Strategic Planning for Water Rights Acquisitions in the Central Columbia Basin: An assessment of regional streamflow response to climate change

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Abstract

Strategic Planning for Water Rights Acquisitions in the Central Columbia Basin: An assessment of regional streamflow response to climate change

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Conflict over scarce water resources in the Central Columbia River Basin is historic and persistent. Human alteration of the natural flow regime, land-use change and other factors have already caused 11 evolutionarily significant units (ESUs) of salmon (*Oncorhynchus spp*.) to be listed as threatened or endangered under the Endangered Species Act (ESA). Further, climate-change projections indicate that the hydrology of snow-dominant sub-basins within the Columbia Basin may be especially vulnerable to climate change. The objectives for this thesis are to identify regions of the Central Columbia River Basin that may be most flow-limited for ESA-listed fish populations and to provide the Washington Water Trust (WWT), a conservation organization, with strategic guidance for water rights acquisitions in these flow-limited regions. To accomplish these objectives, I performed two assessments: an examination of the potential changes in flow availability of the Okanogan, Methow, Wenatchee and Yakima sub-basins and an assessment of the opportunities and threats to the WWT's operational activities. I simulated streamflow under historic and future scenarios to evaluate potential impacts of changes in climate, water use and governance. To assess the WWT's operational activities, I examined water right characteristics in each sub-basin and compared the results to the WWT's stated mission and water right acquisition criteria. Results suggest that overall the Yakima sub-basin is projected to be most flow-limited during the summer months as a result of simulated climate change. Streamflow in the Yakima sub-basin is projected to decrease by an average of 40% in the period 2020 and 54% in 2040, with the greatest reductions occurring at the beginning of the summer. Further, my assessment indicates the Yakima sub-basin's recent water right adjudication, high potential for collaboration with other Yakima-based conservation organizations and the WWT's existing presence in the Yakima sub-basin make it the sub-basin most closely aligned with the WWT's stated mission and acquisition criteria. Ultimately, the hydrologic and organizational assessments suggest that instream flow conservation in the Yakima sub-basin will provide the greatest benefit to ESA-listed species and the operational success of the WWT over the next thirty years.

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Introduction

Conflict over scarce water resources is historic and persistent in the Columbia River Basin. The Columbia River provides the basis for several facets of the Pacific Northwest economy including hydroelectricity production, irrigation for food crops, barge transportation, fishery operations and other revenue generating activities (NRC, 1996). However, the impacts of these activities have cumulatively left a substantial environmental footprint on the terrestrial and aquatic systems of the Columbia River Basin (McConnaha, *et al.*, 2006). Habitat fragmentation, chemical pollution, exotic species invasions, overexploitation and other forces have caused freshwater ecosystem integrity to decline sharply in the last forty years (Alcamo, 2008). As a result of these and other activities, 11 Evolutionarily Significant Units (ESUs) of salmon (*Oncorhynchus spp.*) have been listed as either threatened or endangered under the Endangered Species Act (ESA). Although several forces influence the integrity of salmon populations in the Columbia River Basin, there are four dominant factors driving this research: insufficient streamflow for ESA-listed salmon habitat, the long-term impacts of climate change on hydrology, the emergence of organizations that use market-based mechanisms to conserve instream flows for salmon and the need for improved strategic planning within conservation organizations that may soon operate in ecosystems whose function and composition are without historical precedent.

This research focuses on the operations of the Washington Water Trust (http://washingtonwatertrust.org), a conservation organization that facilitates water rights transactions on a willing-buyer, willing-seller basis to enhance instream flows for ESA-listed salmon habitat. The Washington Water Trust's operations represent an innovative approach to natural resource management that may prove to be an essential complement to the ESA, the primary legal mandate for salmon habitat restoration. Although the Washington Water Trust has an existing strategic plan, the organization does not currently incorporate the potential impacts of long-term ecosystem drivers such as climate change and land-use change into their water right acquisition planning. Improving long-term natural resource planning requires strategically determining where and how managers can have the greatest positive impact on ecosystem integrity and using decision-support tools such as scenario-based modeling efforts to inform management planning and practices (Jackson and Hobbs 2009). I incorporate these strategies in my assessment using the following objectives.

Project Objectives

This thesis incorporates decision support and strategic planning for long-term ecosystem integrity into the Washington Water Trust's organizational activities. My three main objectives, with associated tasks, are:

1. Perform an assessment of the Washington Water Trust's external environmental factors, specifically instream flow quantity, that may impact the Washington Water Trust's activities:
    a. Rank the relative likelihood of flow-limited hydrologic conditions in selected sub-basins during the dry season by analyzing changes in climate, water use and water resource allocation.
    b. Assess potential impacts of increased water diversions for agriculture on endangered salmonid populations during the dry summer months.
    c. Assess the relative influences of the water allocation system on the modeled instream flow, including the quantity and the priority of the instream flow-rule.

2. Perform an assessment of the internal organizational factors that drive the Washington Water Trust's activities:
    a. Identify sub-basins that may provide the Washington Water Trust with the greatest opportunity for water right acquisitions based on the Washington Water Trust's stated acquisition criteria.
3. Use the results of the external environmental assessment and the internal organizational assessment to provide the Washington Water Trust with strategic guidance for water rights acquisitions in the next 30 years.

Background

Why is salmon conservation a priority for federal and local governments?

Salmon hold substantial cultural, economic and ecological importance in the Pacific Northwest (Quinn, 2005). Salmon are an important food source for indigenous peoples in the Northwest, and an integral component of native Americans' cultural and spiritual identities (NRC, 1996). In addition to serving as a form of subsistence, salmon fishing is an important source of revenue in the economy of the Pacific Northwest (NRC, 1996). Salmon also play a critical role in the ecology of Northwestern forests and streams. As salmon travel upstream to their spawning grounds, they carry marine-derived nutrients in their bodies (Naiman *et al.*, 2002; 2009). After spawning, salmon carcasses fertilize the aquatic system as well as the surrounding riparian areas. The nutrient inputs from decomposing salmon carcasses enhance riparian production thereby generating robust riparian vegetation that regulates stream temperature, acts as a control valve for nutrient and sediment inputs, and serves as a source of large wood (Latterell and Naiman, 2007). In this way, the presence of salmon helps maintain the long-term productivity of river corridors in the Pacific Northwest (Naiman, *et al.*, 2009).

The Importance of instream flows in the Columbia River Basin

The natural flow regime of the Columbia River Basin is dominated by winter snowfall and spring snowmelt. During the growing season, agriculturalists rely on water from the Columbia River tributaries to irrigate crops. Water withdrawals cause portions of many streams to experience low flows and in some cases run dry. These low flows often occur in the late summer (August/September), when some adult salmon migrate upstream to their spawning grounds, and some developing juveniles still reside. The instream thermal regime can become too warm for migrating adults and resident juveniles and may reduce the fitness of some populations (Quinn, 2005). After entering freshwater, certain species of salmon have only a few weeks in which to migrate and spawn. Extended migration times due to low flow conditions may result in pre-spawn mortalities (Quinn, 2005).

Several regions are already flow limited during the dry season. For example, the Washington State Department of Ecology has identified 16 critical basins within the Columbia Basin that experience low flows for endangered salmon populations (DOE, 2005). The critical basins identified by the Department of Ecology are the current areas of interest in the Columbia Basin Water Transaction Program (CBWTP). Portions of the Columbia River Basin may experience more drastic low flows during the dry season, and ultimately become inhospitable for salmon and other aquatic species (Stanford, *et al.*, 2006).

Traditional Approaches to Natural Resource Management

Until recently, managers and natural resource policy makers primarily relied on deterministic approaches to natural resource management. For example, restoring stream reaches without considering upstream impacts (Hagans and Weaver, 1986); or restoring physical aspects of fish habitat without ensuring that adequate stream flow will make the habitat accessible to fish (Reeves, *et al.*,1991). While these approaches provide the foundation for current understanding of ecosystem function, they often reduce ecosystem complexity, alter natural flow and disturbance regimes, and fail to consider the impacts of management actions on food webs, nutrient cycles or connectivity (Ostrom, 2007).

Novel Approaches to Salmon Habitat Conservation: the emergence of market-based water-right transactions

In 2002, the National Fish and Wildlife Foundation (NFWF), along with the CBWTP, introduced a market-based approach to salmonid habitat conservation: facilitating water-right transactions that keep water instream for salmon in critical habitat areas. The Northwest Power and Conservation Council (NWPCC), working in conjunction with Bonneville Power Administration (BPA) and NFWF, facilitates this form of water conservation for instream flows. Qualified Local Entities (QLEs), including the Washington Water Trust and the Washington Department of Ecology, partner with NFWF to facilitate water rights transactions in the Columbia Basin. These transactions take place on a willing-buyer, willing-seller basis and can provide benefits to both struggling fish populations and agricultural irrigators. The flexibility of this market-based system may greatly enhance the existing efforts the existing efforts to conserve salmon habitat as mandated by the ESA.

Implications of Climate Change for Water Resources in Washington State

The effects of climate change are expected to be extensive in the western United States (Leung and Ghan, 1999). Water systems in the West largely rely on snow pack and seasonal melt patterns. Global climate change has already influenced long-term changes in the hydrologic systems, and is projected to further alter the hydrologic regimes in Washington State (Elsner *et al.*, 2009; Beechie, *et al.*, 2009). For example, certain sub-basins within the Columbia Basin are changing their fundamental hydrologic typology from snow dominant to rain dominant systems (Elsner *et al.*, 2009; Vano *et al.*, 2009; ISAB, 2007a). Hydrologic systems within Washington State are experiencing (Elsner *et al.*, 2009):

- Lower Spring snow water equivalent
- Changes in the timing of stream discharge due to decreased snow pack
- Greater seasonal discharge due to gradual increases in annual precipitation

Although it is important for managers to consider statewide hydrologic impacts of climate change, it is equally necessary for managers to assess future hydrologic changes at scales of finer resolution (i.e., sub-basins, or even reaches). Currently, only one published study examines climate change impacts on hydrology at the sub-basin level within the Columbia River Basin (Vano, *et al.*, 2009). Shifts in land use and population change may also prove to have critical impacts on salmon populations. However, I focus on climate-induced changes in the flow regime of the Central Columbia for the purposes of my analysis.

Application of Climate Forecasting to Natural Resource Planning

Modeling capabilities are advancing quickly for climate forecasting as well as for ecosystem processes. However, until recently, status quo approaches have been perpetuated in the context of slow policy and institutional change (Stakhiv, 2003). Several initiatives are underway to establish ways of incorporating climate change observations into water resources management (Pulwarty, 2001; Snover, 2003). For example, government and non-profit entities have participated in similar efforts to plan for the regional impacts of climate change and potentially water scarce future conditions (Table 1). Currently, there are several efforts examining the potential impacts of climate change on the hydrology of the Columbia Basin system (Elsner *et al.*, 2009). These initiatives stand as evidence that the tools required to incorporate future climate projections into today’s planning already exist. However, these examples are exceptional in their inclusion of climate change in research and planning, and are not reflective of the vast majority of natural resource studies and plans currently being implemented (Bernhardt, *et al.*, 2005).

Table 1. Existing efforts to incorporate decision-support and long-term planning into water resource management in the Western United States.

Name of Entity	**Publication Title and Date**	**Region of Interest**	**Emphasis of Research**
Western Water Assessment Douglas Kenney, Natural Resource Law Center, University of Colorado	The Growing Mismatch Between the Timing of Spring Snowmelt and the Diversion Schedules Specified in Prior Appropriation Water Rights: A Preliminary Overview and Comparison of Circumstances in the Western United States Unpublished	Intermountain West	Brings potential future climate scenarios to bear on water right allocation systems of the Intermountain West
Western Water Assessment	Reconciling Projections of Future Colorado River Streamflow Nick Graham (HRC), Dan Cayan (CAP), Dennis Lettenmaier, Andy Wood (CIG), Robert Webb, Brad Udall, (WWA) Martin Hoerling (NOAA-WWA), Jonathan Overpeck, Holly Hartman (CLIMAS) 2005	Colorado River	Assesses the similarities and differences between streamflow projections in the Colorado River Basin. Qualifies the variation in various projections
Intermountain West Climate Summary	Recent Research on the Effects of Climate Change on the Colorado River**,** Brad Udall, May 2007	Colorado River Basin	Report on the possible impacts of potential climate-induced changes in hydrology of the Colorado River
CLIMAS Rebecca H. Carter and Barbara J. Morehouse Report #CL1-03	Climate and Urban Water Providers in Arizona: An Analysis of Vulnerability Perceptions and Climate Information Carter, *et al.* , 2003	Arizona	Brings potential future climate scenarios to bear on water resource planning for municipal uses in the Southwest
CLIMAS Rebecca H. Carter and Barbara J. Morehouse Report #CL2-01	An Examination of Arizona Water Law and Policy from the Perspective of Climate Impacts Carter, *et al.* , 2001	Arizona	Identifies assumptions in the state of Arizona’s water law and highlights areas that law-makers and policy makers may need to re-evaluate
California Climate Change Center	Using Future Climate Projections to Support Water Resource Decision Making in California Chung, *et al.* , 2009	California	Identifies potential climate scenarios vulnerabilities in California’s water resource infrastructure

Table 1 Continued. Existing efforts to incorporate decision-support and long-term planning into water resource management in the Western United States.

