." Because of the Columbia River's anadromous fishes, both the U.S. Fish and Wildlife Service and NOAA Fisheries have responsibilities for implementing the requirements of the Endangered Species Act in the basin. Between 1991 and 1992, Snake River salmon species were listed under the ESA. Ultimately, Biological Opinions (BiOps) issued in 1993 and 1994 were rejected by federal courts. A 1995 Biological Opinion established stronger protections, including increased flows and measures to improve water quality and temperature. The Biological Opinion set a goal of adopting a revised biological opinion by the end of 1999. It also obligated the U.S. Army Corps of Engineers to prepare an environmental impact statement on breaching the Snake River dams. The 1995 Biological Opinion was amended to incorporate additional protections as several other Columbia and Snake River runs have been declared threatened or endangered. Between 1995 and 1999, nine

[7] White House, Background Paper on the Hanford Reach National Monument at 2 (nd).
[8] *Id.* at 4.
[9] Id. at 5.

additional species of fish throughout Columbia River basin were listed under the ESA. There are now twelve listed populations. In 2000, another Biological Opinion was issued for the Federal Columbia River Power System. In 2002, NOAA Fisheries concluded that federal agencies were successfully implementing 176 of 199 Reasonable and Prudent (RPA) actions of the 2000 Biological Opinion requirements.

Significance for the Columbia River middle reach: The federal Endangered Species Act, and the biological opinions produced under it, are the principal federal regulatory constraints on federal agency actions affecting the Columbia River.

Federal Power Act

Since the passage of the Federal Water Power Act in 1920, the Federal Power Commission and its successor, the Federal Energy Regulatory Commission (FERC), have been responsible for the licensing of hydroelectric power dams and facilities on navigable waterways. Typically, these licenses have been for 50-year periods. Two provisions of the Federal Power Act allow the Federal Energy Regulatory Commission to impose license conditions protective of fish. Under section 10(j), FERC must impose conditions "based on recommendations received pursuant to the Fish and Wildlife Coordination Act from the National Marine Fisheries Service (today NOAA Fisheries), the United States Fish and Wildlife Service, and State fisheries and wildlife agencies" [16 U.S.C. § 803(j)]. Section 18 of the Federal Power Act also mandates that FERC "require the construction, maintenance, and operation by a licensee at its expense of . . . such fishways as may be prescribed by the Secretary of Interior or the Secretary of Commerce, as appropriate."

Significance for the Columbia River middle reach: One of the Columbia River basin key hydroelectric facilities, the Idaho Power Company's Hells Canyon complex of three dams on the Snake River, is currently undergoing relicensing by the Federal Energy Regulatory Commission (FERC). The current license expires in 2005. One of the main issues in the proceeding before FERC is how the dams should be operated or altered to protect salmon. It will thus be uncertain for several years how much water, and when, Idaho Power Co. will have to release to protect instream values downstream of the dams. Instream flows below the Hells Canyon complex will likely not be reduced during FERC proceedings.

STATE LAWS AND INSTITUTIONS

Near the beginning of the twentieth century, western states began to vest state administrative agencies with increasing amounts of authority to permit and manage the states' water resources. Many of these efforts were a reaction to courts that had allowed many western streams to become over-appropriated. Many of the efforts resulted from the scientific management movement that sought to rationalize business and governmental processes. The efforts were also encouraged by the Progressive conservation movement that sought multiple uses of natural resources (Hays, 1959). With passage of the Reclamation Act in 1902, western states had an incentive to systematize their water right records so they would be more

competitive in securing federally supported reclamation projects.

Washington

Washington Department of Ecology

Washington was one of several states to reorganize governmental structure to better address the increased priority on environment issues during the 1970s. The Department of Ecology was established in 1970 with the goals to prevent pollution, clean up pollution, and support sustainable communities. Several smaller agencies were combined into a single department that encompasses a wide range of tasks including among others water allocation, the protection of water quality, and land use planning, jobs that are separated at the federal level and in many other states. The comprehensive, holistic jurisdiction of the Department of Ecology allows the consideration of spill-over or second order effects of environmental decisions from one medium to another. For example, consequences of land use decisions may be traced to effects on air and water quality and water use within a single organization. With regard to funding for the agency's water resources program, budget year 2001-03 included an appropriation that was lower than in years 1993-95. The program staff was reduced, including a reduction in water rights permit staff from 55 to 20. From 1997 to 2001, Ecology enforcement staff was reduced from 9 to 1 full time equivalent.

Water Permit System

Washington state water law reflects a combination of the riparian doctrine and the prior appropriation doctrine. Although riparian rights initially framed the state's water laws, the state made a gradual transformation to the prior appropriation doctrine that culminated in 1917 with passage of a water code establishing permits as the exclusive way to obtain surface water rights. In 1945, the permitting system was expanded to include groundwater (with some exceptions). Although prior riparian rights were guaranteed in this legislation, the Washington Supreme Court later ruled that riparian rights not used by 1935 had been forfeited.[10]

A continuing problem in many western states has been the development of an adequate procedure for recognizing water rights established prior to or otherwise outside the state permitting system. In Washington, these nonpermitted rights include rights established before the 1917 surface water code, groundwater rights established before the 1945 amendment, groundwater uses exempted from the 1945 act, riparian rights, and prescriptive rights (until this means of appropriation was abolished). In 1967, the state enacted the Water Right Claim Registration Act (later amended) allowing claimants to register these nonpermitted water rights. A timely and proper registration afforded the claimant with prima facie evidence of the quantity and priority of the claimed right. The failure to file a claim constituted a waiver and relinquishment of the water use. Since 1917, water adjudications have also been used to determine surface water rights, especially in basins where tribes and federal agencies assert

[10] Department of Ecology v. Abbott (In re Deadman Creek Basin), 694 P.2d 1071 (Wash. 1985).

reserved water right claims. The largest of the pending adjudications involves the Yakima River basin, commenced in 1977 and now nearing completion.

According to the current permitting procedure prescribed by state law, the Department of Ecology cannot issue a water right unless four conditions are met:

- Water is available;
- The intended use is beneficial;
- The right will not impair existing water rights, and;
- The public interest will not be harmed.

The importance of the public interest criteria is reinforced by Washington State's administrative rules, which may be found at Washington Code of Regulations 90.54.020(3)(a):

> Perennial rivers and streams of the state shall be retained with base flows necessary to provide for preservation of wildlife, fish, scenic, aesthetic, and other environmental values, and navigation values. . . . Withdrawals of water which will conflict therewith shall be authorized in only those citations where it is clear that overriding considerations of public interest will be served.

The test for uses deemed in the public interest would seem to consider of the following:

- Consistency with Department of Ecology, other state and federal natural resources management plans, and local land use and growth management plans. Consistency with applicable coordinated water system or utility plans.
- Effects on navigation, water quality, public health and safety.
- The extent to which the proposal advances water conservation and efficient water use. Maximum net benefits to state and region including opportunity costs of foregone uses.
- The merits of the proposed allocation in comparison with alternative sources and methods of water development (including costs external to the applicant).
- The extent to which the use of water creates new burdens on the public agency for monitoring, regulation, oversight, and adjudication.

This public interest provision has been interpreted by the Washington Pollution Control Hearings Board, in cumulative effect situations, as follows:

> When chronic water shortages have resulted in three water rights adjudications in a basin and reduced flows are depressing fish populations, even very minor irrigations applications may be validly denied. Though the effect of one small diversion may not be noticeable in isolation, the allowance of many such diversions would have a substantial impact. The potential for cumulative impacts may sustain a denial on public interest grounds [(Byers v. DOE, PCHB No. 89-168 (1990); Holubat v. DOE, PCHB No. 90-36 (1990)].

Significance for the Columbia River middle reach: This interpretation of the public interest criteria is relevant to scenarios that posit additional diversions from the mainstem over the next twenty years. The rules emphasize the importance of cumulative effects and suggest that any individual diversion must be considered in the context of

other likely calls on the river and environmental needs and changes. Once the permitting process is reopened, it may be expected that additional applications will be made from other sources within Washington. Also, if other upstream states anticipate the creation of downstream rights, this situation may provoke the filing of water rights applications in those states.

Instream Flow Protection Program

Washington's instream flow program originated with legislation passed in 1969.[11] Pursuant to this legislation, administrative rules were adopted by the Department of Ecology in 1980, and minimum instream flow values were established for the mainstem Columbia River upstream of Bonneville Dam.[12] The rules established minimum instantaneous flow requirements at five locations on the mainstem for seventeen different time periods during the year. The rules also established minimum average weekly flows at five locations on the river for the same time periods.[13] In low water flow years, the Director of the Department of Ecology can reduce the minimum instantaneous and/or average weekly flows by up to 25 percent. However, outflow from Priest Rapids Dam can never be less than 36,000 acre-feet. Also, the Columbia River must provide at least 39.4 million acre-feet per year at The Dalles.[14]

These instream flow rights have been recognized as appropriations with priority dates as of the effective dates of their establishment (1980 for the Columbia mainstem).[15] As such, the instream flow rights are subordinate to "existing water rights, riparian, appropriate, or otherwise, existing on the effective date of this chapter, including existing rights relating to the operation of any navigation, hydroelectric, or water storage reservoir, or related facilities."[16] The instream flow rights are also subordinate to any water withdrawal at the request of the U.S. Bureau of Reclamation for the complete development of the Columbia Basin Project.[17] Approximately one-half of the Columbia Basin Project authorized lands are not yet irrigated, and any water diverted for these new lands at the project would also be senior to the mainstem instream flow rights. The instream flow rights are also subordinate to any federal agency or tribal reserved water right established before 1980. Thus, this collection of various rights (existing pre-1980 rights, pre-1980 reserved water rights, and additional water withdrawn for the Columbia Basin Project) are essentially senior to the instream flow rights. They are also referred to as "uninterruptible water rights." Such rights include approximately 4,530,000 acre-feet of water rights based on state law. In addition, an indeterminate quantity of water based on pre-1980 federal reserved water should also be considered as uninterruptible.

The instream flow rules authorized the Department of Ecology to approve additional mainstem diversions, but they would be junior to the instream flow rights and subject to

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[11] *See* WASH. REV. CODE §§ 90.22.010, -020 (2004).
[12] See WASH. ADM. CODE §§ 173-563-010 et seq. (2003).
[13] *Id.* § 173-563-040.
[14] *Id.* § 173-563-050.
[15] Hubbard v. Department of Ecology, 936 P.2d 27 (App. 1997).
[16] WASH. ADM. CODE § 173-563-020(3).
[17] Shortly after passage of the National Reclamation Act in 1902, the Washington Legislature authorized the United States to ask the state for withdrawal of water necessary for planned reclamation projects. This withdrawal was initially effective for one year but could be extended repeatedly if construction was underway. *See Id.* § 90.40.030. The legislature later allowed water to remain withdrawn for the ultimate development of the Columbia Basin Project, so long as the project was not abandoned. *Id.* § 90.40.100.

additional conditions imposed by the administrative rules.[18] For the first 4,500 cubic feet per second (cfs) of water rights issued subsequent to the instream flow rights, these later rights are subject to priority administration if April-September flows at The Dalles are forecast to be 60 million acre-feet or less *and* it is further predicted that minimum average weekly flows will not be met at one or more locations. Any water rights beyond the initial 4,500 cfs flow are subject to priority administration when the flow forecast is less than 88 million acre-feet and it is likely that minimum average weekly flows will not be met[19]. These post-1980 water rights, which are junior under some circumstances to the instream flows, are called "interruptible rights." "Interruptible rights" totaling 172,358 acre-feet have been issued (Gerry O'Keefe, 2004, Washington State Department of Ecology, personal communication).

In the spring of 1992, the Department of Ecology adopted emergency rules withdrawing unappropriated waters of the mainstems of the Columbia and Snake rivers from further appropriations. This moratorium was extended in 1994 in an effort to rebuild the weak anadromous fish population and respond to ESA listings. In the 1994 rule, the moratorium was scheduled to expire in 1999 or when the Department of Ecology established an instream resources management program. However, the Department of Ecology has postponed new allocations pending the availability of additional information about the status of fish and expert opinion (including this report). In 1997, the Washington State legislature passed a law stating that the Department of Ecology could not use these minimum values to make decisions on future, new applications. However, approximately 300 water rights already issued out of the mainstem were subject to minimum flow requirements and could be interrupted as they were in the 2001 season. Because of the moratorium, it is difficult to estimate how large the demand for new permits on the Columbia River mainstem would become in Washington if the permit process was fully opened.

As part of Washington's Columbia River Initiative, there have been discussions regarding the permitting of uninterruptible water rights. The Department of Ecology is apparently considering the exchange of traditional, priority-administered appropriative water rights for "uninterruptible" water rights that would be exempt from normal rules of priority administration. Water law scholars generally agree that rigorous priority administration of water rights is rarely practiced in western states. In theory, and in some highly administered basins such as those in Colorado, priority-in-time administration is a hallmark of the prior appropriation doctrine. Holders of senior rights are entitled to the full amount of their appropriation before junior appropriators can divert water (so long as the "call" on the junior right would not be a futile effort, because of conveyance losses or other reasons, in actually delivering water to the senior user). Uninterruptible water rights would appear to jump to the front of the line in terms of state-administered water right priorities.

The major advantage of uninterruptible rights is that they provide a greater certainty of water supply and encourage more efficient use and application of water. Apparently, these more efficient rights would be satisfied before legally senior water rights. The Department of Ecology is in a more informed position to assess the constitutionality of such as approach, but some senior water right holders would likely claim a taking of the most valuable aspect of their water right—its priority. Also, some legal experts argue that conserved water is available to satisfy the

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[18] The instream flow rules apply to public surface water and "any ground water the withdrawal of which is determined by the department of ecology to have a significant and direct impact on the surface waters of the main stem of the Columbia River." WASH. ADM. CODE § 173-563-020(1). Thus, certain post-1980 groundwater diversions are junior to, and can be administered to benefit, the instream flow rights.

[19] *Id.* § 173-563-056.

unserved needs of junior users or is available for new appropriations. If the goal is to enhance instream flows, state law must ensure that conserved water is dedicated to the stream. Also, it is unclear how uninterruptible rights could be immunized from other uses and demands on the river unless base flows for salmon area diminished. Federal and state water quality and endangered species requirements may trump the exercise of uninterruptible rights. The State of Washington will likely be unable to control upstream development in Canada, on Indian reservations, or in other U.S. states. If upstream uses reduce instream flows in the Columbia River's middle reach, the guaranteed exercise of uninterruptible rights compounds the situation and potentially compromises the water necessary for healthy aquatic habitat and fisheries.

Significance for the Columbia River middle reach: One apparent legal basis for this initiative is a rules provision allowing the Director of the Department of Ecology to allow "[f]uture authorizations for the use of water which would conflict with the provisions of this chapter [Columbia River main stem instream resources] . . . when it is clear that overriding considerations of the public interest will be served."[20] These new uninterruptible water rights would have seniority over the 1980 instream flow rights. They could not be curtailed to maintain the minimum instantaneous flow or average weekly flow requirements of the instream flow rules. These new rights would be subordinate to other pre-1980 water rights. It is unclear how these new uninterruptible rights would be administered in relation to other mainstem rights established between 1980 and 2004.

In exchange for this jump in priority, the Department of Ecology proposes that the new uninterruptible rights be issued only on the condition that the water user employ state-of-the art water conservation technology. The Department of Ecology previously adopted a rule requiring that the authorized quantity of any new Columbia River mainstem water rights "accurately reflect the perfected usage consistent with up-to-date water conservation practices and water delivery system efficiencies."[21] The proposal would potentially increase the amount of water that could be diverted ahead of the instream flow protections. These rights would be in addition to the approximately 4,700,000 acre-feet of rights to water (apparently not including tribal reserved rights) that now may be exercised before the state's minimum flow requirements may be activated.

Oregon

Oregon has a more rigorous permitting procedure than most western states and also placed more adjudicatory power in the state's Water Resources Department. Permits for new uses are submitted to the department. The department makes a preliminary review of the adequacy of the application and a proposed determination as to whether the application will be granted. If the proposed determination is protested, a contested case hearing is held before the department. Thereafter, a final agency decision is rendered. Oregon is conducting an adjudication of all pre-1909 surface water rights and all pre-1955 groundwater rights. The Oregon Water Resources Department reviews claims, holds administrative hearings, and files its proposed determinations with the state circuit court. The court reviews the findings, holds hearings on protests, and issues a decree officially upholding or modifying the department's

[20] *Id.* § 173-563-080.
[21] *Id.* § 173-563-060.

conclusions. The state has completed 94 adjudications representing approximately 70 percent of the state. In 1975, the department commenced an adjudication of claims to surface water rights in the Klamath River basin.

Significance for the Columbia River middle reach: Because Oregon initiated its permitting program in 1909 and vested an administrative agency with the major role in adjudicating pre-1909 water rights, its inventory of water rights and the associated legal entitlement is better than most other western states. Even the reserved rights of the Warm Springs Reservation have been determined (see earlier discussion); however, the method of calculation (assigning to the tribes water in excess of 1996 non-Indian uses) leaves a large margin for future tribal development. Thus, while Oregon is in a rather good position in calculating existing rights and uses that affect the Columbia, future development remains uncertain.

Idaho

In Idaho, the Department of Water Resources approves new permits and changes in existing water rights.[22] Since 1963, permits have been required for groundwater diversions. In 1971, this requirement was extended to surface water appropriations as well. Once water under a permit has been developed, the applicant submits proof of beneficial use and DWR examines the use of water under the permit. If such use is deemed satisfactory, DWR issues a license for the water right. The issuance of a water right license by DWR is prima facie evidence of the existence of such a right, and is binding upon the state as to the right of such licensee to use the described amount of water. Once established pursuant to state permit and license procedures, a water right is real property under Idaho law and may be acquired by lease or purchase. While instream flow may be a beneficial use in Idaho, only the state Water Resources Board may apply for and hold such a right. To address water rights not represented by licenses and permits, as well as federal reserved water rights, the Snake River Basin Adjudication (SRBA) is pending before state court. The SRBA encompasses most of the surface water in the state except for the Bear River basin and the state's panhandle region. Initiated in 1987, the SRBA has proceeded faster than most state adjudications but remains many years away from completion due in part to the large number of claims involved.

