REPORT ON BIOLOGICALLY BASED FLOWS FOR THE YAKIMA RIVER BASIN

Report To:

The Secretary of the Interior

From:

The System Operations Advisory Committee

MAY 1999

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Members

Yakama Indian Nation	US Fish and Wildlife Service
(Robert Tuck)	(Jeff Thomas)
Washington Department of Fish and Wildlife	**Yakima Basin Joint Board**
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Yakima Washington

MAY 4, 1999

ABBREVIATIONS and ACRONYMS

AEAM:	Adaptive Environmental Assessment and Management
BPA	Bonneville Power Administration
ESU:	Evolutionarily Significant Units
FWS:	U.S. Fish & Wildlife Service
GIS	Geographic Information System
IFIM:	Instream Flow Incremental Methodology
MIF	Million Acre Feet
MMS:	Modular Modeling System
NAWQA:	National Water-Quality Assessment Program
NPPC:	Northwest Power Planning Council
R.M.:	River Mile
RVA:	Range of Variability Approach
SOAC:	System Operations Advisory Committee
Title XII:	Title XII of the Act of October 31,1994 Public Law 103-434
TMDL:	Total Maximum Daily Load
USBR	U.S. Bureau of Reclamation
USGS/BRD:	U.S. Geological Survey, Biological Resources Division
WARSMP:	Watershed and River Systems Management Program
WDFW:	Washington Department of Fish & Wildlife
WDOE:	Washington Department of Ecology
YBJB:	Yakima Basin Joint Board
YIN:	Yakama Indian Nation
YRBWEP:	Yakima River Basin Water Enhancement Project

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ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

REPORT ON BIOLOGICALLY BASED FLOWS FOR THE YAKIMA RIVER BASIN

PURPOSE, SCOPE, and AUTHORITY

Authority for the development of this report was provided within Section 1205(a)(6)(B), Title XII of the Public Law 103-434 which obligates the System Operations Advisory Committee (SOAC) with producing this document. The members of SOAC are fishery biologists representing the U.S. Fish and Wildlife Service (FWS), the Yakama Indian Nation (YIN), the Washington Department of Fish and Wildlife (WDFW), and irrigation entities identified as the Yakima Basin Joint Board (YBJB).

The purpose of this report is to provide Congress and the Secretary of the Interior with a review of factors affecting anadromous fish resources in the Yakima River and recommend processes and procedures required to determine biologically based flows for increasing the abundance of salmon and steelhead. Flow management of the Yakima River by the U.S. Bureau of Reclamation, (USBR)Yakima Project would provide the primary mechanism through which these recommendations would be enacted.

In determining the steps necessary to establish biologically based flows, SOAC interpreted its responsibility under Title XII to include evaluating many aspects of riverine ecology and consider flow management strategies which will potentially recover and maintain the aquatic ecosystem, rather than to evaluate reach-specific biological effects of the designated flows in Section (1).

WATER DEVELOPMENT, OTHER HUMAN INFLUENCES, and the SALMON RESOURCE

The Yakima River system has been modified by a complex array of reservoirs, diversion dams, canals, and drains used to convey water. Humans have not only changed the “basic plumbing” of the system, but have modified the timing, quantity, and quality of the flow in the river and its tributaries. In addition, flood control dikes and highway construction have reduced the extent of the river’s floodplain, disrupting connectivity to historically wetted areas and impacting ecosystem productivity. These changes, along with adverse conditions outside of the Yakima River Basin, have reduced the historically abundant runs of salmon and steelhead to critically low levels; the native anadromous sockeye, summer chinook, and coho salmon populations are extinct.

APPROACH and PHILOSOPHY

Scientific literature indicates that maintenance of river ecosystem function and its key component, flow regime, is necessary for salmonid recovery. A key assumption is that natural, unaltered flow regimes formed ecosystem conditions that favored abundant populations of salmonids. Human- induced flow regime changes have altered the ecosystem and reduced salmonid abundance. There is potential to improve salmonid production through altering the flow regime in incremental steps away from the current baseline conditions.

SOAC proposes that the USBR immediately begin a process of carefully designed incremental changes in flow regimes consistent with Title XII based on test hypotheses regarding physical, chemical, and biological responses of the river ecosystem. These carefully monitored actions would become part of an adaptive process to guide management actions in a comprehensive program to recover the aquatic ecosystem and the anadromous salmonid populations which depend on it.

RECOMMENDATIONS

Recommendation 1: Review and Synthesize Exiting Yakima River Ecosystem Health – Immediately review and synthesize all available data on flow management; water quality; land use activities; and biological communities and their relationship to ecosystem integrity and function. Information would be complementary to development of the other recommendations.

Recommendation 2: Develop an Historic Flow Template – Immediately develop a model of estimated historic flow regime conditions. These conditions, when compared to current conditions, would provide an assessment of changes that have occurred and are essential to Recommendations 3 and 4.

Recommendation 3: Development of a Watershed Hydrologic Model – Near real-time assessments of water availability and use are needed to develop and modify flow management. Completion of U.S. Geological Survey (USGS) and USBR Watershed and River Systems Management Program (WARSMP) model for the Yakima River Basin is supported.

Recommendation 4: Implement a Normative Flow Regime – Within the various restraints associated with river development, immediately initiate some level of modified flows to incrementally move toward pre-development hydrologic parameters.

Recommendation 5: Investigate Longitudinal, Lateral, and Vertical Connectivity – Aerial reconnaissance and GIS technology should be utilized to map the present and historic floodplain boundaries, and to assess elevations and channel morphometry to ascertain the extent of functional floodplain loss with river flow stage. Flow dynamics would be identified and linked to food web analysis to better identify expectations and benefits of normative flows.

Recommendation 6: Assess Status of Food Web – Establish study reaches to assess distribution, abundance of zoobenthos species, and flow connectivity in conjunction with estimates of primary and secondary production and assessments of inhabiting fish species which may indicate potential problems and suggest corrective measures.

Recommendation 7: Develop a Stream Network Water Temperature Model – A thermal assessment is needed to identify temperature constraints to correlate with habitat availability.

Recommendation 8: Evaluate Salmonid Habitat Conditions – Existing information on spawning, incubation, and rearing microhabitat needs to be reassessed. Additional evaluations of microhabitat availability should be undertaken using the more advanced habitat modeling methodologies developed in recent years.

Recommendation 9: Develop a Salmon Pre-Smolt Production Model – Develop an application of the SALMOD model (USGS/BRD) for the Yakima River Basin as one means to assess the effects of regulated flow regimes on anadromous salmonid production and quantitatively evaluate alternative water management practices.

Recommendation 10: Adaptive Environmental Assessment and Management – Initiate adaptive management program as soon as interim flow regimes are implemented to link management actions with monitoring and evaluation results, including smolt production and condition assessment.

1.0 INTRODUCTION

1.1 PURPOSE STATEMENT

The Yakima River Basin (Yakima Basin), historically a major producer of anadromous salmonids, is the site of the Yakima Project, a large irrigation project operated and managed by the U.S. Bureau of Reclamation (USBR). This report reviews factors affecting the production of salmon and steelhead in the Yakima River Basin and recommends processes and procedures to determine a biologically based flow regime. The objective of developing and implementing biologically based flows is to increase the survival and thereby, in the long-term, the production of salmon and steelhead smolts. The System Operations Advisory Committee (SOAC) produced this report for the United States Congress and the Secretary of the Interior to comply with the task assigned by Congress in Section 1205 (a)(6)(B), Title XII, Public Law 103-434 (Title XII).

1.2 LEGISLATIVE BACKGROUND

Title XII is the most recent in a series of Congressional acts that affect water resources in the Yakima River Basin. Following a series of years of below average runoff, Congress enacted Public Law 96-162 in 1979, the Yakima River Basin Water Enhancement Project (YRBWEP), authorizing the USBR to conduct a feasibility study addressing water resource needs in the Basin. The goals of YRBWEP are to: (1) provide supplemental water to presently irrigated lands; (2) provide water for new irrigation development on the Yakama Indian Reservation; (3) provide water to increase streamflow to protect and enhance salmon and steelhead runs; and (4) develop a comprehensive water management plan for the Basin.

The USBR initiated the feasibility study in 1980. Implementation of the YRBWEP began with Phase I in 1984, when Congress authorized the construction of fish ladders and screens, pursuant to the Northwest Power Planning and Conservation Act, Public Law 96-501. The USBR, Northwest Power Planning Council (NPPC), Bonneville Power Administration (BPA), the State of Washington, the Yakama Indian Nation (YIN), irrigation entities, and others have worked together to jointly fund and construct these facilities.

As fish ladders and screen facilities were being designed and constructed, alternative ways to improve the reliability of the Basin's water supply for irrigation and instream flows were being identified and evaluated. These studies led to passage of Title XII authorizing implementation of Phase 2 of YRBWEP. Title XII includes the following purposes: (1) "to protect, mitigate, and enhance fish and wildlife through improved water management; improved instream flows; improved water quality; protection, creation and enhancement of wetlands; by other appropriate means of habitat improvement; (2) to improve the reliability of water supply for irrigation." Further, Congress views Title XII as a "Federal action to improve streamflow and fish passage conditions and shall be considered part of a comprehensive program to restore the Yakima River Basin anadromous fishery resources" (Section 1203(d)(2)).

A primary component of Title XII is a voluntary Yakima River Basin Water Conservation Program that provides financial incentives for Basin interests to plan and implement water conservation measures. Implementation of water conservation measures by irrigation entities should improve system efficiencies and result in reduced water diversions. Two-thirds of the conserved water will be dedicated to instream flow needs for fish and wildlife protection, enhancement, and recovery, while the remaining water will be used to improve the reliability of the water supply for irrigation. Water may also be acquired to enhance instream flows by purchase or lease of land and/or water. A third component is the creation of additional storage by raising the height of the radial gates at Cle Elum Dam. Title XII also establishes new targets for instream flows at two locations in the lower Basin, and it provided for further increases in flows below Prosser Dam.

1.3 SOAC's CHARGE UNDER TITLE XII

SOAC is an advisory board to the USBR consisting of fishery biologists representing the U.S. Fish and Wildlife Service (FWS), the YIN, the Washington Department of Fish and Wildlife (WDFW), and irrigation entities represented by the Yakima Basin Joint Board (YBJB). The USBR provides a fishery biologist as a liaison to SOAC. Since 1981, SOAC has provided information, advice, and assistance to the USBR on fish-related issues associated with the operations of the Yakima Project, which are the responsibilities of the Project Field Office Manager.

Title XII specified target flows at Sunnyside and Prosser Diversion dams on the Yakima River (Table 1). These target flow levels have been implemented as required by Section 1205(a)(1)(B). The target flows are based on estimated water supply available for the remaining portion of the irrigation season, rather than biological criteria. Accordingly, SOAC has interpreted its responsibility under Title XII as a request to evaluate what is necessary to have biologically based flows, rather than to evaluate the specific biological effects of the designed flows in Section 1205(1).

Table 1. Yakima River target flows specified by Congress in Section 1205 (a)(1), Title XII, Pub. L. 103-434.

Water Supply Estimate for Period (million acre-feet):				Target Flow From Date of Estimate Thru October Downstream of (cubic feet per second):	
April thru September	May thru September	June thru September	July thru September	Sunnyside Diversion Dam	Prosser Diversion Dam
3.2	2.9	2.4	1.9	600	600
2.9	2.65	2.2	1.7	500	500
2.65	2.4	2.0	1.5	400	400
Less than line 3 water supply				300	300

The following sections provide the conceptual framework needed to perform an evaluation; a general summary of environmental and other features considered; a review of protocols and methodologies; recommendations for a process to determine biologically based flows; and necessary monitoring and research. Included are water management measures that can be implemented immediately or in the near term without additional studies to facilitate the objectives of Title XII for anadromous salmonid recovery.

1.4 FRAMEWORK UNDERLYING BIOLOGICALLY BASED TARGET FLOW REPORT

In order to evaluate the target flows specified by Congress and determine the steps necessary to establish biologically based target flows for anadromous salmonids, SOAC will evaluate many aspects of riverine ecology and consider flow management strategies which will potentially recover and maintain the aquatic ecosystem. From the headwaters to the mouth, a river system displays a continuous gradient of in-channel physical conditions such as width, depth, velocity, flow, sediment load, and temperature which create habitat and influence the distribution and abundance of aquatic organisms. The physical conditions of the river Basin are determined largely by the local geology and climate (Vannote et al., 1980; Stanford et al., 1996). The biological components of a river basin interact with the physical conditions, forming the river ecosystem.

Human activities influence the biological components and the physical conditions (i.e. habitat) of a river basin, altering the river ecosystem. The biotic components are influenced directly by activities such as habitat alteration, fisheries harvest, and introduction of exotic plant and animal species. Habitats are altered by activities such as dam and levee construction, water diversions, encroachments by urban development and agricultural activities, and highway construction. Activities that change the physical conditions frequently lead to unpredictable changes in riverine biotic communities (Ward and Stanford, 1995a). The physical condition of the Yakima Basin watershed and river channels has been significantly altered from the pre-development conditions. The fluvial processes which form and maintain aquatic habitats have been disrupted and severe habitat degradation has occurred as the Basin has been transformed into a major population area with an economy based on 500,000 acres of irrigated agriculture.

The key to recovering anadromous fish populations in the Yakima Basin is to re-establish lost or altered ecosystem functions within the framework of the “normative ecosystem concept” (Williams et al., 1996). A normative ecosystem may be described as an ecosystem that biologically sustains all life stages of diverse salmonid populations. Further, “The normative ecosystem is not a static target or a single unique state of the river. It is a continuum of conditions from slightly better than the current state of the river at one end of the continuum, to nearly pristine at the other end” (Williams et al., 1996). By emphasizing the concepts and analytical tools of contemporary river ecology, SOAC’s goal is to recommend a process for determining flows capable of re-establishing a sustainable, “normative” ecosystem. SOAC believes that a normative river ecosystem will lead to increased survival rates for juvenile life stages and result in increased smolt production and ultimately, harvestable returns of adult anadromous salmonids.

SOAC recognizes that factors outside of the Yakima Basin, such as environmental conditions and harvest levels in the mainstem Columbia River and the ocean, have also impacted Yakima Basin anadromous salmonid populations. Because these factors are beyond the jurisdiction and scope of Title XII, changes in adult salmon and steelhead returns are not appropriate indices to evaluate the effects that changes in Yakima Basin water management may have on anadromous salmonid production. SOAC has determined that intra-basin indicators, including salmon and steelhead early life stage survival and smolt production in addition to indices of habitat quality and quantity, are the most suitable criteria for evaluating the effects of flow management.