Name of Entity	**Publication Title and Date**	**Region of Interest**	**Emphasis of Research**
California Department of Water Resources	Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water CDWR, 2008	California	Identifies possible policy and municipal planning responses to potential climate change with reference to California's water resource management
California Department of Water Resources Technical Memorandum Report	Progress on Incorporating Climate Change into Management of California's Water Resources CDWR, 2006	California	Identifies work to date on building future scenario analysis into California's water resource planning. Also identifies areas for improvement in incorporating climate change planning
The Wilderness Society, Scenario Network for Alaska Planning	Climate Change Impacts on Water Availability in Alaska TWS, 2009	Alaska	Assesses potential future climate scenarios in the context of hydrology and water resources in Alaska
Salmonid Rivers Observatory Network Flathead Lake Biological Station The University of Montana	The Riverscape Analysis Project: Physical Complexity of Pacific Salmon Rivers and the Influence of Climate Change on Flow and Temperature Patterns Stanford, *et al.*, 2010	Pacific Rim	Provides an assessment of potential future climate scenarios with reference to physical fish habitat, instream temperature and water availability in the Pacific Rim.

Improving Natural Resource Planning

Globally, substantial funding and resources are dedicated to restoring ecosystem processes and functions to pre-defined historical reference points. However, mounting evidence suggests that resource managers may soon be operating in ecosystems that have composition and function unlike any ecosystem that has existed in human history – meaning they will have no historical reference point (Hobbs and Cramer, 2008). This presents a dilemma, as managers do not know how the expensively restored ecosystems will function in a future that is without precedent. In response to this dilemma, there have been increasing calls for long-term strategic planning efforts using decision-support tools in order to determine where managers may be able to have the greatest beneficial impact with their restoration efforts, and where their efforts are less valuable (Jackson and Hobbs, 2009). This thesis represents an effort to integrate long-term strategic planning using decision-support into the existing operations of the Washington Water Trust. In so doing, I bring potential hydrologic futures to bear on the Washington Water Trust's water right acquisition planning.

Study Area

The Columbia River Basin System

The Columbia River has its headwaters in British Columbia and empties into the Pacific Ocean near Astoria, Oregon. The Basin drains 647,500 km^2, and 58 of the River's ~600 reservoirs are hydroelectric dams which produce two thirds of the electricity in the Pacific Northwest (NWPCC, 2010). Consequently, reservoir management plays a major role in determining the annual hydrograph of the mainstem Columbia River. The region of focus in this study is comprised of four sub-basins within the Columbia Basin (Figure 1). These include the Okanogan, Methow, Wenatchee and Yakima sub-basins (or Water Resource Inventory Areas). These river basins comprise a total of 30,830 km^2, about 55% of which are publicly owned.

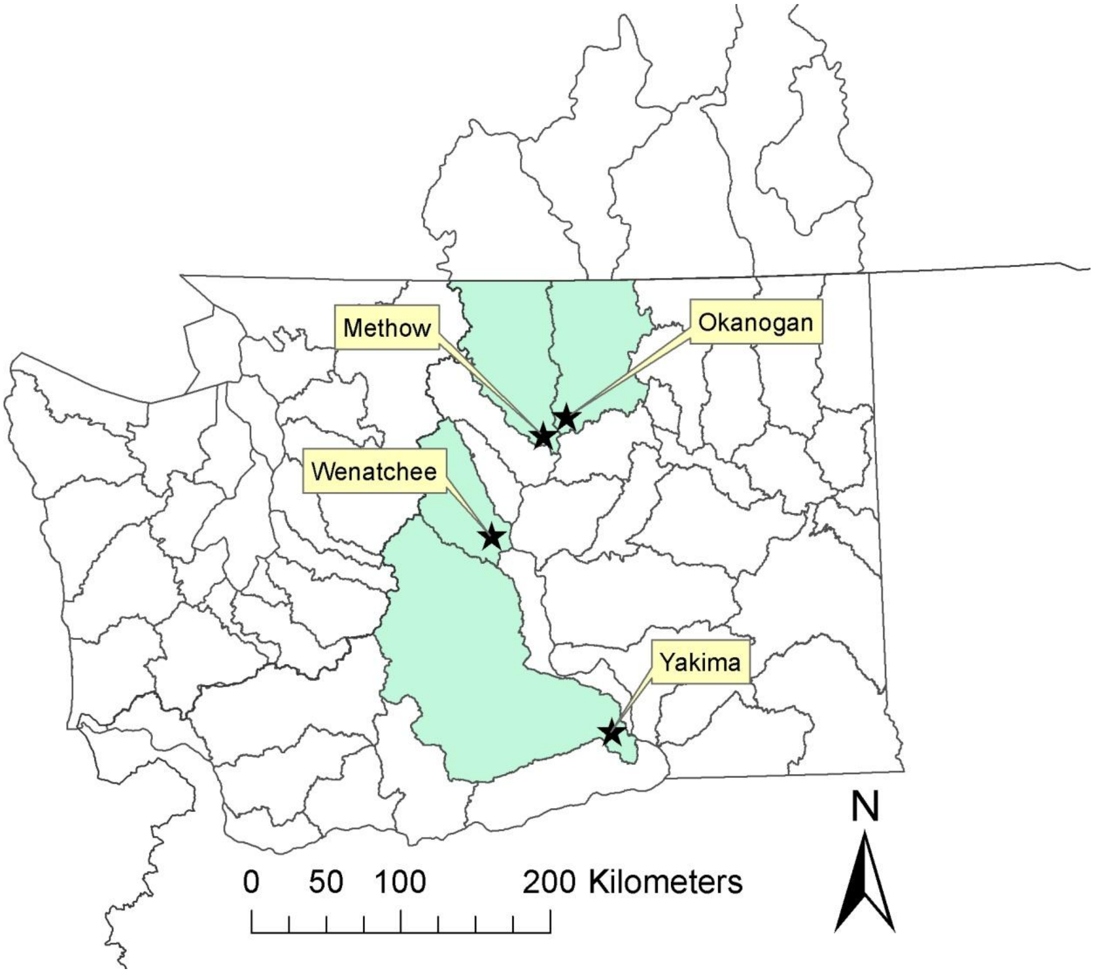

Figure 1. Map of sub-basins of interest (Okanogan, Methow, Wenatchee, Yakima) within the Central Columbia Basin. The stars denote the location of the streamflow forecasts and the existing USGS gages used to calibrate the modeled flows.

Each sub-basin examined has a distinctive character in terms drainage area, annual river discharge, fundamental hydrologic characteristics, human water use, and instream habitat available to salmon (Table 2). However, the sub-basins of interest share one commonality: agricultural water use represents the majority of the overall water use. Therefore, streamflow in all of the sub-basins of interest is highly sensitive to marginal changes in the quantity of water used for irrigation. Even moderate increases in agricultural water use (for example 20% increase over the next 10 years) may have substantial impacts on the instream habitat available for ESA-listed salmon. Additional information on each sub-basin is provided in the External Environmental Assessment in the Methods section below.

Table 2. Description of land area, annual discharge, fundamental hydrology, human water use and relative health of salmonid species within the Okanogan, Methow, Wenatchee and Yakima sub-basins.

Sub-basin Name	Drainage Area (km^2)	Average Annual Discharge (cms)	ESUs listed as Threatened or Endangered under ESA	Irrigated agriculture		Hydrologic Typology
				km^2	% Perennial Crops	
Okanogan	6,677.3	85.5	Steelhead, Spring Chinook	135	40%	Snow/Transient
Methow	4,675.0	45.3	Steelhead	56	10%	Snow Dominant
Wenatchee	3,548.3	93.4	Spring Chinook, Bull Trout, Steelhead	100	90%	Snow Dominant
Yakima	15,928.5	102.0	Spring Chinook, Steelhead, Coho	2341	30%	Transient

Several ESUs of salmonids occupy these sub-basins including spring and summer Chinook (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), coho (*Oncorhynchus kisutch)* and bull trout (*Salvelinus confluentus*). These ESUs are listed as either threatened or endangered under the Endangered Species Act (NOAA, 2009). Given that these species are already threatened or endangered, the impacts of climate change and water withdrawals may greatly limit habitat and impair migration for these species in the future, and further threaten their existence.

Methods

My research methods are based on a strategic planning framework. A strategic plan has two primary components: an external environmental assessment and an internal organizational assessment (Medley, 1988). These two primary planning components are used as organizational sections within this document and the organization of interest is the Washington Water Trust. I use the results of the internal organizational assessment and the external environmental assessment to provide the Washington Water Trust with recommendations for setting a strategic direction, defining a plan for the future, implementing the strategy and assessing performance of the strategy over time (Figure 2).

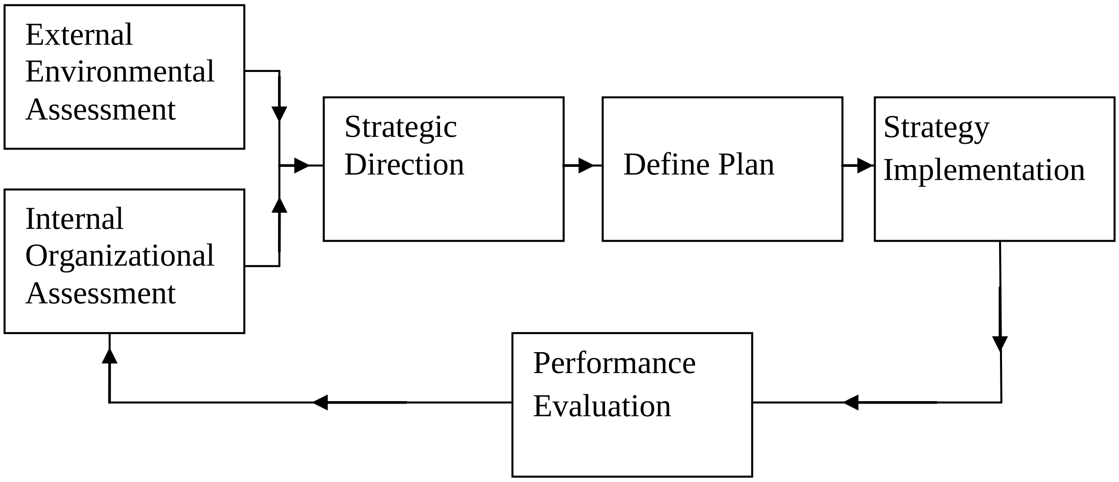

Figure 2. The Strategic Planning Process. The strategic planning process includes two assessments: the external environmental assessment and the internal organizational assessment. The results of these assessments inform an organization's strategic direction, which will serve as a guiding concept for the organization's strategic plan. Once the organization's strategic plan is implemented, periodic performance assessments help the organization re-evaluate their internal and external environments and guiding strategic concepts (Medley, 1988).

I. The External Environmental Assessment

The purpose of the external environment assessment is to identify opportunities and threats that have confronted, are confronting, and/or may confront the organization (Medley, 1988). By systematically assessing the operating environment in which the organization functions, I identify ways by which the organization is positioned to accomplish its mission and goals. Of equal importance, I learn the ways in which the organization can change its program functions to become better aligned with its operating environment (Lederman, *et al.*, 1984). In this case, I focus on changes in the physical and ecological environments to ascertain potential impacts on the institution's capacity to meet its stated goals.

I began the external environmental assessment with selection of particular sub-basins for evaluation. Four criteria are most likely to influence future basin hydrology (Dunne and Leopold, 1978; Ward and Trimble, 2003; Salathé *et al.*, 2007):

1) High relative potential for future hydrologic change as defined by Elsner, *et al.* (2009)
2) Listed Evolutionary Significant Units of salmon
3) "Critical basin" status as defined by the Washington State Department of Ecology
4) High relative water use for irrigation.

After consulting the basin planning documents (OCD, 2009; OCBC, 2005; DOE, 2006; TriCounty Water Resource Agency, 2003) for six sub-basins within the Columbia River Basin I performed a GIS-based assessment of the hydrology, water use, presence or absence of listed salmonids and status as a critical basin (as defined by the Washington State Department of

Ecology). Based on this assessment, I selected the Okanogan, Methow, Wenatchee and Yakima sub-basins for further investigation.

Modeling Framework and Data

To fulfill the first and second objectives, I modeled potential future hydrology of the selected sub-basins using a multi-model framework with three components (Figure 3, Table 3): The HadCM General Circulation Model (GCM) using the A1B greenhouse gas emission scenario generated by the Intergovernmental Panel on Climate Change (IPCC, 2007), the macroscale Variable Infiltration Capacity (VIC) hydrology model and an integrated water resource management model created using the Water Evaluation and Planning system (WEAP).