Significance for the Columbia River middle reach: Pending completion of the Snake River adjudication, existing water use entitlements are difficult to estimate. Fortunately, the reserved rights of the Fort Hall Reservation have been settled (see earlier discussion), and the potentially large claims of the Nez Perce are likely to be predominantly instream flow rights. Snake River flows are being affected by upper basin groundwater uses; and because groundwater rights are not being adjudicated in the Snake River adjudication, the extent and effect of groundwater use will be difficult to measure and control. Idaho is a rapidly growing state with increasing amounts of economic activity, so it is expected that its future water needs will likewise increase.

[22] These provisions set forth in Idaho Code tit. 42.

Montana

Montana was one of the last western states to require permitting of all but the smallest water uses. Prior to 1973, water uses in Montana could be established under "use rights" (actual diversions of water) or optional state filing requirements. With passage of the Water Use Act in 1973, Montana adopted one of the most comprehensive permitting programs in the West. Except for small uses, permits issued by the state Department of Natural Resources and Conservation are required for surface water diversions and, unlike many other western states, for groundwater withdrawals. Although Montana is developing sound water right records for post-1973 appropriations, the pre-1973 water rights are a jumbled collection of water rights established under a hundred years of changing state legal requirements, compounded by the unquantified reserved rights appurtenant to many Indian reservations and federal land holdings. To rectify this problem, the state commenced (first in 1973 and then, in 1979, in an expanded form), a statewide general stream adjudication of most pre-1973 surface and groundwater uses including claims for federal reserved water rights. Although claims have been filed in all basins of the state, the adjudication pending before the Montana Water Court is proceeding slowly and relatively few final decrees have been entered for tributaries of the Columbia River system.

Under Montana law, adjudication of reserved water rights is stayed while the particular Indian reservation or federal agency engages in negotiations with the Montana Reserved Water Rights Compact Commission. Although several pioneering compacts have been reached throughout the state, negotiations with the Salish and Kootenai Tribes of the Flathead Indian Reservation, one of the largest claimants on the Columbia system, remain stalled. Those tribes assert a variety of instream and consumptive uses in a rapidly growing valley area in northwestern Montana.

Significance for the Columbia River middle reach: Both Montana's Clark Fork River and Flathead River systems provide large contributions of water to the Columbia River mainstem. These tributaries are important water courses in the most rapidly growing region of Montana, the Stevensville-Missoula-Kalispell corridor. In projecting future water uses in upstream states, the Department of Ecology has provided no assumptions for Montana's future needs. Indeed, because of the incomplete general stream adjudication and inchoate nature of the claims associated with the Flathead Indian Reservation, water uses that might occur under existing water rights, based on federal and state law, and under future permits, are difficult to predict. This uncertainty adds to the risk of additional permitting in the Columbia River middle reach.

SUMMARY

Applications for water withdrawal permits from the mainstem Columbia River, and from groundwater within one mile of the river, have been pending within the State of Washington for several years. Most of these applications are for the reach of the river between Grand Coulee Dam and John Day Dam. Permitting decisions must be balanced with the state's obligations to protect and enhance the environment, which includes salmon habitat. As this chapter has pointed out, however, Columbia River hydrology and salmon habitat along the Columbia River in Washington are also influenced by upstream water management activities and policies. The challenges involved in the State of Washington's permitting decisions are magnified by the fact

that many upstream areas are likely to increase future water withdrawals, including British Columbia, Indian reservations, and the states of Idaho and Montana. Thus, new water permits in Washington may be subordinate, or "junior," to future water development in other upstream jurisdictions. As long as upstream development does not exceed Canada's ultimate entitlement and equitable state shares of interstate water, additional water use in Montana, Idaho, Oregon, and other basin states will be senior to new permits in Washington. In most cases, tribal reserved water rights will also have priority over these new state permits. With increases in water diversions—both in upstream areas and under new permits in the middle reach of the Columbia River—water available to salmon will diminish unless other regulatory programs, such as ESA requirements, are triggered. These trends suggest that water resources managers and decision makers in the Columbia River basin would be well advised to explore ways to better manage existing water supplies, create more flexible management regimes, and better manage the numerous risks and uncertainties that attend salmon and water management. Basin entities, for example, could develop reversible management actions and approaches that are actively monitored and evaluated, and that aim to meet new water demands in areas such as the middle reach of the Columbia River.

The next two chapters of this report examine the topics of better management of existing supplies, risks, and uncertainties. Chapter 6 reviews market-based approaches, such as water transfers, water banks, and conservation measures that are being used in many parts of the U.S., and Chapter 7 discusses strategies for better managing risks and uncertainties.

6

Better Management of Existing Water Supplies

Increasing demands for water in many areas across the U.S., constraints on traditional engineering approaches to augmenting supplies, and concerns over environmental impacts of additional water withdrawals, have prompted the search for non-traditional means for procuring new supplies of water to meet shortfalls during drought periods or to provide for more permanent uses. Market-based mechanisms, or water transfers, have been implemented in many western states in an effort to lend greater flexibility to water allocation and to re-allocate water to higher-value uses without increasing water diversions. This chapter examines water's economic dimensions, as well as experiences with water transfers and other nonstructural measures that could be used to help augment supplies. These market-based measures have the potential to contribute to economic and human needs. Furthermore, because they focus on improved water use efficiencies, they do not require additional water withdrawals and can thus also contribute to viable salmon populations and a healthy Columbia River ecosystem.

THE ECONOMIC VALUE OF WATER

As described through this report, the waters of the Columbia River today sustain a wide variety of economic activities. Columbia River salmon populations have important commercial, recreational, and cultural values. The Federal Columbia River Power System provides an abundance of low-cost electricity that has been crucial to the region's economic growth. The Columbia River is important for irrigation, as it supports the Columbia Basin Project and hundreds of irrigation farms. The river provides water for municipal and industrial uses in the Tri-Cities of Washington. The river also assimilates and carries away agricultural, industrial, and municipal waste. Given the increasing demands for water from the Columbia River and its tributaries, it is important to understand how the value of water varies across each type of water use.

Water resources in the western U.S. traditionally have been allocated across competing uses via legal or institutional means, and not by markets. As noted in Chapter 5, western water is typically allocated by the prior appropriation doctrine, which tends to fix the allocation of water across a specific set of uses. In an attempt to add flexibility to the prior appropriation doctrine, traditional definitions of "beneficial use" are being reconsidered in many western U.S. states by specifying how water rights holders use water. This requires some understanding of water values. There is a rich literature on the value of water in a number of uses, including agricultural, industrial, municipal, recreational, and hydropower uses. Estimates of water value can be influenced by a variety of factors. These include the measurement techniques employed, the nature of the data used in the assessment, and assumptions made in the estimation. Spatial and temporal aspects involving use of water also affect its value.

The economic definition of value is tied to the concept of *willingness to pay*. This concept holds that the value of an item is equal to what an individual is willing to pay for it (in monetary terms) or in terms of what they would give up to obtain the item. This concept of willingness to pay is also related to the notion of "demand" and is related to the relationship between the demand for a good and its price. Specifically, a price-demand relationship can be viewed as an expression of marginal willingness to pay for the item (the term "marginal" refers to the value of the next or incremental unit demanded). This marginal willingness to pay usually declines with units consumed. In addition to the direct measurement of marginal willingness to pay for water, the concept of alternative cost can be used to assign values to water in various uses. With this concept, the value of water is defined as the cost of the least expensive alternative to water (Gibbons, 1986). The following values for various use categories are derived primarily from a review of literature by Gibbons (1986), who synthesized values from a number of studies in each use category. Values listed in this report are expressed in 1999 U.S. dollars, unless indicated otherwise.

Agriculture

In discussions regarding the value of water to agriculture, it is important to note the assumptions that underlie the procedures used to assign a value to water, as these assumptions influence the derived water values. Historically, as western water was allocated primarily in accord with the doctrine of prior appropriation, and not by market mechanisms, there were thus no market prices from which to determine its "value." As a result, initial efforts at valuing agricultural water usually relied on techniques that imputed or inferred a value to water by comparing all expenses associated with producing a crop with the revenues received from sale of the crop. The residual value (the difference between revenues and assigned costs) was assigned to the unpaid input—in this case, water. However, the residual value reported in some studies may also include other values, such as a return to the farmer's management, as well as to land. It is thus important to claim only the residual due to water in assigning a value to water. The values reported in Gibbons (1986) appear to be for those associated only with water, as are additional references cited below. Another factor that affects water values is whether the value is assigned to water diverted (applied) to the field, or assigned to water actually consumed (where consumed refers to evapotranspiration, or ET). Since diversions always exceed ET, water values calculated using diversions will be lower than those based on ET. The values in this section are assumed to be based upon diversions.

Since water use is an input in the agricultural production process, its value depends primarily on the value of the crop that is being produced. Thus, a farmer's demand for irrigation water is a derived demand that depends on the demand for the crop being sold. The effect of crop value on water value is confirmed in numerous studies that have shown that the marginal value of water is higher for high-value crops than for low-value crops. For example, several studies conducted at different locations in the western U.S. give estimates for the marginal value of water for grain sorghum (a low value crop) in the range from $3 to $40 per acre-foot (1999 US$), while estimates of the marginal value of water in the production of fresh vegetables (high value crops) often exceeds several hundred dollars per acre-foot.

Although many studies provide crop-specific marginal values of water, other studies estimate marginal water values based on the current proportion of acreage dedicated to each crop

type at a given location. For example, in a study of irrigated farmland in Oregon's John Day River basin, the U.S. Bureau of Reclamation estimated the value of water for the production of a mix of crops including pasture, alfalfa, and wheat to be in the range of $20 to $48 per acre-foot (Adams, 1999). At a different location in Oregon, Adams and Cho (1998) reported values for four regions of the Klamath Irrigation Project in southern Oregon and northern California. In a region of the project dominated by low-value crops, the marginal value of water across the crops in the region was $42/acre-foot; in another region dominated by high-value crops, the marginal value of water across the set of higher-valued crops was $80/acre-foot (ibid.).

The marginal value of water not only depends on the value of the crop to which it is applied, but also on the quantity of water used by the crop and the nature of crop yield-water response relationships. Although there is debate over precise relationships, as more water is applied, the effect on yield generally begins to decline. Also, as efficiency (the proportion of water applied to the crop actually used by the plants) increases, one expects that the value of the water (or willingness to pay for water) will increase. Empirical evidence of this effect is found in a study in which marginal values for a representative Columbia River basin crop mixture were inferred to be $46 per acre-foot when water was tightly restricted, but valued at only a few dollars per acre-foot when water available to the crop was not restricted (Bernardo and Wittlesey, 1989).

The range of the value of water in agricultural applications in the western U.S. generally varies from values as low as $3 per acre-foot for low-value crops under conditions of adequate water supplies (no water stress), to values in excess of $200 per acre-foot for high-value crops. Median values for most mixed cropping systems in the Pacific Northwest suggest that the agricultural value is in the $40 to $80 per acre-foot range. For example, in a recent study of the economic impact of the scenarios defined in the Washington Department of Ecology's Columbia River Initiative (CRI), Huppert et al. (2003) estimated a value for additional agricultural water of $32 to $101 per acre-foot. The authors assumed that any new allocation of Columbia River water under the CRI will be used on high-value crops (primarily orchard crops). It should be noted that farmers will be less likely to plant high-value irrigation crops with "interruptible" water rights, given the risk associated with loss of investment in drought years. This pattern of risk aversion is observed throughout other regions of the West, where farmers with junior water rights tend to favor lower valued crops. This is especially the case when water supplies vary substantially from year to year, as junior appropriators may have their allocations cut off under conditions of limited water flows and supply.

These values are estimated values, based on various economic assessment methods. These values are supported, however, by recent, real world experiences with water bank transactions in the western U.S. For example, the California Water Bank, created in 1998 and 1999 to address water shortages due to drought, found equilibrium prices for water transfers between irrigators to be approximately $75 per acre-foot. The actual value to irrigators may be slightly lower than this price, given that the sales price includes a "tax" to provide water for environmental uses, primarily in the Sacramento-San Joaquin Delta. In the Klamath River basin in southern Oregon and northern California, a pilot water bank program created for the 2003 irrigation season also established a price of approximately $73 per acre-foot for the purchase of water from irrigators for environmental uses (this is the value averaged across both high and low valued crops). During a drought in 2001, a temporary water bank was created within the Bureau of Reclamation's Yakima Project in south-central Washington. Substantial quantities of water were transferred from irrigation districts with more senior rights and low value crop mixes, to

districts with junior rights and higher valued crops. For example, the Roza Irrigation District, which is dominated by high-value perennial crops such as tree fruits, purchased over 16,000 acre feet of water at a season average price of approximately $120.00 per acre foot (Northwest Economic Associates, 2004). In summary, the pattern of water values observed in real world transactions within water banks in California, Oregon, and Washington are as expected (of higher water values for higher valued crop mixes) and provide general corroboration of the estimated values (cited previously) of water found in the economic literature.

This information from economic assessments and actual transactions establishes a general set of values for irrigation water. Recently, however, the U.S. Supreme Court approved values for water in irrigation at substantially higher levels than those generally found in the economic literature or in market transactions. Specifically, in the case of *Kansas vs. Colorado* (533 U.S. 1 (2001)) concerning a dispute over Arkansas River water used for agricultural irrigation, the Supreme Court accepted values of approximately $125 per acre-foot (1999 dollars) for water used on a mix of wheat, corn, grain sorghum, and hay (low to medium value crops). These values were estimated by Whittlesey and Willis (1999) on behalf of the State of Kansas as part of the damage phase of the trial.[1] The values were accepted initially by the Supreme Court's special master in the case and ultimately approved by the U.S. Supreme Court as part of the damage assessment. The implications of the values accepted by the Supreme Court for agricultural water may be significant, particularly in litigation concerning reductions in irrigation water deliveries to agriculture arising from state or federal policies or actions.

Municipal

The marginal value of water for residential purposes depends on the end use and the level of current consumption; marginal value is typically less for outdoor consumption (e.g., lawns) than for indoor consumption, and it typically declines as more water is consumed. In an early survey of water value estimates, Young and Gray found that published household valuations of water range from $63/acre-foot for lawn watering to $403/acre-foot for indoor water use. Gibbons (1986), on the other hand, synthesized three water demand studies and used the estimated demand equations to calculate marginal willingness to pay estimates. Her estimates range from $34/acre-foot to $56/acre-foot for summer consumption (primarily outdoor uses) and from $50/acre-foot to $212/acre-foot for winter consumption (primarily indoor uses).

In a water transfer agreement negotiated in 2002 between the Imperial Irrigation District (IID) and the San Diego County Water Authority (SDCWA), water ultimately intended for municipal uses was valued at a minimum of $230/acre-foot. This price equals the cost of conserving the water plus an incentive to encourage participation by Imperial Valley farmers. The water's price reflects considerable effort by the IID and the SDCWA to assess the cost of on-farm conservation measures, including systems to capture and reuse water and the lining of earthen irrigation canals. The actual cost of water delivered to residential users in San Diego will be substantially higher than $230/acre-foot. The Imperial Irrigation District—San Diego agricultural-urban water transfer is a good example of how conserved water can be transferred to a use of greater economic value, and how water supplies might be augmented in order to sustain

[1] The values were developed for the State of Kansas and accepted by the special master are for direct effects only; that is, they are representative of the effects on farmers' incomes only and thus do not include secondary effects on the local economy that may arise from reductions in water to farmers).

economic growth without increasing withdrawals from surface or groundwater supplies. As with all water transfers, "third party" effects should also be considered in the interests of equity.

Industrial

Industries utilize water for cooling, processing of products (e.g., washing materials, conveying inputs, input in the end product), and for in-plant sanitary and other purposes (Gibbons, 1986). Since water costs constitute a very small portion of industrial costs, industrial demand for water is expected to be quite inelastic (i.e., there is little change in demand with changes in price). The amount of water used by industry is influenced by raw material quality, relative price of inputs, output mix, and government regulations. The cost of water to industry includes intake costs, treatment of water for recirculation, and waste treatment of effluent. When the price of water rises, firms typically reduce intake and increase treatment of water for reuse. Thus, the marginal value of water for industry is often estimated by the alternative cost of internal recirculation of water (Gibbons, 1986). Alternative costs of recirculation depend on the use to which the water is applied, and on current processes. As water efficiency of the current technology increases, the marginal value of water also generally increases. Process recycling costs also vary widely by industry and current processing technology. One study of a textile finishing plant (Kollar et al., 1976) estimated marginal costs of $269 per acre-foot to increase the percent of process water recycled from 48 percent to 76 percent, while another study investigating a meat packing plant (Kane and Osantowski, 1981) with an extensive water reuse system estimated marginal costs of recycling process water at $660 to $939 per acre-foot. As water users become more efficient, the marginal value of water in industry rises.

Hydropower Generation

The Columbia River and its tributaries power one of the world's largest hydroelectric systems: in 1998, for example, the system produced an average of 12,000 megawatts of electricity (enough to supply a city ten times the size of Seattle). Reduced stream flow thus has important implications for the value of water in hydropower production. The magnitude of the marginal value of water for hydropower depends upon where the water is in the Columbia system; the higher the elevation of the water, the higher its marginal value, as water at higher elevation in the system will generally pass through more generation facilities.