Title XII target flows do not provide for normative ecosystem function and cannot be expected to fully achieve the objectives of enhancing and recovering anadromous fish populations. Water supply-based mean monthly flows do not address the problem of unnatural, severe flow fluctuations below both control points, which may negate the fish and invertebrate habitat benefits of higher base flows. Additionally, Title XII target flows at the two control points do not address fish habitat and food web needs at the basin level, and thus, by themselves cannot be expected to lead to recovery of anadromous fish runs. Adequate information on ecosystem processes, and how these processes are affected by Yakima Project operations, is currently available to identify those elements which should be evaluated to derive biologically based instream flows. Therefore, SOAC’s recommendations, described in detail in Section 4.0 of this report, define a process to more fully explore and evaluate the relationships between river flow manipulations and the river ecosystem, allowing the USBR to manage Title XII flows for maximum benefit to the ecosystem.

SOAC recognizes that the time frame for implementing certain recommendations is necessarily long-term, which is undesirable from the standpoint of timely implementation of measures that may help prevent further decline of anadromous fish runs. Preliminary to the comprehensive investigations recommended in this report, an interim biologically based flow regime could be developed within the Title XII framework. Such a flow regime may prevent further decline of Yakima Basin salmon and steelhead populations while long-term studies are conducted that will lead to refinement (or replacement) of the interim flow regime. Therefore, SOAC also recommends actions that may be implemented immediately to improve the integrity of the aquatic ecosystem.

SOAC strongly recommends that the USBR proceed with management changes to benefit anadromous fish by incorporating the process of adaptive management (Holling, 1978). That is, changes in water management practices should be implemented as scientific experiments, with a description of hypotheses, test conditions, and clear experimental designs. Peer review and adequate documentation is critical to this process. In order for adaptive management to succeed, the documentation and results of such experiments must be clearly and openly described, presented to water-managers, and incorporated into management decisions. The end result should improve management responses to environmental problems.

2.0 BACKGROUND

Contemporary ecological theory recognizes the importance of considering not only the biology of organisms, but also the biogeochemical processes that control the distribution and production of biota, and human influences on those processes (Stanford et al., 1996). The following sections summarize the general environmental features in the Basin and factors considered by SOAC in developing this report.

2.1 GENERAL DESCRIPTION OF THE YAKIMA RIVER BASIN AND RESOURCES

The Yakima River Basin is located in south-central Washington and encompasses the majority of Yakima and Kittitas Counties, the northern half of Benton County, and a small part of extreme northern Klickitat County (Figure 1). The Basin contains a diversity of land forms, including the high, glaciated peaks and deep valleys of the Cascade Mountains in the western portion of the Basin, broad river valleys in the eastern and southern portions of the Basin, and a series of southeast-trending anticlinal ridges. The Yakima Project includes approximately 500,000 acres of irrigated agriculture within the Yakima River Basin (Figure 2). The Yakima River is more than 214 miles in length and has a drainage area of approximately 6,155 square miles. The river begins at the outlet of Keechelus Lake, elevation 2,517 feet, then flows in a southeasterly direction through a series of valleys and ridges to its confluence with the Columbia River at an elevation of 340 feet (Johnson, 1964). Figure 3 is a schematic diagram showing relative positions of selected tributaries, diversion canals, return flows and stream-gaging stations in the Yakima River Basin.

The Yakima River Basin lies across two distinctly different geologic terrains made up of basaltic lava flows and sediments interbedded with and overlying the basalts (Figure 4) (Kinnison and Sceva, 1963). Bedrock in the mountainous areas north of Snoqualmie Pass (upper mainstem and upper Cle Elum River drainages) is mostly intrusive volcanic rock a few tens of millions of years old. The Teanaway River and lower Cle Elum River drainages contain a sequence of continental sedimentary rocks including sandstone, shale, and coal seams, overlying older oceanic basement rock. The Columbia River Basalt eruptions filled pre-existing topography and left a broad low plateau. Subsequent uplift in the Cascades caused dissection of the major river valleys and ranges and reduced precipitation in the Basin. Folding of the plateau created the numerous southeast-trending anticlinal ridges and synclinal valleys of the eastern Yakima River Basin. Deposits of volcanic debris shed from now-extinct Cascade volcanoes (the Ellensburg Formation) partially filled the valleys to thicknesses exceeding one thousand feet. The Yakima River cut through the rising ridges creating the Yakima Canyon and the water gaps at Selah and Union Gaps.

Precipitation varies from approximately 128 inches along the crest of the Cascade Mountains to less than 8 inches in the eastern half of the Basin. Much of the precipitation falls as snow during the fall, winter, and early spring. The snowpack provides much of the streamflow during the course of the year. The major land-use activities in the Basin include timber production, grazing, irrigated agriculture, and urbanization. Yakima County is among the leading agricultural counties in the United States (BOR, 1999).

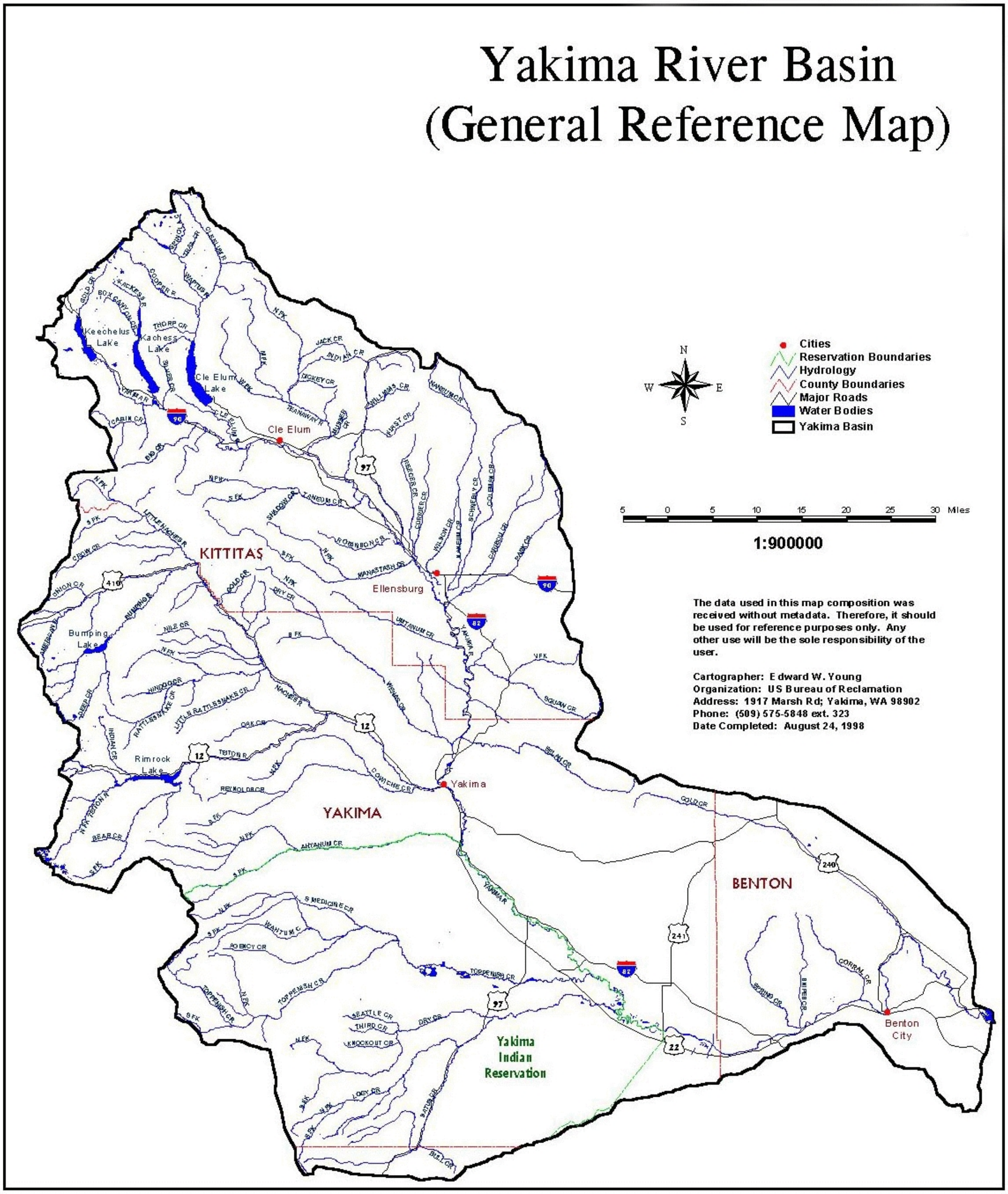

Yakima River Basin
(General Reference Map)
N
W
E
S
Cities
Reservation Boundaries
Hydrology
County Boundaries
Major Roads
Water Bodies
Yakima Basin
5 0 5 10 15 20 25 30 Miles
1:900000
The data used in this map composition was received without metadata. Therefore, it should be used for reference purposes only. Any other use will be the sole responsibility of the user.
Cartographer: Edward W. Young
Organization: US Bureau of Reclamation
Address: 1917 Marsh Rd; Yakima, WA 98902
Phone: (509) 575-5848 ext. 323
Date Completed: August 24, 1998
Keechelus Lake
Kachess Lake
Cle Elum Lake
Cle Elum
Ellensburg
KITTITAS
Bumping Lake
Rimrock Lake
Yakima
YAKIMA
BENTON
Benton City
Yakima Indian Reservation
90
97
410
82
12
240
241
22

FIGURE 1

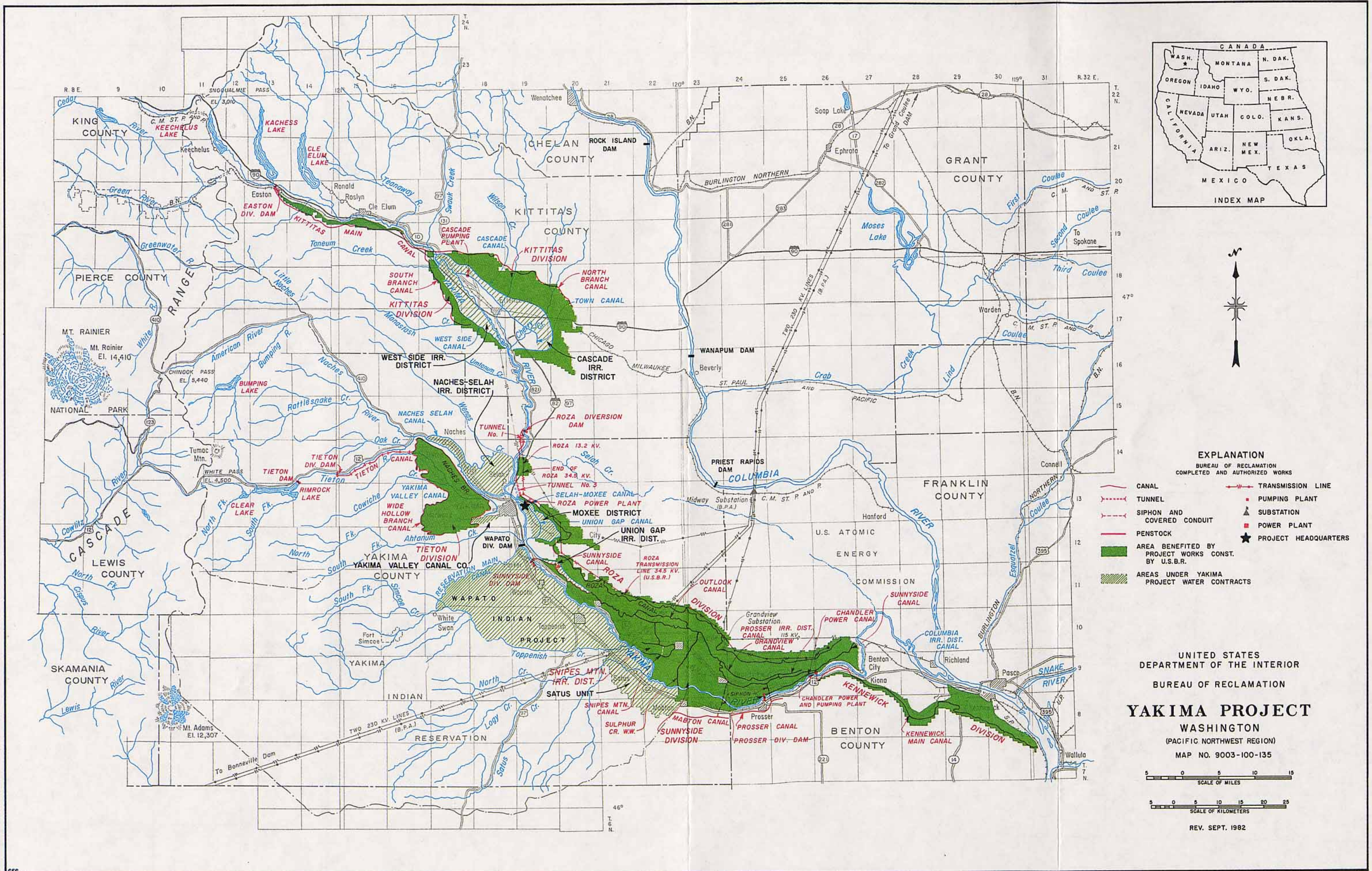
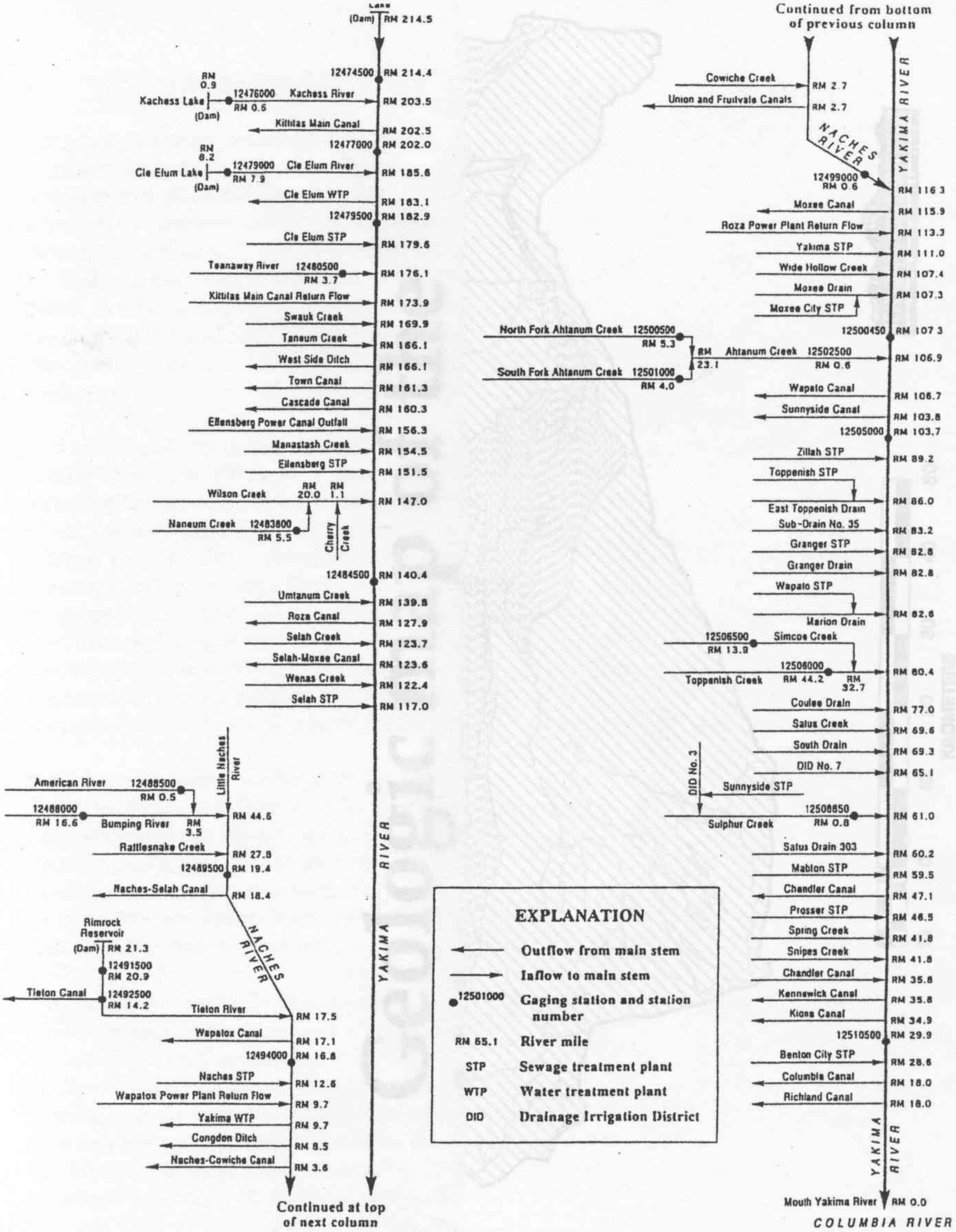