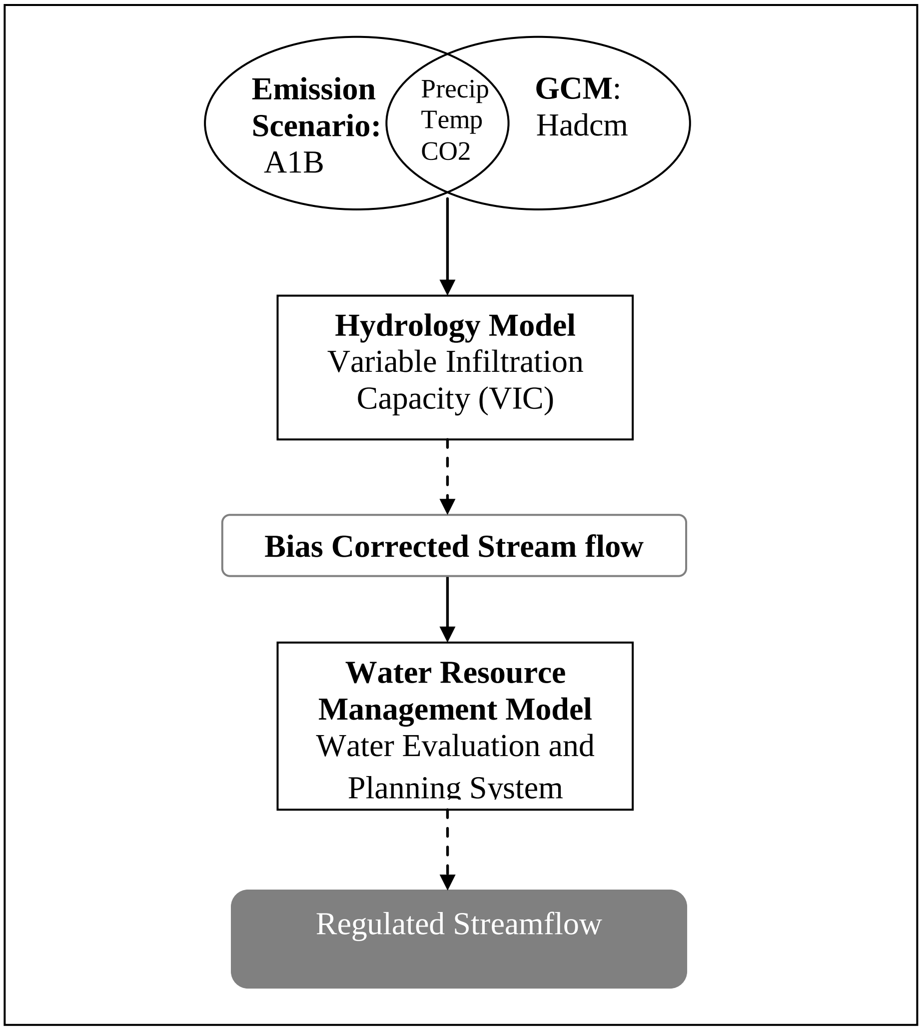

Figure 3. Multi-model approach for simulating climate-induced hydrologic change in selected sub-basins. This figure depicts the relationship between the linked models that I used to ultimately generate managed streamflow quantities for the selected sub-basin. The models are described in detail in Table 3. Climate and hydrology data from the University of Washington's Climate Impacts Group are routed the data through a Water Evaluation and Planning Model to ultimately project future managed streamflow under a variety of scenarios.

General Circulation Models (GCMs)

GCMs are useful in creating potential hydrologic futures. It is therefore appropriate to use them to assess sensitivities of water resource systems to future climate change, and to determine the feasibility of alternative adaptation strategies (Payne, 2002). Of the 20 GCMs assessed by the University of Washington's Climate Impacts Group, the HadCM model has the lowest bias for both temperature and precipitation in Washington State (Mote, *et al.*, 2005). For this reason, I used HadCM climate data as input for the VIC hydrology model.

There are a host of techniques for 'downscaling' the large GCM grids to finer scales (Morrison *et al.*, 2002). Downscaling is necessary because the spatial resolution of GCMs is too coarse to capture important sub-grid scale processes like regional topography and water bodies (Xu *et al.*, 2008). A preferred downscaling technique, the hybrid delta method, combines two other commonly used downscaling methods: the delta method and the bias correction and statistical downscaling method (A. Hamlet, University of Washington, personal communication, 2010). I chose data that the Climate Impacts Group generated using the hybrid delta downscaling method because it preserves the behavior of the time series and spatial correlations from the gridded temperature and precipitation observations, but transforms the entire probability distribution of the observations at monthly time scales based on the bias corrected GCM simulations (A. Hamlet, University of Washington, personal communication, 2010).

Table 3. Summary of Models used to generate future scenarios of regulated streamflow in the Columbia Basin (see also Figure 3). The table below provides information on the models used in the external environmental assessment including: the name of the model and the reference information, model type, data used to drive the model, the source of data used as input, method of downscaling (if applicable), and a description of the model output used in this study.

Model Name and Reference	Model Type	Data Inputs	Data Source	Downscaling Method	Outputs
A. Global Climate Model (GCMs) HadCM IPCC, 2007	Predictive Climate Model	Daily historic precipitation and temperature; greenhouse gas emissions scenario A1B (IPCC 2007).	Climate Impacts Group (University of Washington)	Hybrid Delta Method	Predicted daily precipitation and temperature changes from the present through 2020 & 2040
B. Variable Infiltration Capacity (VIC) Liang *et al.* 1994, 1996, 1999	Hydrology Model	Future precipitation and temperature forcings	(Output from GCM)	Data do not require downscaling	Monthly naturalized streamflow for 2020 & 2040
C. Water Evaluation and Planning System (WEAP) Yates, 2005	Water management model	Daily records of historic and future streamflows	(Output from VIC)	Data do not require downscaling	Monthly regulated streamflow in the Columbia Basin for 2020 & 2040

Variable Infiltration Capacity (VIC) Model

The Variable Infiltration Capacity (VIC) model is a semi-distributed grid-based hydrological model which parameterizes hydrometeorological processes taking place at the land surface - atmosphere interface (Liang *et al.*,1994, 1996, 1999). VIC uses sub-grid parameterizations for infiltration and the spatial variability of precipitation. Consequently, it accounts for sub-grid scale heterogeneities in key hydrological processes.VIC uses three soil layers and one vegetation layer, with energy and moisture fluxes exchanged between the layers. I used output from the VIC hydrology model as input for a water management model to predict the effect of water withdrawal, irrigation, and reservoir operation decisions on downstream flows.

VIC has been successfully linked with GCMs to model the effects of a changing climate on regional hydrology in other studies (Hamlet and Lettenmaier, 1999a; Hamlet and Lettenmaier, 1999b) and can be used to determine potential hydrologic futures (e.g., to assess sensitivities of water resource systems to changes in future climate) (Liang 1994, 1996; Nijssen, 1997).

Water Evaluation and Planning System (WEAP)

WEAP is a software-based tool created by the Stockholm Environmental Institute for integrated water resource planning (Yates *et al.*, 2005). WEAP operates using the principle of a water balance – weighing the demand side of the problem equally with the supply side – and is commonly used for assessing alternative water management strategies (Yates, *et al.*, 2008; Purkey, *et al.*, 2007; Huber-Lee, *et al.*, 2006). WEAP solves flow optimization at each time step by sending water to each demand site based on available flow and status in the priority scheme.

I imported spatial data layers including rivers and lakes, WRIAs, reservoirs and counties to the WEAP mapping interface to lay a graphical foundation for the process-based model. In the mapping interface, I specified supply sources, including tributaries to the Columbia River and the mainstem Columbia River; reservoir management; water withdrawals and return flows; and ecosystem requirements (Table 4). I used outputs from the VIC hydrology model as water supply inputs for WEAP.

Table 4. WEAP Data Sources. Data source for the water supply, reservoir management, water withdrawals, return flows and ecosystem requirements used to build the water resource management model in WEAP.

Data	**Water Supply**	**Reservoir Management**	**Water Withdrawals**	**Return Flows**	**Ecosystem Requirements**
Source	Naturalized stream flow generated by the UW Climate Impacts Group using the VIC hydrology model	Spatial data from the Washington state Department of Ecology; United States Department of Reclamation, Hydromet Data (http://www.usbr.gov/pn/hydromet/)	Basin Planning Documents (OCD, 2009; OCBC, 2005; DOE, 2006; TriCounty Water Resource Agency, 2003)	Basin Planning Documents (OCD, 2009; OCBC, 2005; DOE, 2006); TriCounty Water Resource Agency, 2003) and calculated evaporative losses	Washington state Department of Ecology existing instream flow-rules (http://www.ecy.wa.gov/laws-rules/ecywac.html#wr) ; Basin Fish Habitat Analyses Using the Instream Flow Incremental Methodology (DOE, 1992; USFWS, 1988; CCNRD, 2005; DOI, 1984; USFWS, 1988)

WEAP was selected over other water resource models because of its flexibility in scenario analysis, user-friendly interface, focus on water resource management and hydrologic mass balance. Although several other types of modeling software are available (RiverWare, BASINS, HEC-HMS, COLSIM) none of the alternative options has all the beneficial characteristics listed above.

WEAP Scenario Analysis

I apply five potential future scenarios in the WEAP model for two projected periods: 2020 and 2040 (Table 6). The two time periods are modeled using 90 years of precipitation variability under the projected climate and hydrology conditions of the respective time period (the projected climate conditions of either 2020 or 2040). In other words, I used 90 replicates of future climate and hydrology data for the periods 2020 and 2040 to capture the potential variability in climate for those time periods. The results of modeled scenarios in each time period were then compared with modeled historical flows that were calibrated with observed USGS gauge data.

The first scenario is the potential impact of climate change alone on instream flow in the selected sub-basins. I use the Intergovernmental Panel on Climate Change's A1B greenhouse gas emission scenario, which is considered a moderately high greenhouse gas emission scenario relative to other emission scenarios (IPCC, 2007). Scenarios two through five are considered independently as well as in combination with potential future climate change.

In the second and third scenarios, I impose potential future increases in agricultural water withdrawals of 20 and 40 percent respectively, in combination with the aforementioned influence of climate change. Agricultural water use accounts for the majority of the water use in all sub-basins and is therefore the most influential water use sector for determining the amount of streamflow available for ESA-listed fish species. I selected these percentage increases in agricultural water use as a means of assessing the potential impacts of a moderate, and more severe (20% and 40%) increase in the primary water-using sector.

I use the fourth and fifth scenarios to assess the relative influence of the water governance system on the modeled instream flow. The fourth potential future scenario involves setting the existing instream flow-rule, as defined by the Washington State Department of Ecology, as the 1st priority in the allocation scheme (Table 5) (DOE, 1991).

Table 5. Current monthly instream flow requirements (cms) for the Okanogan, Methow, Wenatchee and Yakima sub-basins as defined by the Washington State Department of Ecology (DOE, 1991).

Month of the Year	Okanogan	Methow	Wenatchee	Yakima
1	23.9135	9.905	23.206	16.98
2	23.3475	9.905	22.923	16.98
3	24.4795	9.905	26.036	22.64
4	25.82375	20.5175	43.865	25.47
5	40.3275	45.846	70.75	28.3
6	107.54	62.826	83.485	39.62
7	83.485	41.7425	41.035	16.98
8	19.81	19.81	21.225	8.49
9	18.678	8.49	19.81	8.49
10	24.1965	11.1219	19.81	14.15
11	26.885	12.0275	22.64	16.98
12	25.8945	10.471	22.64	16.98

The fifth potential future scenario includes creating a biologically-based instreamflow-rule using Weighted Usable Area (WUA) curves created by the Washington State Department of Fish and Wildlife (DOE, 1992; USFWS, 1988; CCNRD, 2005; DOI, 1984; USFWS, *et al.*, 1988) and setting it as the first priority in the allocation scheme. WUA is an index which uses the available instream flow to quantify fish habitat value. WUA is expressed as a percentage of habitat area predicted to be available per unit length of stream at a given flow (DOE, 1992). WUA figures included in the model can be found in Appendices A-G.

Table 6 Graphical representation of scenarios included in WEAP scenario analysis. The table below depicts scenarios examined in the WEAP model. The first scenario is a change in climate; the second scenario is a 20% increase in agricultural water uses; the third scenario is a 40% increase in agricultural water uses; the fourth scenario uses the Washington State Department of Ecology's existing instream flow-rule and sets it as the first priority in the water allocation scheme; the fifth scenario uses a biologically-based instream flow-rule and sets it as the first priority in the water allocation scheme.

Time Period	Scenario 1: Climate Change with A1B Greenhouse gas emission	Scenario 2: 20 % Ag Increase	Scenario 3: 40 % Ag Increase	Scenario 4: Instream flow-rule 1st priority	Scenario 5: Biologically-based Flow-rule 1st Priority
2020	X				
2020	X	X			
2020	X		X		
2020	X			X	
2020	X				X
2040	X				
2040	X	X			
2040	X		X		
2040	X			X	
2040	X				X

WEAP Hydrology Inputs and Bias Correction

I used VIC naturalized flows generated by the Climate Impacts Group (CIG) at the University of Washington as input for the river systems in WEAP (Elsner *et al.*, 2009). USGS observed gage flow and simulated flows were used for the selected sub-basins for the period 1915-2005. To ensure that simulated VIC flows reflect historical conditions, I performed a simple bias correction using a 'conservation of mass' approach (ASCE Hydrology Handbook, 1996). This is necessary because the hydrograph of the USGS flows are highly altered by agricultural activities and reservoir management. Peak and low flows in a naturalized system are attenuated by these forms of management.

To bias correct VIC data, I added the estimated basin losses to USGS flows. Then I compared the total discharge volumes of USGS (semi-naturalized flow) for a specified time period to the VIC naturalized flow of the same time period. I then applied a multiplier to correct the VIC flow so that the total discharge volume matches USGS semi-naturalized flows. This preserves the natural hydrograph's peak and low flow timing (ASCE Hydrology Handbook, 1996). Additionally, the conservation of mass bias correction, which uses total flow volume in a given river over a given time period, accounts for any evaporative losses due to the abundant small impoundments on farms in the sub-basins.

WEAP Reservoir Management

For each sub-basin I aggregated all of the existing reservoirs containing over 1,233,482 m^3 (~1,000 acre-feet) of storage volume. I then included the storage capacity, volume elevation curve, net evaporation, top of conservation, and timing of release for the largest dams (as defined by the dam managers, often the U.S. Bureau of Reclamation). Subsequently, I calibrated the reservoir rule curves to ensure that the modeled flows reflected the pattern and variability of the observed USGS hydrographs. It is important to note that although I only included reservoirs over 1,233,482 m^3 (~1,000 acre-feet) of storage volume, there may be as many as 600 smaller reservoirs distributed throughout the Columbia Basin. These small reservoirs may be less significant in terms of their water storage, but they may have large implications for the Central Columbia region (NWPCC, 2010).