One study estimated marginal values of water in the Columbia system at various points along the river (Hastay, 1971). The study estimated water values for energy generation based on the alternative cost of requiring more thermal power generation to replace reduced hydropower generation. Marginal values of water were estimated at $4.5 per acre-foot at the downriver location of McNary Pool and a marginal value of roughly $20 per acre-foot at Upper Salmon (Butcher et al., 1972). A study by McCarl and Ross (1985) estimated the hydroelectric value of Columbia River water by calculating how much electricity costs would rise due to additional water being diverted for irrigation. The alternative cost of requiring more thermal generation to replace the decreased hydroelectric generation was found to range between $14 to $76 per acre-foot of additional irrigation diversions. The higher values corresponded to the value of water diversion farther upriver, while the lower values were based on water located in the middle reach

of the Columbia. In a study of Canadian hydropower, Gillen and Wen (2000) defined water's economic value differently. They defined the economic rent (marginal value) per kilowatt-hour of electricity from hydropower to be the difference between the competitive market price of electricity and average costs to produce electricity. Using long-run electricity supply contracts to estimate the competitive price and power utility financial records to estimate costs, the authors estimated cost savings arising from hydropower produced by Ontario Hydro at 3.4 cents/kilowatt-hour relative to the price of per kilowatt-hour from other sources. Applying this measurement of value to the Columbia River system, the loss of its hydropower would imply a doubling of electricity costs to the region if alternative (fossil fuel) generation were required.

Recreation

The value of water for recreation is based on the value of recreation activities taking place both on the water (e.g., boating, fishing, and windsurfing) and adjacent to water (picnicking and camping). Studies of the marginal value of water for recreation indicate that estimates of water values differ substantially, depending on recreation activity, magnitude of stream flow, and quality of the water. In a study of reservoirs in Colorado, the estimated average recreational benefit of water retained in the reservoirs was estimated at $72 per acre-foot for each additional day retained (Walsh et al., 1980). A study by Ward estimated the value of water for angling and white-water boating in the Rio Chama River in New Mexico at $46/acre-foot. A study of recreation in Colorado estimated marginal values of water at alternative streamflow. Marginal values of $41 per acre-foot for fishing, $10.25 for kayaking, and $7.70 for rafting were estimated along one stream stretch (Walsh et al., 1980). The dependence of water values on the levels of stream flow is evident in a study by Amirfathi et al. (1974) of angler benefits on the Blacksmith Fork in northern Utah. Marginal benefits were zero when flow was reduced by 50 percent, but increased to $130 per acre-foot when flows were to 20-25 percent of peak levels. Studies often estimate the value of recreational fishing in terms of value per visitor day. The more fish of a given species present in a body of water, the more anglers it can support and the higher the total value of water. The value of water for fishing per angler also depends on the number of other anglers present. The value of the fishing experience will likely be lower when usage of the river by other anglers is greater, due to congestion (Lin et al., 1996).

Navigation

The Columbia and Snake rivers can be navigated as far upriver as Richland, Washington and Lewiston, Idaho, respectively, the latter of which is 465 miles from the Pacific Ocean. Combined with barge traffic from the Willamette River, these stretches carried approximately 38,000,000 metric tons of cargo into Portland in 2000, which represents approximately 5 percent of the Portland metro tonnage from all sources of transportation (Bingham, 2002). The majority of this cargo was grain: in the period 1990 to1998, between 35 percent and 50 percent of all grain receipts at Columbia River terminals were shipped by barge on the Columbia River system, with the remaining portion shipped primarily by rail (Casavant, 2000). Waterway transportation can be advantageous because of its relatively low cost of transporting bulky, low value commodities such as grain.

Short-run estimates of water value for navigation typically utilize the alternative cost method; value of navigation is equal to the savings of using water-based transport over railroad transport, minus the costs of operation and maintenance of the waterway. Long-run estimates include the costs of construction of the waterway (it is assumed that railroad rates reflect all fixed and variable costs, while barge rates reflect only private costs and not waterway costs, since user fees are uncommon). The marginal value of water is either equal to zero (at all levels except the level at which the water flow is reduced such that navigation is no longer possible) or equal to the entire economic value of navigation (level at which navigation is made possible). Therefore, average values (as opposed to marginal values) are typically used to estimate the value of water for navigation.

Ecosystem Goods and Services

The Columbia River provides an abundance of goods and services that include goods like food and fiber (salmon and other aquatic species), drinking water, services such as waste assimilation, and broader values such as biodiversity and aesthetic pleasure. These goods and services sustain important economic activities, such as commercial and sport fisheries. As an example of the value of ecosystem services, the value of the Columbia River for assimilating wastes (based on the alternative cost of providing additional wastewater treatment) has been estimated at $.20 to $.28 per acre-foot (Hastay, 1971).

Non-Market Values

In addition to the direct economic value derived from the use of water and other ecosystem goods and services, there is a demand for values from the river that are not exchanged in markets. For example, the Columbia River system provides habitat for many valued fish species, and also sustains populations of waterfowl, aquatic mammals, and other wildlife. Fish and wildlife provide non-consumptive values to photographers, hikers, and others who enjoy outdoor recreation. People may also value the existence of salmon and other species in the Columbia system even when they do not directly observe or "use" them (so-called "existence" or "non use" values). Although it is more difficult to estimate existence values than values associated with direct use, numerous studies have shown that people express a positive willingness to pay for preserving ecosystems and the species within them. For example, in a study of passive-use values for coho salmon in the Columbia River, Olsen, Richards, and Scott (1991) estimated passive-use value of $21.80 for each adult coho male that reaches its natal stream. Huppert et al. (2003) reported a range of existence values for salmon in the Pacific Northwest of $66 to $268. Although existence values appear to be very site and context specific, studies of existence value for other species and ecosystems suggest that the value of the waters in the Columbia River system in providing habitat for diverse species is high and of importance when making public policy decisions concerning the basin's water resources. Ideally, when comparing the efficiency of alternative water allocations, policy makers should obtain estimates of the sum of all use and non-use values to determine the "total economic value" of a particular water allocation.

Cultural Values and Other Public Goods

Another category of passive use values includes what are sometimes referred to as symbolic or lifestyle values, which account for the economic impacts imposed upon areas of origin in water transfers. These values can relate to traditional means of livelihood, and relate to the maintenance of ways of life and social cohesion (Brown and Ingram, 1987; Howe and Ingram, 2002). Farm families, often going back several generations, place a high value on a ranch or farm lifestyle, and sometimes "stick it out" even when the economic activity becomes unprofitable (Weber, 1990). This category of values also includes symbolic values that may be placed on an undiminished river or stream. In the context of the Columbia River basin, salmon have particularly important cultural and symbolic values. Although not quantifiable in economic terms, these types of values frequently enjoy considerablepolitical support.

The cultural values inherent within the Columbia River system are part of a larger category of services and values described as "public goods," which have three broad features: 1) one person consuming them does not prevent another person from consuming them ("non-rival"); 2) if one person can consume them, it is impossible to prevent another person from consuming them ('non-excludable"), and; 3) people cannot choose to not consume them even if they want to ("non-rejectable"). Public goods are not normally provided by the private sector and might not be provided at all if left to market forces. Examples of public goods include flood control, clean air, and national defense. Many ecological goods and services from the Columbia River, such as the benefits of aquatic habitat and clean water, have features of public goods. Some public goods are provided in part by the government and are paid for through taxation. An example in the Columbia River basin is the habitat restoration programs funded through annual expenditures of the Bonneville Power Administration. Such public expenditures (to which hundreds of millions of dollars are devoted) illustrate that society greatly values these types of services, which suggests that the consideration of public goods should be part of debates and decisions regarding appropriate uses of Columbia River water and associated resources.

Summary

There are substantial differences in water values across different categories of water use in the western U.S. and across the Columbia River basin. Table 6.1 summarizes these values by use category. The significance of the differences across uses is that there is a great potential to promote economic growth and increase overall social benefits by transferring increments of water between uses (from low to higher valued uses). The actual benefits from transfers will depend on the quantities of water transferred or diverted and the costs of such transfers. The following section examines means by which market-based mechanisms might help effect those transfers, some limitations of market-based measures, and some examples of their application across the West.

TABLE 6.1 Marginal Value of Water per Acre-Foot

Use	Value Range/Acre-foot (1999 US$*)
Agriculture	$3 - $200
Municipal	$34-$403
Industrial	$10-$1248
Hydropower	$4-$62
Recreation	$7.70-$130
Navigation	$5.60
Waste Assimilation	$.20-.28
Passive Uses	Not available on an acre-foot basis

*Converted into 1999 US$ using Consumer Price Index annual figures.

WATER MARKETS AND WATER BANKS

States across the West generally began using water markets in the 1970s as a means to address some of the inflexibilities inherent in the doctrine of prior appropriation (NRC, 1992). Water markets and water banks were developed as a means to reallocate water from lower-value uses to higher-value uses (or to environmental uses). *Water markets* refer to the temporary or permanent transfer of a water right or a contract entitlement for the use of water. The term *water bank* generally infers two types of arrangements (Miller, 2000). One can be labeled as a groundwater storage bank. For example, in California's Kern County, the Kern County Water Bank provides for the purchase and underground "storage" of water in wet years, with that water then available in dry years for sale to the State of California. The process of recharging groundwater through wells into an aquifer for later use is also referred to as aquifer storage and recovery (ASR) and its applications are being explored in other parts of the U.S., as well, such as in the Florida Everglades (NRC, 2001). "Water bank" also refers to a formal mechanism created to facilitate voluntary exchanges of the use of water under existing rights.

The rationale behind water markets is that willing buyers and sellers should be allowed to engage in mutually beneficial transfers of water. For example, an individual who lacks water rights or holds junior rights may be willing to pay more for water than an individual with superior water rights can realize by using the water. In such a case, both parties would gain from a trade or transfer of water and society would have realized greater value from the water through this transfer. To facilitate the creation of water markets, western states have changed laws and rules associated with the doctrine of prior appropriation to allow a water right to be separated from the land to which it was originally applied. In such cases, the right is redefined as a particular flow or volume of water instead of a diversion at a particular location. Thus, under a water market or bank, a downstream user can purchase or lease water from an upstream user. The magnitude of the gain from such a transaction is determined by the seller's increase in returns (over the value of the water generated from use on site) plus the additional increase in income or averted loss realized by the downstream purchaser. It is assumed that trades will not occur unless they are of mutual benefit to buyer and seller. The existence of a market also allows other prospective water users, such as parties who currently hold water rights, to obtain water previously unavailable to them. For example, conservation groups or fisheries agencies

may purchase water to maintain instream flows. In Washington, the Department of Ecology has created a program to acquire water for instream uses. In addition, the Washington Water Trust (a private organization) has been acquiring water for instream flow purposes. In some western states (e.g., Colorado, Arizona), municipalities purchase agricultural water rights through water markets to meet rising water demands driven by human population growth.

Although most water markets are intra-state, an interstate water market was recently authorized by the federal government to allocate waters of the Colorado River. In October, 1999, then Secretary of the Interior Babbitt issued rules authorizing trading among Arizona, California, and Nevada of Colorado River water. The plan calls for Arizona to act as the "bank," building on the Arizona Water Bank (which was created in 1996). The significance of this rule is that it sets a precedent for states to develop joint water markets. The advantage of broadening the scope of a water market is to create more opportunities for trade and the prospects of realizing greater social benefits. Such an inter-state water bank seems well-suited to improving water use efficiencies within the Columbia River basin.

Limits of Markets

Water banks hold the potential to increase social benefits associated with water uses, but they contain some limitations, and their successful implementation poses challenges. A key consideration in water transfers is the notion of *third party effects*. Most water uses do not consume all water that is diverted. Some portion of unused water moves back to the stream through surface flows or it percolates to groundwater, where it becomes available for other users. Water transfers may disturb this pattern of return flows and have effects on parties ("third parties") outside of a market-based transfer. These third party effects can be remedied by adjusting and reducing the amounts of the water right available for transfer. There are situations, however, when third party effects are difficult to quantify and monitor. Further, parties may be so unequal in resources and bargaining power that some sales are at least potentially coercive. In a study of water sales in eight western states, it was found that 90 percent of the water exchanged through markets went to municipal, federal, and state agencies, and that 96 percent of transactions involved these relatively large and powerful participants (Brookshire et al., 2003). Farmers looking to sell water typically are not equal in resources, in negotiating experience, or in bargaining power, especially when there is only one large possible buyer. The city of Tucson, for example, was able to purchase most of the groundwater rights in the Avra Valley near the city, transferring water use from agriculture to urban uses at modest prices that left many farmers with bitter feelings toward the city. Avra Valley farmers believed that as long as the city was aggressively buying up water rights, the rural economy had no real future, and individual farmers feared that if they did not sell, their neighbors would undercut their price. In addition to these types of potential drawbacks of water transfers, there can be significant transaction costs associated with locating willing buyers and sellers, legal services, and hydrologic studies (Miller, 2000).

Damages to localized rural economies of large-scale water transfers to urban areas are real and significant. Seed, fertilizer, and implement sellers, as well as retailers, suffer when large portions of their customer base disappear. Governmental services are adversely affected in rural counties when tax rolls decline. Damages can be partially mitigated by "area of origin" protections that provide for transfer payments made from urban to rural counties involved in

water transfers. There are values associated with water that are often poorly reflected in market transactions. Water in the western United States has long been associated with opportunity: areas with ample amounts of cheap water available for development have a future, while those that do not have water face a more uncertain future. Rural areas of origin in water transfers often perceive that they have compromised their future.

Cultural values associated with water are among the public values that are not likely to be protected in private water markets. These values are especially important to Native Americans and to ranching and farming communities where water is an important part of the lifestyle. Some commentators mourn the changes in the interior West where agribusinesses have replaced family farms and the vast majority of the population now lives in cities (Little, 2003). Some fear that water markets will further facilitate this transformation of the West.

Infrastructure for Water Markets

Water markets are only as good as the governmental authorities that regulate them. But simply facilitating the creation of markets will not allow governments to get out of the business of managing water. On the contrary, water markets must be managed just as intensively as water permitting, and additional skills and infrastructure are required for their effective execution. In fact, water markets must be based on secure property rights or permits, and permitting authorities are implicated in the task of quantifying transferable water made uncertain by changes in uses affecting points of diversion, return flows, and instream flows. To operate well, water markets must be transparent. Governments have important roles to play in ensuring this transparency by facilitating a free flow of information to prospective sellers and buyers. At a minimum, this involves establishing real-time information data bases or electronic bulletin boards that reflect ongoing market transactions. Government also has a role as a monitor and referee in lease and option arrangements. Additional resources may be necessary in the Columbia River basin to help state agencies perform these duties if such markets are pursued.

Governments as participants in water markets need skill and resources that go beyond those required in regulating markets. Where state governments enter markets to buy or lease water for fisheries restoration or other instream uses, state agencies must build skills in buying and selling water which involve financial as well as ecological risk. For example, fisheries managers have faced a steep learning curve in operating the Environmental Water Account through which water for fish is acquired in the California CALFED Bay-Delta Program, which is a joint state-federal partnership for managing the San Francisco Bay-Sacramento River-San Joaquin River Delta. Fisheries managers have been accused of paying too much for some water as well as hoarding water as a hedge against uncertainties that might occur later in the year rather than releasing it to save fish endangered early in the season. The human resources requirements for effectively supporting such activities include staff with backgrounds in business, economics, and marketing—skills and expertise typically not widely found in most natural resources agencies.

Applications

Applications of water markets and water banks are increasing across the West. Many of

the 17 western states presently allow water to be sold or leased. The use of water banks, in particular, especially increased during the 1990s. Since water banks typically involve the temporary transfer (lease) of a water right, they can be particularly useful during drought periods. Water banks also reduce some of the negative effects of a permanent transfer of a water right. Farmers and rural communities often are thus more receptive of the water bank concept than of sales of water rights (Keenan et al., 1999).

Water banks hold promise for water problems such as those that recently occurred in the Klamath River basin. A U.S. Bureau of Reclamation Biological Assessment (2002) and related operating plans for the Klamath Project call for the creation of a water bank of up to 100,000 acre-feet of water per year. This water would come from groundwater sources and from surface water obtained by idling lands within and outside the project. Funding for purchases of such water would be provided by Bureau of Reclamation. The "banked" water would be used for environmental purposes, primarily to maintain water levels of Upper Klamath Lake and streamflows on the lower Klamath River. The State of Oregon, however, has not finished the adjudication process for water rights in the Klamath River basin. In the short term, water banking will need to rely mostly on water sales among Klamath Project farmers in the California portion of the basin who may have water available for transfer, such as from wells.

The State of California has pioneered several market-based programs and agreements aimed at shifting water among users, with many good results. For example, in response to a pronounced drought that started in the late 1980s, the state established several emergency water banks that were viewed by many as highly successful at redressing imbalances between availability and demands during shortages (Miller, 2000). For example, one study estimated that the net benefits of the 1991 water bank at $91 million, with net benefits of $32 million to the agricultural sector (Howitt et al., 1992). Water for the 1991 water bank came from three sources: fallowing, groundwater, and surface storage. This and other water banks in California are managed by the State Department of Water Resources.

In December, 2002, the Imperial Irrigation District and the San Diego County Water Authority approved an agreement for the long-term transfer of conserved water from the Imperial Valley to the San Diego region. This agreement is a principal component of the Quantitative Settlement Agreement, California's plan to live within its Colorado River water allocation (California regularly exceeds its allocation by about 20 percent). Under this agreement, the Imperial Irrigation District and its agricultural customers would conserve water and sell it to the SDCWA for at least 45 years. Deliveries in the first year of the contract would total 20,000 acre-feet, and would increase annually in 20,000 acre-foot increments until they reach a maximum of 200,000 acre-feet. In the event of water shortages in the Colorado River, the IID and the SDCWA would share shortages proportionately. The price of the transferred water between IID and the SDCWA is currently set at $248 per acre-foot. This price equals the cost of conserving the water plus an incentive to encourage participation by Imperial Valley farmers. The water's price reflects considerable effort by the IID and the SDCWA to assess the cost of on-farm conservation measures, including systems to capture and reuse water and line earthen irrigation canals with concrete. Specifically, price is calculated in the contract by a formula that indexes the water's price to the Metropolitan Water District (MWD) of Southern California's water rate minus the SDCWA's cost to transfer the water to San Diego County. A discount is applied to the price that begins at 25 percent in year one and declines gradually over 17 years to stabilize at 5 percent for the remainder of the contract. Under this formula, water price is comparable to that of other supplies available to the SDCWA (*www.iid.com/*

water/transfer.html; accessed Janauary 11, 2004).