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
YAKIMA PROJECT
WASHINGTON
(PACIFIC NORTHWEST REGION)
MAP NO. 9003-100-135
SCALE OF MILES
SCALE OF KILOMETERS
REV. SEPT. 1982
EXPLANATION
BUREAU OF RECLAMATION COMPLETED AND AUTHORIZED WORKS
CANAL
TUNNEL
SIPHON AND COVERED CONDUIT
PENSTOCK
AREA BENEFITED BY PROJECT WORKS CONST. BY U.S.B.R.
AREAS UNDER YAKIMA PROJECT WATER CONTRACTS
TRANSMISSION LINE
PUMPING PLANT
SUBSTATION
POWER PLANT
PROJECT HEADQUARTERS
INDEX MAP
CANADA
MEXICO
KING COUNTY
PIERCE COUNTY
LEWIS COUNTY
SKAMANIA COUNTY
CHELAN COUNTY
KITTITAS COUNTY
YAKIMA COUNTY
GRANT COUNTY
FRANKLIN COUNTY
BENTON COUNTY
KEECHELUS LAKE
KACHESS LAKE
CLE ELUM LAKE
BUMPING LAKE
CLEAR LAKE
RIMROCK LAKE
EASTON DIV. DAM
KITTITAS MAIN CANAL
CASCADE PUMPING PLANT
CASCADE CANAL
KITTITAS DIVISION
SOUTH BRANCH CANAL
NORTH BRANCH CANAL
TOWN CANAL
WEST SIDE CANAL
WEST SIDE IRR. DISTRICT
CASCADE IRR. DISTRICT
NACHES-SELAH IRR. DISTRICT
NACHES SELAH CANAL
ROZA DIVERSION DAM
TUNNEL No. 1
ROZA 13.2 KV.
END OF ROZA 34.5 KV.
TUNNEL No. 3
SELAH-MOXEE CANAL
ROZA POWER PLANT
MOXEE DISTRICT
UNION GAP CANAL
UNION GAP IRR. DIST.
TIETON DIV. DAM
TIETON CANAL
TIETON DAM
YAKIMA VALLEY CANAL
WIDE HOLLOW BRANCH CANAL
TIETON DIVISION
WAPATO DIV. DAM
YAKIMA VALLEY CANAL CO.
SUNNYSIDE CANAL
SUNNYSIDE DIV. DAM
ROZA TRANSMISSION LINE 34.5 KV. (U.S.B.R.)
ROZA DIVISION
OUTLOOK CANAL
WAPATO INDIAN PROJECT
PROSSER IRR. DIST. CANAL
GRANDVIEW CANAL
CHANDLER POWER CANAL
SUNNYSIDE CANAL
COLUMBIA IRR. DIST. CANAL
SNIPES MTN. IRR. DIST.
SATUS UNIT
SNIPES MTN. CANAL
SULPHUR CR. W.W.
MABTON CANAL
SUNNYSIDE DIVISION
PROSSER CANAL
PROSSER DIV. DAM
CHANDLER POWER AND PUMPING PLANT
KENNEWICK DIVISION
KENNEWICK MAIN CANAL
ROCK ISLAND DAM
WANAPUM DAM
PRIEST RAPIDS DAM
COLUMBIA
U.S. ATOMIC ENERGY COMMISSION
MT. RAINIER NATIONAL PARK
Mt. Rainier El. 14,410
Mt. Adams El. 12,307
CASCADE RANGE
YAKIMA INDIAN RESERVATION
Moses Lake
Soap Lake
Ephrata
Wenatchee
Ellensburg
Yakima
Selah
Naches
Wapato
Toppenish
Sunnyside
Grandview
Prosser
Benton City
Kiona
Richland
Pasco
Kennewick
Wallula
Beverly
Warden
Connell
Hanford
To Spokane
To Bonneville Dam
TWO 230 KV. LINES (B.P.A.)
BURLINGTON NORTHERN
CHICAGO MILWAUKEE ST. PAUL AND PACIFIC
SNOQUALMIE PASS EL. 3,010
CHINOOK PASS EL. 5,440
WHITE PASS EL. 4,500

FIGURE 2



Schematic diagram showing relative positions of selected tributaries, diversion canals, return flows, and stream-gaging stations in the Yakima River Basin, Washington.

Yakima River Basin Schematic

FIGURE 3

Geologic map of the Yakima River Basin

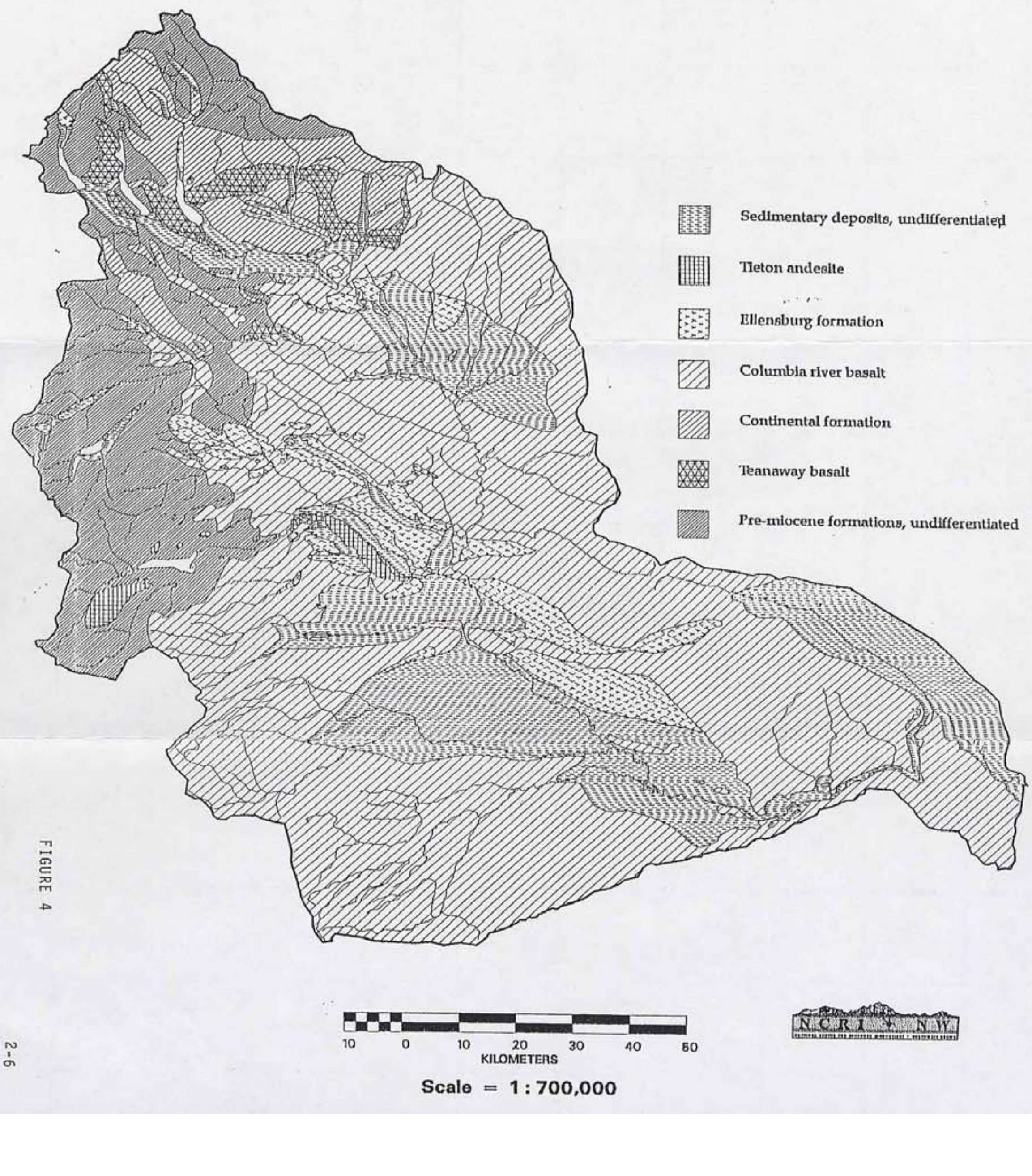


FIGURE 4

2.2 HISTORIC HYDROLOGIC SETTING

The geologic history described above produced features that regulate the hydrologic cycle and aquatic ecosystem in the Yakima River Basin. Contemporary river ecology emphasizes the importance of alluvial floodplain reaches. The Basin contains many extensive floodplain reaches separated by relatively short canyon reaches which effectively subdivides it into several alluvial subbasins. Within each, surface water downwells and recharges the shallow groundwater zone at the upstream end; most of this water upwells to the surface again near the downstream end of the reach. In other western river basins this pattern of downwelling and upwelling flow and the associated interstitial flow through alluvium has been shown to drive most biological productivity (Stanford, 1996, 1997). Kinnison and Sceva (1963) show the major gaining and losing stream reaches in the Yakima River Basin.

In the Yakima River Basin, streamflow was historically moderated by natural storage processing (Parker and Storey, 1916), particularly groundwater storage and storage in natural lakes, including the large natural lakes that existed at the current sites of major storage reservoirs, Cle Elum, Kachess, Keechelus, and Bumping Lakes. These processes captured peak flows and released water gradually, sustaining river flows through extended periods of little precipitation. Pre-irrigation system maps show that historically, the channel system in the Basin was much more complex with myriad side channels and dense riparian vegetation. Without the current reservoirs capturing or regulating most of the winter and spring runoff, overbank flows were much more frequent. Flood waters infiltrated into the floodplain alluvium and were naturally released later (natural groundwater storage) sustaining summer flows and moderating water temperatures (Parker and Story, 1916; Kinnison and Sceva, 1963).

Published information on the natural hydrograph of the Yakima River is found in Parker and Story (1916) and in historical streamflow records of the U.S. Geological Survey. Parker and Story estimated that natural flow at Parker gage station followed a basic pattern of peak runoff during April through June in the range 7,000-12,000 cfs. Flows receded throughout the summer months with annual lows occurring in September and October. The lowest estimated mean-monthly flow was approximately 800 cfs. Flows were higher at Parker in the late summer and fluctuated less than with the current level of development and reservoir operations.

"Major floods historically (and presently) occur during the winter (mid-November through February), usually resulting from a "rain-on-snow" precipitation event coupled with a rapid thaw. With only one million acre-feet (1 MAF) of Yakima Project storage capacity and a large catchment basin producing a mean annual runoff in excess of 3.5 MAF, significant "channel-forming" flood events still occur at relatively short intervals. Major floods provide sufficient hydraulic energy to periodically reshape the river channel and associated riparian vegetation. A 25,000 cfs peak instantaneous flow at the Yakima River gaging station at Parker, currently has a recurrence interval of 10 years. A 58,000 cfs event in February 1996 had a 120-year recurrence interval (Table 2). Table 2 also illustrates the effect of Yakima Project storage development on natural flood events. The difference between the "estimated unregulated" peak discharge (Q_U) and the observed discharge reflects the "flood-moderating" influence of the storage reservoirs.

Early 20th century flood events, including the record event in 1933, show a smaller difference between Q_U and the observed peak discharge because of the incremental construction of the five major storage reservoirs over a 25-year period (1910-1935).

Table 2. YAKIMA RIVER BASIN FLOOD FLOWS BASED UPON YAKIMA RIVER @ PARKER

Highest Known Floods Above 25,000 cfs Since 1908 in Order of Magnitude

#	DATE OF CREST	WATER YEAR	GAGE HT. STAGE-FT.	REG. INST. PEAK DISCHG. (CFS)	EVENT[1] FREQ. IN YRS.	INST. (UNREG.) CFS	EVENT[2] MEAN DAILY UNREG. QU(CFS)
1	DEC. 23, 1933	1934	(17.7)	65,000	150		81,662
2	FEB. 09, 1996	1996	16.21	58,150*	110	92,700	85,298
3	DEC. 30, 1917	1918	16.8	52,900	85		
4	MAY 29, 1948	1948	15.0	37,700	30		60,683
5	NOV. 30, 1995	1996	14.61	36,500*	25	76,300	80,777
6	DEC. 13, 1921	1922	14.7	35,800	25		
7	NOV. 26, 1990	1991	14.50	35,620*	25	56,400[3]	
8	NOV. 25, 1909	1910	14.6	35,000	25		
9	DEC. 02, 1977	1978	13.97	34,320	25		64,460
10	DEC. 27, 1980	1981	13.44	31,675	20		65,955
11	JAN. 16, 1974	1974	13.3	27,700	10		42,351
12	DEC. 04, 1975	1976	13.3	27,600	10	61,800	56,713
13	NOV. 24, 1959	1960	13.2	27,400	10		48,440
14	JUNE 19, 1916	1916	12.7	24,800	10		

Note: all gage height stage-feet based upon present site datum

* Based upon Provisional Data (Calculated)
[1] Based upon cumulative frequency curve, April 1986, Brown/Merkle
[2] May not be same day as peak regulated discharge = peak PARW QD + SYS QU day before
[3] Event primarily driven by upper Yakima Basin runoff

2.3 MODIFICATION OF THE HYDROLOGIC REGIME

By 1902, approximately 121,000 acres were under irrigation in the Yakima River Basin (BOR, 1999). In that year, Congress passed the Reclamation Act and the Reclamation Service was created to develop water resources in the West. The citizens of Yakima County petitioned the Secretary of the Interior on 28 January 1903, requesting the development of irrigation facilities in the Yakima River Basin. Federal involvement in the management of the water resources in the Basin began in 1905 with authorization to build various components of what is now the Yakima Project.