The Yakima sub-basin has more complex reservoir and irrigation systems than any of the other sub-basins (TriCounty Water Resource Agency, 2003), and therefore required extensive calibration. The reservoir and irrigation systems in the Yakima sub-basin increase infiltration and base flows thereby significantly altering the annual hydrograph (Izuka, 2006). VIC cannot simulate the response of sub-surface flow to reservoir and irrigation systems because it only models natural surface water processes. To account for the influence of reservoir and irrigation management, I increased reservoir storage by including an additional reservoir in the Yakima sub-basin that could account for sub-surface water storage not captured in the VIC simulations. For the entire time series between 1915 and 2006, I estimated monthly differences between observed flow and simulated flow and made monthly corrections to optimize the reservoir rule curve values so that flows generated using the optimized rule curves would closely resemble those of the observed USGS gauge data.

Evaporative losses from reservoirs were estimated by considering the total surface area and total storage volume, and applying Class A pan evaporation methods (Ward and Trimble, 2003). Some sources indicate that Class A pan evaporation methods may overestimate evaporation rates, so my reported reservoir evaporation rates may be relatively high estimates in terms of the effects of reduced instream flows for salmonids (Ward and Trimble, 2003). To calculate lake evaporation volume, I used a pan coefficient reported by the U.S. Bureau of Reclamation and pan evaporation depth (in millimeters) reported by the Oregon Climate Service (Jones, 1992; OCS, 2010) in the following equation to solve for lake evaporation depth, and multiplied the lake evaporation depth by reservoir surface area (Equation 1).

$$(Pan\ Coef)(Pan\ Evap\ Depth) = Lake\ Evap\ Depth \qquad (1)$$

Water Withdrawals and Management

I identified sub-basin specific water withdrawal data for the purposes of irrigation, municipal/domestic consumption and commercial/industrial uses by contacting local water managers. Annual water withdrawal and management information were obtained from the Watershed Planning Documents for each respective sub-basin (OCD, 2009; OCBC, 2005; DOE, 2006; TriCounty Water Resource Agency, 2003; Appendices H-K). I estimated monthly agricultural withdrawals using the Soil Conservation Service (SCS) Blaney-Criddle Method to include seasonal changes in actual evapotranspiration (SCS, 1970):

$$U = K \sum_{i=1}^{n} f_i \qquad (2)$$

Where U is the seasonal consumptive use in cm/season; K is the seasonal consumptive use coefficient for a crop with a normal growing season; n is the number of months in the season. The monthly consumptive use factor (f) is calculated by taking the product of mean monthly air temperature in degrees Celsius and the mean monthly percentage of annual daytime hours; then converting to a percentage. To quantify losses due to crop evapotranspiration, I quantified the crop types and the spatial area that the crops occupy in each sub-basin (Table 7).

Table 7. Crop distribution in each Water Resource Inventory Area (WRIA) of interest. Total square kilometers irrigated, type of crop and square kilometers associated with the crop are reported

WRIA	Total Irrigated km^2	Crop	km^2 Crop Coverage
Methow	55.94	Alfalfa	43.08
		Orchards	5.03
		Pasture	7.27
WRIA	**Total Irrigated km^2**	**Crop**	**km^2 Crop Coverage**
Okanogan	134.88	Hay	26.98
		Cherries	17.53
		Pears	17.53
		Apples	17.53
		Alfalfa	20.23
		Pasture	20.23
		Other	14.84
WRIA	**Total Irrigated km^2**	**Crop**	**km^2 Crop Coverage**
Wenatchee	100.32	Pears	43.47
		Apples	33.44
		Cherries	20.06
		Wheat	3.34
WRIA	**Total Irrigated km^2**	**Crop**	**km^2 Crop Coverage**
Yakima	2,340.80	Corn	100.32
		Wheat	668.80
		Barley	6.69
		Potatoes	100.32
		Kentucky Bluegrass	30.10
		Alfalfa	167.20
		Hay	167.20
		Asparagus	30.10
		Other vegetables	334.40
		Orchards	501.60
		Hops	117.04
		Mint	50.16
		Other	66.88

I converted the reported annual municipal/domestic uses and commercial/industrial consumption to monthly water use values using the USGS' *National Handbook of Recommended Methods for Water Data Acquisition* (USGS, 1978). I applied suggested consumption efficiency figures to extrapolate monthly usage from annual figures (Appendices M-P).

I calculated return flow for municipal/domestic, and commercial/industrial water withdrawal nodes using reported average return flows (OCD, 2009; OCBC, 2005; DOE, 2006; TriCounty Water Resource Agency, 2003). I calculated return flows for agriculture by calculating the difference between water delivered for agricultural use and the calculated evapotranspiration rate (see Blaney-Criddle method above). The return flows from municipal and industrial water uses are based on the assumption that percent water consumption is equal in each respective water sector (municipal and industrial) regardless of sub-basin.

To define the water allocation scheme in the WEAP model, I aggregated water sectors (agricultural, municipal and domestic and commercial and industrial) and defined the allocation priority system. As agricultural water users generally possess the majority of the senior water rights, I identified agricultural water users as the first priority in the allocation scheme, municipal and domestic water users as the second priority and commercial and industrial users as the third priority in the allocation scheme. This is a necessary simplification of the very complex existing water allocation system (Alcamo, 2008b).

II. The Internal Organizational Assessment

The purpose of an Internal Organizational Assessment is to evaluate the strengths, weaknesses, opportunities and threats to an organization. Often, internal organizational assessments can be used to assess institutional performance in light of the adopted mandate (Andrews, 1990). I performed an internal assessment to assist the Washington Water Trust in determining whether the proper amounts of resources are being committed to realize the organization's objectives. Additionally, this assessment provides an opportunity to evaluate institutional processes and procedures currently being implemented by the Washington Water Trust and includes recommendations for improving the focus of existing organizational actions. I assess two primary components of the Washington Water Trust's organizational activities: Their existing purchase criteria and existing water right characteristics present in each sub-basin.

Washington Water Trust's existing purchase criteria

The Washington Water Trust has an annual acquisition budget of ~$1,000,000 USD. To ensure that the limited funds go toward projects providing the greatest return on investment, the Washington Water Trust uses specific criteria to select water rights that are likely to have a significant beneficial impact on the instream environment. These criteria fit in four general categories: validity of water right, potential ecological impact, social impact, and economic feasibility/risk (Table 8).

Table 8. Washington Water Trust's existing purchase criteria. The Washington Water Trust’s existing purchase criteria include the validity of the given water right, the potential ecological impact to the instream environment of purchasing the right, the social impact in the region of acquisition and the economic feasibility associated with the risk. This information provided by the Washington Water Trust.

Validity of Water Right:	**Ecological Impact**	**Social & Washington Water Trust Impact**	**Economic Feasibility/Risk**
Uninterruptible water right	Contributes to LFA (limiting factors analysis) of flow quantity needed for fish	Public relations (goodwill); political capital	Impacts to water market
Sufficient documentation exists	Potential for reaching target flows	Recreational Opportunities	Funding Support
Water can be protected (primary / secondary)	Passage (barrier issues)	Also beneficial for farming	Element of permanence
Level of difficulty in proving water right	Habitat potential	Innovative	Pricing of water
Measuring devices installed	Number of ESUs in stream	Leverage future projects	Administrative costs
Level of compliance to water code in creek	Lifecycle Phases	Working with partners	Legal costs
	LFA or CWA (Clean Water Act) listed for water quality	Complimentary restoration efforts ongoing on this tributary	Opportunity cost of water right
	LFA or CWA listed for water temperature	Water Acquisition within Local Plans	Cost/cubic meter
	Length of protection	Improve donor base or portfolio for improved competitiveness for grant funds	
	Instream acquisition amounts to 5%	Learning experience for staff	
	Time flows fish inadequate during WR season	Legal Incentives (ESA/Tribal Rights pressures)	
	Water withdrawal is primary low flow cause		

Water Right Characteristics of Each Sub-basin

The characteristics of the water rights present in each sub-basin influence whether or not the Washington Water Trust has a vested interest in purchasing rights in that particular region. The basin-specific water right characteristics include: the average irrigated area, the average instantaneous flow quantity associated with the rights in the particular basin, the average annual flow volume, the number of listed species present in the basin, whether or not the Washington Water Trust has had previous activity in the basin, and the most recent adjudication of the rights in the basin. I acquired a comprehensive database of water rights in each of our four sub-basins of interest from the Washington State Department of Ecology and compared the water rights in each basin to the Washington Water Trust's water right selection criteria (discussed in section 1 of the internal organizational assessment). Using the Washington Water Trust's water right selection criteria, I assess the sub-basins in terms of the potential acquisition opportunities available and consider the relative instream benefit of the rights within each basin (Table 14, Table 15). I perform this assessment for two sets of water rights: all water rights located in the respective sub-basin and the water rights that are in the 7.5% most senior rights in the respective sub-basin. Water rights adjudicated as senior rights in the Yakima sub-basin represent 7.5% of all the water rights in the sub-basin (DOE, 2010). To make comparisons of the most senior rights across sub-basins, I used 7.5% as the cut-off value to represent the most senior rights in all sub-basins.

Results

I. External Environmental Assessment

Scenario 1: Impacts of Climate Only

Comparison of sub-basins for the A1B greenhouse gas emission scenario for the period 2020 indicate that the Yakima sub-basin is projected to experience the greatest monthly reductions in streamflow (22-58%) during the dry summer months relative to historic conditions. Similarly, for the 2040 time period, the simulated streamflows for the Yakima sub-basin were on average 78%, 53% and 32% lower than historical conditions for the dry July, August and September months (Figure 4, Table 9).

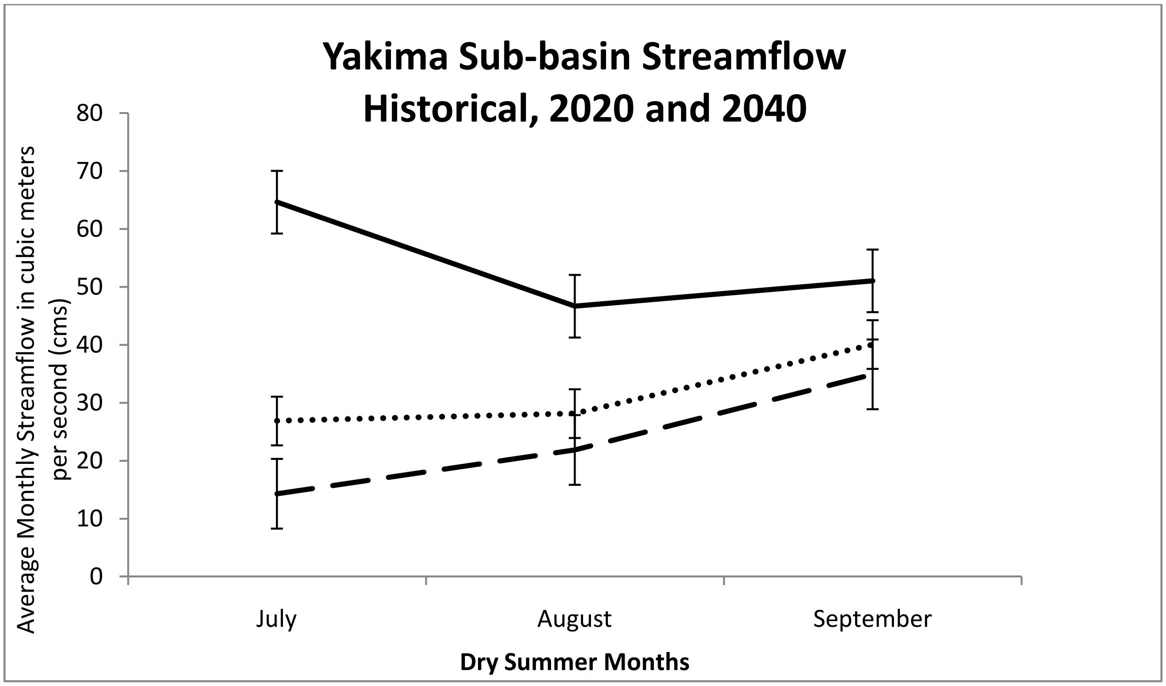

Figure 4. Projected average monthly reductions in discharge in the Yakima River for the periods 2020 and 2040 under the A1B carbon dioxide emission scenario. The solid black line represents streamflow in cubic meters per second (cms) during the dry summer months under the historical scenario. The dotted line represents streamflow (cms) during the summer months under the A1B carbon dioxide emission scenario in the period 2020. The dashed line represents streamflow (cms) during the summer months under the A1B carbon dioxide emission scenario in the period 2040.

Simulated streamflows in the Wenatchee sub-basin also indicate substantial reductions under a warming climate. For example, for the 2020 time period, streamflows in the month of July are 15% lower than that of the historical simulation. The months of August and September show reductions of 40% and 35%, respectively. For the year 2040, the Wenatchee sub-basin is projected to experience 33%, 62% and 56% reductions in streamflow relative to historic conditions for the months of July, August and September (Figure 5, Table 9). While the Yakima sub-basin tends to be most flow limited at the beginning of the summer months, the Wenatchee sub-basin tends to be most flow limited at the end of the summer months.