Four state and federally-funded water transfer programs exist or are being developed in California to facilitate water transfers to the environment. The projects are the Environmental Water Account (EWA), the Environmental Water Program (EWP), the Water Acquisition Program (WAP), and Drought Water Bank (DWB). The EWA and EWP are part of the CALFED Bay-Delta Program (the San Francisco Bay/Sacramento-San Joaquin Delta Estuary). CALFED is a cooperative effort that, among other goals, aims to provide a long-term solution to the problems affecting the environmental health of the Bay-Delta. The Water Acquisition Program, formed under the authority of the Central Valley Project Improvement Act (CVPI), is a U.S. Department of the Interior joint program of the Bureau of Reclamation and the U.S. Fish and Wildlife Service. The WAP acquires water for protecting, restoring, and enhancing fish and wildlife populations to meet the goals of the CVPIA. Table 6.2 shows the water acquired between 1993 and 2001 by the WAP. As the table indicates, substantial amounts of water have been transferred for fish and wildlife purposes, at a wide range of prices.

The Environmental Water Account was established to make additional water available at critical times during the life-cycle of various endangered and threatened species while not adding additional costs or uncertainty to urban or agricultural users. The EWA has a portfolio of variable and fixed water assets. It acquires water from willing sellers, and banks, borrows and transfers water from one location to another. In the three years it has been operating it has helped provide security to users, while also allowing fishery managers additional water supplies at critical times. The main criticism has been that EWA managers may have paid too much for water at certain times, although it is reasonable to expect that agencies with little experience in water markets may make some mistakes.

The Columbia River basin has had some experiences with market-based water transfer mechanisms. The State of Idaho, for example, has implemented a water banking scheme. The Idaho scheme differs somewhat from the water banking system managed by California's Department of Water Resources. The Idaho water banking programs aim to help irrigation districts earn a modest return from the sales of surplus water in wet years, and to keep water in irrigated agriculture during drought years (Miller, 2000). As drought conditions worsened in

Table 6.2. Summary of WAP water transactions

Fiscal Year	Total Water Acquired (acre-feet)	Price Range ($ per acre-foot)
2001	190,424	60-150
2000	64,995	25-125
1999	232,500	60
1998	91,100	15-700
1997	273,539	15-70
1996	47,152	25-40
1995	101,832	36-50
1994	43,322	50
1993	1,559	34-40
Total	1,046,423	15-700

Source: *http://www.usbr.gov/mp/cvpia/wap/docs/summary.html*

Idaho in the early 1990s, the level of water transferred through Idaho's established banks declined (as opposed to increasing levels of transfers in California during drought). A study comparing California's and Idaho's experiences with water banks thus concluded that in Idaho, "from the perspective of the broader society, the banks did not promote the most efficient use of the available resource" (Miller, 2000).

The United States is not the only nation grappling with the issues of limited water supplies, increasing demands, and environmental concerns. In Australia, for example, the Murray-Darling Basin Commission (MDBC) works in a setting with some parallels to the Columbia, including an arid climate and an important irrigated agricultural sector. In response to environmental stresses on the Murray-Darling River ecosystem, in the 1995 the Commission's Ministerial Council introduced an interim "Cap" on diversions of water from the basin (inter-basin transfers from the Murray-Darling are an important source of irrigation water), which was confirmed as a permanent Cap in 1997 (see Box 6.1). Lessons from experiences in the Murray-Darling River basin in balancing economic and environmental needs may hold lessons for water managers in the Columbia River basin and across the western United States.

BOX 6.1
The Murray-Darling River Basin Cap

The Murray-Darling River basin covers much of southeastern Australia and includes some of Australia's best farmland and some 2 million inhabitants. Diversions of water from this river basin have increased steadily since the 1950s, which resulted in both important economic benefits and substantial changes to the rivers' flow regimes. Median flows in the lower stretches of the River Murray were reduced to 21 percent of pre-development flows. The environmental effects of these reduced flows included losses of wetlands, reductions in the number of native fish, and an increase in salinity levels.

In 1995, the Ministerial Council of the Commission produced a report (*An Audit of Water Use in the Murray-Darling Basin*) that confirmed increasing levels of diversions (much of them for cotton production) and attendant declines in ecosystem health. The council determined that a balance needed to be struck between significant economic and social benefits that had been obtained from water development and from instream flows. The council thus implemented a permanent cap on diversions of water from the basin in 1997. The cap does not attempt to reduce diversions, but rather to prevent them from increasing, as it aims to restrain diversions, not development. The establishment of the cap marked a substantial change in the nation's water sharing framework, and it will require considerable adjustments from water users and management entities in the basin. In enacting the cap, the Ministerial Council is promoting a new emphasis on water use efficiencies, reductions in groundwater withdrawals, and a more efficient framework for water trading between states and between individuals. The Australian Bureau of Agricultural and Resource Economics has estimated that more widespread use of water trading in the basin would increase economic output by around $48 million (Australian) annually (for more information on the Cap, see *http://www.mdbc.gov.au/naturalresources/the_cap/the_cap.htm*;accessed February 16, 2004).

Water Conservation

Water markets are designed to enable transfers of water supplies among potential users. Typically, the supply of available water is assumed fixed over a particular time period. However, it is possible to increase the amount of water available for transfer by encouraging water conservation. In many parts of the country, water conservation has emerged as an important source of "new" water supply. In places where available surface and groundwater supplies are fully appropriated or over appropriated, making more efficient use of existing supplies frees up additional water to serve new demands. Substantial opportunities exist in all sectors to reduce the volume of water used and to decrease adverse impacts upon water quality. Partly in order to meet water quality standards, many industries have installed closed systems, which recycle water supplies and consequently reduce the amounts of industrial water used.

Irrigated agriculture has made great strides in increasing water efficiency through such means as the lining of ditches, laser leveling of fields, and water delivery systems with higher efficiencies. Incentives for such changes have sometimes been legal institutions. The concept of beneficial use includes prevention of waste, and most legal authorities view the concept of beneficial use as useful in encouraging the installation of conservation infrastructure. For instance, as part of the Active Management Areas in Arizona created by the Arizona Groundwater Management Act, beneficial use has been defined as a best management practice. In Arizona, groundwater rights are periodically adjusted downward as conservation technologies improve. The program initiated by the State of Washington under the Columbia Basin Initiative appears to be taking an unusual approach in that water rights become more secure (i.e., non interruptible), when better management practices are installed on participating farms.

Conservation infrastructure in agriculture is expensive, and farmers are not likely to make such investments without incentives to do so. Even if conservation leads to better crop yields and reduced pumping costs, the cost of initial investment may be prohibitively expensive. The federal government, through the Natural Resources Conservation Service of the U.S. Department of Agriculture, is providing low interest loans, cost sharing arrangements, and other incentives to make such investments more attractive. If farmers are able to transfer or sell conserved water, as is the case in Oregon, conservation investment is a more attractive proposition. As discussed earlier in this report, farmers in California's Imperial Valley have negotiated with the Metropolitan Water District to transfer conserved water to urban users in exchange for financial support in the installation of conservation technologies, and similar strategies would seem to hold promise in the Columbia River basin. It should be remembered that water conservation measures may reduce diversions or losses (e.g., seepage to groundwater through unlined conveyance canals), but that they do not reduce crops' physiological needs. The implications of this fact for the quantity and quality of return flows should be considered in discussions of potential water transfers.

Municipal water use is the fastest growing demand in the West. Urban water pricing, use, and conservation policies can be valuable in helping reduce lower-cost and wasteful uses. For example, a recent study of California urban water use and policies concluded that "California's urban water needs can be met into the foreseeable future by reducing water waste through cost-effective water-saving technologies, revised economic policies, appropriate state and local regulations, and public education" *(http://www.pacinst.org/reports/urban_usage/waste_not_want_not_exec_sum.pdf,* last accessed March 23, 2004*)*. Building codes requiring low flow toilets and other water saving appliances can make a substantial difference in indoor

water use. In most cities in the arid West, outdoor watering in the summer constitutes a large water use that can be affected by water conservation policies. Many cities have differential summer and winter rate structures, with additional costs levied upon users whose use rises sharply in the summer. Also, many cities have increasing block rate structures in which the more urban residents use, the more they pay. Most cities also engage in public information campaigns stressing the scarcity of water and the need for conservation. The urban water conservation literature notes that the artificially low water rates common to most cities undercut conservation incentives. Elected officials are often reluctant to raise water rates. Some experiences suggest that such actions may have political costs; for example, in the 1970s, several members of the Tucson, Arizona city council were removed for sharply raising water rates during the summer. On the other hand, some water user surveys have indicated that customers have a high willingness-to-pay for safe, reliable, high-quality water services (AWWARF, 1998; NRC, 2002b). As long as relatively cheap sources of additional water are available for diversion, there is little incentive for urban water utilities to press elected officials to adopt rate increases sufficiently to prompt serious urban water conservation. In establishing fees for urban water permits, the impact of fees on conservation incentives should be considered.

Adjusting to Water Shortages

The climate of the Columbia River basin is characterized by annual fluctuations in snowpack, precipitation, and streamflow. Both natural systems (e.g., fish species) and managed systems (e.g., irrigated agriculture) have evolved in ways to accommodate variations in precipitation and streamflow. In the case of irrigated agriculture, the ability to adapt to changes in water supplies is central to this sector's economic viability. This section reviews the adjustments that agricultural users, both in and outside the basin, routinely make in response to drought. The ability to make such adjustments can provide insights into the consequences of water permitting decisions. That is, what adjustments are available to agriculture if new permits are limited and some classes of water rights (interruptible) are not changed?

One means by which farmers respond to drought is by securing water supplies from alternative sources. For example, in the Klamath Basin of Oregon during the 2001 drought, the Oregon Water Resources Department permitted the development of several drought/supplemental use wells (OSU/UC, 2002). California growers have routinely used wells to supplement surface water supplies during drought periods. Continued use of wells in Oregon, specifically during non-drought years, will be limited by growers' ability to obtain permanent water rights for them. Recently drilled wells are generally permitted for use only during declared droughts (Ibid.). The use of such wells during non-drought years will also be challenged by water quality issues, interference with previously permitted wells, and high operating expenses. In addition, there is evidence of marked groundwater drawdowns during drought periods. Although emergency wells offer important flexibility during a drought, their usefulness during future droughts is thus not always certain.

For farmers (both those who are able to secure additional water through wells or purchases and those who must adjust to reduced supplies), a basic decision in the face of drought is to determine which combination of crops and fields could be successfully planted, irrigated, and harvested under a changed water supply. For example, acres that would not receive sufficient irrigation are usually left fallow. Crop rotation and selection is an important

management tool employed by irrigators, regardless of water availability. Rotation of low and high value crops maintains soil productivity, reduces disease, and moderates interannual variability in revenue. In addition, since water requirements differ across crops, if one of the crops used in the rotation requires less water per acre to produce a harvestable yield, some excess water may be available for other crops in the rotation. In fact, rotation patterns and the resulting harvest and income patterns often continue relatively undisturbed, even in drought years.

During a water shortage, a farm's water is typically directed first to high-value perennial crops, such as apples or grapes, or to high value annual crops such as potatoes. Producers plant high-value crops in fields with reliable water supplies, sometimes despite the presence of inferior quality soil. Low-value crops, like wheat and hay, are either deficit irrigated, or not planted at all during a drought (Faux and Perry, 1999). Jensen and Shock (2002) suggested a set of specific responses to drought by irrigators in the Pacific Northwest:

- Leave some ground idle, applying water first to high value crops.
- Avoid over-irrigating by using evapotranspiration charts to estimate crop water need, soil moisture monitoring equipment, graphing soil moisture readings, and knowing the water holding capacity of different soils on each farm.
- Know the drought tolerance of different crops, and plant them according to water availability.
- Implement alternative irrigation methods, such as surge irrigation on the first irrigation to reduce water loss to deep percolation.
- Switch to sprinkler or drip irrigation for high value crops like orchard crops, if it is cost effective.
- Change irrigation sets when water reaches the ends of the furrows, rather than at specified times of the day.
- Eliminate deep watering of shallow rooted crops. Replace with frequent, light irrigations to keep water in the plants' root zones.
- Use catch basins to capture and reuse runoff.

Historically, irrigators have incorporated flexibility in annual cropping and irrigation decisions to help moderate inter-annual variability in exogenous factors, like weather and prices. In general, producers manage their crops during a drought year as they do through an average or wet year, with a diverse set of crops, flexible planting, irrigating and harvesting schedules, and an expectation that low yields during dry years will be offset by high yields during average and wet years. However, prolonged droughts, failure to secure operating capital due to lenders' perceptions of risk, and institutional mandates, such as provisions of the ESA, pose special challenges to irrigators. These types of adjustments to reduce water will take on increasing importance as the demand for water from other uses increases.

SUMMARY

The economic value of water in different uses varies widely in the western U.S. Equity, inter-generational considerations, and other factors suggest that water should not always simply be allocated to the highest bidder; nonetheless, willingness-to-pay indices demonstrate that water does provide different types and amounts of economic and social benefits in different uses. The

traditional doctrine of prior appropriation in the western U.S. allocated water rights according to the principles of "first in time, first in right" (thus establishing a system of seniority of rights), and "use it or lose it," in which water rights must be applied or be open to forfeiture. Prior appropriation requires that water be put to beneficial uses, but it does not prioritize water rights based upon willingness-to-pay or the economic, or social, return of water applications.

Water uses and water demands changed greatly across the West during the twentieth century. The "New West" (cf. Riebsame, 1997) features increasing urban populations, changing employment patterns and changing cultural and leisure preferences, an increase in non-traditional economies and employment (e.g., recreation and tourism), and a decreasing economic reliance on traditional activities such as ranching and irrigated agriculture. Traditional sectors remain important, however, in many areas in the West, and there are increasing pressures and competition for often-limited water resources. Some of the pressures for water resources take the form of demands to not divert water from streams, but rather allow these "instream" flows in place for ecological and related social benefits. The doctrine of prior appropriation did not historically recognize instream flows as "beneficial," but changes in the doctrine in many western states during the late twentieth century were made to recognize the social benefits of instream flows.

The pressures of increasing human population and shifting social preferences with regard to water resources represent both opportunities and potential conflict in the West. Opportunities exist for water rights holders in traditional sectors, such as irrigated agriculture, to sell their water rights for a profit to higher-value uses. Opportunities also exist for traditional users to manage water better—through conservation or better technology—and to sell a portion of this "saved" water. Problems may arise, however, when market-based sales of water between willing buyers and sellers result in third party effects, which should be carefully guarded against, as these effects can be economically and socially damaging. Conflicts may also arise when traditional users are not interested in selling, or when traditional users and newer users vie for the same, limited water resources. These conflicts also suggest some roles for governmental bodies in helping prevent and reduce third party conflict and in making decisions about allocations between competing users. These opportunities and conflicts exist across the West, with some of them manifested in the Columbia River basin and along the mainstem Columbia River.

The doctrine of prior appropriation has limited flexibility in allowing water rights to be transferred or sold. For example, in some states, water rights under prior appropriation are not attached to land rights and may thus be sold separately from land, which helps effect some water rights transfers and sales from lower- to higher-value uses. Water markets and water banks attempt to increase this flexibility by improving communication and effecting interactions between potential buyers and sellers of water. Although they are not perfect, water markets and banks have demonstrated advantages in producing both flexibility and security in a number of contexts. Programs in market arrangements—and several of them have been used to good effect across the West—such as water banks, environmental water accounts, and water rights sales and leases, along with careful monitoring of outcomes, would allow management organizations to learn more about the value (or lack thereof) of these various programs. These market-based measures can also improve incentives for water conservation through better management or new technologies, as conserved water could be sold for profit through markets or banks. These nonstructural water management measures also offer alternatives to traditional means of "increasing" available water (e.g., additional storage reservoirs or diversions). Thus, in addition to helping increase overall social benefits of water uses, these measures also hold the prospects

for decreasing conflicts over limited water supplies. Water management entities across the Columbia River basin should cooperate on exploring the utility of these measures in helping to support the regional economy, but that does not require additional withdrawals of Columbia River water, as the well-being of salmon habitat and salmon is also an integral part of the economy. Water conservation measures and means for re-allocating water, such as water banks and water markets, should be promoted in a quest to increase "water productivity" and to contribute to a healthy regional economy and Columbia River ecosystem.

As this chapter has discussed, water markets and water banks present their own unique set of implementation and operational challenges. Such programs often require the creation of significant administrative structures, leadership skills, and wisdom in order to ensure that potential buyers and sellers have good information and are aware of each other's demands, that there are adequate, effective data bases that reflect ongoing transactions, and the monitoring and fair execution of lease and option arrangements. They also require adequate storage and conveyance facilities to store and re-allocate water, and capital investments in such facilities may also be required. The human resources requirements to ensure the transparency and the credibility of such programs may be considerable. Moreover, the range of business, economics, and administrative skills necessary for such programs are often not widely on tap in most natural resources agencies. Successful creation of water markets and water banks thus often holds great potential to identify "new" sources of water and may therefore increase beneficial uses and reduce tensions; but human resources investments to ensure that adequate organizational, environmental, and social frameworks are essential and may be substantial. **The State of Washington and other Columbia River basin entities should continue to explore prospects for water transfers and other market-based programs as alternatives to additional withdrawals.**

7

Water Resources Management, Risks, and Uncertainties

Decisions regarding permit applications for consumptive water withdrawals from the Columbia River involve imprecise calculations and assumptions of salmon's physiological needs, river flows, and present and future amounts of upstream water uses. These decisions must thus consider and balance a variety of imperfectly understood risks. This chapter examines issues associated with managing these risks. It also examines challenges associated with using scientific information in decision making applications. Part of this study includes the review of several water management scenarios (also listed in Appendix B). Comments on these scenarios are located near the end of this chapter.