Development of the Yakima Project included the construction of Bumping Dam (1910), Kachess Dam (1912), Clear Creek Dam (1914), Keechelus Dam (1917), Tieton Dam (1925), and Cle Elum Dam (1933) (BOR, 1981). The Yakima Project now consists of seven divisions: a storage division comprising the six reservoirs with a total capacity of approximately 1.07 million acre-feet; and six water delivery divisions-Yakima-Tieton Irrigation District, Sunnyside Valley Irrigation District, Wapato Irrigation Project, Kittitas Reclamation District, Roza Irrigation District, and Kennewick Irrigation District. The Wapato Irrigation Project is located on the Yakama Indian Reservation and is operated by the Bureau of Indian Affairs.

Annual estimated unregulated runoff at the stream gauge located on the Yakima River near Parker averages 3.5 million acre-feet. The average annual irrigation diversion requirements are approximately 2.2 million acre-feet (BOR, 1999). The other requirements for water in the Basin include instream flows, municipal and industrial uses, and hydropower generation. The Yakima Project now exists as a complex array of reservoirs, diversion dams, canals, and stream channels that are utilized to store, divert, and convey water. Human influences on the river system have not only changed the basic "plumbing," but have modified the timing and quantity of flow in the Yakima River and its tributaries.

Reclamation operates the Yakima Project to provide irrigation water, instream flows, a measure of flood control, and for other purposes. Typically, reservoirs are operated to store water from the end of the irrigation season in October until releases for irrigation are required the following spring or summer, the onset of "storage control." During the storage control period, reservoirs are drawn down to meet irrigation demands. Flood control operations are implemented as required based on reservoir content, snowpack, and projected and actual runoff. Reservoir releases may be made to maintain space in the reservoirs for expected runoff in the fall, winter, or spring, depending upon the previously noted factors.

The USBR maintains a network of stream gauging stations throughout the Basin. Streamflow data are brought into a computerized data management system, known as the Hydromet, which is primarily used to support reservoir operations. These data have also been utilized in a hydrologic model of the Basin developed and used during the YRBWEP planning process. The model allows calculation of estimated unregulated flows (Q_u) at a limited number of gauging locations. This flow data from the Yakima River at Easton, Naches River at Naches, and the Yakima River near Parker were used to characterize the magnitude of changes in the flow regime due to regulation (Figure 5). Average daily flows for the period from 1986 through 1995 were used to represent current operations of the system. Figure 5 demonstrates the relative magnitude of changes that have occurred at the selected sites.

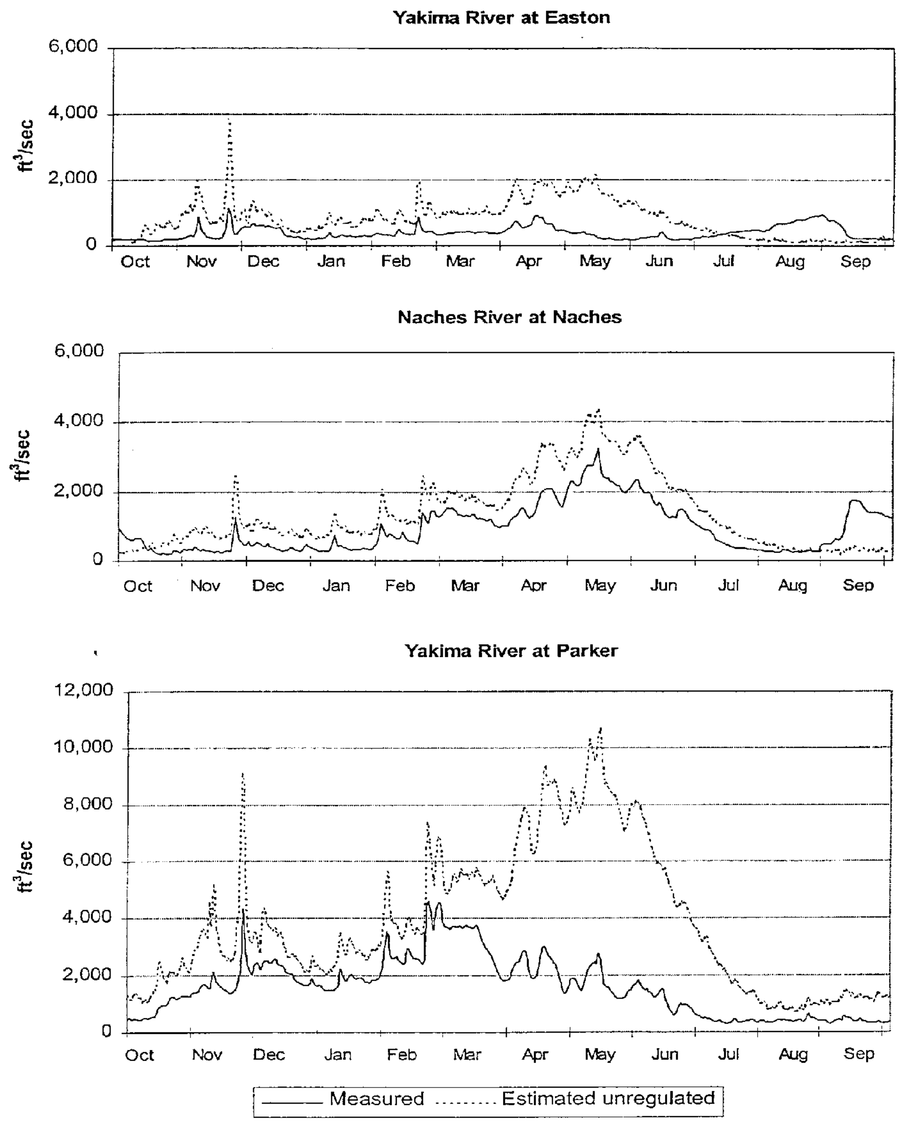


Figure 5. Comparison of average daily measured and estimated unregulated flows at three locations in the Yakima River basin, 1986-1995.

The Yakima Project is also operated to provide some instream flows for the partial protection of anadromous fish. Under Title XII, specific instream-flow levels are to be maintained below Sunnyside and Prosser dams. From time to time, flows may be provided to assist the out-migration of juvenile salmon and steelhead during the spring and summer.

Pursuant to a 1980 decision of Federal District Court for the Eastern District of Washington (KRD v. SVID, Civil No. 21), the Yakima Project is operated to protect incubating spring chinook eggs and alevins in the upper Yakima River Basin. This operation has become known as "flip-flop," and is implemented as follows: Through early September, most irrigation water requirements are met from reservoirs on the Yakima arm (Keechelus, Kachess, and Cle Elum) with minimal releases from Naches arm reservoirs (Rimrock and Bumping). On or near September 10th, major releases are transferred from the reservoirs on the Yakima arm to the reservoirs on the Naches arm.

The purpose of this flow manipulation is to reduce the potential impact of incubation flows on the irrigation water supply while protecting incubating spring chinook eggs and alevins in the upper river between Easton and the confluence of the Teanaway River (river mile 203.5 to 176.1). That is, lower spawning flows force spring chinook to construct their redds (nests) lower in the river channel, thereby requiring lower incubation flows. Because the Keechelus to Easton reach normally receives significant natural inflow, the need for winter augmentation of incubation flows is minimal. The redds located in the Cle Elum River downstream of Cle Elum Dam receive minimal natural inflow and require significant reservoir releases. Spawning and incubation flows are recommended by SOAC and others, with the final decision being the responsibility of the Yakima Field Office Manager.

A comparison of the effects of regulation on the variability of hourly flows was performed (Figure 6). Measured flow data was used because of the uncertainty associated with the calculated unregulated flow (Q_u). Two sites located in the upper Basin, the Little Naches River and the Teanaway River were chosen to characterize the unregulated patterns. There is little or no development or water diversions upstream from these sites. The Yakima River near Parker was used to characterize a regulated site because of its position in the Basin and location immediately downstream from two major diversions. Hourly flows for the period from 15 June through 31 July 1996, were used for this comparison. Flow variability was examined because it has been demonstrated that the excessive, cyclic de-watering and re-watering of shallow or slack water habitats on weekly, hourly, or even daily schedules can result in dramatic reductions in biotic productivity (Perry, Perry, and Stanford, 1986; Reckendorfer et al., 1996; Schiemer et al., 1991; Travnichek et al., 1995; Weisberg et al., 1990). Stable shallow or slack water habitats are especially important to the survival of early life history stages of fish that cannot survive in the strong currents of the main channel (Stanford et al., 1996). Stability of these habitats allows the food webs that these early life history stages depend upon to develop in areas where the fish can maintain a positive energy balance.

A diurnal variation in flow is expressed in both the Little Naches River and the Teanaway River. However, the percent change in flow from one hour to the next rarely exceeds three percent (Figure 7). In contrast, the Yakima River at Parker data displays a very different pattern. Although a general decrease in flows occurs early in the period, wide variations occur throughout (Figure 6). Two-fold reduction and increases in flow often occur over periods as short as one day. This pattern of greater discharge (water-level) fluctuations in the lower mainstem relative to the upper tributaries is opposite the normal pattern in unregulated rivers where mainstem water-level fluctuations are dampened by nonsynchronous contributions from larger channel capacity and the effect of floodplain storage.

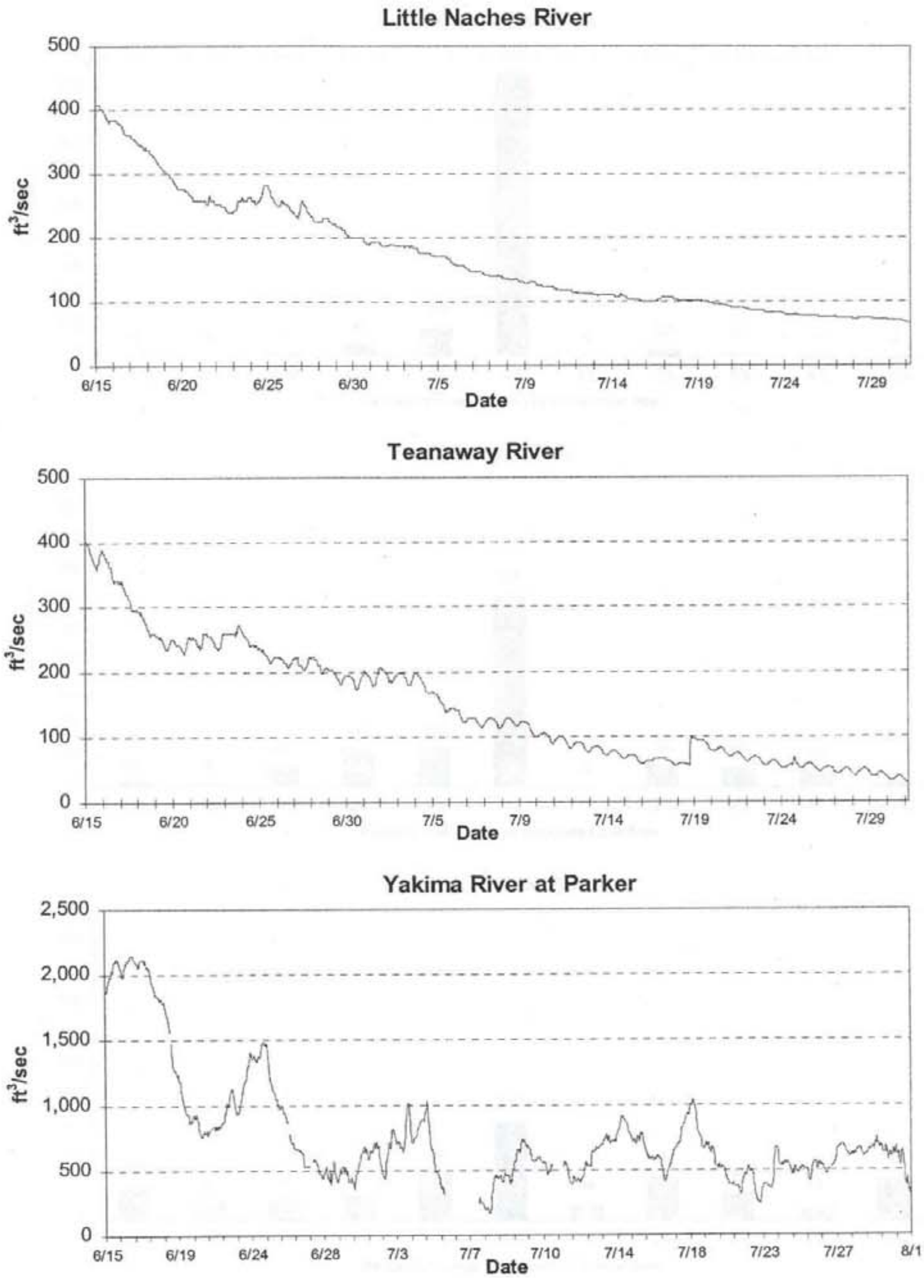


Figure 6. Hourly flows at three locations in the Yakima River basin, 15 June to 31 July 1996.