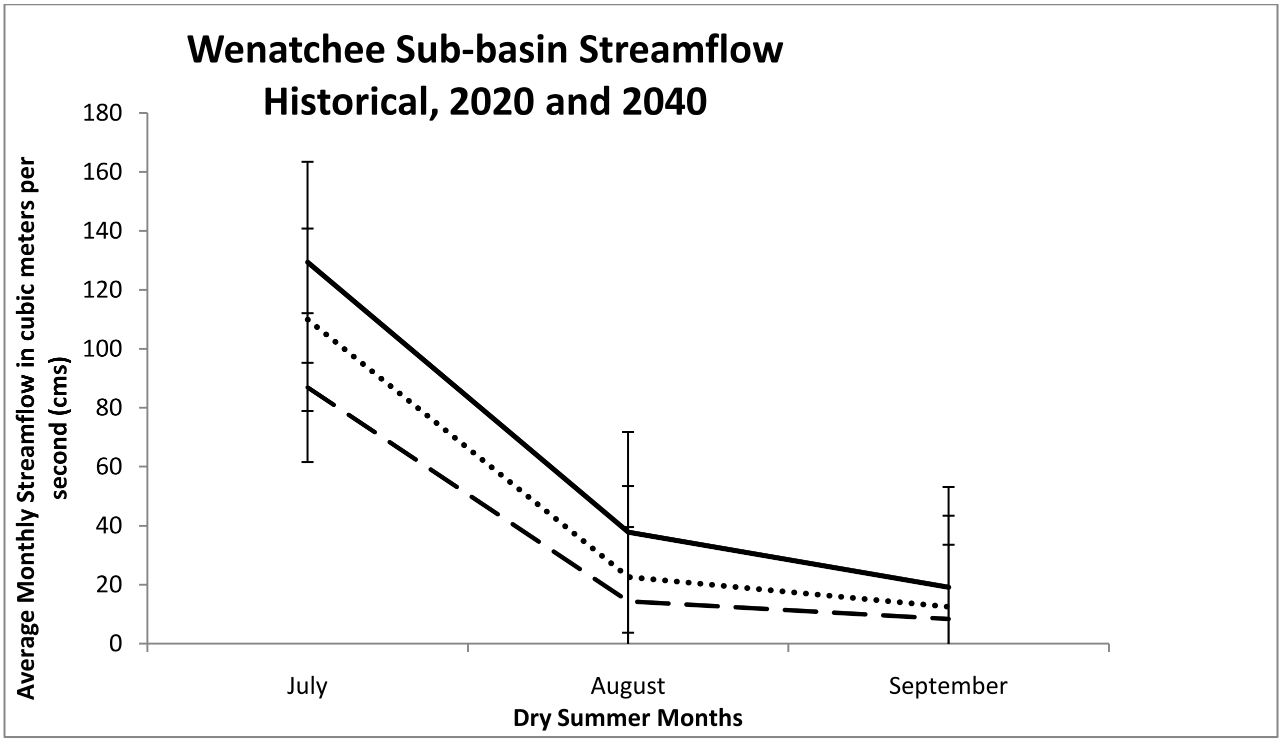

Figure 5 Projected average monthly reductions in discharge for the Wenatchee River for the periods 2020 and 2040 under the A1B carbon dioxide emission scenario relative to historic conditions. The solid black line represents streamflow in cubic meters per second (cms) during the dry summer months under the historical scenario. The dotted line represents streamflow in cms during the summer months under the A1B carbon dioxide emission scenario in the period 2020. The dashed line represents streamflow in cms during the summer months under the A1B carbon dioxide emission scenario in the period 2040.

Simulations in the Methow sub-basin exhibited the third most severe reductions in streamflow relative to historic conditions (Table 9). For the months of July, August and September, the Methow sub-basin is projected to experience a reduction of 26%, 37% and 24%, respectively, for the period 2020. For the period 2040, the Methow experienced 44%, 45% and 33% reductions in streamflow for the same dry months (Figure 6, Table 9).

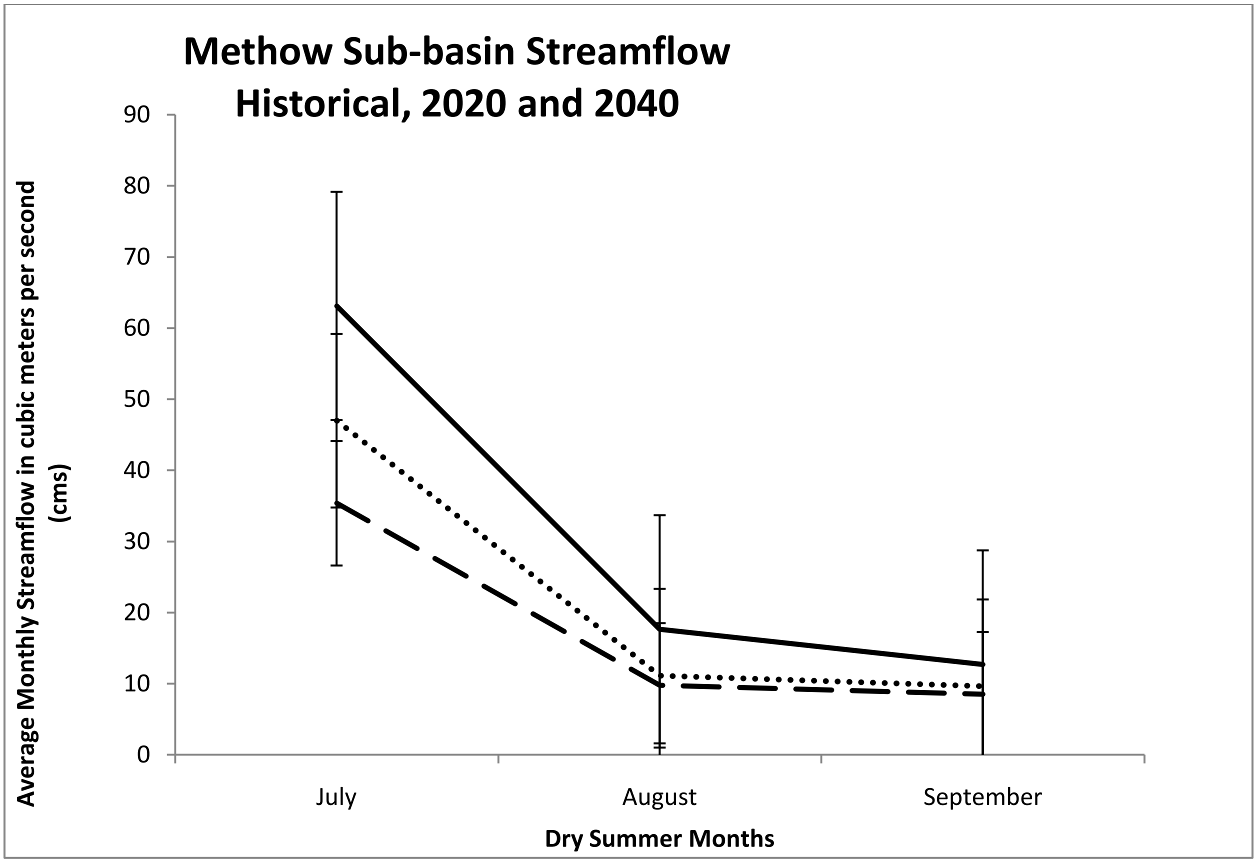

Figure 6. Projected average monthly discharge in Methow River for the periods 2020 and 2040 under the A1B carbon dioxide emission scenario relative to historic conditions. The solid black line represents streamflow in cubic meters per second (cms) during the dry summer months under the historical scenario. The dotted line represents streamflow in cms during the summer months under the A1B carbon dioxide emission scenario in the period 2020. The dashed line represents streamflow in cms during the summer months under the A1B carbon dioxide emission scenario in the period 2040.

Finally, simulated streamflow in the Okanogan sub-basin exhibited the least severe reductions in streamflow relative to historic conditions for both 2020 and 2040 (Table 9). For the period 2020, Okanogan sub-basin streamflow simulations were 17%, 15% and 20% lower than historical conditions for the months of July, August and September. Similarly, for the 2040 time period, the dry summer months exhibited 30%, 17% and 28% reductions in streamflow relative to the historical scenario (Figure 7, Table 9).

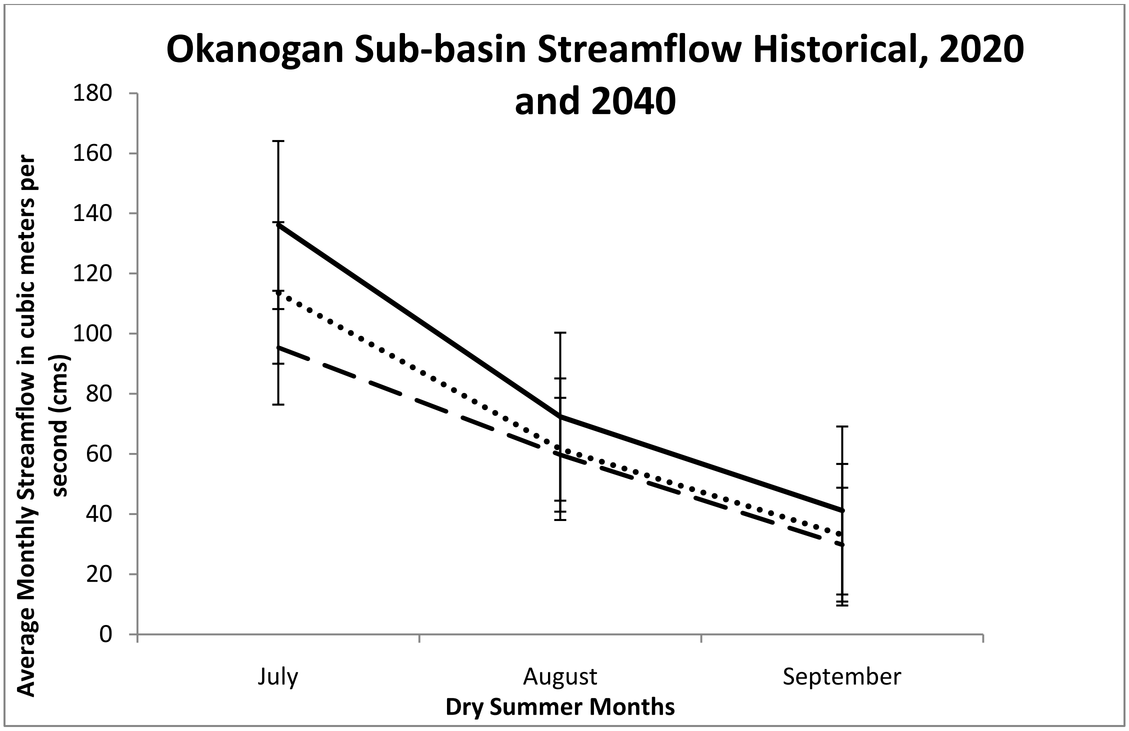

Figure 7. Projected average monthly discharge in Okanogan River for the years 2020 and 2040 under the A1B carbon dioxide emission scenario relative to historic conditions. The solid black line represents streamflow in cubic meters per second (cms) during the dry summer months under the historical scenario. The dotted line represents streamflow in cms during the summer months under the A1B carbon dioxide emission scenario in the period 2020. The dashed line represents streamflow in cms during the summer months under the A1B carbon dioxide emission scenario in the period 2040.

Table 9. Projected percentage reduction in average monthly streamflow during the dry summer months (July, August and September) relative to historic conditions for the years 2020 and 2040 under the A1B carbon dioxide emission scenario. Sub-basins that experience the greatest average reduction in streamflow for the given month are shaded gray. The Yakima sub-basin experiences the greatest average reduction in streamflow in the early summer for both 2020 and 2040. Whereas the Wenatchee sub-basin experiences the greatest average reduction in streamflow relative to historic conditions in the later summer for both 202 and 2040.

	2020 Climate Only			**2040 Climate Only**		
Sub-basin Name	**July**	**August**	**September**	**July**	**August**	**September**
Okanogan River	17%	15%	20%	30%	17%	28%
Methow River	26%	37%	24%	44%	45%	33%
Wentachee River	15%	40%	35%	33%	62%	56%
Yakima River	58%	40%	22%	78%	53%	32%

Scenarios 2 and 3: The influence of climate and simulated increases in agricultural water use

Agricultural water use accounts for the majority of water use in all of my sub-basins of interest (Table 10). In the Methow and Wenatchee sub-basins, agricultural water use accounts for 56% and 60% of the overall water use respectively. Whereas in the Okanogan and Yakima sub-basins, agricultural water use accounts for 87% and 95% of the overall water use, respectively. Therefore, changes in water withdrawals in the agricultural sector have the greatest influence on water availability for instream fish habitat in the Yakima River relative to other sub-basins. For example, simulations of increased water withdrawals in the Yakima sub-basin indicate that under a 20% increase in agricultural water withdrawals, the instream flow of the Yakima River declines an average of 41% during the summer months in 2020. Similarly, a simulated increase of 40% agricultural water withdrawals yields an average reduction of 56% during the summer months in 2040 (Figure 8).

Table 10. Comparison of historical average monthly summer stream discharge (cms) and average monthly summer water use (cubic meters). This table shows that out-of-stream water withdrawals is highest in the Wenatchee and Yakima sub-basins, especially during the summer months.