RISKS AND WATER MANAGEMENT

A Simple Stream

This example assumes a stream with three users, all under the jurisdiction of one state: User A in the headwaters, User B in the middle reach, and User C in the lower reach. The average instream flow is 15 units of water. For purposes of this example, recognizing that reality is far more complex, it is assumed that salmon need a minimum of 4 units of water. Three possible variations are considered:

> Variation 1: User A consumptively uses 5 units of water. After this use, 10 units remain in the stream at the top of the middle reach. User B consumptively uses 3 units of water, but wants to expand use to 5 units. The state could permit User B to do so, since 5 units of water would still remain in the river, one more than the salmon need.
>
> Variation 2: After the new uses contemplated in Variation 1 occur, User A wishes to expand use in the upper reach. The state could permit the consumptive use of 1 additional unit in the upper reach without adverse effects to salmon in the middle reach under average or normal conditions. When upper basin water supply is less than normal, however, users A and B will both continue their uses until the water available to salmon is exhausted, unless that water is afforded legal protection. Thereafter, User A's junior rights will be curtailed in favor of User B's senior downstream rights. Unless the water requirements of salmon in the middle reach have legal protection, however, the salmon will suffer adverse effects in below-average water years.

Variation 3: Now consider User C's downstream uses that require 5 units (they could be consumptive or nonconsumptive). In a normal water year, User B must pass that much water through the middle reach. Since this "pass-through" water also benefits salmon in the middle reach, User B can still consumptively use 5 units in the Middle-Reach (10-5=5 units "pass-through"). An additional 1 unit of development can occur in the headwaters or middle reach. Beyond that margin, the water needed for salmon will be reduced.

If the stream is wholly within the jurisdiction of one state, these variations can be successfully managed so long as salmon needs have some legal protection. Such protection can result from a water right or water reservation with its own priority date that is administered along with all other priorities on the stream. Legal protection also can result from a regulatory program, perhaps under the Endangered Species Act or under a water quality statute that requires maintenance of a given streamflow. Without legal protection for the water necessary for salmon in the middle reach, however, water will be increasingly diminished to the extent upstream uses increase faster than the amount of water that must be bypassed to the lower basin.

A Complex Stream

Legal and Water-Availability Uncertainties

A more complex situation (and more similar to that in the Columbia River basin) is considered below. Rather than a basin within a single state, the Columbia River is subject to a complex jurisdictional web. User A is no longer a single user whose uses are permitted by a single state. In the Columbia River basin, "User A" is the collective of many upstream governments and entities. Looking upstream, water is used in Canada, Montana, Idaho, and Wyoming, as well as in Washington and Oregon. There are also potential future uses, such as potential Canadian claims under international law, equitable claims of Montana and Idaho to the waters of an interstate system, and indigenous and reserved water right claims of upstream Indian tribes.

Water availability in the middle reach is also subject to existing and future downstream claims as well, User C in our earlier example. These include claims for sufficient water for navigation, senior water rights for federal reclamation projects, other senior water rights, the claims of downstream Indian tribes for instream and diversionary purposes, and the equitable claims of Oregon, Nevada, and Utah to the waters they contribute to the interstate system. Other so-called "federal regulatory water rights," such as sufficient flows for water quality and the protection of listed species under the Endangered Species Act, impose limits on water use both upstream and downstream of the middle reach.

Whether one looks at upstream or downstream rights, it would be incorrect to assume that present flows in the Columbia River mainstem accurately reflect current legal allocations. In addition to climate trends and variations, actual withdrawals may be augmented by water rights not being currently used and water rights applied for but not yet adjudicated. Although legal entitlement is supposed to be contingent on actual and continual use, water use is not always carefully monitored. Some water-right holders may go many years without diverting their full entitlement. This is important because unless full rights are extinguished for lack of use, they

may emerge as significant withdrawals at some unpredictable future time. Further, even in Washington, some surface waters have not been adjudicated. Approximately 160,000 pre-1917 surface water claims and pre-1945 groundwater claims remain unadjudicated statewide, although it is uncertain how many of these claims are contiguous to the Columbia River. Approximately 100 pre-1917 claims for surface water list the Columbia River in eastern Washington as a source.

On the other side of the ledger, illegal diversions may inflate actual withdrawals from the river. The National Marine Fisheries Service's December 21, 2000 Biological Opinion suggests that controlling illegal use of water by the Bureau of Reclamation irrigation projects could substantially reduce stream flow depletions. This opinion was pursuant to a 1994 Inspector General report detailing unauthorized uses within Bureau projects, some of which are situated on the Columbia River. Although the Bureau of Reclamation is aware of unauthorized uses, it does not now have a dedicated program or schedule in place to address and resolve all instances of unauthorized use. The Bureau has undertaken specific efforts including GIS mapping of the Columbia River Project. The Bureau states that onsite review would be necessary to determine with any accuracy the extent of unauthorized use and that it lacks the staff and resources needed for such a review. The unauthorized use report issued by the Bureau warns of farmer resistance that could make it difficult to quantify unauthorized uses, and that efforts to limit unauthorized diversions must be cautious and collaborative (U.S. Bureau of Reclamation, 2000). The bottom line is that current flows of the Columbia River do not present an accurate picture of legal entitlements to withdrawals.

The Columbia River system can no longer be managed under a simple set of priorities. A legal inventory may tell only part of the story. Canada has treaty and equitable rights to the river. Other Columbia River basin states also have equitable apportionment claims. The water rights of these sovereigns, although impossible to predict, constitute "first" claims on the river. In addition to their fisheries rights, many of the basin tribes have reservations with arable land. Under federal law, many of these tribes have reserved water rights for irrigation and other "permanent homeland" purposes. The priorities of these rights may vary depending on evidence of aboriginal use, treaty entitlements, when lands were acquired, and many other factors. State-law water rights for reclamation projects and other uses in Washington and other states may not be fully developed; and, short of a basin general basin-wide stream adjudication, it is difficult to determine how much additional water use is authorized and, if developed, whether priorities of these uses will relate back to the original dates of filing or appropriation. These legal uncertainties operate in a backdrop of variable water supplies. During normal climatic situations, precipitation may vary considerably from year-to-year. With growing indications of significant multiyear climatic changes, water availability is likely to be even more erratic.

Risk and Uncertainty Involving Endangered Species

Threatened and endangered species, such as salmon and steelhead, can further complicate water management decisions. A National Research Council committee has previously (NRC, 1995) addressed risk assessment in the context of the Endangered Species Act. That report identified the two types of risk that are addressed by this statute: the risk of species extinction and the risk of potentially unnecessary expenditures of money and curtailment of resource use given the uncertainties about the risk of extinction. The report enumerated major factors that appear to influence the risk of extinction and discussed the difficulties of estimating the risks of

extinction, many of which are presented in considering potential new diversions from the Columbia River. In addition to this report, other National Research Council committees have examined issues of the use of risk analysis in water management and risk communication (NRC, 2000; NRC, 1996). Based on definitions and applications in those reports, this report uses *risk* as the probability that some undesirable event occurs, as well as the combination of that probability and the corresponding consequence of the event. *Uncertainty* is used to describe the lack of sureness about something.

A key risk in many situations where species face extinction is the relatively small population size of the species. In small populations, even random demographic or environmental changes can have large consequences for species survival. Catastrophes such as drought or fires can suddenly reduce population numbers. In small populations, genetics can also be a negative factor as "mildly deleterious genes, previously kept at low frequency by natural selection, can rise to high frequency by change" (NRC 1995, p. 133). The species' ability to adapt genetically to environmental changes is also diminished because genetic variation, the key to species' adaptation, is reduced (ibid., p. 134-135). That report also noted that "populations need about 1,000 individuals to maintain their genetic variation" (ibid., p. 135; the report also noted that this actual number depended upon the biology of the organisms involved). Applying these findings, random demographic and genetic changes are likely not primary risk factors for the threatened and endangered salmon runs in the Columbia River. These factors are more detrimental in populations of fewer than 1,000 individuals; and the Columbia River salmon runs, although in jeopardy, are more numerous. Habitat fragmentation is another important risk factor and, because of the many physical alterations of the Columbia River system, more of a concern to salmon survival. The report also noted that the effects of even minor detrimental changes in specific habitat areas may accumulate over time—an especially relevant observation in the context of this report's considerations of how Columbia River water withdrawals affect salmon survival rates. As the report states:

> Not enough is known about cumulative effects and threshold points . . . . When considering the probable effects of incremental human activities, it is reasonable to assume that additional activity means additional risk, but we rarely know whether the relationship . . . is linear or whether there might be critical levels of activity above which the risk of extinction increases dramatically (ibid., p. 156).

Compounding of Uncertainties

All these legal, economic, biological, and water-availability uncertainties intersect in water-permitting decisions concerning the Columbia River middle reach. There are many legal and economic uncertainties regarding how much additional water will be consumptively used upstream by Canada, other states, and tribes. While downstream uses help "pull" water downstream for salmon, similar legal and economic uncertainties exist about the growth of these downstream uses. Ocean conditions may also influence seasonal salmon returns to the Columbia. Climatic uncertainties confound precise predictions of how much water will be available to use throughout the basin.

The "risk-based" nature of permitting in the Columbia River middle reach is suggested by Table 7.1. The rows of this table represent different assumptions about water availability in a particular year, with high flows (risk value 1) presenting the least risk to salmon and low flows

(risk value 3) presenting the most risk. The columns display different risk assumptions about the extent of upstream consumptive use in that year. If little additional water has been allocated for consumptive use in the upper basin, the risk to salmon in the middle reach is low (risk value 1). If much upstream allocation has occurred, the risk to salmon in the middle reach is high (risk value 3). The shaded cells in Table 7.1 suggest the interaction of these water availability and consumption risks. The darker portions of the table suggest high risk to salmon in the middle reach of the Columbia River in circumstances of low water availability and high levels of upper basin water development (i.e., a high risk of low flows compounds the situation of having high levels of use in the upper basin).

Table 7.1 depicts risks to salmon presented by the varying relationships between river flows and upstream consumption. Similar tables could be drawn for all the other variables (e.g., temperature, habitat) that affect salmon survival. The problem for water managers is that the risk factors in such tables represent overlap. That is, the risk to salmon viability is a composite of all these individual risk factors. If managers are confident in scoring all these risk factors low (lightest color cell), additional permits can be issued with assurance that impacts on salmon will be minimal. However, if managers score many or all the individual risk factors high (darkest color cell), additional permitting could affect salmon adversely. Perhaps an even greater challenge is that seldom are these varying risks to salmon quantified as precisely as suggested in Table 7.1. In nearly all cases, risks are only partially understood and entail some qualitative understanding and a need for professional judgment in decision making.

COLUMBIA RIVER MANAGEMENT DECISIONS

Anticipated Permitting Decisions

Under optimal conditions, a permitting agency could make confident predictions of existing and anticipated water use, especially above the reach in which additional permitting is planned. The permitting agency would also have reliable estimates of future water availability and the distribution of those flows throughout the year. Potential permitting decisions for the middle reach of the Columbia River, however, present a less than optimal situation since, from a legal perspective, existing and future upstream water uses are difficult to determine and water availability is subject to variability at various time scales. Further decreases in flows or increases

TABLE 7.1: Hypothetical Risks to Columbia River Salmon

Columbia River Flows for Specific Water Year	Different Levels of Upstream Consumption			
		Low (1)*	Medium (2)	High (3)
	Low flows (3)*	Risk to salmon = L x L = 3	Risk to salmon = L x M = 6	Risk to salmon = L x H = 9
	Medium flows (2)	Risk to salmon = M x L = 2	Risk to salmon = M x M = 4	Risk to salmon = M x M = 6
	High Flows (1)	Risk to salmon = H x L = 1	Risk to salmon = H x M = 2	Risk to salmon = H x M = 3
	*Hypothetical risk factor with (1) lowest and (9) highest			

in water temperature will increase the risks associated with managing water resources and salmon, and are likely to reduce survival rates. The confluence of some, or all, of the many factors that threaten to reduce Columbia River flows poses serious risks for salmon, many of which are federally endangered. Given the current setting and likely future climatic and other trends, additional water withdrawals from the Columbia River during seasons characterized by low flows (particularly in drought years) will pose additional risks to salmon survival. These greater risks to salmon survival should be carefully considered in decisions regarding potential future Columbia River withdrawals during low flows.

Interjurisdictional Cooperation

Many of the risks that confound permitting decisions in the middle reach of the Columbia River result from upstream uncertainties that Washington has little control over. An inventory or model of water rights on the Columbia cannot be reliability created because the extent of many of the largest rights cannot be determined until adjudications, other litigation, or settlements are completed. An interjurisdictional water organization would afford an opportunity to promote adaptive management while reducing these uncertainties. Such an organization could provide a forum for improving information and assessing the consequences of major management actions on the Columbia, as well as providing a broader setting for discussion and learning. Such an organization should include the basin sovereigns—the Canadian and U.S. governments, U.S. basin states and Canadian provinces, and Indian tribes. The body should establish a means to incorporate and discuss scientific input. This body should establish a threshold(s) volume of proposed new withdrawals that would be likely to concern more than one government. For instance, any proposed new use of water of more than an agreed-on amount could be considered presumptively suspect and would have to be referred to the interjurisdictional organization for deliberation. The organization's decision rules might require hearings and a complete record on the basin consequences before the project could continue. The rules might also require the organization's approval before the permit could be issued.

Incremental Actions and Adaptive Management

The consideration of water permit applications in the State of Washington takes place in a contentious and turbulent science and policy context. The body of scientific knowledge of Columbia River salmon is complex and incomplete, and there are competing scientific theories regarding some of the relations between salmon and environmental variables. There are also many decision makers with differing goals. As stated in a 1989 article on Columbia River management "A . . . problem is the large number of hands on the steering wheel" (Lee, 1989).

The setting of multiple political jurisdictions, competing stakeholder groups, endangered species, a complex ecosystem, and a large but imperfect body of scientific knowledge is not unique to the Columbia River, and in fact is characteristic of many major U.S. river systems. In an effort to implement management regimes that help reduce stakeholder disputes, and that strike a more amenable balance between legal obligations and authorizations, some management agencies are exploring the prospects of "adaptive management" strategies. Adaptive management has its foundations in many different fields, but its theories and concepts were formalized by ecological scientists in the 1970s (Holling, 1978; see also Gunderson, Holling, and

Light, 1995: Gunderson, 1999; Lee, 1993, 1999; Walters, 1986). Elements of adaptive strategies include:

- An explicit recognition of uncertainty and the need to learn more about coupled ecological-social systems in order to enhance learning and reduce uncertainties.
- Recognition that adaptive management entails a process, not a final answer or a series of management "endpoints" to be rigidly pursued.
- Learning while doing. Adaptive management does not postpone management actions until "enough" information is available (Lee, 1999). It seeks management actions that can be reversed in the light of new information, and actions that can help improve ecological understanding while also meeting economic and environmental needs. Adaptive management is not "trial and error" management, but rather entails carefully designed management actions, with purposeful monitoring of outcomes in a structured learning process.
- Flexible, incremental actions that enhance learning and that seek to avoid catastrophic error.
- A means of gathering information on environmental and economic outcomes of management decisions.
- A vision or a model of the ecosystem that is being managed (Walters, 1986). This vision or model provides a baseline for defining surprises. Surprises and other new information help increase knowledge and understanding of the system (Lee, 1999).
- Organizations that can learn from new information and policies that can be adjusted in light of new information.
- A collaborative structure for stakeholder participation. Participants should be willing to negotiate, try a variety of temporary measures, and evaluate promising measures before they are implemented. Adaptive management does not seek to eliminate differences of opinion or conflict, but rather to provide a framework for their discussion. Adaptive management is not a substitute for willingness to compromise and give-and-take, however, and unless stakeholders are willing to agree on basic questions or lines or inquiry to be pursued by an adaptive approach, formal adaptive management will be inappropriate. Well-managed conflict can be a resource for new ideas and approaches and mutual learning, but one cannot manage adaptively in the absence of stakeholder flexibility (Gunderson, 1999).

An adaptive management approach would encourage Columbia River basin entities to move forward incrementally and to try a variety of approaches. Decisions and policies should promote flexibility while their outcomes are being evaluated and better understood. A broad range of stakeholder groups from across the Columbia River basin should be engaged in crafting these decisions.

A variety of approaches to meet water demands in the middle reach might be explored. Chapter 6 identified several economic based alternatives, such as cost-shared water conservation improvements, reallocating existing uses, water banks, and water transfers. Most or all of these types of measures could be implemented incrementally and could be amenable to change as new economic and environmental information is gained. Adaptive management aims to yield better information about ecological, economic, and policy conditions, reduce uncertainties, and to engage participants in a collaborative learning process aimed at solving complex problems, such as Columbia River management. The following section discusses the use of scientific information in decision making contexts that are laden with uncertainty.

Science and Decision Making

A vast amount of scientific research on Columbia River salmon has been conducted over a period of several decades. The resulting body of knowledge provides a broad understanding of salmon life cycles and histories, physiological characteristics of salmon, and environmental variables important to salmon survival. As explained in Chapter 4 and in other sections of this report, Columbia River salmon inhabit and travel through extensive oceanic and riverine systems during their lifetimes. The size and the complexity of these systems, and the biological complexities of salmon, frustrate attempts to understand any of these factors with high precision and certainty. Substantial resources have been devoted to investigating Columbia River salmon, and today these fish species are one of the most intensively studied in the U.S., if not the world. Although scientific understanding of the salmon has improved over the decades, perfect understanding of all factors and relationships that affect salmon life cycles is beyond current and foreseeable future scientific means.