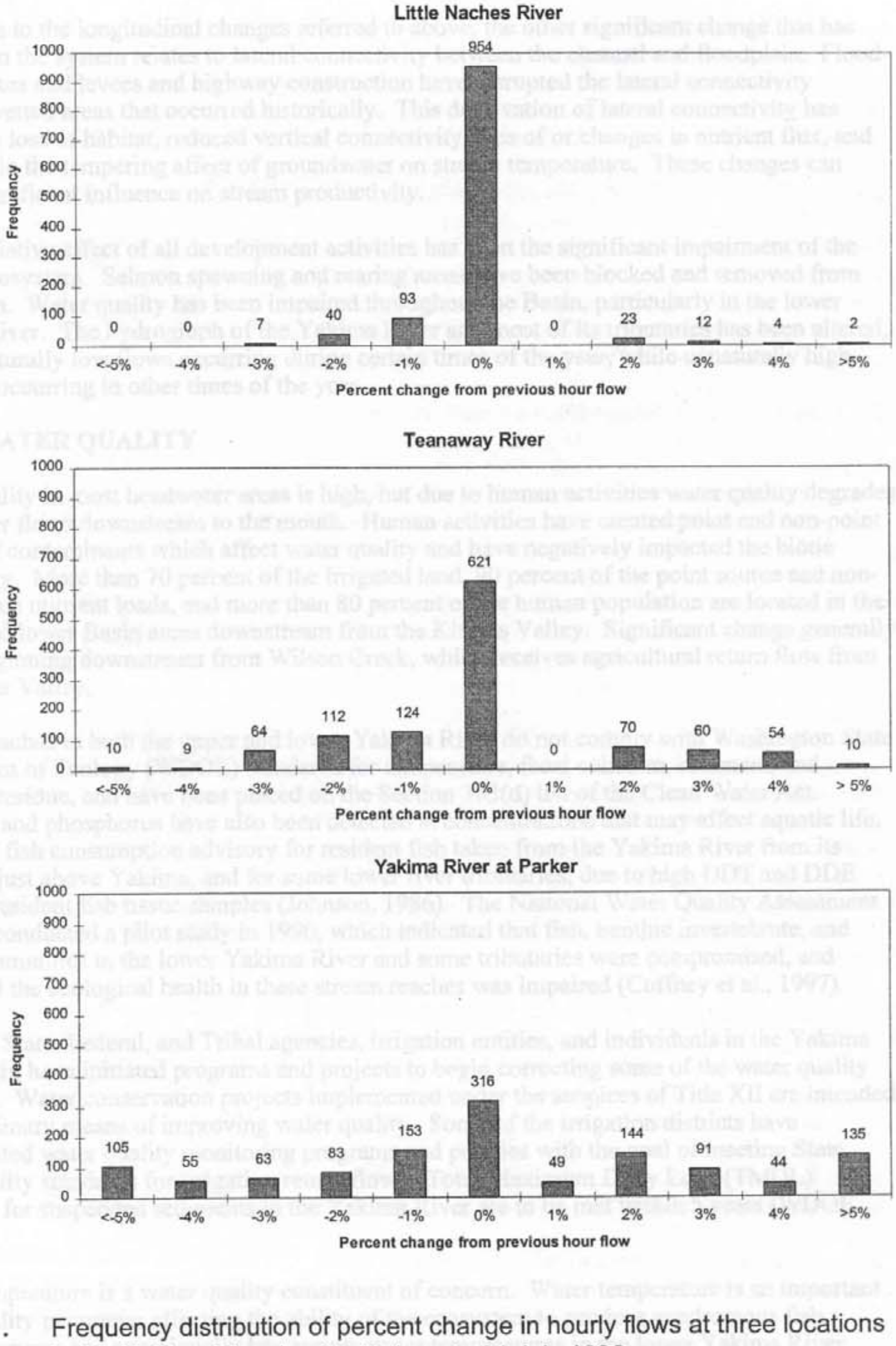


Figure 7. Frequency distribution of percent change in hourly flows at three locations in the Yakima River basin, 15 June to 31 July 1996.

In addition to the longitudinal changes referred to above, the other significant change that has occurred in the system relates to lateral connectivity between the channel and floodplain. Flood-control dikes and levees and highway construction have disrupted the lateral connectivity between wetted areas that occurred historically. This deprivation of lateral connectivity has resulted in loss of habitat, reduced vertical connectivity, loss of or changes in nutrient flux, and reduction in the tempering affect of groundwater on stream temperature. These changes can exert a significant influence on stream productivity.

The cumulative effect of all development activities has been the significant impairment of the aquatic ecosystem. Salmon spawning and rearing areas have been blocked and removed from production. Water quality has been impaired throughout the Basin, particularly in the lower Yakima River. The hydrograph of the Yakima River and most of its tributaries has been altered, with unnaturally low flows occurring during certain times of the year, while unnaturally high flows are occurring in other times of the year.

2.4 WATER QUALITY

Water quality in most headwater areas is high, but due to human activities water quality degrades as the river flows downstream to the mouth. Human activities have created point and non-point sources of contaminants which affect water quality and have negatively impacted the biotic community. More than 70 percent of the irrigated land, 90 percent of the point source and non-point source nutrient loads, and more than 80 percent of the human population are located in the middle and lower Basin areas downstream from the Kittitas Valley. Significant change generally occurs beginning downstream from Wilson Creek, which receives agricultural return flow from the Kittitas Valley.

Certain reaches in both the upper and lower Yakima River do not comply with Washington State Department of Ecology (WDOE) standards for temperature, fecal coliform, sediment, and pesticide residue, and have been placed on the Section 303(d) list of the Clean Water Act. Turbidity and phosphorus have also been detected at concentrations that may affect aquatic life. There is a fish consumption advisory for resident fish taken from the Yakima River from its mouth to just above Yakima, and for some lower river tributaries, due to high DDT and DDE levels in resident fish tissue samples (Johnson, 1986). The National Water Quality Assessment Program conducted a pilot study in 1990, which indicated that fish, benthic invertebrate, and algal communities in the lower Yakima River and some tributaries were compromised, and concluded the ecological health in these stream reaches was impaired (Cuffney et al., 1997).

Recently, State, Federal, and Tribal agencies, irrigation entities, and individuals in the Yakima River Basin have initiated programs and projects to begin correcting some of the water quality problems. Water conservation projects implemented under the auspices of Title XII are intended to be a primary means of improving water quality. Some of the irrigation districts have implemented water quality monitoring programs and policies with the goal of meeting State water quality standards for irrigation return flows. Total Maximum Daily Load (TMDL) standards for suspended sediments in the Yakima River are to be met within 5 years (WDOE, 1997).

Water temperature is a water quality constituent of concern. Water temperature is an important water quality parameter affecting the ability of the ecosystem to produce anadromous fish. During summer and occasionally late spring, water temperatures in the lower Yakima River become lethal for juvenile and adult anadromous salmonids (Vaccaro, 1986). Water temperatures in the Yakima River are influenced by many factors, including: air temperature, flow volumes, tributary and irrigation return flow temperatures, riparian shading, surface and groundwater interactions, and reservoir operations (Bartholow, 1989). The influence of Yakima Basin water management with the interaction of natural processes on water temperature, habitat conditions and the aquatic ecology of the Yakima Basin requires further study.

2.5 BIOLOGICAL: FISH COMMUNITY DESCRIPTION

The Yakima River Basin historically produced significant runs of four species of anadromous salmon and trout: chinook, sockeye, coho, and steelhead (Northwest Power Planning Council, 1986). Currently, production and distribution are greatly reduced from historic levels. Following is a brief description of each species historically produced in the Basin. The scientific name of each species is given in Table 2.

2.5.1 Anadromous Salmonids

Anadromous salmonids spawn in fresh water and migrate to the ocean where they rear to maturity. The freshwater portion of their life-cycle includes adult migration, adult holding, spawning, egg and fry incubation, juvenile rearing, and juvenile migration to the ocean. Depending on specific species and environmental conditions, the timing and duration of any life-cycle phase may vary. In order for anadromous salmonids to successfully complete their life-cycle, a number of specific conditions must be present, including: (1) open and free access to the ocean; (2) an adequate supply of high-quality water; (3) an adequate supply of appropriate food; (4) the presence of clean spawning gravel; and (5) adequate amount of high quality juvenile rearing habitat.

Chinook salmon in the Columbia River are generally categorized into three separate runs: spring, summer, and fall, based on the time of entry into freshwater from the Pacific Ocean. All three runs historically existed in the Yakima River Basin, and production of chinook occurred throughout the Basin, from small tributary streams to the lower mainstem. Summer chinook are extinct in the Basin. Spring chinook currently spawn in the upper Yakima and Naches Rivers, and certain tributary streams. Spring chinook adult returns have ranged from 9,300 to 645 for the period 1986 to 1997. Fall chinook currently spawn in the lower Yakima River from Sunnyside Dam to the mouth, and in Marion Drain. Returning adult fall chinook number in the 2,000-4,000 range.

Historically, steelhead were widely distributed in the Yakima River Basin, spawning in streams of every size, from the mainstem Yakima River to small creeks with intermittent flow. Currently, steelhead production is much reduced, and is concentrated in Satus and Toppenish Creek in the lower Yakima Basin. Scattered spawning occurs in the Naches River, in the upper Yakima River and the Teanaway River. The number of returning adult steelhead has varied in recent years from a low of 204 in 1980, to a high of 2,601 in 1987. Steelhead in the Yakima River Basin are included in the mid-Columbia ESU and are proposed for listing as Threatened under the Endangered Species Act of 1973, with a final listing due in March 1999.

Native coho and anadromous sockeye are extinct in the Yakima River Basin. Adult coho currently return to the Basin as a result of hatchery smolt releases conducted pursuant to the Columbia River Fish Management Plan. Scattered spawning has been documented in recent years in several lower Basin tributaries. Historically, sockeye were produced in several lakes, including Bumping, Kachess, Keechelus, and Cle Elum.

2.5.2 Resident Fish

Resident salmonids native to the Yakima River Basin include kokanee, rainbow trout, bull trout, cutthroat trout, and mountain whitefish. Rainbow trout are the resident form of steelhead, and are widely distributed throughout the Basin. Kokanee are the resident form of sockeye salmon, and significant populations exist in storage reservoirs, where they support important sport fisheries, particularly in Rimrock Lake. The cutthroat trout present in the Yakima River Basin appear to be the westslope subspecies. Cutthroat trout populations are much reduced from historic levels, and are generally restricted to upper tributary streams. Bull trout populations are currently fragmented and much reduced from historic levels, and were listed as Threatened under the Endangered Species Act of 1973, on June 10, 1998. Mountain whitefish are abundant throughout the Basin. A number of other native, resident fishes occur in the Basin (Table 3), including a variety of minnows, suckers, and sculpins.

A number of fish species have been introduced to the Yakima River Basin (Table 3). These fishes did not occur in the Northwest historically, but were brought here from other regions of North America for a variety of reasons. Many of them are now common throughout the interior Columbia River Basin. Patten et al., (1970) reported 10 introduced fish species had become established in the Yakima River Basin, including two salmonid species, brook trout and brown trout. In addition, eight warm water species were established: largemouth bass, smallmouth bass, pumpkinseed, bluegill, black crappie, carp, black bullhead, and yellow perch. Subsequent to Patten's survey in the 1950's, four other introduced species have been documented: channel catfish, mosquitofish, brown bullhead, and walleye. With the exception of carp, which are present in the Yakima River from the mouth to near Ellensburg, the warm water introduced fishes are generally restricted to the lower Yakima River downstream of Sunnyside Dam. Several introduced species, especially smallmouth bass, pose a predation threat to anadromous salmonids, and also compete with anadromous salmonids for food and habitat. Water management and land-use activities may alter river habitats in ways that favor introduced fishes over native fishes, compounding the effects of species introductions (Stanford et al., 1996).

SOAC recognizes that additional knowledge is necessary to determine the relation between variability of flows, food web development, and resultant salmon productivity in the Yakima River Basin. Therefore, additional investigation is described in Section 3 (Approach/Methods) with specific recommendations in Section 4.

Table 3. List of fish species found in the Yakima River. An asterisk (*) follows the common name of fish species that have been introduced to the basin and did not occur historically.

Common Name	**Scientific Name**
western brook lamprey	*Lampetra richardsoni*
pacific lamprey	*Entosphenus tridentatus*
mountain whitefish	*Prosopium williamsoni*
brown trout*	*Salmo trutta*
cutthroat trout	*Salmo clarki*
brook trout*	*Salvelinus fontinallis*
bull trout	*Salvelinus confluentus*
coho	*Oncorhynchus kisutch*
rainbow trout	*O. mykiss*
steelhead	*O. mykiss*
chinook	*O. tshawytscha*
kokanee	*O. nerka*
carp*	*Cyprinus carpio*
chiselmouth	*Acrocheilus alutaceus*
redside shiner	*Richarsonius balteatus*
longnose dace	*Rhinichthys cataractae*
leopard dace	*R. falcatus*
speckled dace	*R. osculus*
northern squawfish	*Ptychocheilus oregonensis*
peamouth	*Mylocheilus caurinus*
largescale sucker	*Catostomus macrocheilus*
mountain sucker	*C. platyrhynchus*
bridgelip sucker	*C. columbianus*
channel catfish*	*Ictalurus punctatus*
brown bullhead*	*I. nebulosus*
black bullhead*	*I. melas*
mosquitofish*	*Gambusia affinis*
three-spine stickleback	*Gasterosteus aculeatus*
largemouth bass*	*Micropterus salmoides*
smallmouth bass*	*M. dolomieui*
black crappie*	*Pomoxis nigromaculatus*
bluegill*	*Lepomis macrochirus*
pumpkinseed*	*L. gibbosus*
walleye*	*Stizostedion vitreum*
yellow perch*	*Perca flavescens*
piute sculpin	*Cottus beldingi*
torrent sculpin	*C. rhotheus*
mottled sculpin	*C. bairdi*

3.0 APPROACH TO DETERMINE BIOLOGICALLY BASED FLOWS

A focus of the Title XII legislation was on the instream flow requirements for anadromous salmonids in two reaches of the lower Yakima River, specified as target flows at the Sunnyside and Prosser Diversion dams. To establish a biological basis for target flows, SOAC considers this limited focus to be too restrictive both conceptually and spatially. The entire Yakima River Basin provides important habitats for anadromous salmonid spawning and rearing. An approach for evaluating flows necessary to recover and sustain anadromous salmonid populations in the Basin should incorporate much broader concepts and analyses. Such an approach would utilize rigorous scientific methodologies and include not only salmonid habitat analyses but also investigations relating to floodplain functionality, impacts to the aquatic food web, and the role which natural hydrologic variability plays in sustaining the aquatic ecosystem. A target flow regime, established without considering the health of the entire river ecosystem, will likely fail to sustain increased production of anadromous salmonids. [Note: flow regime as referred to here, and throughout the remainder of this document, applies to the mainstem Yakima River and its tributaries]. A growing body of scientific literature supports this assertion (Stanford, 1997; Dombeck et al., 1997; Kauffman et al., 1997; Coutant, 1997; Roper et al., 1997; Poff et al., 1997; Stanford et al., 1996; Naiman et al., 1995; Stanford and Ward, 1992).

An important component of the river ecosystem is the flow regime (Vannote et al., 1980). An underlying assumption is that the natural, unaltered (i.e., historic) flow regime produced the ecosystem conditions necessary to sustain abundant anadromous salmonid populations, and that human alterations of this flow regime impacted the ecosystem resulting in reductions in these populations. Thus, in a river basin with extensive flow regulation such as the Yakima, managing aspects of the flow regime to more closely resemble natural conditions may recover some ecosystem functions and offers the potential to improve salmonid production. The degree to which the flow regime must change to effect an ecosystem response is unknown and SOAC recognizes that flow management alone cannot fully recover the ecosystem. Land use practices and other activities within the watershed also impact aquatic ecosystem health. However, SOAC believes the recovery process can begin by immediately implementing incremental changes that shift the flow regime towards a "normative condition," defined by Stanford (1996, 1997) as. . . "the goal of sustaining ecological integrity of watersheds while also maximizing uses of water resources by humans." A normative flow regime would seek to mimic many of the characteristics of the historic, pre-development hydrograph. It would not duplicate historic flow volumes; this would be infeasible in the Yakima River Basin. Rather, it should be considered a scaled-down version of the historic flow regime. The key is to determine physical, legal, and institutional constraints that represent the "side-boards" within which the flexibility to manipulate the flow regime exists.