	Historical Average Monthly Summer Flow Volume (km^3) (before withdrawals)			**Average Monthly Summer Water Use (cubic meters) (for the entire sub-basin)**					
Sub-basin Name	**July**	**August**	**September**	**Agriculture**		**Domestic**		**Commercial**	
				Water Use km^3	**% of average summer discharge**	**Water Use km^3**	**% of average summer discharge**	**Water Use km^3**	**% of average summer discharge**
Okanogan	3.17	1.40	1.01	0.16	8.60%	0.01	5.40%	0.01	5.40%
Methow	1.69	0.65	0.46	0.089	9.64%	0.0016	0.17%	0.067	7.20%
Wenatchee	3.34	1.14	0.65	0.11	6.43%	0.0066	0.39%	0.067	3.91%
Yakima	5.47	4.85	4.09	3.31	9.64%	0.15	3.12%	0.03	0.62%

The Wenatchee sub-basin serves as an example of a system that is less dominated by the influence of agricultural water use than the Yakima sub-basin. The Wenatchee sub-basin is projected to experience average streamflow reductions of 34% in 2020 relative to the historical scenario. Whereas in 2040, the Wenatchee sub-basin is projected to experience average streamflow reductions of 53% during the summer months relative to the historical scenario (Figure 9). Therefore, on average, the Wenatchee sub-basin is projected to be less impacted by increases in agricultural water use than the Yakima sub-basin.

The Okanogan and Methow Rivers are also projected to be reduced in response to increases in agricultural water use. The Methow sub-basin is projected to experience streamflow reductions that are on average 34% less than historical conditions in 2020. In 2040, the Methow sub-basin is projected to experience streamflow reductions of 45% on average, relative to historical conditions. The Okanogan sub-basin is projected to experience reductions in streamflow of 20% on average relative to historical conditions in 2020, and 28% in 2040 (Table 11).

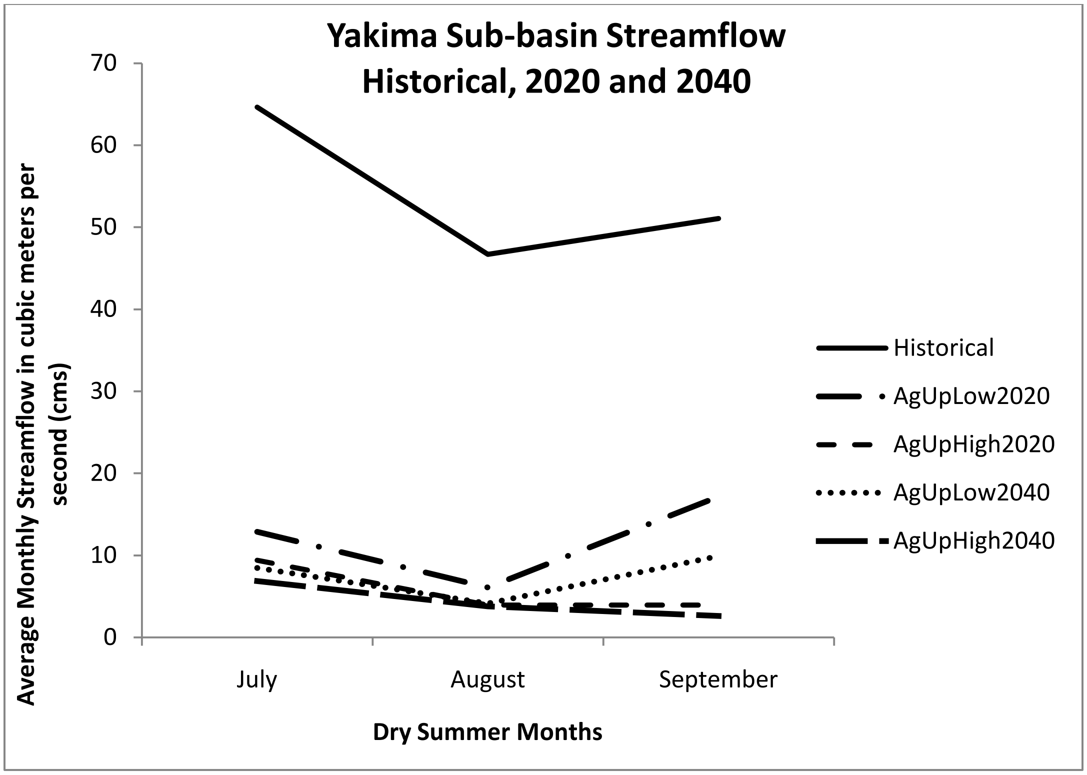

Figure 8. Changes in stream discharge in the Yakima sub-basin in response to increased agricultural water withdrawals and climate change. This figure depicts a simulation of a 20% and 40% increase in agricultural water withdrawals in the historical, 2020 and 2040 time periods. All increases in water withdrawals greatly reduce streamflow availability in the Yakima.

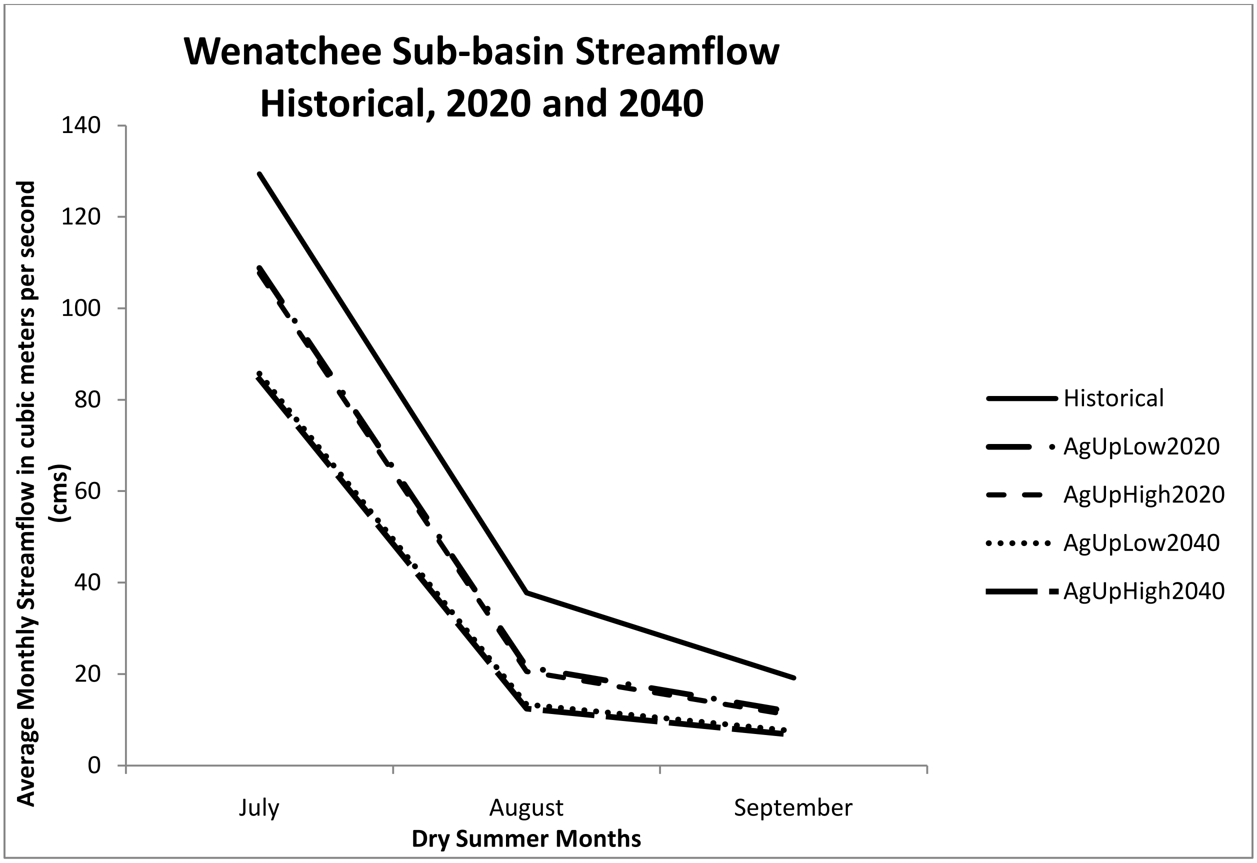

Figure 9. Changes in stream discharge in the Wenatchee sub-basin in response to increased agricultural water withdrawals and climate change. This figure depicts a simulation of a 20% and 40% increase in agricultural water withdrawals in the historical, 2020 and 2040 time periods. As a sub-basin that is substantially less dominated by agriculture, streamflow in the Wenatchee River is less responsive to increases in agricultural water use and more responsive to changes in climate.

Scenario 4: Percent of Instream Flow Requirement Attained Using the Washington Department of Ecology's Instream Flow-rule as the 1st Priority in the Allocation Scheme

Even under historical conditions, differences exist between each sub-basin in the degree that instream flow-rules are met (or the percentage of flow-rule volume that is met). For example, in the Okanogan sub-basin, simulated historical flow is sufficient to meet 99% of the existing instream flow-rule volume. However, in the Methow and the Wenatchee sub-basins, only 86% and 87% the instream flow-rule volume was attained, respectively (Table 12). The streamflow in the Yakima sub-basin met 98% of the instream flow-rule volume under the historical simulation (Table 12). Under simulated climate change using the A1B greenhouse gas emission scenario, all of the sub-basins were projected to experience a reduction in streamflow needed to meet their existing instream flow-rules (Table 5). The Wenatchee sub-basin experienced the greatest average reduction in the percent of time that the flow-rule is met during the summer months relative to other sub-basins under simulated climate conditions for the periods 2020 and 2040 (Figure 10). The percent of the instream flow-rule that is met in the Wenatchee decreased by 10% during the period 2020, and 29% during the period 2040, relative to historical conditions. The Yakima sub-basin experienced similar average reductions in the percent of instream flow-rule that is attained, with reductions in the volume of instream flow that is attained of 14% in 2020 and 28% in 2040. The Methow sub-basin was also projected to experience similar average reductions the percentage of instream flow-rule that is met with reductions in coverage at 10% during the 2020 period and 20% during the 2040 period. However, the Okanogan sub-basin only a 1-2% change in the percent of instream flow-rule that is met by available flow.

Table 11. Simulated average monthly streamflow in cubic meters per second under all scenarios for the periods 2020 and 2040.

	Okanogan			Methow			Wenatchee			Yakima		
Scenario	**July**	**August**	**September**	**July**	**August**	**September**	**July**	**August**	**September**	**July**	**August**	**September**
Climate 2020A1B	114	62	33	47	11	10	110	23	12	27	28	40
Climate 2040A1B	95	60	30	35	10	9	87	14	8	14	22	35
AgUpHigh2020	110	58	31	45	10	9	108	21	11	9	4	4
AgUpHigh2040	92	57	27	34	8	7	85	12	7	7	4	3
AgUpLow2020	112	60	32	46	10	9	109	22	12	13	6	17
AgUpLow2040	94	58	29	35	9	8	86	13	8	8	4	10
BioFloFirst2020A1B	114	63	40	52	18	14	113	31	18	53	46	43
BioFloFirst2040A1B	95	62	38	43	16	13	91	23	14	50	45	40
FishFirst2020A1B	118	59	33	51	17	9	111	28	18	34	29	40
FishFirst2040A1B	102	56	30	41	16	9	89	21	14	27	23	35
Historical	136	72	41	63	18	13	129	38	19	65	47	51

Scenarios 5: Percent of Instream Flow Requirement Attained Using Biologically-based Instream Flow-rule as the 1st Priority in the Allocation Scheme

As a stricter rule than the existing instream flow-rule, the BioFloFirst scenario (which is a minimum flow rate based on WUA curves and set as the first priority in the allocation scheme), is not met during particularly dry years, even when other water users are not receiving their allotment. To attain streamflow volumes that meet biologically-based flow requirements under historic conditions, out-of-stream water users would only be allowed to withdraw water from the rivers after the flow requirement had been met. Even under these circumstances, streamflow in the Methow is only adequate to attain 91% of the biologically-based instream flow rule (Table 12, Figure 10). Further, under simulated climate change, even when other water users are forced to forego water withdrawals, streamflow is insufficient to meet biological flow needs. For example, under a changed climate in 2020, streamflow in the Methow is only able to meet 33% of the biologically-based flow rule during the month of August (Table 12).

Similar reductions (25% of the biologically-based flow volume) are projected to occur in the Wenatchee sub-basin in 2020 during the month of September (Table 12). Under a changed climate in 2040, the Methow and Wenatchee sub-basins are projected to experience even greater reductions in the percentage of the biologically-based flow rule that can be attained with available river flow. For example, during the month of August in 2040, the Methow sub-basin is projected to only attain 30% of the biologically-based flow rule; and the Wenatchee sub-basin is projected to attain 20% of the biologically-based flow rule (Table 12).