More precise scientific information regarding salmon behavior, environmental influences, and rates of survival could, over time, no doubt be obtained. However, significant resources are now being devoted to this pursuit, as federal and state scientists, and scientists from universities and regional consultancies, are involved in extensive salmon research programs. One task pursued in this study concerned the identification of knowledge "gaps" and "scientific information" needed to develop comprehensive strategies for recovering and sustaining listed species and managing water resources to meet human needs" (see Chapter 1, P. 10). This task, however, presupposes that sound management strategies can be devised only when scientific "gaps" are filled, and that it is possible to determine *a priori* the scientific information that will lead to better management decisions. Such suppositions do not reflect contemporary natural resources management realities and the relationships between scientific information and decision making processes.

Identifying the additional scientific information that will prove useful for management is not strictly an issue of scientific inquiry, but also a matter of policy making processes. Scientists are often expected to provide answer for use in decision and policy making. This may place an undue burden upon scientists, however, especially given the uncertainties and risks that revolve around issues such as Columbia River salmon. Science is a key component in these decisions. But rather than looking to science to provide information in strictly a one-way direction, decision makers should collaborate with scientists in a two-way process in which management actions are taken in the face of some inevitable uncertainties, with an eye to learning more about the system(s) at hand. Progress toward "comprehensive" management cannot be accomplished through scientific inquiry alone, but rather requires stakeholders and management agencies to work with scientists in a collaborative learning process, such as that framed by adaptive management principles. As stated, Columbia River salmon management is an exceedingly complex public policy and science issue. The creation of "comprehensive" strategies that reduce tensions, protect and enhance salmon, and respond to shifting human needs, will likely require an approach that mirrors these complexities, as suggested in the following passage by Lee (1989):

> Sustainable development of the Columbia River basin requires managing an ecosystem the size of France. If there is to be a sustainable Columbia, it will be a place governed by rules that approach the complexity of ecological interaction.

In cases where there are sharp conflicts and differences of opinion, management agencies may understandably be reluctant to take decisive actions in the face of uncertainty. Such a stance, however, may contribute to the build-up of tensions among stakeholders. In these settings, an adaptive approach may be useful. Adaptive management does not wait until "enough" information is available, but recognizes that gaps are inevitable, that data collection is expensive and time consuming, and that there are sometimes problems requiring decisive actions in the face of limited information. The approach seeks to create flexible management regimes through a collaborative science and management process. Maintaining flexibility of management decisions to the maximum extent possible is essential. Additional scientific research on Columbia River salmon should continue. Better information on flow-survival relations, for example, can reduce uncertainties and contribute to better management decisions. Scientific inquiry on the salmon should be allied with policymaking and stakeholder participation in an iterative, interactive process. Adaptive management can help participants better understand the ecosystem. However, it also requires willingness among participants to find common ground and a political will to act in the face of uncertainties.

Adaptive management is not a foreign concept in the Pacific Northwest. The Northwest Power and Conservation Council has sought to manage Columbia River fish and wildlife resources under an adaptive management paradigm. The first serious attempt at implementing adaptive management principles began in 1986, and the process has proceeded with a variety of initiatives (Lee and Lawrence, 1986; Volkman and McConnaha, 1993). Adaptive management represents a "work in progress," as experience to date with the concept is limited (Lee, 1999). Although adaptive management holds promise for improving understanding of flow-survival relations in the Columbia River, the political setting is highly contentious, economic interests and values are substantial, and management responsibilities are dispersed among many entities. Its implementation may also be inhibited by the Endangered Species Act, as adaptive management's willingness to accept risks and to accept occasional mistakes as part of a learning process runs counter to the ESA's aversion to risks. Management actions aimed at helping improve understanding of flow-survival relations may indeed, as Volkman and McConnaha (1993) assert, "kick off a new round of battles." There can be no denying the political realities and scientific complexities that attend adaptive management principles. But the complexities of managing Columbia River flows and salmon defy simple solutions and will likely require a management paradigm of similar complexity. Although stakeholders may occupy little common ground, it is important to explore innovative ways to improve upon the current management regime. Although it does not represent a panacea, adaptive management offers a systematic, collaborative learning and management process as an alternative to allowing decisions to be made through court litigation and decrees.

THE MANAGEMENT SCENARIOS

The Washington Department of Ecology ("Ecology") provided five management scenarios for the committee's evaluation under item 5 of its statement of task ("Evaluate the effects of proposed management criteria, specific diversion quantities, and specific features of potential water management alternatives."). The scenarios as provided are in Appendix B but because aspects of those scenarios included many details (and are not entirely transparent), they are paraphrased below.

Scenario 1

In this scenario (as in all the scenarios), it is assumed that water can be used between the Canadian border and Bonneville Dam. New permits would be issued to water users in Washington over a 20-year window (the start date is not specified) up to a total of one million acre-feet. Of that total, 220,000 would be allocated to the Columbia Basin Project. In addition to the million acre-feet made available to Washington users, an additional 427,000 acre-feet of instream flow from the Snake River would be "legally recognized throughout the Washington State reaches of the Snake and Columbia Rivers" and "600,000 acre-feet would be recognized as necessary to meet the water resource needs of the state of Oregon."

This scenario implies that about 1.6 million acre-feet would be used for out-of-stream uses (1 million in Washington and 600,000 in Oregon) and 427,000 would be devoted to instream flow. In addition, permits that currently are interruptible when stream flow reaches a predetermined level could be converted to uninterruptible status if the owner demonstrates "that current water use conforms to state-of-the-art water use efficiency practices." "Uninterruptible water rights" are pre-1980 state law water rights that have priority over main stem instream flow rights established in 1980. Other pre-1980 water rights based on federal law also have priority over these instream flow rights. "Interruptible water rights" are post-1980 state law water rights that, under certain low flow conditions, may be curtailed to protect the mainstem instream flow rights. Ecology proposes to permit additional uninterruptible water rights that would not be curtailed under low flow conditions to protect mainstem instream flow rights.

All new water rights issued by Ecology would also require state-of-the-art efficiency and would be metered. Ecology would periodically assess the management program and use scientific information to accommodate changes in knowledge, with formal re-evaluations at years 10 and 20. Finally, Ecology would seek partners to establish a "functioning water market or 'water bank' for the mainstem of the Columbia River to facilitate a more efficient allocation of existing water resources in the basin."

Scenario 2

Scenario 2 is similar to Scenario 1, with the following differences:

1. All new permits and previously interruptible rights converted to uninterruptible status would be charged $10 per acre-foot per year to support additional efforts towards "salmon health and recovery." The proceeds would be used to acquire water for instream flow in low-water years and to make habitat improvements in the mainstem and tributaries. The money might also be used to explore the development of storage projects. (These storage projects are not described in detail. Because new storage facilities on the Columbia River mainstem are not a viable option, the implication is that additional storage would be gained by new dams on tributaries; by the creation of new reservoirs to be filled by water from the Columbia River; or other methods, all of which would require additional water withdrawals from the Columbia River mainstem.)
2. Of the new permits totaling up to a total of a million acre-feet allocated to users in Washington, 300,000 acre-feet would not be issued until existing users had demonstrated that

"conservation investments were in place for a majority of users on the mainstem."

Scenario 3

Scenario 3 is identical to Scenario 2 except that the charge for new permits and for changing interruptible permits to uninterruptible status would be $20 per acre-foot per year. In addition, the Department of Ecology would provide financial support for new conservation measures.

Scenario 4

This scenario would not allow any new water to be removed from the Columbia River for out-of-stream use by Washington users. New water rights would require "direct mitigation in the mainstem of the Columbia River." All new water rights would require offset water to be obtained through water-right changes and transfers, conservation, or use of new storage. Existing interruptible water rights could be converted to uninterruptible status by payment of $30 per acre-foot per year. The money so obtained would be used to acquire water rights to benefit salmon populations.

Scenario 5

This scenario assumes "that the current existing rule governing water resources of the Columbia River [would continue]." The current rule includes a moratorium on all new permits, however, and this scenario allows for new permits. Each new permit would be issued only after consultation with fish and fishery managers (e.g., Washington Department of Fish and Wildlife, tribes, NOAA Fisheries) and whether and to what degree mitigation would be required would be decided for each permit individually as a result of the consultation with fish and fishery managers. The upper limit—if any—of the total new water permits that could be issued is not specified.

Evaluation and Commentary

In general, the adoption of concepts related to adaptive management, such as periodic review and adjustment of the program and monitoring, and market-based conservation strategies such as conservation, the use of water markets (or "banks"), and charging for water rights, are commendable. As presented within these scenarios, however, those programs are discussed at only a very general level, which precluded a deeper level of investigation and more detailed comments.

A pervasive aspect of the scenarios is the lack of a comprehensive, basin-wide assessment of water uses and needs as a context for evaluating prmit applications. Small (relative to the flows of the Columbia) withdrawal and permitted volumes will only have small, if not minuscule, effects on the water budget of the basin as a whole. All water uses accumulate,

however, both in Washington and elsewhere along the mainstem, as well as the tributaries. If future demands for water increase, however (which seems highly likely given recent and projected demographic and economic trends), the accumulation of risks to salmon survival will be all the greater (given the wide variety of risks that affect salmon survival, assigning levels of risk to changes in flows and temperature is extremely difficult). These effects would be magnified by reductions in low-flow that could attend prospective climate warming , as well as during periodic, unfavorable ocean conditions. The lack of a comprehensive, basin-wide management structure hampers the ability to make comprehensive judgments (both in time and over space), and it supports this report's recommendation for creating a basin-wide framework for coordinating water-use data and strategies.

- *Conversion of interruptible to uninterruptible water rights (scenarios 1 - 4).*

Conversion of interruptible water rights to uninterruptible status makes an adaptive response for the benefit of salmon more difficult. Interruptible water rights are interruptible so that at times of scarcity, instream flows can be protected. Making any out-of-stream right uninterruptible reduces flexibility to retain water in the river whn salmon need it most—during low-flow periods.

The conversion of water rights to uninterruptible status will decrease flexibility of the system during critical periods of low flows and comparatively high water temperatures. Conversions to uninterruptible rights during these critical periods are not recommended.

- *Re-evaluation at 10 and 20 years (scenarios 1-3).*

The idea of re-evaluating the scenarios periodically is excellent. However, for this re-evaluation to be meaningful, the program needs to be designed so that any aspect of it could be undone (reversed) if the evaluation calls for such a reversal. No evidence is provided of any such reversibility. Instead, the result will be *decreasing* reversibility by allowing for some interruptible water rights to become uninterruptible. In some cases, more frequent re-evaluations might be necessary. In addition, criteria for assessing the state of the art of efficiency measures are not described, and the responsibility for making that evaluation is not specified. There also is no requirement for periodic re-evaluation to take advantage of improvements in the state of the art.

- *Monitoring and metering (scenarios 1-3).* Monitoring for compliance with standards and metering are excellent ideas and could be accomplished consistent with this report's recommendation for comprehensive basin-wide water management. Such efforts will require resources, however, and an estimate(s) of the budget and personnel required to perform such monitoring would thus be useful.

- *Charge for water rights (scenarios 2-4).* The disadvantages of uninterruptible water permits were considered within this study, and it was concluded that allowing new uninterruptible permits to come into existence, either through conversion or *de novo*, would decrease the ability of water organizations to manage risks attached to decisions such as the granting of water use permits.

Charges for water rights within this scenario appear to be arbitrarily selected and out of proportion to the probable costs of mitigation and the value of water to the users. For example, the scenarios specify charges of $10-30 per acre-foot per year to be used (among other things) to

acquire mitigation water in low-water years. This scenario thus proposes increasing the priority of a water permit for $10–30 per acre-foot per year and using the money to buy water for what could be several times that amount.

- *Water markets (scenarios 1-4 and perhaps 5).* As discussed in Chapter 6 water markets, water banks, other such market-based mechanisms offer potential improvements over existing systems of water allocation. However, restricting markets only to the Columbia River's mainstem, and only to Washington, is narrowly construed. The Department of Ecology already allows for 600,000 acre-feet per year to be used by Oregon in its assumptions, but no allowance is made for uses by Idaho, Montana, or British Columbia, or by the tribes in the region. Efforts toward developing water markets should be complemented with efforts to evaluate third-party effects and to design proposals for compensating users indirectly harmed in water-rights transfers.

- *Structural storage measures (scenarios 2-4 and perhaps 5).* A lack of specificity in this scenario inhibits the ability to comment extensively upon it. It implies that tributaries are to be used for additional storage (which may have negative consequences for salmon), but the habitat and condition of tributaries are of critical importance for Columbia River water quality and for survival of salmon that use the Columbia River. Tributaries should thus be considered for protection and for mitigation, as well.

- *Scenario 5.* This scenario is not clearly specified. It is not a no-action scenario, which would entail leaving the current moratorium on new permits in place. Although the idea of consultation with fish and fishery managers is good, no mention is made of criteria for the evaluation, how the results of the evaluation might be enforced, who decides how much mitigation is needed, and what if any the limits on new permits might be.

"Mitigation" measures are suggested in most of the management scenarios. Although the idea of "mitigating" impacts is attractive, the reality of most mitigation measures is that they are uncoordinated; that is, a management agency may attempt to offset harmful impacts of water withdrawals in one part of a river system with mitigation measures (e.g., ecosystem restoration) elsewhere. The ultimate outcomes of such varying actions, however, are difficult to accurately predict, measure, and compare (if indeed they are ever measured and meaningfully compared, which they often are not), thus making it difficult to determine if "mitigation" was actually achieved.

SUMMARY

Columbia River basin water management decisions entail varying degrees of risk to salmon survival. These risks are a function of both the magnitude and timing of water management actions, such as water withdrawals. For example, additional water withdrawals during low-demand periods pose smaller degrees of risk than similar withdrawals during periods of high demand. Decisions are confounded because levels of risk are often only understood on a broad, qualitative level. Not only are key variables typically unquantified to a high degree of accuracy, the nature of interactions between key variables are often poorly understood. Some decisions may thus have only limited effects and be made well within a given range of tolerance,

while some may result in critical thresholds being exceeded, without a clear understanding of these different impacts.

In this context of uncertainty and varying degrees of risk, it is important that management and policy decisions promote flexibility, and even an appropriate degree of reversibility, in the event of future unforeseen and dramatic consequences. Examples of means by which risks might be managed include organizational learning strategies (which could employ ex post evaluations to learn from successes and failures), inter-jurisdictional cooperation (which would encourage entities to communicate to ensure that potential gains possible through innovative strategies are not foregone because such strategies are not being employed across an entire watershed), and incremental actions (examples of which include smaller-scale, short-term, and reversible policies). Adaptive management is a strategy that integrates many of these examples. Adaptive management is not a new concept in managing Columbia River basin fisheries resources, and experience and successes with the concept to date are limited. The concept is surely not the clear solution to managing the basin's fisheries and water resources, and some may be quick to dismiss it because of its complexity or inappropriateness. It should be kept in mind, though, that the exceptional complexity of Columbia River salmon management is likely to entail a similarly complex management framework if salmon management is to be sustainable and equitable. More scientific information on salmon will not necessarily lead to the resolution of disputes or to better management decisions. **Sound, comprehensive management Columbia River salmon management strategies will depend not only on science, but also on a willingness of elected and duly appointed leaders and managers to take actions in the face of uncertainties.**

Sound management strategies will also require a process in which managers and elected officials help frame scientific investigations and inquiry. The scientific knowledge of Columbia River salmon, while as extensive as for any other fish species in the world, is still imperfect. Improvements in salmon habitat and return rates will require a willingness to employ existing scientific knowledge to address some of the factors that scientific research suggests have led to their declines. A process in which scientists monitor outcomes of management actions, provide feedback to stakeholders and decision makers, who then adjust management actions accordingly will be instrumental in helping understand how additional scientific research can best support management decisions. This process is generally referred to as "adaptive management."

The management scenarios prepared in connection with this study contain some elements that would promote organizational flexibility and have some commonalities with adaptive management strategies that are being employed across the U.S. and in other parts of the world. Although programs such as water banks, water markets, incentives for water conservation, and better metering of water use were presented only very generally and therefore could not be evaluated in greater detail, they tend to support greater water management flexibility and merit careful consideration. Such efforts could meet with resistance from users who have little to no incentive to implement them. The situation calls for creative programs that provide incentives for water users to decrease uses or that identify alternatives sources of water supplies.

The State of Washington must consider several variables in making decisions and trade-offs regarding water withdrawal permit applications and the protection of salmon populations. Those variables, which include flows, temperature, and salmon's biological and migratory features, are only imperfectly understood and interact in complex ways. Scientific information can reduce uncertainties, but rarely can they be eliminated, especially in the case of issues as complex as Columbia River salmon management. In such settings, decision makers must exercise some degree of professional judgment in balancing a variety of risks and uncertainties.

Given the uncertainty of outcomes of these types of decisions, it is important to promote flexible decision making regimes that can be adjusted as new knowledge is gained.

As this report has discussed, Columbia River salmon today are at a critical point. The basin's salmon populations have long been in a steady decline, and scientific evidence demonstrates that environmental thresholds important to salmon, such as water temperature, are being reached or in some cases exceeded. Salmon are especially imperiled during critical periods of low flows, high demand, and higher temperatures. The risks involved in this context include the risks of additional reductions of salmon populations, risks of extinctions, risks of violations of the Endangered Species Act, as well as risks entailed to other users of the system—such as irrigation farmers—whose water demands may conflict with instream flows needed for salmon and aquatic habitat.