A flow regime can be quantitatively described using five broad categories of hydrologic parameters—magnitude, frequency, duration, timing, and rate of change (Poff et al., 1997). These parameters can be used to characterize the entire range of hydrological events and to explore the ecological consequences of human activities that modify one or more flow regime components. Magnitude of flow can be measured at any time interval—daily, monthly and annual means, and instantaneous extreme values (annual high and low flows). Frequency refers to the recurrence interval of specific magnitude flood or low flows (e.g.,100-year flood event). Duration measures the time span for specific hydrologic events (e.g., the average duration in days for a 10-year frequency low flow). Timing is controlled by climate and precipitation attributes (e.g., driven by snowmelt runoff or rainfall events). Rate of change refers to the stability of flows and the rate and frequency of fluctuations in river discharge over shorter time periods—typically hourly or daily fluctuations. Considering these parameters in comparing the synthesized historic hydrographs from the Yakima River Basin to post-development hydrographs offers a preliminary means of deriving biologically based flows. These comparisons can be made by generating pre- and post-development statistics for each of these five parameters for a variety of locations in the Yakima River Basin. Inferences may then be drawn on the impacts post-development flow management has had on anadromous salmonids and preliminary goals for biologically based flows can be developed.

To develop interim, biologically based flow recommendations reflecting normative conditions, SOAC will utilize a comprehensive hydrologic analysis. Richter et al., (1997) have developed a methodology for setting streamflow-based ecosystem management targets that utilize the hydrological parameters described by Poff et al., (1997). This methodology, the "Range of Variability Approach" (RVA), is intended for use in river basins where recovery and conservation of native aquatic biodiversity and protection of natural ecosystem functions are primary river management objectives. RVA is designed to enable river managers to define and adopt interim management targets before conclusive, long-term research results are available.

RVA, as applied in the Yakima River Basin, will use historic flow data and computer simulation models developed by the USBR and others (Maheshwari et al., 1995; Richter et al., 1996) to synthesize pre-development daily streamflow records at selected locations throughout the Basin. The simulated streamflow record is then characterized using as many as 32 hydrological parameters beneath the five broad categories described by Poff et al. (1997) . The pre-development RVA parameter values represent an "historic flow regime template" which is compared to the existing post-development flow regime to quantify where and when flows outside of the target range occur that may be adversely affecting ecosystem health. This information will be evaluated with respect to the goals set for biologically based flows and interim flow recommendations. Stanford et al., (1996), Poff et al., (1997), and Richter et al., (1997), all acknowledge that in many situations, it is only possible to move incrementally towards RVA flow targets. Even incremental changes will be useful if ecosystem functions and habitat conditions for anadromous salmonids are improved.

With the interim flow regime implemented, scientific investigations will ensue to accumulate information which will be used to refine the normative flow regime. The most obvious of these investigations would seek to quantify the relationship between habitat and streamflow for each life stage of each salmonid species or race, and the water temperature relationship in key reaches. Less obvious, but of equal importance, will be studies to establish relationships between streamflow and other environmental variables which determine ecosystem health. For example, the relationship between flow and food web diversity, abundance, and production and its contribution to anadromous salmonid production in the Yakima River Basin is uncertain. The status of the food web in a river system is a fundamental index of river ecosystem health. Regulated flows that fluctuate more rapidly and with greater magnitude relative to natural flow conditions may alter the composition and productivity of the benthic invertebrate communities, especially in shallow areas of the river. Consequently, such changes may reduce the salmonid rearing potential of the river. Baseline data on the food web, gathered from regulated reaches in the Yakima River where rates of change have exceeded natural fluctuation for many years, will provide critical information needed to assess alternative flow regimes.

River ecosystem health may also be compromised through the loss of physical connectivity between the river channel and the floodplain, resulting in a loss of biological production and diversity (Stanford and Ward, 1993). Connectivity of the channel is three dimensional;

longitudinally between upstream and downstream reaches; laterally across the channel connecting sloughs, side channels and floodplain riparian areas and wetlands; and vertically connecting interstitial flows in the hyporheic zone within the alluvial reaches and floodplain areas. Connectivity also has a temporal component; specifically, that connectivity is related to the seasonal variability of the flow regime (Ward and Stanford, 1995). Reaches in the Yakima River Basin which display potential connectivity problems in any of these dimensions will be studied to determine the extent of the problem and to ascertain if the implementation of a normative flow regime will improve conditions. Lateral connectivity is also affected by development in the floodplain. A significant portion of the floodplain has been disconnected from the Yakima River and its tributaries by the construction of highways, railroads, flood control revetments, and drainage networks. The magnitude of encroachment and reductions in functional floodplain area have not been comprehensively assessed Basin-wide. Such an assessment should be undertaken and opportunities for lateral reconnection of the rivers to their floodplains identified.

Table 4 contains a list of environmental variables and potential methodologies to evaluate the ecological integrity of stream reaches in the Yakima River Basin. Methodologies utilized to determine biologically based flows must not only be capable of relating the ecological conditions of the river system to instream flows, but should also describe how various land and water use activities affect the ecosystem apart from flow. Degraded water quality from non-point source pollutants (e.g., agricultural pesticides) and suspended sediments, competition from exotic species, and predation by these species also impact the river ecosystem. These impacts have likely been a significant factor in the decline of anadromous salmonid populations. Methods of assessing biologically based flows must also consider other ongoing salmon recovery efforts in the Basin including the Yakima Fisheries Project, a salmon supplementation and experimentation complex, and releases of hatchery reared coho and fall chinook salmon smolts (BPA, 1996). The methodologies listed in Table 4 are drawn from a number of disciplines including hydrology, geology, ecology, and biology.

Table 4. Variables and methods to evaluate the ecological integrity of watershed reaches in the Yakima River ecosystem. Variables believed crucial to deriving an ecological basis for instream flows are *italicized*. Details for these methods may be found in the references or in Calow and Petts (1992, 1994) and Hauer and Lamberti (1996).

VARIABLES	ANALYSIS METHODS	REFERENCES
Materials and Energy Flux		
River Discharge		
Surface	USBR/USGS maintain gages that measure river flow throughout the Yakima Basin.	Parker and Storey, 1916 Kinnison and Sceva, 1963
Interstitial	Piezometer transects and well networks.	Kinnison and Sceva, 1963
Thermal		
Mainstem	Models rely on field data to integrate a wide range of variables including stream geometry, meteorology, hydrology, and water quality.	Bartholow, 1989 Vaccaro, 1986
Edge	Remote sensing and field surveys can detect thermal gradients.	
Interstitial	Thermographs installed in monitoring wells.	
Materials		
Dissolved matter	Depth-integrated samples.	
Suspended matter	Depth-integrated samples.	WDOE, 1997
Deposited matter	Bedload samplers and sediment cores can track the movement of river substrates and evaluate their quality for salmon habitat.	Hill et al., 1991 McNeil and Ahnell, 1964 Arnsburg et al., 1992
Hydrologic Connectivity		
Longitudinal	Inter-reach water mass balance measures water gain/loss to the stream.	Kinnison and Sceva, 1963
Lateral	Aerial mapping and remote sensing are used to identify historic channel and floodplain boundaries.	
Vertical	Monitoring well networks in key alluvial reaches measure subsurface flow related to discharge.	Stanford et al., 1994

Biophysiology of Mainstem, Edge, and Groundwater Habitats		
Land cover	**Remote sensing and spatial analysis.**	
Characters or units	**Physical habitat assessments.**	**Frissell et al., 1986** **Amoros et al., 1988**
Biotic indices	**Quantitative sampling of food web components can measure impacts from various land and water use activities.**	**Karr, 1996** **Cuffney et al., 1997**
Primary production	**Isotope uptake analysis.**	
Secondary production	**Cohort analysis.**	
Non-salmonid indicator species		
Abundance	**Species specific quantitative sampling.**	**Patten et al., 1970** **Mongillo and Faulconer, 1979** **Cuffney et al., 1997**
Behavioral thresholds	**Analyses of life history patterns.**	
Bioaccumulation	**Analysis of trace organic compounds in fish and invertebrate tissues indicate potentially adverse effects.**	**Johnson et al., 1986**
Juvenile salmonids	**Species and stock specific analyses.**	
Abundance	**Quantitative sampling.**	**Major and Mighell, 1969**
Growth rate/fish health	**The condition factor is a weight-length relationship that quantitatively describes fish growth and health.**	
Productivity	**Egg to smolt survival studies can estimate the productivity of various life stages and may indicate improvements in survival as a function of flow.**	
Adult salmonids	**Species specific quantitative sampling.**	
Spawner abundance	**Redd surveys.**	
Productivity	**Adult-to-smolt survival analyses model the number of offspring produced per spawner as an index of stock productivity.**	

Passage indices	**Mark-recapture studies measure the survival of smolts migrating through various river reaches in relation to environmental variables.**	
Viability indices	**Population viability analysis may determine the likelihood a population will persist into the future.**	**Hanski and Gilpin, 1997**

*****Note: All variables need to be monitored over the long-term to determine the utility of interim flows in an adaptive management context. All data must be collected and analyzed in time-series so that the key attributes (flux, connectivity, biotic integrity of salmonid habitat) can be modeled for the river basin as a whole (e.g., Jourdonnais et al., 1990; Jourdonnais et al., 1992).**

3.1 ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT

Traditional approaches to river management have difficulty addressing the complex relationships which exist in an aquatic ecosystem. Scientific knowledge relating to species interactions is limited and often system specific, while the interactions between the abiotic and the biotic elements of an ecosystem are also difficult to predict. The concept of ecosystem management is not new, but a "how-to" manual does not exist. Given this, it is important to emphasize not just flow recommendations and non-flow management alternatives, but the implementation of a new paradigm of river management built on the two decade old concept of adaptive environmental assessment and management. (See also Hilborn and Walters, 1992).

Adaptive Environmental Assessment and Management (AEAM) is a formal, systematic, and rigorous program of learning from the outcomes of management actions, accommodating change, and improving management (Holling, 1978). Such a program combines assessment and management. Most agency and task force structures do not allow both to go on simultaneously (International Institute for Applied Systems Analysis, 1979). The basis of adaptive environmental assessment and management is the need to learn from past experience, data analysis, and experimentation. AEAM combines experience with operational flexibility to respond to future monitoring and research findings and varying resource and environmental conditions. AEAM uses conceptual and numerical models and the scientific method to develop and test management choices. Decision makers use the results of the AEAM process to manage environments characterized by complexity, shifting conditions, and uncertainty about key system component relationships (Haley, 1990; McLain and Lee, 1996).

The AEAM approach requires teams of scientists, managers, and policymakers to jointly identify and define management problems in quantifiable terms (Holling, 1978; Walters, 1986). In addition, the AEAM approach recognizes that "the information we base our decisions on is almost always incomplete" (Lestelle et al., 1996). This recognition encourages managers to treat management actions as experiments, whose results can be used to better guide future decisions. An AEAM program not only monitors changes in the ecosystem, but also develops and tests hypotheses of the causes of those changes. The result is informed decisions and increasing certainty within the management process.

Modern management strategies must have explicit and measurable outcomes. There are not many clear cut answers to complex hydraulic, channel structure, and water quality changes, but the AEAM process allows managers to adjust management practices (such as reservoir operations) and integrate information relating to the riverine habitats and the ecosystem response as new information becomes available. Alluvial river systems are complex and dynamic. Our understanding of these systems and predictive capabilities are limited. Together with changing social values, these knowledge gaps lead to uncertainty over how to best implement habitat maintenance or recovery efforts on regulated rivers. Resource managers must make decisions and implement plans despite these uncertainties. AEAM promotes responsible progress in the face of uncertainty.

A well designed AEAM program: 1) defines goals and objectives in measurable terms; 2) develops hypotheses, builds models, compares alternatives, and designs system manipulations and monitoring programs for promising alternatives; 3) proposes modifications to operations that protect, conserve and enhance the resources; and 4) implements monitoring and research programs to examine how selected management actions meet resource management objectives. The intention of the AEAM program is to provide a process for cooperative integration of water control operations, resource protection, monitoring, management, and research. AEAM assesses the results and effects of reservoir operations and water resource allocations on biotic resources. The results of the assessments sustain or modify future operations. A conceptual model of a ten-step AEAM process for the Yakima River Basin, with a brief description of each step in the process, may be found in Appendix A.

3.2 CONCLUSION

The approach described herein is intended to provide immediate benefits to anadromous salmonid populations and the ecosystem on which they depend. Of greater import, it is intended to provide for long-term recovery and maintenance of the fishery and the ecosystem through the application of scientifically based management decisions. This can be accomplished only through a commitment to cooperation and understanding between all stakeholders in the Yakima River Basin. SOAC is committed to fostering such an atmosphere in the Basin whereby river management alternatives can be generated and considered in light of the needs of the resource, the interests of those who value the anadromous fishery for economic or cultural reasons, and the concerns of those who rely on the water supply for their livelihoods.

4.0 RECOMMENDATIONS FOR BIOLOGICALLY BASED FLOW ASSESSMENT

SOAC submits the following recommendations to establish biologically based flow regimes in the Yakima River Basin. The recommendations represent part of a comprehensive program designed to recover the aquatic ecosystem and the anadromous salmonid populations which depend on it. To immediately improve habitat conditions needed to prevent further decline of these populations, the first four recommendations are designed to establish interim flow regimes for the Basin's rivers as soon as possible. These flow regimes will be based on the best scientific information currently available. Recommendations five through nine represent long-term study efforts addressing critical ecosystem concerns including floodplain and channel connectivity, food web status, water temperatures, water quality, and salmonid habitat conditions. The information obtained from these studies will be used to refine, if necessary, the interim flow regimes already implemented. Detailed study plans for the recommended studies will need to be prepared and submitted by potential investigators. It is proposed that the review and approval of these plans be the responsibility of SOAC. In the last of the recommendations, SOAC emphasizes an adaptive approach to assess progress towards ecosystem recovery and direct management actions. This approach recognizes the need to learn from past experience, data analysis, and experimentation to accommodate change and improve management.

Following each recommendation an estimate has been provided to indicate the funding which will be necessary to implement the recommendation and the time it will take to complete. As noted above, detailed study plans have yet to be submitted. These are rough estimates and should be used for preliminary planning purposes only.

Recommendation 1: Review and Synthesize Existing Yakima River Ecosystem Data

The health of the Yakima Basin aquatic ecosystem should be described through a comprehensive review and synthesis of available data on Yakima River flow management, water quality, habitat condition, land use activities, and biological communities. These data will be analyzed relative to contemporary literature on aquatic habitat, community ecology, food web impacts, and other ecological relationships in regulated and unregulated rivers. This review and synthesis would identify the areas in the watershed where changes in water management or Yakima Project operations offer the greatest potential to recover the aquatic ecosystem. This task should begin immediately and is intended to provide information which would be used, in part, to formulate interim instream flow recommendations of benefit to the ecosystem and thus, salmon and steelhead populations.