Table 12. Percent of instream flow-rule that is attained in sub-basins of interest under all scenarios for the periods 2020 and 2040

	Okanogan			Methow			Wenatchee			Yakima		
Scenario	**July**	**August**	**September**	**July**	**August**	**September**	**July**	**August**	**September**	**July**	**August**	**September**
Climate 2020A1B	94.4	100.0	100.0	76.7	54.5	96.8	96.6	71.2	59.3	57.2	93.7	98.9
Climate 2040A1B	90.9	100.0	100.0	66.7	47.9	90.5	91.6	54.9	40.3	25.2	87.2	98.7
AgUpHigh2020	92.8	100.0	100.0	74.8	47.6	90.5	95.8	64.8	51.9	9.0	2.8	15.4
AgUpHigh2040	88.6	100.0	99.7	64.2	40.8	80.2	90.0	47.0	32.4	4.2	2.2	3.6
AgUpLow2020	93.6	100.0	100.0	75.8	51.1	94.2	96.2	68.0	55.6	15.6	21.7	86.5
AgUpLow2040	89.8	100.0	99.9	65.5	44.4	85.5	90.8	50.9	36.4	8.2	6.2	63.2
BioFloFirst2020A1B	100.0	100.0	91.4	77.2	32.8	35.5	96.3	52.6	25.2	100.0	100.0	100.0
BioFloFirst2040A1B	100.0	100.0	86.3	68.5	29.8	33.0	91.7	40.3	19.9	100.0	100.0	100.0
HistoricalBioFlow	100.0	100.0	100.0	91.8	93.1	100.0	100.0	99.2	95.7	100.0	100.0	100.0
FishFirst2020A1B	99.6	100.0	100.0	86.4	86.5	100.0	98.8	95.3	85.2	100.0	100.0	100.0
FishFirst2040A1B	99.4	100.0	100.0	79.7	81.7	100.0	97.5	85.7	70.1	100.0	100.0	100.0
Historical	97.3	100.0	100.0	85.3	74.2	98.6	98.3	85.3	78.3	94.2	100.0	99.0

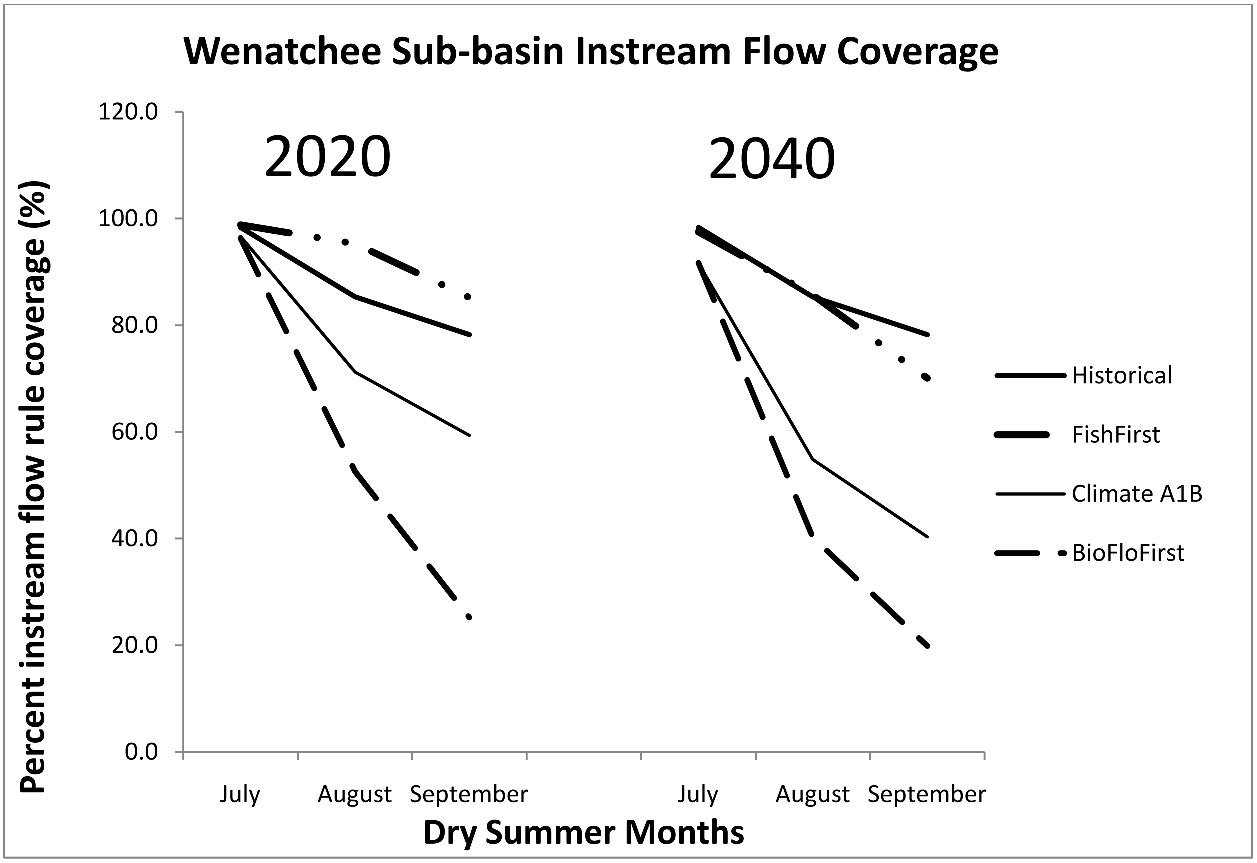

Figure 10. Instream flow-rule coverage for the Wenatchee sub-basin under all simulated changes to the instream flow requirement for the periods 2020 and 2040.

In summary, the results of the external environmental assessment indicate that the Yakima sub-basin is projected to be the most flow-limited, on average, during summer months for both the 2020 and 2040 time periods. Under the climate only scenario, the Wenatchee sub-basin is also projected to experience flow limitations later in the summer, during the month of September. While the Methow and Okanogan sub-basins are also projected to experience flow reductions as a result of climate change, they experience moderate reductions in comparison to the Wenatchee and Yakima sub-basins for the periods 2020 and 2040.

Similarly, the Yakima sub-basin is projected to be the most impacted by increased agricultural water use. Although agriculture plays a dominant role in all of the sub-basins of interest, the Yakima sub-basin experiences the greatest influence of irrigation. Consequently, there is a strong trade-off between meeting the water needs of irrigators and maintaining instream flow requirements, particularly in the Yakima sub-basin.

As a result of the projected reductions in streamflow under the climate only scenario, the Wenatchee and Yakima sub-basins are also the least likely to meet their instream flow requirements in both the 2020 and 2040 periods under climate change only. Simulated agricultural diversions are projected to reduce streamflow in the Yakima sub-basin to only 15-20% of the existing instream flow rule. However, changes to the allocation scheme, including setting instream flow rules as the first priority in the allocation scheme are projected to maintain streamflows in the Yakima sub-basin at a flow volume that can attain the existing flow rule.

II. Internal Organizational Assessment

Water Right Characterization of Each Sub-basin

The water rights characteristics, when considered in the context of the Washington Water Trust's acquisition criteria, reveal that the Wenatchee and Yakima sub-basins contain water rights that may be most desirable for conserving fish habitat for ESA-listed species. The Wenatchee has both the highest average number of irrigated acres associated with the water rights and the highest average instantaneous water volume associated with water rights in the basin (Table 14). The Yakima and Wenatchee sub-basins contain the largest number of listed species and may therefore require the most work on the part of the Washington Water Trust and other affiliated organizations to restore the habitat quality for the listed species (Table 13, Table 14).

Table 13. Quantitative population estimates for ESA-listed spawning salmonids. Common name, location, period of record, period of record average estimate, period of record high estimate and period of record low estimate are included.

ESU	Common Name	Location	Period of Record	Period of Record Average	Period of Record High	Period of Record Low
Upper Columbia River Spring-run Chinook	Chinook Salmon	Methow River	1960-2008	1,686	11,144	33
Upper Columbia River Spring-run Chinook	Chinook Salmon	Wenatchee River	1960-2008	2,078	6,718	58
Middle Columbia River Steelhead	Steelhead	Yakima River upper mainstem	1985-2009	117	267	32
Upper Columbia River Steelhead	Steelhead	Methow River	1977-2009	2,249	9,743	22
Upper Columbia River Steelhead	Steelhead	Okanogan River	1977-2009	1,648	5,296	158
Upper Columbia River Steelhead	Steelhead	Wenatchee River	1978-2009	2,183	5,895	304

The Yakima sub-basin and the Okanogan sub-basin have approximately three times as many senior water right users, proportional to the overall number of water rights, in comparison to the Methow and Wenatchee sub-basins (Table 14). While the total number of senior water right users is not particularly useful to the Washington Water Trust in their decision-making about water right acquisitions, the total and instantaneous streamflow volumes associated with the most senior rights is of considerable importance for the organization.

Finally, the most recent adjudication of water rights took place in the Yakima sub-basin. This information provides the Washington Water Trust with valuable information about the validity and interruptability of the water rights that they might consider acquiring. As a result of the adjudication in the Yakima, the water rights in the sub-basin are categorized as either senior, pro-ratable or junior.

Table 14. Water right characterization by sub-basin (data provided by the Washington Department of Ecology). The following table shows water right characteristics in the Okanogan, Methow, Wenatchee and Yakima sub-basins including: average irrigated area, average instantaneous volume, average annual volume, listed species, number of water rights in the most senior 7.5% of rights in the respective sub-basin and adjudication status. N indicates the total number of rights assessed in each sub-basin. Shaded cells indicate the sub-basin with the highest rank for the water right characteristic.

	Okanogan (N = total number of rights) N =7096	**Methow (N = total number of rights) N =3165**	**Wenatchee (N = total number of rights) N =1680**	**Yakima (N = total number of rights) N = 8687**
Average irrigated area associated with rights (km^2)	0.35	0.21	2.7	2.0
Average instantaneous volume (cms) of water associated with rights	3.6	0.3	5.6	1.5
Average annual volume of water (thousand cubic meters) associated with rights	3,661.8	0.5	2,984.8	1,182.8
Listed species	Steelhead, Spring Chinook	Steelhead	Spring Chinook, Steelhead, Bull trout	Spring Chinook, Steelhead, Coho
# Rights that are most senior	7.5% = 530	7.5% = 240	7.5% = 126	7.5% = 637
Most recent adjudication	Partially complete; some petitions pending	Partially complete; some petitions pending	Tributaries complete; mainstem pending	Pending

Table 15. Water right characteristics of the most senior water right holders by sub-basin (data provided by the Washington Department of Ecology). The following table shows water right characteristics for the most senior water right holders in the Okanogan, Methow, Wenatchee and Yakima sub-basins including: average irrigated area, average instantaneous volume and average annual volume.

	Okanogan	**Methow**	**Wenatchee**	**Yakima**
Average irrigated area associated with rights (km^2)	1.78	0.20	19.9	0.23
Average instantaneous volume (cms) of water associated with rights	1.41	0.03	1.5	0.11
Average annual volume of water (thousand cubic meters) associated with rights	239 (0.03% of lowest summer flow)	134 (0.09% of lowest summer flow)	1,319 (0.1% of lowest summer flow)	3,267 (0.05% of lowest summer flow)

On the whole, the water rights in the Wenatchee sub-basin have the largest irrigated area by a margin of 0.7 km^2 over the Yakima sub-basin, nearly five times greater instantaneous flow volume than the Yakima and the same number of ESA-listed species as the Yakima (3 listed species). However, the Yakima sub-basin has nearly three times as many senior water right holders as any of the other basins. Further, the senior water right holders in the Yakima sub-basin also are associated with average annual volumes that are approximately three times greater than the Wenatchee and more than one hundred times greater than the Okanogan or the Methow sub-basins. Perhaps most importantly, the water rights in the Yakima sub-basin have a high degree of validity due to their recent adjudication, which is not true of any of the other sub-basins.

Discussion

I. External Environmental Assessment

Streamflow: Impacts of Climate, Increased Agricultural Water Withdrawals, and Modified Allocation Scheme

Tensions over water availability remain high in the Central Columbia Basin. My results indicate that predicted climate change may exacerbate the current state of water scarcity and subsequent conflict in the central Columbia sub-basins, and especially in the Yakima and Wenatchee. Simulated climate-induced reductions in streamflow and potential increases in agricultural water use suggest that by 2020, the trade-off between agricultural water withdrawals and instream flow requirements for fish will be increasingly binary. Under the simulated A1B green house gas emission scenario, the Methow, Wenatchee and Yakima sub-basins provide nearly 100% of the agricultural water needs during the summer months for the period 2020. However, these sub-basins are only able to provide between 76% and 83% of the water needs for the existing instream flow-rules for the same period.

Alternatively, under the simulated FishFirst scenario in which the existing instream flow-rule is set as the first priority in the allocation scheme, the sub-basins of interest provide, on average, between 86% and 100% instream flow-rule coverage for the period 2020; and only 50% to 80% agricultural water needs are met. Further, under a simulated increase in agricultural water withdrawals for the period 2020, the Yakima River provides nearly 100% of the agricultural water needs, but only 10% of instream flow water needs on average. This tradeoff is projected to be even starker in 2040, with agricultural water demand in the Yakima sub-basin still met nearly 100% of the time and only 4% of instream volume attained for ESA-listed species. Overall, the scenario analysis shows that there is insufficient flow in the sub-basins of interest to satisfy both instream flow requirements for listed salmonid populations and agricultural water demand. The Yakima sub-basin provides the most salient example of the conflict inducing trade-off between agricultural and instream water withdrawals.

In summary, the results of the external environmental assessment suggest that as instream flows become substantially less abundant under various potential future scenarios, streamflows in the Yakima and Wenatchee sub-basins are less likely to be adequate to meet agricultural water demands or instream water mandates for listed fish salmonid populations. Consequently, the Yakima and Wenatchee sub-basins stand to benefit the most from market-based water-right transactions that may facilitate redistribution of instream flow deliveries where they are needed most and reduce social conflicts that might arise from the scarcity of available water.

Based on these findings, in the following internal organizational assessment I set aside the Okanogan and Methow sub-basins and only discuss the Washington Water Trust's purchase criteria with respect to the Yakima and Wenatchee sub-basins. I then provide the Washington Water Trust with recommendations for future water right acquisitions.

II. Internal Organizational Assessment

In the external environmental assessment, I determined that the Yakima and Wenatchee sub-basins are projected to be the most flow limited of the sub-basins of interest under potential future scenarios. In the following internal organization assessment, I provide a detailed description of the strengths and weaknesses of the Washington Water Trust's current operating conditions. I then describe the opportunities and threats that the Washington Water Trust might face if it were to pursue water right acquisitions in either the Yakima sub-basin or the Wenatchee sub-basin.