The ultimate decision whether to issue additional water withdrawal permits from the Columbia River and nearby areas is a decision to be resolved by duly elected officials and their appointees within the arena of public policy. But in this setting of high risk and uncertainty, if additional permits are issued, they should be issued within a framework that seeks to increase flexibility of water management systems and organizations. Efforts to enhance flexibility are especially critical given that so many social and physical trends in the Columbia River basin-such as potential additional water claims from tribal lands and other upstream areas, human population growth, and possible climate warming-point to possible reduced water supplies during critical periods and increased risks associated with salmon management. **Decisions regarding the issue of additional water withdrawal permits are matters of public policy, but if additional permits are issued, they should include specific conditions that allow withdrawals to be discontinued during critical periods. Allowing for additional withdrawals during the critical periods of high demand, low flows, and comparatively high water temperatures identified in this report would increase risks of survivability to listed salmon stocks and would reduce management flexibility during these periods.**

Water permitting decisions made by the State of Washington, as well as by other basin entities, are made with little consideration or obligations of their upstream or downstream implications. This fragmented decision making basis is a barrier to better water management and a barrier to a more comprehensive and coordinated approach for managing the risks and uncertainties that attend Columbia River and salmon management. The Northwest Power and Conservation Council, and its predecessor organization, the Northwest Power Planning Council, have served as key entities for promoting cooperative, basin-wide Columbia River management for over twenty years. The council has accomplished many good things, and adding a responsibility to consider permit decisions to its mandate may seem consistent with its natural resources management duties. But trying to integrate these functions in an existing entity could entail complications and drawbacks. A basin-wide forum for considering water withdrawal permit applications above a given threshold would provide a regional consideration of the system-wide implications of a proposed diversion. This forum would not entail anything binding other than an obligation to refer the applications. At a minimum, proposed diversions would be subjected to professional and public scrutiny, magnitude of risk, possibilities of mitigation, and system-wide equities. A basin-wide forum for considering withdrawal permit applications would enhance unified water management across the Columbia River basin. **The State of Washington and other basin jurisdictions should create a joint forum for documenting and discussing the environmental and other consequences of proposed diversions that exceed a specified threshold.**

8

Epilogue

The Columbia River basin is a vast hydrologic system subject to large and often unpredictable physical, biological, and human-induced changes. The river's flows vary on many different time scales and often in ways that are not fully predictable. In addition, prospective future changes in climate are likely to affect seasonality of flows, as well as water temperature. Additional diversions from existing projects and users, as well as additional demands from human population growth (currently increasing and highly likely to continue), are likely to diminish streamflows.

Columbia River salmon populations have been affected by a variety of human activities and have declined over the past century. The declines have been steady but have also exhibited considerable variability, with occasional years of low returns and occasional years of abundant returns, such as those witnessed in the early 2000s. The long-term decline of salmon populations, especially wild fishes, however, is undeniable. Documented increases in Columbia River water temperature are approaching, or have exceeded, thresholds of physiological importance to many salmonid stocks. Migratory behavior and survival rates of salmon are also affected by low river flows. Columbia River salmon are today at a critical point. This situation is especially troubling because of prospective future climate warming (which could entail not only higher water temperatures, but also further decreases in low flows) and demands for additional diversions of Columbia River water during low-flow periods. Further increases in water temperature and further reductions in low flows would exacerbate risks to salmon survival. As this report has noted, the effects of prospective additional withdrawals in July (234,000 acre-feet) could be substantial. July is a period of high demand for Columbia River water. The upper end of the range of the prospective additional withdrawals considered in this study would increase July withdrawals from their current value of roughly 6.8 percent of mean Columbia River flows to roughly 8.6 percent of mean Columbia River flows. Under *minimum* July flow conditions, the effects would be greater: the upper end of the proposed range of diversions would increase current July withdrawals from roughly 16.6 percent to roughly 21 percent of Columbia River *minimum* flows.

The seasonality of Columbia River flows and changing demand patterns for additional water from various users in different parts of the river basin suggest that sound water management decisions require a comprehensive, basin-wide water management scheme. Ideally, the management framework would have the flexibility to respond to the seasonality of Columbia River flows and the flexibility to responsibly transfer water from lower-value to higher-value uses. Increased flexibility in managing the Columbia River will require greater emphasis on non-traditional approaches to augmenting water supplies, such as water marketing and water transfers, and greater cooperation of political entities across the basin. These market-based

programs may require capital investments in physical infrastructure and human resources investments in experts with skills in fields such as finances, marketing, and public administration. Programs such as water transfers, groundwater banking, and other measures to increase the efficiency of water use hold promise in helping sustain the regional economy in ways that do not require ever-increasing water withdrawals. Although water uses across the basin should not be simply channeled to the highest bidders for water, such measures hold promise for helping support both economic and environmental goals and should be carefully considered.

A key problem in managing the basin's water is that water permitting decisions are currently made in a piecemeal fashion, with little to no consideration of their effects on other users or of their degree of consistency with other decisions across the basin. If water resources and risks to salmon survival are to be better managed, Columbia River water permitting decisions must be made in a more holistic fashion, with consideration of how additional diversions would affect other users and sectors across the entire river basin. A joint forum composed of Columbia River basin entities would allow for more accurate inventorying, monitoring, and enforcement of existing water rights. There is also a need for stronger efforts aimed toward water conservation and market-based management strategies, which could help reduce present tensions related to competition over water supplies. Many of these types of non-traditional means for augmenting water supplies have been applied to good effect in some water-short areas of the West. Their prospective applications in the Columbia River basin should be carefully explored

Water withdrawal applications and permitting decisions are highly contentious both in the State of Washington and in other parts of the Columbia River basin. Inflexibilities in the traditional western U.S. water apportionment prior appropriation doctrine have contributed to these tensions. A greater degree of flexibility in traditional water permitting and rights processes is paramount to better water management and to decreasing tensions and conflicts in the Columbia River basin. This report has recommended implementation of a joint, basin-wide water management forum and pursuit of non-traditional water marketing and conservation strategies. A water permitting and rights process that more explicitly recognizes seasonality of flows should also be devised. Decisions whether or not to issue water rights to pending applicants are issues to be decided in the public policy arena, but additional water withdrawals during critical high demand and low-flow periods discussed in this report will increase risks of survival to listed salmon stocks. It will also decrease the flexibility of management institutions to allocate water between different uses in critical low-flow conditions. To increase the flexibility of water management organizations and programs, and to better recognize uncertainties regarding future supplies and demands, a new permitting process should be created that allows for withdrawals to be discontinued during periods of low-flow and during periods of comparatively high water temperature.

To reiterate and reinforce this report's six key findings and recommendations, they are listed below:

- **Within the body of scientific literature reviewed as part of this study, the relative importance of various environmental variables on smolt survival is not clearly established. When river flows become critically low or water temperatures excessively high, however, pronounced changes in salmon migratory behavior and lower survival rates are expected. (Chapter 4).**

- **The State of Washington and other Columbia River basin entities should continue to explore prospects for water transfers and other market-based programs as alternatives to additional withdrawals (Chapter 6).**
- **The conversion of water rights to uninterruptible status will decrease flexibility of the system during critical periods of low flows and comparatively high water temperatures. Conversions to uninterruptible rights during these critical periods are not recommended (Chapter 7).**
- **Sound, comprehensive management Columbia River salmon management strategies will depend not only on science, but also on a willingness of elected and duly appointed leaders and managers to take actions in the face of uncertainties (Chapter 7).**
- **Decisions regarding the issue of additional water withdrawal permits are matters of public policy, but if additional permits are issued, they should include specific conditions that allow withdrawals to be discontinued during critical periods. Allowing for additional withdrawals during the critical periods of high demand, low flows, and comparatively high water temperatures identified in this report would increase risks of survivability to listed salmon stocks and would reduce management flexibility during these periods (Chapter 7).**
- **The State of Washington and other basin jurisdictions should convene a joint forum for documenting and discussing the environmental and other consequences of proposed diversions that exceed a specified threshold (Chapter 7).]**

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Appendix A

Columbia River Initiative Draft Management Scenarios
July 7, 2003

BACKGROUND

The Department of Ecology has developed the following set of alternative draft management scenarios as the next step in the Columbia River Initiative (CRI). The draft management scenarios reflect a range of potential water resources management strategies for the Columbia River mainstem. Each scenario describes a specific hypothetical management approach to water use and mitigation, if required, and generally describes the approach that would be used by Ecology decision-makers as they review water rights applications.

The scope of work for the National Research Council's committee includes a requirement to review and comment upon a set of management scenarios to be provided by the Department of Ecology. In the form described herein, the alternative scenarios represent early thinking about a range of possible outcomes relating risk to salmon and water use and establishing sufficient difference for scientific consideration. They should not be interpreted as a set of final proposals, nor as a package intended to constrain the potential outcomes of the scientific review. The management program that is eventually proposed by the Department of Ecology as a formal rule will have been shaped by feedback from the scientific review and would likely include elements that are yet to be suggested by interested parties.

As information becomes available from the science review, a management program will be developed for further refinement and will be drafted as a proposed rule by the Department of Ecology. Both formal and informal public review and comment will be included as elements of the rule-making process. Final adoption of the rule will take place following the publication of the National Research Council's report.

The management program developed as the basis for rule-making will become the most important product to result for the Columbia River Initiative. The guidance this program will provide to the Department of Ecology would in large part define the permitting program in regards to new water allocation and mitigation decisions and would be the basis upon which the State of Washington implements its dual responsibilities to manage water resources and protect the environment.

FIVE MANAGEMENT SCENARIOS

The following five draft scenarios are submitted to the National Research Council for review. With the exception of the No Action Scenario, each scenario describes an amount of water to be allocated for out-of-stream use, and any mitigation that might be undertaken in

conjunction with the increased use of water. The scenarios are further distinguished based upon a set of premises regarding the risk to salmonid populations that would arise from additional water withdrawals from the mainstem of the Columbia River.

Scenario 1: Water Allocation Linked to Current Salmon Efforts

The key premise of Scenario 1 is that there is a low risk to salmon survival resulting from existing and new allocations of water and that the state's current salmon recovery efforts are adequate, i.e. the benefits from current efforts exceed the risks associated with new water allocations. For Scenario 1, it is assumed that the state and region will continue to make current or increased investments in existing salmon recovery-related environmental activities, but that these investments are relatively unrelated to new Washington water resources management program that would allocate or recognize up to 2 million acre feet of new water over a 20-year period, 1 million of which would be for out-of-stream uses in Washington State.

As embodied in the Northwest Power Planning Council's Fish and Wildlife Plan and Washington's Statewide Strategy to Recover Salmon, existing salmon-related environmental activities include direct investments in salmon recovery projects made by the Salmon Recovery Funding Board and local salmon recovery groups, state and local investments in watershed planning, ongoing efforts to establish instream flows in tributaries to the Columbia River, the state program to purchase water rights to support instream flows, state and federal funding of irrigation efficiency. (Detailed descriptions of these programs will be provided to the National Research Council committee.)

In Scenario 1, it is assumed that water resources could be made available for use between the Canadian Border and the Bonneville Dam. New permits would be issued by the State of Washington during a 20-year window, not to exceed 1 million acre feet in total. Within the total amount of water allocated by Scenario 1 approximately 220,000 acre-feet would be made available to meet demand within the Columbia Basin Project. In addition to the 1 million acre feet to be allocated to Washington water users by Scenario 1, 427,000 acre-feet, representing flow and temperature management actions taken in the Snake River, would be legally recognized through the Washington State reaches of the Snake and Columbia Rivers, and 600,000 acre feet would be recognized as necessary to meet the water resources needs of the state of Oregon. Commitments of water resources in this scenario total 2 million acre feet, of which 1.6 million could be developed for out-of-stream use over the next 20 years.

Permits that are currently subject to interruption when stream flows reach a predetermined level could be, at the owner's option, converted to uninterruptible status. These water rights could be converted to uninterruptible status by demonstrating that current water use conforms to state-of-the-art water use efficiency practices. Likewise, all new water rights issued by the state would require state-of-the-art efficiency in proposed uses and would also be metered.

Periodic assessment of the state's water resources management program would be integral and ongoing. Scientific information would be used to adapt the program as necessary to accommodate changes in knowledge over time. Formal re-evaluations of the program would take place at year 10 and year 20.

In addition, the state would seek partners to create a functioning water market or "water bank" for the mainstem of the Columbia River to facilitate a more efficient allocation of existing water resources in the Basin.

Scenario 2: Incremental Mitigation Linked to New and Modified Permits

Scenario 2 presumes that a new level of contribution to salmon health and recovery would be required to secure sufficient additional benefits for fish and to offset the risk created by additional water withdrawals from the river. Revenue to support the additional level of effort would be generated by a $10 per acre foot per year usage charge on new permits and on existing rights that are converted from an interruptible to an uninterruptible status. The elements of the scenario would be in addition to the ongoing state and regional actions, assessment, and water bank described in Scenario 1.

New permits would be issued during a 20 year window, not to exceed 700,000 acre feet in total. The state would issue an additional 300,000 acre feet (a total of 1 million acre feet) from the mainstem once existing users demonstrate that conservation investments are in place for a majority of water users on the mainstem. Applicants for new permits or conversion of existing permits to uninterruptible status would also be required to demonstrate compliance with state-of-the-art efficiency standards.

Revenue generated would provide funds to acquire mitigation water in low water years and to make habitat improvements in the mainstem and tributaries. In addition to existing salmon-related environmental activities, the development of storage projects could be explored using these resources. Fisheries managers would be asked to prioritize the use of these resources, and would consider implementing a low water year strategy.

Scenario 3: Enhanced Level of Mitigation

This alternative would incorporate the current salmon recovery-related environmental activities and other proposed actions described in Scenarios 1 and 2. However, this scenario is premised on the notion that a more robust contribution to salmon health and survival would be necessary to secure additional benefits to fish and to offset the risks caused by additional water withdrawals from the river. Revenue to support the additional level of effort would be generated by a $20 per acre foot per year usage charge on new permits and on existing rights that are converted from an interruptible to an uninterruptible status. Revenue generated by the usage charge would be used to benefit salmon recovery projects. Consistent with Scenario 2, this alternative would create a 20-year window to issue new water use permits, in an amount not to exceed 1 million acre feet in total.

To supplement actions supported by the usage charge on new permits and on existing rights that are converted to an uninterruptible status, the state would provide financial support to install new conservation measures. The state would also actively explore other means to provide additional water for offstream and instream uses, e.g. storage developments. Fisheries managers would be asked to prioritize the use of these resources, and would consider implementing a low water year strategy.

Scenario 4: In-Place, In-Kind, and In-Time Mitigation

Scenario 4 assumes that the risk to salmonid survival that would result from additional water withdrawals from the Columbia River is so significant that it must be directly offset in

proportion to consumption. No new water rights would be permitted without being offset by direct mitigation in the mainstem of the Columbia River.

Under Scenario 4, all new water rights could be required to offset water use through water right changes and transfers, conservation, and/or utilizing newly developed storage capacity. The state would pursue conservation savings from existing rights and would also actively pursue storage projects that could provide the capacity to support new water resources for out of stream appropriation.

Existing water rights could be converted to an uninterruptible status by conforming to state-of-the-art water use efficiency standards and by paying a $30 per acre foot per year usage charge. Revenue generated would provide funds to acquire mitigation water in low water years and to make habitat improvements in the mainstem and tributaries.

Scenario 5: No Action Scenario

Scenario 5 assumes that the existing rule governing the water resources of the Columbia River, the Department of Ecology would require consultation with fish managers (Washington Department of Fish and Wildlife, Tribes, National Oceanic and Atmospheric Administration – Fisheries Division) prior to allocating new water rights. Under this scenario whether or not mitigation is required and the type and quantity of that mitigation is a decision that is made on each permit on a case by case base as a result of the consultation.

Appendix B

Resources Group

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2. Hal Beecher, Washington Department of Fish and Wildlife, Olympia
3. John Covert, Washington Department of Ecology, Olympia
4. Steve Hays and Joe Lukas, Mid-Columbia Public Utilities Districts
5. Robert Heineth, Columbia River Inter-Tribal Fish Commission, Portland, Oregon
6. Nate Mantua, University of Washington, Dept. of Atmospheric Sciences, Seattle
7. Tony Nigro, Oregon Department of Fish and Wildlife, Salem
8. Charley Petroskey, Idaho Department of Fish and Game, Boise
9. Howard Schaller, U.S. Fish and Wildlife Service, Vancouver
10. Paul Wagner, NOAA Fisheries, Seattle

Appendix C

Calculations on Annual Discharges of Water From the Columbia Basin Project

As was shown in Figure 3.3 gauged data are available on water withdrawals from Lake Roosevelt that serve as the principal supply water to the three irrigation districts in the Columbia Basin Project (CBP). In contrast, the total discharge from CBP that returns back into the main stem of the Columbia River is not measured or estimated. An attempt is hereby made to calculate irrigation return flows through an annual mass (volume) balance on water (Tanji and Kielen, 2002).

The annual mass balance on water from an irrigation project is defined as

$$\textit{Volume Water Inflows} - \textit{Volume Water Outflows} = \pm\Delta\ \textit{Storage} \quad (1)$$

If the control volume (system of interest) for CBP includes both the vadose and saturated zones of the CBP, Eq. (1) expands to

$$(\textit{Surface Water Inflows} + \textit{Subsurface Water Inflows}) - (\textit{Surface Water Outflows} + \textit{Subsurface Water Outflows}) = \pm\Delta\ \textit{Storage} \quad (2)$$

For a comprehensive mass balance on water in CBP the components of inflows and outflows may include:

$$\textit{Surface Water Inflows} = \textit{Irrigation water} + \textit{Precipitation} + \textit{Captured natural rim inflows} \quad (3)$$

$$\textit{Subsurface Water Inflows} = \textit{Ground water rim inflows} + \textit{Seepage inflow from river} \quad (4)$$

$$\textit{Surface Water Outflows} = \textit{Crop ET} + \textit{Non-crop ET} + \textit{Precipitation E\&ET} + \textit{Reservoir evaporation} + \textit{Irrig. canal \& lateral evaporation} + \textit{Drain canal Evap} + \textit{Operational and lateral spills} + \textit{Surface irrigation drainage into river} \quad (5)$$

$$\textit{Subsurface Water Outflows} = \textit{Ground water rim outflows} + \textit{Ground water outflows into river} + \textit{Phreatophyte ET} \quad (6)$$

Natural rim inflows refer to surface water inflows from the watershed into CBP such as Crab Creek watershed that is impounded in the Potholes Reservoir for use as irrigation water. Ground water rim inflows are the subsurface inflows of ground water from lands adjacent to CBP. Seepage inflows from river denote subsurface inflows into CBP from the main stem of the

Columbia River. The symbol *ET* is defined as evaporation losses (*E*) from moist soil and transpiration (*T*) losses of water from cropped plants as well as non-cropped or native vegetation other than phreatophytes that extract water from the saturated zone such as open drains and wetlands. Ground water rim outflows are subsurface flows from CBP to adjacent lands and ground water outflows into river are subsurface accretions of water into the Columbia River. The above components of water flows are typically available only when an irrigation project has been subjected to detailed hydrologic investigations and/or hydrologic modeling.