The information which would be obtained through this recommendation was deemed essential to the Yakima River Basin Water Enhancement Project (YRBWEP). A contract has been awarded through YRBWEP to Dr. Jack Stanford to implement the recommendation and to produce a summary document by the end of Fiscal Year 1999. This work was funded by YRBWEP at a cost of $147,000.

Recommendation 2: Develop an Historic Flow Regime Template

SOAC recommends that historic and synthesized hydrologic data be used to create an historic flow regime template for selected rivers in the Basin. These templates would describe the natural, pre-development hydrograph for each year in the period of record and are expected to yield values for five categories of hydrologic parameters (magnitude, frequency, duration, timing and rate of change) compatible with the RVA. This recommendation should be implemented immediately. The historic flow regime templates are essential to proceed with Recommendation No. 4, the Development and Implementation of Normative Flow Regimes.

The tasks outlined under this recommendation would likely require the full-time services of a hydrologist with modeling expertise for a period of six month. The estimated total cost, including the necessary computer equipment, software, and supplies would be $65,000.

Recommendation 3: Development of a Watershed Hydrologic Model

To formulate recommendations which would modify existing flow management strategies in the Basin, there is a need for near real-time assessments of water availability and use. A Basin-wide hydrologic and water management model should be developed to provide these assessments. The U.S. Geological Survey (USGS) and the USBR are currently working collaboratively in the Basin on a project termed the Watershed and River Systems Management Program (WARSMP). The goal of the program is to couple watershed and river-reach models that simulate the physical hydrologic setting with routing and reservoir management models that account for water availability and use. The need for this information is immediate and essential to enable water managers to determine the physical feasibility of proposed flow regime manipulations and to identify alternative flow management strategies. The efforts of USGS and USBR in the continued development of WARSMP for the Yakima River Basin should be supported.

To fulfill this recommendation, the services of a full-time hydrologist would be needed to work with WARSMP and develop additional capabilities specific to developing biologically based streamflow recommendations. It is estimated that this effort will take six months at a total cost of $75,000, including equipment.

Recommendation 4: Develop and Implement a Normative Flow Regime

A normative flow regime is one that represents historic flow conditions to the greatest extent possible given the cultural, legal, and operational constraints associated with river basin development. The implementation of normative flows is expected to improve aquatic ecosystem conditions in the Basin. A promising method for developing quantitative normative flow regime recommendations is the RVA, which would utilize the historic flow regime templates. The RVA flow template is derived by selecting a range of variation around the mean of each historic flow regime parameter (see Recommendation No. 2). Once normative flow ranges are adopted for each variable, the "rate of attainment" on an annual basis (percent attainment over the period of record) is determined for each variable using baseline (i.e., current) river management conditions.

Identifying parameters that display low rates of attainment may provide the means to link current ecosystem conditions with baseline flows. This would guide progress towards developing flow recommendations to improve ecosystem conditions. Using the historic, unregulated hydrographs developed in Recommendation No. 2, a water-year classification system would be developed allowing flow recommendations to be correlated to the natural water supply in a given year. Depending on water-year type, recommended streamflows may vary significantly between years.

Once developed, the feasibility of implementing the normative flow regimes would be assessed. There are numerous constraints that limit RVA target range attainment for hydrologic variables considered critical for river ecosystem health. The comprehensive hydrologic and water management model(s) developed under Recommendation No. 3 would address operational constraints. Additional water available for instream flows as a result of the YRBWEP and increased operational flexibility through new water management infrastructure investments would be incorporated into these models. Institutional and legal constraints should be identified and potential remedies explored.

Flow recommendations reflecting normative flow conditions would be made after a comprehensive feasibility assessment and should be implemented immediately thereafter, consistent with Title XII. The recommended flow regimes should be considered interim (i.e., temporary) until such time as additional information becomes available, based on the scientific investigations described in the remainder of these recommendations, indicating that modifications are necessary to achieve progress towards ecosystem recovery.

This recommendation represents the culmination of the first four, a decision point, and would require considerable time and effort. It is dependent on completion of the first three recommendations. To perform the tasks listed above, the time and cost estimates are 18 months and $135,000, respectively.

Recommendation 5: Investigate Longitudinal, Lateral, and Vertical Connectivity

Connectivity of the river channel is three dimensional-longitudinally between upstream and downstream reaches; laterally across the channel connecting sloughs, side channels and floodplain riparian areas and wetlands; and vertically connecting interstitial flows in the hyporheic zone within the alluvial reaches and floodplain areas. The loss of ecosystem functions resulting from longitudinal, lateral, and vertical disconnectivity in some reaches in the Yakima River Basin is suspected but not well documented. The connection of the river channel with side-channel, backwater, and floodplain areas provides habitat diversity and enhances food web productivity. Land use practices and extensive floodplain development, coupled with the managed flow regime, are believed to have substantially reduced the channel dynamics in the Basin. The extent to which disconnectivity, in any dimension, occurs should be assessed Basin-wide.

It is recommended that present and historical floodplain boundaries be mapped, using aerial reconnaissance and Geographic Information System (GIS) technology, to assess elevations and channel morphometry. These data would be used to determine the extent of functional floodplain loss, both that associated with the regulated flow regime and losses which have occurred as the result of structural modifications (e.g., levees, revetments) relating to flood protection. An essential part of this analysis will include a correlation of river flow with longitudinal and vertical connectivity over a range of river discharge. These studies would take approximately two years at an estimated cost of $1,000,000. The related flow dynamics would be identified and linked with food web analyses. The assessment should provide a more complete realization of the expectations and benefits of implementing normative flow regime.

Recommendation 6: Assess Status of the Food Web

The food base influences salmonid productivity, growth, and distribution. If the rivers in the Basin have experienced a reduction in food web productivity, it may be apparent in the zoobenthos community structure. To implement this recommendation, representative study reaches should be established along the entire river continuum. Data gathered in the reaches would be used to assess distribution and abundance of zoobenthos species and flow connectivity. Concurrently, estimates of primary and secondary production and assessments of inhabiting fish species would be analyzed. These assessments would reveal the condition of selected components of the food web in comparison to similar streams reported in the scientific literature, and may indicate potential problems and suggest corrective measures. These studies would take approximately two years at an estimated cost of $1,000,000.

Recommendation 7: Develop a Stream Network Water Temperature Model

Water temperature directly influences anadromous salmonid survival and growth during the freshwater stages of their life history. SOAC recommends a seasonal assessment of water temperatures in the Yakima River and its tributaries to identify if, and where, unsuitable temperatures diminish habitat suitability for all life stages. A stream network temperature model should be developed from hydrologic, meteorologic, and water temperature data collected throughout the Basin. Such a model would be capable of predicting the water temperature versus streamflow relationship for selected reaches in the Yakima River watershed. With adequate data, the model could be calibrated to derive daily mean, maximum, and minimum water temperatures over a range of streamflows for various meteorologic conditions. Methods that can detect thermal gradients should also be employed to reveal thermal refugia where adults and juveniles may find preferred temperatures.

The comprehensive water temperature model for the Yakima Basin would be developed in two phases: data collection and model calibration. For data collection, Reclamation would need to upgrade the existing Hydromet system to collect water temperature data, and devote staff time to managing the data, at an estimated cost of $250,000. The model calibration phase, a multi-year effort, would include gathering and analyzing hydrology, stream geometry and meteorology data, upgrading the existing temperature model software to current standards, and developing a calibrated model at an estimated cost of $300,000. In addition, sampling throughout the watershed to identify thermal refugia for salmon and steelhead would cost an estimated $200,000. The complete water temperature characterization program for the Yakima Basin would require approximately four years to complete.

Recommendation 8: Evaluate Salmonid Microhabitat Conditions

Microhabitat can be described as the physical space required for an aquatic organism to develop, grow, and reproduce. The amount of microhabitat available at a given streamflow is generally determined from area measurements, structural descriptions (e.g., substrate, cover), and quantification of hydraulic conditions (i.e., water depths and velocities). A microhabitat versus streamflow relationship can be derived using models developed and calibrated from data collected at only a few stream discharges. The most widely accepted means of deriving this relationship utilizes the suite of hydraulic and habitat models contained within the Instream Flow Incremental Methodology (IFIM) developed by the FWS in the late 1970's. (Reiser et al., 1989). Output from these models is intended to be used, in part, to develop flow recommendations and to evaluate alternative flow regimes.

Between 1981 and 1984, the FWS conducted an instream flow study using IFIM models on the Yakima River and most of its tributaries. The results of the study described the microhabitat versus streamflow relationships for spawning adult, fry, and juvenile (rearing) anadromous salmonids in the Yakima River Basin. Aspects of these studies are still useful, however, a new habitat modeling effort is considered necessary for two primary reasons: 1) There have been significant improvements in habitat modeling techniques since the study was conducted. This includes the development of two-dimensional hydraulic models which have much improved capabilities to accurately represent complex channel forms (e.g., braided channels, island complexes) which are present in many areas of the Basin. The multiple channels present in these areas characteristically provide important salmonid rearing habitats; and 2) The methods employed in the FWS study are not compatible for use in the development of SALMOD, a habitat-based smolt production model (see Recommendation No. 9). SOAC recommends that the new habitat models be developed to establish the microhabitat/streamflow relationship for each life stage of all anadromous salmonid species which inhibit the Yakima River Basin. These models would not only improve the reliability of the predicted habitat-flow relationships, but would also be compatible in the development of SALMOD.

A Basin-wide microhabitat analysis employing state-of-the-art technology and modeling capabilities would require considerable manpower, time, and equipment expense. This is a river basin whose mainstem river of 214 miles long from source to mouth having numerous tributaries which also support anadromous salmonids. The data requirements for this modeling effort would be huge. While difficult to estimate in the absence of a detailed study plan, the analysis should be expected to take five years at a cost of $250,000 per year (all inclusive).

Recommendation 9: Develop a Salmon Pre-smolt Production Model

Many fishery scientists agree that the continued survival of wild anadromous salmonid populations depends on improving the quality of the freshwater habitat over the short and long term, and on continued monitoring. Several techniques have been used to quantify the relationship between riverine habitat and streamflow, but few have attempted to estimate the consequences to the fish population of changing the quality of the habitat. Such a technique has been developed by the U.S. Geological Survey, Biological Resources Division (USGS/BRD). Their SALMOD model was developed to assess the effects of regulated flow regimes on anadromous fish stocks, the objective being to mimic the temporal and spatial dynamics of the stream population well enough that managers can use it to quantitatively evaluate alternative water management practices. The model's premise is that fish mortality is directly related to spatially and temporally variable fish habitat limitations, which are a function of the amount, timing, and duration of streamflow and water temperature. Considering the objectives of the previous recommendations and recognizing the potential utility of SALMOD, it is recommended that this modeling effort be undertaken.

Because the development of SALMOD is dependent on the flow-habitat and flow-water temperature relationships discussed in previous recommendations, it will necessarily be a long-term project requiring 5-6 years to complete. The estimated cost to develop the model is $500,000. SALMOD would be directly linked to the RiverWare model being applied to the Yakima Basin by the USGS Water Resources Division. This kind of model integration fits well with the Modular Modeling System (MMS), a model building framework to simulate a wide range of interdisciplinary environmental and physical processes as a part of the joint USBR/USGS sponsored Watershed and River system Management Program. Linking SALMOD and RiverWare would require additional funds, estimated at approximately $100,000.

Recommendation 10: Adaptive Environmental Assessment and Management

The implementation of interim flow regimes is the first step in the long-term effort to recover the Yakima River Basin aquatic ecosystem. These regimes should be viewed as experiments which will come under close scientific scrutiny under the Adaptive Environmental Assessment and Management (AEAM) program SOAC recommends for the Yakima River Basin. This program is described in detail in Section 3 and Appendix A of this report. The response of the ecosystem to the new management actions would not be immediate. However, the AEAM program should be initiated as soon as the interim flow regimes are implemented.

A key element of AEAM is documentation and monitoring to provide baseline data that would facilitate comparative evaluations. A monitoring program must be designed specifically to provide data to assess the ecological effects of flow modifications or other management actions. Consequently, proposed changes in water management intended to benefit salmon and steelhead populations should include specific statements of measurable biological/ecological objectives with biotic and abiotic variables that can be tracked through time to measure ecosystem response.

The ultimate measure of AEAM success is increased production and survival of anadromous salmonid smolts. A primary objective of the program would be to monitor both the number of smolts exiting the system and the condition of rearing juveniles. The Yakama Indian Nation has developed an anadromous salmonid monitoring program that is as extensive as any within the Columbia Basin. Enumeration facilities are currently located at Prosser, over 40 miles from the river's mouth. However, there is no ability to assess juvenile salmonid survival as it relates to habitat conditions in the river below Prosser Dam. It also severely limits the ability to estimate the number of smolts leaving the system since the lower river is believed to be a significant "bottleneck" constraining the populations. A successful monitoring program would depend on developing an additional enumeration facility near the mouth of the Yakima River.

Survival, and thus production, is also closely linked to the condition of rearing juveniles. Fish in poor condition cannot be expected to survive their seaward migration without significant mortality. Specimens should be taken throughout the Yakima River Basin to evaluate juvenile condition (K factor), total energy content, and length-age distribution. These evaluations would allow a general assessment of rearing habitat quality and will help in identifying other ecosystem constraints (e.g., lack of food web productivity, water quality) which might be affecting juvenile condition.

5.0 GLOSSARY

Abiotic: Non-living components of an ecosystem; basic elements, and compounds of the environment, such as air, rocks, soil, etc.

Anadromous: Pertaining to fish that migrate from freshwater to the sea as juveniles and mature in the ocean before returning to freshwater to reproduce.

Aquatic Ecosystem: a. A water-based ecosystem; an interacting system of water with aquatic organisms (plants and animals). b. Any body of water, such as a stream, lake, or estuary, and all organisms and non-living components within it, functioning as a natural system.

Baseline: The conditions occurring during the reference time-frame, usually referring to water supply, habitat values, or population status.

Biologically based flows: Flow management strategies which will potentially recover and maintain the healthy functioning aquatic ecosystem.

Biotic: Refers to natural living components of an ecosystem, e.g., plants and animals; especially to characteristics of entire populations or ecosystems.

Biodiversity: The variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of genera, families, and still higher taxonomic levels.

Channel: A natural or artificial watercourse with a definite bed and banks to confine and conduct continuously or periodically flowing water.

Community: An assemblage of populations of living organisms in a common spatial arrangement having mutual relationships among themselves and to their environment.

Connectivity: Referring to the physical connection between aquatic, riparian and hyporheic habitats in three dimensions— laterally across the floodplain, longitudinally along the river channel gradient and vertically into the underlying, permeable substrata. Also refers to the ability of biota to move freely between adjacent habitats as life history requirements change.

Ecology: a. From Greek *oikos*, meaning "house" or "place to live;" literally the study of organisms at home. Also, the science of the interrelationships or organisms or group of organisms with their environment. b. The science of the interrelationships between organisms and their environments.

Ecosystem: A complex of plant and animal communities within a defined area interacting with each other and with the chemical and physical elements of their environment.