Over decades of time, ±Δ Storage in Eq. (1) may be assumed to be zero, so that

Water Inflows = Water Outflows (7)

The irrigation return flow (IRF) from CBP into Columbia River consists of spills from canals and laterals, surface irrigation drainage and ground water outflow into the river. When certain data like surface irrigation drainage and subsurface outflows into the river are not available as in the case of CBP, the above mass balance equations may be used to obtain these flows as a closure term (i.e., by difference). For the case of CBP, the principal missing data are surface irrigation drainage for Surface Water Outflows into the river as well as ground water outflow into river for Subsurface Water Outflows.

Fortunately, a Report on Water Supply, Use and Efficiency in the Columbia Basin Project is available from Montgomery Water Group, Inc. (1997). This Report, however, does not contain all of the water flow components identified in Eqs. (3) to (6) and therefore a more simplified water balance is utilized taking into consideration only the major components of water flow. The rationale for the simplification and neglecting certain flow components are as follows:

1. Annual average precipitation in the CBP is only about 10.1 inches, much of which is lost through ET, and hence precipitation and precipitation E&ET may be neglected.
2. Ground water rim inflows into CBP and rim outflow from CBP as well as seepage from the Columbia River into CBP are difficult components to estimate and herein assumed to cancel each other.
3. Non-crop ET or ET from native vegetation is assumed to be small as compared to crop ET and because of low annual precipitation, ET from phreatophytes is also assumed to be small.

If one accepts the above assumptions and simplifications, the annual mass balance on water in CBP may be rearranged to

(River withdrawal + Captured natural rim inflows) – (Crop ET + Reservoir evaporation + Canal & Lateral evaporation + Operational and lateral spills) = (Surface irrig. drainage + Ground water outflows into river) (8)

Appendix Table 1 contains the annual mass balance on water for CBP from 1975 through 1994. Column J gives the combined surface irrigation drainage and ground water outflow into the Columbia River, the closure term. In this mass balance it is not possible to separate out ground water outflow from surface irrigation drainage. The latter could be monitored comparatively easily but not the former. The ratio of irrigation return flow to total inflow averages 0.30 or 30% of supply water. This also means consumptive water use (evaporated to the

atmosphere) is 70% because ΔS is assumed to be zero. The irrigation return flow ratio for the Columbia Basin Project is similar to those of irrigation districts in California, e.g., Glenn-Colusa Irrigation District in the Sacramento Valley (0.29) and Panoche Water District in the San Jaoquin Valley (0.31) (Tanji, 1981), and Imperial Irrigation District in the Imperial Valley (0.36) (Kaddah and Rhoades, 1976).

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	A	B	C	D	E	F	G	H	I	J	K	L
1	Table Mass balance on water for Columbia Basin Project in millions of ac-ft/yr											
2	Closure on unmeasured flows:											
3	(Irrig water + Natural inflow) - (Crop ET + Res&Canal evap + Canal&Lateral spills) = (Surface irrig drainage + Ground water outflow to rive											
4												
5	A	B	C	D	E	F	G	H	I	J	K	L
6				(B+C)					(E+F+G+H)	(D-I)	(H+J)	(K/D)
7				Total			Canal&Lat	Canal&Lat				
8	Year	Irrig water	Nat inflow	inflow	CropET	ResEvap	Evap	Spills	Losses	Closure	IRF	Ratio
9	1975	2.14	0.271	2.411	1.32	0.179	0.182	0.191	1.872	0.539	0.73	0.303
10	1976	2.34	0.24	2.58	1.349	0.185	0.218	0.221	1.973	0.607	0.828	0.321
11	1977	2.627	0.057	2.684	1.4	0.181	0.219	0.21	2.01	0.674	0.884	0.33
12	1978	2.247	0.17	2.417	1.386	0.179	0.213	0.234	2.012	0.405	0.639	0.264
13	1979	2.671	0.117	2.788	1.309	0.182	0.238	0.203	1.932	0.856	1.059	0.38
14	1980*	1.454	0.139	1.593	1.315	0.176	0.199	0.241	1.931	-0.338	-0.097	-0.06
15	1981	2.913	0.079	2.992	1.303	0.177	0.213	0.245	1.938	1.054	1.299	0.434
16	1982	2.394	0.146	2.54	1.306	0.176	0.205	0.25	1.937	0.603	0.853	0.336
17	1983	2.055	0.156	2.211	1.355	0.17	0.202	0.249	1.976	0.235	0.484	0.219
18	1984	2.244	0.286	2.53	1.33	0.174	0.212	0.285	2.001	0.529	0.814	0.322
19	1985	2.269	0.118	2.387	1.37	0.177	0.226	0.271	2.044	0.343	0.614	0.257
20	1986	2.641	0.171	2.812	1.353	0.177	0.231	0.278	2.039	0.773	1.051	0.374
21	1987	2.548	0.117	2.665	1.324	0.176	0.267	0.29	2.057	0.608	0.898	0.337
22	1988	2.741	0.063	2.804	1.352	0.183	0.256	0.342	2.133	0.671	1.013	0.361
23	1989	2.621	0.168	2.789	1.352	0.179	0.25	0.294	2.075	0.714	1.008	0.361
24	1990	2.712	0.04	2.752	1.375	0.179	0.255	0.31	2.119	0.633	0.943	0.343
25	1991	2.773	0.071	2.844	1.393	0.178	0.277	0.309	2.157	0.687	0.996	0.35
26	1992	2.729	0.05	2.779	1.393	0.174	0.264	0.29	2.121	0.658	0.948	0.341
27	1993	2.417	0.102	2.519	1.482	0.179	0.225	0.302	2.188	0.331	0.633	0.251
28	1994	2.354	0.058	2.412	1.463	0.179	0.25	0.287	2.179	0.233	0.52	0.216
29	ave	2.444	0.131	2.575	1.362	0.178	0.23	0.265	2.035	0.54	0.805	0.302
30												
31		*Eruption of Mount St Helens interrupted irrigation										

Appendix D

Climate Change and Hydrologic Impacts

The regional climate of the Pacific Northwest influences water temperatures, the flows of the Columbia River, and the soil moisture and groundwater availability in the Columbia Basin. The flows and the temperature requirements for salmonids resources and the threatened and endangered stocks should be evaluated in the context of historic and potential future variability and change in both water temperatures and stream flow. Prospective changes in climate are important, as climate shifts over the past 30 years have produced shifts in the distributions and abundance of many species, and appears to be responsible for one species-level extinction (Thomas et al., 2004).

The regional climate influences water temperatures of the Columbia Basin. These water temperatures have been increasing over the last 45 years (1953-1998) in the Columbia River at a rate of about 0.38°C per decade or 1.9°C per 50 years (Figure 3.3). Some of this increase can arguably be accounted for by non-climatic changes in the river basin such as dams and reservoirs, changes in land use, increases in water withdrawals, and other factors. However, the nearest river to the Columbia River of similar dimensions is the undammed Fraser River in Canada, which also has experienced temperature increases from 1953-1998 of about 0.2°C per decade or almost 1°C per 50 years (British Columbia Ministry of Water, Land and Air Protection). Average August temperatures of the Columbia River (figure 3.3) are now about 5°C higher than the average summer temperatures of the Fraser River.

Historically, winter conditions contributing to winter snow pack, maximum stream flow in spring, and maintenance of summer and even winter flows have varied greatly over the last century. They are expected to vary and change in the future. The influence of inter-year and inter-decadal variability on the hydrograph at the Dalles Dam have been summarized from 1900-1998 by Miles et al. (2000; see also Hamlet and Lettenmaier, 1999). A dominant source of the inter-year variability in flows (Figure 3a from Miles et al. 2000) has been driven by the climate variability associated with El Niño-Southern Oscillation (ENSO) and La Niña conditions. The Pacific Decadal Oscillation (PDO) also drives variability of flows (Miles et al., 2000). These two large-scale climatic drivers (ENSO and PDO) can interact to affect the lowest and the highest flows. Although these climate change drivers are important and must be noted, a detailed analysis of these was beyond the scope of this report.

Prospective future climate changes (driven by greenhouse gas emissions) have been simulated, with many simulation model results suggesting that water supply of the Columbia River may be reduced in the next half century. Scenarios of future changes in the Columbia River hydrograph suggest that future warming will move the river towards conditions, on average, that are more similar to those observed during the warm phases of ENSO and PDO during the last century (Hamlet and Lettermaier, 1999; Miles et al., 2000). These simulations

were generated with two general circulation models (GCMs) for the years 2025, 2045, and 2095 using expected rates of CO_2 emissions. One model was from the Max Plank Institute in Germany and the other was the Hadley 2 model from the Hadley Center in the United Kingdom. Both models indicate warming in all months relative to historical air temperature from 1961-1997. For 2045, the projected air temperature increases in individual months range from about 1°C to about 4°C. The fact that the Hadley 2 model projects wetter conditions than observed historically especially in summer and fall, while the Max Planck model projects dryer conditions in the summer and fall, demonstrates the uncertainties associated with climate change model projections of changes in precipation associated with temperature increases. As noted, the models are more consistent in projecting temperature increases.

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Appendix E

Committee Biographical Information

ERNEST T. SMERDON, *Chair*, recently retired as vice-provost and dean of the College of Engineering and Mines at the University of Arizona. Dr. Smerdon has served as an advisor to the U.S. federal government and several foreign governments on water resources and agricultural development issues for four decades. He has authored over 100 professional papers on water resources planning, engineering, and irrigation. He has also served on several NRC committees and boards. He is a member of the National Academy of Engineering. Dr. Smerdon received his B.S. degree, his M.S. degree, and his Ph.D. degree, all in engineering, from the University of Missouri, Columbia.

RICHARD M. ADAMS is a professor of agricultural and resource economics at Oregon State University. Prior service includes assistant and associate professor, University of Wyoming. He has served as editor of the American Journal of Agricultural Economics and associate editor for Water Resources Research and the Journal of Environmental Economics and Management. He is a member of various government committees dealing with climate change, air and water pollution and other environmental issues. His current research focuses on the economic effects of air and water pollution, implications of climate change for agriculture and water resources, and tradeoffs between agricultural activity and environmental quality. Dr. Adams received his B.S. degree in resource management; his M.S. degree in agricultural economics, and his Ph.D. degree from University of California, Davis.

DONALD W. CHAPMAN is a consulting biologist, who lives in Eagle, Idaho. He was an inland fishery and stock assessment biologist with UNFAO in Cartagena, Colombia, and Kigoma, Tanzania. Earlier he was a professor and fishery unit leader at the University of Idaho, and a visiting professor at Montana State University and the University of Wisconsin. He formerly was Director of Research for the Oregon Fish Commission, Executive Secretary of the Oregon State Water Resources Research Institute, and coordinator of the Alsea Watershed Study. His interests include catch and stock assessment, anadromous fish passage problems, habitat evaluations, salmonid ecology, and fishery resource management. He has a B.S. in forest management, and an M.S. and Ph.D. in fisheries from Oregon State University.

DARRELL FONTANE is the director of the International School for Water Resources and a professor in the civil engineering Department at Colorado State University. His areas of interests are water resources decision support systems, computer aided water management and integrated water quantity and quality management. As director of the International School for Water Resources, he organizes non-degree programs for international engineers in various aspects of water resources engineering. His responsibilities also include graduate teaching and research in water resources systems analysis and computerized decision support systems. Dr. Fontane received his B.S. degree in civil engineering from Louisiana State University, his M.S. degree in civil engineering from the Georgia Institute of Technology, and his Ph.D. in civil engineering from Colorado State University.

ALBERT E. GIORGI is president and senior fisheries scientist at BioAnalysts, Inc. in Redmond, Washington. Dr. Giorgi has been conducting research on Pacific Northwest salmonid resources since 1982. Prior to 1982, he conducted research in marine invertebrate ecology and marine fish life history. In his capacity as a salmon biologist he specializes in migratory behavior, juvenile salmon survival studies, biological effects of hydroelectric development and operation, and population modeling. Dr. Giorgi's clients include: the Bonneville Power Administration; Northwest Power Planning Council; U.S. Army Corps of Engineers; Chelan, Douglas, and Grant County Public Utility Districts; and a number of engineering firms including: CH2M Hill Dames and Moore, Harza, HDR, INCA, and Montgomery Watson. He received his B.A. and M.A. degrees in biology from Humboldt State University, and his Ph.D. in fisheries from the University of Washington.

HELEN M. INGRAM is a professor of social ecology and the Drew, Chace and Erin Warmington Chair in the Social Ecology of Peace and International Cooperation at the University of California, Irvine. Her research interests include transboundary national resources, particularly on the U.S./Mexico border, water resources and equity, public policy design and implementation, and the impact of policy upon democracy and public participation. Dr. Ingram received her Ph.D. degree from Columbia University.

W. CARTER JOHNSON is a professor of ecology in the Deparment of Horticulture, Forestry, Landscape, and Parks at South Dakota State University in Brookings, South Dakota. Before going to South Dakota State University, he was with the Department of Biology at Virginia Tech. Dr. Johnson's research interests are in streamflow regulation and riparian ecosystems, restoration of ecological and economic sustainability of western reangelands, and global climate change and prairie wetlands. He received the W.S. Cooper Award in 1996 from the Ecological Society of America. Dr. Johnson served as a member of the NRC Committee on the Missouri River Ecosystem Science. He received received his B.S. degree in biology from Augustuna College, and his Ph.D. degree in botany from North Dakota State University.

JOHN J. MAGNUSON is emeritus professor of zoology and limnology at the University of Wisconsin-Madison. He is past director of the university's Center for Limnology and North Temperate Lakes Long-term Ecological Research Program. Dr. Magnuson's

research interests include long-term regional ecology, climate-change effects on lake ecological systems, fish and fisheries ecology, and community ecology of lakes as islands. He received his B.Sc. and M.Sc. degrees from the University of Minnesota and his Ph.D. degree in zoology with a minor in oceanography from the University of British Columbia.

STUART MCKENZIE is retired from the U.S. Geological Survey. While with the USGS in Maryland, he studied the salt-water interface movement in Maryland coastal streams and long-term trends of water quality in Delaware. When at the University of Delaware, he helped assess groundwater resources in the Dover area. In Oregon, he has studied quality of urban runoff and impacts of agricultural runoff on streams, and worked on the Willamette River Quality Assessment, Yakima River Basin Water Quality Assessment and Intergovernmental Task Force on Monitoring Water Quality. He is currently compiling and evaluating water temperature data from across the Columbia River. He received his B.S. degree in physics from the University of Puget Sound, and his MCE degree in civil engineering from the University of Delaware.

DIANE M. MCKNIGHT is a professor in the Department of Civil, Environmental, and Architectural Engineering and a fellow of the Institute of Arctic and Alpine Research at the University of Colorado. Dr. McKnight was a research scientist at the U.S. Geological Survey, Water Resources Division. She studies biogeochemical processes, aquatic ecology and reactive solute transport in streams and lakes in the Rocky Mountains and in polar desert areas of Antarctica. Dr. McKnight is the acting president of the Biogeosciences section of AGU. Currently, she is a member on USGCRP and IPCC committees on climate change and water resources. Her major research interest is in limnology and biogeochemical processes in natural waters. She received her B.S. degree in mechanical engineering, her M.S. degree in civil engineering, and her Ph.D. degree in environmental engineering from the Massachusetts Institute of Technology.

TAMMY J. NEWCOMB is the Lake Huron Basin Coordinator for the Michigan Department of Natural Resources Fisheries Division in Lansing, Michigan. In this position, she coordinates ecosystem- and watershed management for the Lake Huron drainages and the Lake Huron sport, tribal, and commercial fisheries. Dr. Newcomb is also an adjunct faculty member at the Virginia Polytechnic Institute and State University with a research focus on salmonid population dynamics, watershed and stream habitat management, and stream temperature modeling. Dr.Newcomb earned her Ph.D. degree at Michigan State University.

KENNETH TANJI is a professor emeritus of hydrologic science in the Department of Land, Air and Water Resources at the University of California, Davis. He is a Fellow of three professional societies. His major research interest is on water quality aspects of irrigation and drainage. Dr. Tanji has served on three previous NRC Committees. Dr. Tanji received his B.A. degree in chemistry from the University of Hawaii, Honolulu, his B.S. and M.S. degrees in soil science from the University of California, Davis, and his Sc.D. degree on Agricultural Science from Kyoto University, Japan.

JOHN E. THORSON is an Administrative Law Judge with the California Public Utilities Commission (CPUC) in San Francisco. An attorney, Thorson was Special Master for the Arizona General Stream Adjudication. He has served as regional counsel for the Western Governors' Conference; director of the Conference of Western Attorneys General; consultant to many state governments and courts; and director of the Missouri River Management Project for the Northern Lights Institute. Dr. Thorson received a B.A. degree from the University of New Mexico, a J.D. degree in 1973 from University of California, Berkeley, and a doctorate in public administration from the University of Southern California.

STAFF

JEFFREY W. JACOBS is a senior program officer at the National Research Council's Water Science and Technology Board. Dr. Jacobs' research interests include policy and organizational arrangements for water resources management and the use of scientific information in water resources decision making. He has studied these issues extensively in both the United States and in mainland Southeast Asia. Since joining the NRC in 1997, he has served as the study director for thirteen study committees. He received his B.S. degree from Texas A&M University, his M.A. degree from the University of California, Riverside, and his Ph.D. degree (all in geography) from the University of Colorado.

Appendix F

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