Ecosystem Functions, (Processes): The physical, chemical, and biological processes that regulate or influence the structure, composition, and pattern. These include nutrient cycles, energy flows, trophic levels (food chains), diversity patterns in time/space development and evolution, cybernetics (control), hydrologic cycles, and weathering processes.

Ecosystem Health: The state of an ecosystem in which processes and functions are adequate to maintain diverse communities similar to those which were indigenous.

Food Web: The interlocking pattern of food chains in an ecosystem. A food chain is a transfer of energy from plants through a series of animals.

Floodplain: The nearly level land forming the bottom of a river valley which is periodically subject to flooding.

Flow: The volume of water passing a given point per unit of time.

> **Base Flow**: The sustained low flow of a stream, contributed solely from the shallow groundwater zone in the absence of significant precipitation or runoff events.
>
> **Estimated Unregulated**: Estimation of system flow deregulated of the effect of storage and/or diversions and return flow.
>
> **Instream Flow Requirements**: That amount of water flowing through a stream course needed to sustain instream values.
>
> **Interstitial Flow**: The portion of the surface water that infiltrates the streambed and flows subsurface.
>
> **Managed Flow**: Operating a system of reservoirs and diversions to meet economic and environmental objectives.
>
> **Regulated Flow**: Natural flow conditions modified by reservoirs, diversions, or other works of humans to achieve a specified purpose or objective.
>
> **Return Flow**: The non-consumption portion of water previously diverted from a stream and subsequently returned to that stream or to another surface water body.
>
> **Unregulated Flow**: The flow regime of a stream as it would occur under completely natural conditions; that is, not subjected to modification by reservoirs, diversions, or other human works.

Gradient: The slope or rate of change in vertical elevation per unit of horizontal distance of the water surface of a flowing stream.

Hydrograph: The pattern of stream discharge at a specific location for a given time.

Hydrology: The science relating to the properties, distribution, and cycling of water on and below the earth's surface and in the atmosphere.

Hyporheic zone: The groundwater zone "in continuity" (connected) with surface flow in rivers caused by the high porosity of channel bed substrate which allows surface water to penetrate the river bed. Water may upwell from or downwell into the hyporheic zone depending on valley constrictions and the depth of impervious bedrock.

Indicator: An organism, species, or community which indicates the presence of certain environmental conditions.

Interim Flow Regime: A flow regime for the Yakima River Basin which is recommended or implemented, consistent with Title XII, based on the best information currently available and is intended to be temporary until such time as “better” information becomes available to warrant modification.

Production: The number of juveniles or adults of a particular species produced from a natural environment or from fish culture facilities.

Productivity: The number of surviving offspring (recruits) per spawner measured at any stage in the life history of the organism.

Riparian: Refers to transitional areas between terrestrial and aquatic ecosystems.

River Continuum: The continuous gradient of physical conditions from a river’s headwaters to its mouth resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization, and storage of organic matter along the length of a river. Biological communities are predictably structured along this gradient.

Salmonid: Fish of the salmon or trout family.

Stage: The elevation of a water surface above or below an established reference.

Sustainability: The ability to sustain diversity, productivity, resilience to stress, health, renewability, and/or yields of desired values, resource uses, products, or services from an ecosystem while maintaining the integrity of the ecosystem over time.

Thermal Refugia: Discrete areas in a river which provide suitable water temperature conditions for an organism within a more extensive area of less suitable conditions.

Watershed: Drainage basin that contributes surface or groundwater to the flow at that point; a drainage basin or a major subdivision of a drainage basin.

Wetland: An area subjected to continuous or periodic inundation, usually with soil and vegetation characteristics that separate it from non-inundated areas.

Zoobenthos: The aggregate of animal organisms living on or at the bottom of a body of water, or living in the gravel substrate connected to a river.

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APPENDIX A

Conceptual Model of a Ten-Step AEAM Process for the Yakima River Basin

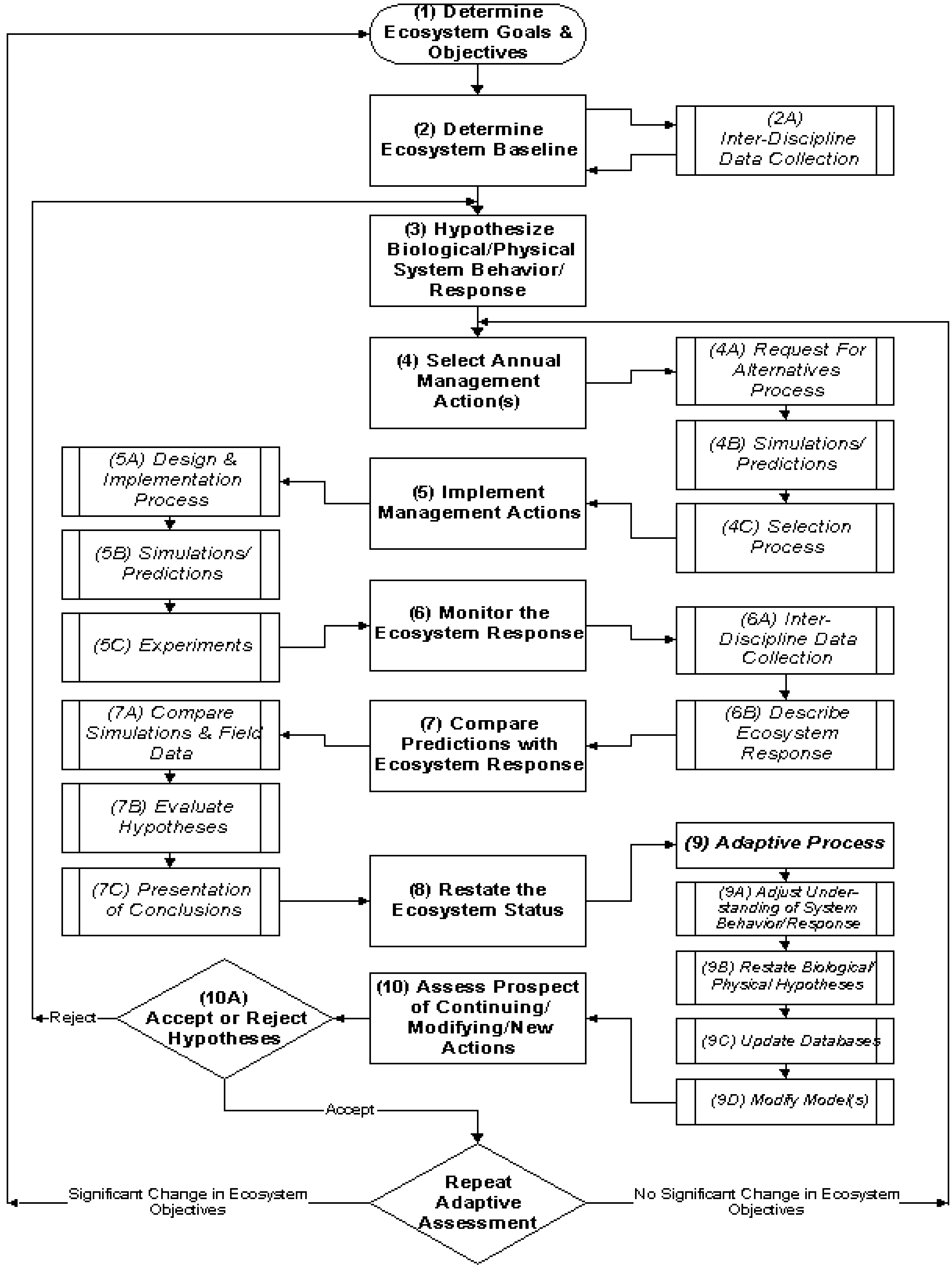

Figure A-1. The adaptive assessment and management process for the annual selection and evaluation of river system operation procedures and criteria.

1. <u>Determine Ecosystem Goals and Objectives</u>

Resource agencies and stakeholders form the ecosystem recovery goals through a watershed planning process. A key to successful watershed planning and ecosystem recovery is a combination of democratic stakeholder processes, technical input, and leadership. It is an error to assume that people will protect a stream if "educated." Management should: work towards creating common ground where there are win/win outcomes; consider competitiveness, environmental soundness, and social/political issues; clarify areas of conflict and view conflict as an opportunity to learn; maintain a policy evaluation framework that assumes, and is adaptable to, changing objectives; and address clearly stated conflicting alternatives, not a single, presumed social goal (Holling, 1977).

Once goals for restoring or sustaining the ecosystem are firmly in view, the technical processes may begin. The first step clarifies past trends and the current status of the ecosystem and watershed. The scientists must then translate the goals into a set of measurable end points (objectives for ecosystem response).

2. <u>Determine the Ecosystem Baseline</u>

The ecosystem baseline includes all relevant data, past and present, describing physical, chemical, and biological features of the river system. This will become the reference condition from which progress toward the management goals are measured.

3. <u>Hypothesize Biological/Physical System Behavior/Response</u>

Develop hypotheses of system behavior and responses of the biological, chemical, and physical components of the river ecosystem to directed management actions.

4. <u>Select Future Management Actions</u>

Based upon the past and current condition of the ecosystem, and armed with hypotheses about the consequences of management actions, the adaptive philosophy applies two processes for changing management activities. The first is to identify alternative management procedures to achieve the stated habitat and biota response objectives and the second is to compare and select from the alternatives those that appear to move the system toward management objectives. For regulated rivers this should be an annual process along with a review of current system operating criteria and procedures. If alternative actions are proposed to achieve the same response then designed experiments compare the alternatives (perhaps in consecutive years) leading to selection of the action that most efficiently achieves the measurable objective(s).

- Simulations/Predictions - Using state-of-the-art models, the disciplinary scientists simulate and predict the outcomes of the proposed management action alternatives. The results of the simulations and predictions form the basis for selecting the best management alternative.

- Selection Process - Examine water supply forecasts, status of the biota and anticipated life history needs of keystone species. The selection process must be a rational, well-regulated process, open to review and control by the management authority. The alternative selected should have the highest probability for successful implementation and achieving the annual management objectives based upon the water supply (e.g., water year type) and hypotheses for the system response.

5. Implement Management Actions

- Design & Implementation - The disciplinary scientists and management collectively are responsible for the design of the operating criteria and procedures for implementing the management actions prescribed by the selection process.

- Simulations/Predictions - Experts at modeling, simulating, experimental design, and predicting the outcome of management actions will endeavor to forecast seasonal responses to the selected annual operating criteria and procedures. The task is to expertly simulate and predict measurable physical, chemical and biological responses of the river ecosystem to the selected management actions. Rigorous application of the scientific method tests each iteration (annual forecasts/predictions) of simulation models through post audit comparisons of observed vs. expected results.

- Experiments - Management must be open to the support of short-term and long-term scientific experiments as part of an operations post-audit evaluation program. Experiments may be necessary to compare alternative hypotheses or alternative operating protocols that advocates present to achieve identical (or very similar) measurable objectives. When uncertainty in system response leads to differing scientific opinions, experiments are set up as alternative management actions compared between years.

6. Monitoring the Ecosystem Response

- Data Collection - The purpose of the data is to continue adding to the understanding of the ecosystem and its current status.

- Update Database(s) - Annual monitoring data are summarized and incorporated into an open and shared database.

- Experimental Design - Annual monitoring programs designed to test results of annual operating procedures are essential to establish scientific validity of the management actions taken.

- Describe Ecosystem Response - Data collected during the monitoring process is used to describe the response of the ecosystem to imposed management actions. The purpose is to establish scientific validity for the management program, gain management control over the causal processes, understand how management actions cause changes in the ecosystem, and support or refute ecosystem response hypotheses and improve model predictions.

7. Compare Predictions with Ecosystem Response

- Post-Audit Comparisons of Simulations & Field Data - These comparisons form the basis for evaluating the accuracy of the model simulations. Comparisons of model predictions with field observations are made and recommendations given for model improvement and changes to the operating criteria and procedures and monitoring program as appropriate. Replace model validation with invalidation - the process of establishing a degree of belief for each of a set of alternative model simulations (Holling, 1979). The scientific objective is to offer opinions on an annual basis of acceptance or rejection of the system response hypotheses and to continually improve predictive capability.

- Presentation of Conclusions - Sharing the conclusions in an open atmosphere will encourage participation and input from stakeholders. When scientific debate challenges management actions, stakeholders with differing opinions on operating criteria and procedures are requested to offer testable alternative hypotheses rather than simply argue to discredit the selected management procedures.

8. Restate the Ecosystem Status

After the implementation of specific operating criteria and procedures, the status of the ecosystem is reassessed and described. The new state is compared to the baseline state in order to measure progress toward ecosystem objectives.

9. Adaptive Process

The adaptive component of the management process is the learning and evolution of understanding. This process encourages stakeholders to converge their views of the ecosystem, its behavior and response to management actions, and the potential for achieving stated objectives.

- Adjust Understanding of Ecosystem Behavior/Response - The most difficult part of the AEAM process is for individual stakeholders to adjust their understanding of how the ecosystem functions. Treat assessment as an ongoing process and not as a one-time screening prior to a resource development decision (Holling, 1979). Given each annual water supply forecast, the suite of models is utilized to predict physical, chemical, and biological responses under the annual operating criteria and procedures, or designed experimental releases as appropriate. The adjustment takes honest examination of the data and scientific analyses following careful, deliberate management actions.

- Modify Models - Based upon the degree of congruence between model predictions and post-audit observations certain models may be re-calibrated, modified by reformulating certain relations or in some situations being replaced with new models. Following the annual updating of the suite of models the next round of management actions can commence. So long as monitoring data support the stated system hypotheses and model projections are reasonable, the models are simply re-calibrated or slightly modified to increase their predictive ability.

10. Assess Prospect of Continuing/Modifying/New Actions

- Restate Biological/Physical Hypotheses - An ongoing element of the process is to constantly challenge the stated system hypotheses and improve the ability to predict the behavior and response of the ecosystem so that progress towards the management objective is positive and rapid. If certain hypotheses of system response are not supported then new hypotheses must be proposed, modeled and in turn tested. Learning to guess better is an ongoing management endeavor, using all available tools and monitoring, based upon accepting or rejecting hypotheses of system response to management actions.

- The scientists must offer an annual statement of the system hypotheses presenting evidence in support or rejection of tested hypotheses.

- Recycle Through Adaptive Processes

- Design annual management actions (operating criteria and procedures). If system hypotheses are supported (not rejected), then recycle through the process by going back to step four and selecting annual operating criteria and procedures for the forecasted water supply (water year type).

- If system hypotheses are rejected, recycle through the process by going back to step three stating alternative hypotheses to achieve the same management goals.

- Redefine Ecosystem Goals When Appropriate - On occasions such as natural disasters, toxic spills or major legislative actions, the ecosystem management (social) goals may change. In such events recycle through the adaptive process by going back to step one. Restate the system goals, perhaps requiring a different or modified baseline and certainly the generation of new hypotheses of system response translated to new measurable system objectives.