Water Right Characterization of the Yakima and Wenatchee sub-basins

Washington Water Trust's Existing Strengths

The Washington Water Trust has several inherent strengths in its approach to habitat conservation for listed salmonid populations. In the absence of a regulatory change concerning instream flow-rules and their priority in the existing water use framework, water resource managers must rely on alternative methods of instream flow conservation to increase water availability for both agriculture and instream habitat for listed fish populations. The Columbia Basin Water Transaction Program and the Washington Water Trust employ market-based conservation techniques to work toward this goal. Before the CBWTP began operation in 2002, efforts to conserve instream habitat for listed fish populations were mostly government initiated and relied on command and control legislation (Garrick, *et al.* 2009). The United States government also relied on water right holders to voluntarily forego withdrawing water to maintain instream flows. The CBWTP and the Washington Water Trust provide an alternative approach that complements the existing government regulations. The Water Trust's non-regulatory approach, primarily market-based water-right transactions facilitated by the CBWTP, is more flexible than government mandates and provides opportunity for participation with a wider group of water right holders than the small minority who would voluntarily forego withdrawing the water they have a right to. In addition to being flexible, Washington Water Trust's market-based approach is also more economically efficient than command and control regulation.

Washington Water Trust's Existing Weaknesses

While the market-based conservation approaches introduced by CBWTP and the Washington Water Trust are highly innovative, provide opportunity for broad citizen involvement and have proven to be more economically efficient than government regulation alone, the Washington Water Trust also has two inherent weaknesses in its approach. The largest and perhaps most influential weakness has bearing not only on the Water Trust's approach, but also in the larger water management methods in the central Columbia River Basin. This weakness is the general lack of monitoring and enforcement of water withdrawals before and after water-right transactions. Although metering is now mandatory in the state of Washington, few individual water right holders have a metered gauge on their property. Therefore, it is difficult to track how much water is actually withdrawn from a stream. This is an example of a case in which water managers do not always have a strong understanding of their management starting point – without a restoration benchmark, assessing restoration becomes very difficult (Bernhardt, 2005).

Further, even if the Water Trust were able to determine that the water right lessor is not foregoing the water withdrawals that he or she has agreed to, there are few enforcement mechanisms in place to take action against the lessor. Extensive monitoring and enforcement could greatly strengthen the existing operations of the Washington Water Trust and other water managers in the Columbia River Basin.

Opportunities for the Washington Water Trust Regarding Water Right Acquisitions in the Yakima and Wenatchee Sub-basins

The Washington Water Trust stands to gain distinct opportunities from water right acquisitions in the Yakima sub-basin and Wenatchee sub-basin. The water rights within the Wenatchee sub-basin have characteristics that are highly aligned with the Washington Water Trust's stated mission and purchase criteria. Relative to the other sub-basins, water rights in the Wenatchee have by far the largest average size of irrigated parcels. The Wenatchee sub-basin also possesses water rights that have the highest average instantaneous flow rate. Purchasing water rights that are associated with a relatively large irrigated area, and have relatively large average instantaneous flow rates gives the Washington Water Trust the opportunity to keep more water instream for the same administrative cost and effort of smaller instream flow quantities. It also reduces the number of individual water right holders that the Washington Water Trust must maintain a consistent relationship with. In other words, the water rights in the Wenatchee sub-basin provide the Washington Water Trust with the ability to conserve large portions of instream flow for listed populations, while at the same time, reducing the number of staff hours spent arranging and facilitating the transaction of the given quantity of water. Further, the most senior 7.5% of the water rights in the Wenatchee sub-basin also posses the largest irrigated area, the highest average instantaneous flow rate and the second highest average annual volumes relative to the most senior 7.5% of the water rights in any of the other sub-basins (Table 18). This provides the added benefit of not only gaining a large volume of instream flow for listed fish populations with less staff time, but also provides a high degree of insurance against interruption of the instream flow benefit. By purchasing the most senior water rights in a basin, the Washington Water Trust is less likely to lose access to the conserved instream flows during the dry season.

The Yakima sub-basin also possesses water right characteristics that are closely aligned with the Washington Water Trust’s stated mission and purchase criteria. The Yakima has a higher number of water rights overall and, therefore, a higher number of water right holders in the most senior 7.5% of right holders than the Wenatchee sub-basin (Table 14, Table 15). The relatively high number of senior water rights in the Yakima sub-basin makes it attractive for water rights acquisition because of the low likelihood of interruptability that comes with senior water rights. However, the senior water rights in the Yakima sub-basin do not have the same beneficial characteristics that the senior water right holders in the Wenatchee basin have (i.e., large irrigated area, the high average instantaneous flow rate and high average annual volumes).

Aside from the specific water right characteristics, the Yakima sub-basin possesses a number of highly favorable conditions for water right acquisition by the Washington Water Trust. For example, the Yakima sub-basin is currently completing a comprehensive adjudication[1] of the existing water rights (DOE, 2010). Once all rights are adjudicated, water-right transactions within the Yakima sub-basin will become much less complex and transaction time and costs will likely fall. The adjudicated rights of the Yakima sub-basin are particularly attractive to the Washington Water Trust for purchase because the amount of time and effort staff members dedicate to proving the validity of the right (often a costly and time consuming process) would be greatly reduced, saving valuable staff and financial resources for outcome delivery.

Currently, there are more than 60 conservation and salmonid habitat restoration initiatives underway in the Yakima sub-basin, with a total cost of at least $20,000,000 per year (YBFWRB, 2009). These habitat restoration initiatives stand to greatly enhance the Washington Water Trust's water-right transactions in this region. For example, the Washington Water Trust's work

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[1] A general adjudication is a legal process conducted through a superior court to determine the extent and validity of existing water rights. An adjudication can determine rights to surface water, ground water, or both. An adjudication does not create new water rights, it only confirms existing rights (DOE, 2010).

in flow restoration cannot substantially benefit salmonid populations if the physical habitat is of poor quality. For this reason, the existing restoration efforts in the Yakima sub-basin hold great opportunity for enhancing the Washington Water Trust's work. Additionally, these existing initiatives may present the Washington Water Trust with opportunity to collaborate with other conservation entities that have similar missions, and even engage in new types of conservation approaches (e.g., Kittitas County Conservation District, Washington Department of Fish and Wildlife, Yakima County Public Services, Cascade Land Conservancy, Yakama Nation, Cowiche Canyon Conservancy).

Finally, the Washington Water Trust has a satellite office in nearby Ellensburg, WA, giving the organization a unique opportunity to build lasting relationships with the local clientele, hold workshops and publicize their organizational activities, increasing the likelihood of future water-right transactions with local right holders. In fact, the Washington Water Trust is already pursuing many of these activities in the Yakima sub-basin (48 current and completed projects: http://washingtonwatertrust.org/projects). Increased visibility and staff member access to the local right holders is an invaluable asset to facilitating future water-right transactions.

Threats to the Washington Water Trust Regarding Water Right Acquisitions in the Yakima and Wenatchee Sub-basins

The Washington Water Trust also faces several threats from potential water right acquisitions in the Yakima and Wenatchee sub-basins (Table 16). For example, while the existing water rights in the Wenatchee sub-basin possess qualities that are highly attractive for fulfilling the Trust's mission, the rights in the Wenatchee sub-basin are not adjudicated. This means that although the Washington Water Trust stands to gain access to unique acquisition opportunities in the

Wenatchee, a certain degree of legal and ecological risk is transferred along with any Wenatchee water right transfers. It may be difficult for Water Trust staff to verify the validity of rights in the Wenatchee, which may cause unforeseen expenses or require additional staff hours to address any inconsistencies that arise with the transfer of rights. Additionally, the Wenatchee sub-basin provides significantly fewer opportunities for the Washington Water Trust to collaborate with other conservation organizations than the Yakima sub-basin would. Although it is noted that abundant collaborators can be a strength as well as a weakness. Further, the Washington Water Trust does not have access to the local water right holders in the Wenatchee sub-basin in the way that they have the ability to perform outreach in the Yakima sub-basin. Obtaining the same degree of organizational capacity in the Wenatchee sub-basin would require substantial financial commitments and the financial capacity to support additional staff members.

Table 16. Comparison of the opportunities and threats that the Washington Water Trust faces in the Wenatchee and Yakima sub-basins

	Wenatchee	**Yakima**
Opportunities	• Largest average size of irrigated parcels associated with water rights • Highest average instantaneous flow associated with water rights • Most senior water rights also have highest average instantaneous flow	• Highest overall number of water rights • Highest number of senior water rights • Water rights in the sub-basin are adjudicated • Conservation/restoration momentum in the sub-basin • Opportunities of collaboration, increased visibility • Office in Ellensburg can facilitate outreach with local community
Threats	• Fewer senior rights to acquire • Not adjudicated (risk) • Fewer opportunities for collaboration • Less outreach potential, less visibility • Abundance of perennial crops = Low flexibility for water right leases	• Lower average size of irrigated parcels • Portions of sub-basin severely degraded (worth restoration effort?) • High potential for future dam building (may further impact fish communities)

However, the most important threat to the Washington Water Trust of purchasing water rights in the Wenatchee sub-basin is the low flexibility of water right holders in the Wenatchee sub-basin in terms of water right leases. Many of the agricultural water right holders in the Wenatchee sub-basin irrigate orchards. Orchard trees have much longer life spans and very specific irrigation needs relative to other crop types (Hinman and Watson, 2003). Water right holders who irrigate orchard trees are unable to lease water for a year at a time and regain access to their water right the following year, the way an irrigator of a different crop might. On the contrary, orchard irrigators must provide consistent irrigation for their trees over their entire life span. Water-right transaction opportunities might only be possible if irrigators are changing their land use, perhaps leaving the business of producing orchard fruit – in which case an outright sale to the Washington Water Trust is possible. However, these opportunities would be far less frequent than the opportunities for split season or annual leases commonly available in the Yakima sub-basin.

General Considerations

To preserve or to restore?

Given this information, the Washington Water Trust is left with two options: to acquire water rights in areas that may prove to be most flow-limited for fish populations in the next 30 years, or to acquire water rights in areas where instream flows for fish are not as severely impacted by climate and land-use change. These options represent fundamentally different conservation philosophies. The first philosophy is that in the short term (in the next 30 years), the Washington Water Trust should employ restoration efforts in areas that will be most flow-limited (i.e., the Wenatchee and Yakima sub-basins) to mitigate the potential impacts of climate change on available fish habitat. The second philosophy is that the Washington Water Trust should instead work to preserve less degraded habitat (i.e., the Okanogan and the Methow sub-basins) on the grounds that in the long-term (more than 30 years), the most flow-limited regions may not be able to support salmonid populations at all.

I suggest that the Washington Water Trust use the first philosophy and focus on the Wenatchee and Yakima sub-basins, as they may benefit most from their organizational activities in the next 30 years. I make this suggestion for two primary reasons. First, the Washington Water Trust primarily acquires water rights through leases, not purchases. As a result, not all of the water the Trust leases in the present will be preserved in perpetuity. Outright purchases of water rights might prove to be very beneficial in less impacted areas like the Okanogan. However, given that purchases are relatively rare in the Washington Water Trust’s operations, the Yakima sub-basin stands to gain the greatest benefit from the organization’s current infrastructure and operations. Second, the planning horizon for my study is only 30 years from the present day. Given that the

Washington Water Trust has a highly established network in the Yakima sub-basin and a satellite office in nearby Ellensburg, WA, the organization is well-positioned to take immediate actions.

What is the scale of the Washington Water Trust's operations?

As previously discussed, the Washington Water Trust has a limited conservation budget. Some might argue that the organization also may be limited in their benefit to ESA-listed species with only $1 Million USD annually available for water right acquisitions. However, the following example demonstrates that with careful planning and targeting of particular water rights, the Washington Water Trust can significantly improve instream habitat for listed fish species.

The average annual lease price for water rights in the Yakima sub-basin is ~$10,000 per year.

The average annual volume associated with water rights in the Yakima is ~320,000 m^3.

Assuming that all of the Washington Water Trust spends its entire acquisition budget in the Yakima sub-basin on water rights with an average annual volume, at an average annual price, the Washington Water Trust could acquire approximately 100 water rights and a total of 32,000,000 m^3 of instream benefit. Although 32,000,000 m^3 represents just 1% of the average annual discharge of the mainstem Yakima River (3.2 billion m^3) (where my instream flows are modeled), the potential acquisition volume represents a much greater proportion of the small tributaries to the mainstem that are critical habitat for ESA-listed salmon. Unlike my modeled flows, the Washington Water Trust operates primarily on these small tributaries. While this example is a simplification of reality, and there are many obstacles to water right transactions, it demonstrates the potential for the Washington Water Trust's work.

III. Recommendation and Conclusion

The results of the external environmental assessment indicate that the Yakima sub-basin is likely to be the most flow-limited sub-basin in the next thirty years under climate and land-use change. Similarly, the internal organizational assessment indicates that the Washington Water Trust stands to benefit most from opportunities for water-right transactions in the Yakima sub-basin. Further, the Washington Water Trust is also likely to experience the fewest organizational threats from potential water right purchases in the Yakima sub-basin. Accordingly, I recommend that Washington Water Trust focus its future water right acquisition efforts in the Yakima sub-basin. Doing so will provide the greatest instream benefit for ESA-listed salmonid populations under reduced flow conditions, help reduce the conflict that is likely to arise from tradeoffs between agricultural water withdrawals and instream flow needs and use the Washington Water Trust's existing strengths to maximize the organization's financial and organizational efficiency.

Applications: beyond the Washington Water Trust's operations

The objectives covered in this thesis represent some of the challenges and decisions that global water resource managers and practitioners face every day. Habitat fragmentation, chemical pollution, exotic species invasions, overexploitation and other forces have caused freshwater ecosystem integrity to decline sharply in the last forty years (Alcamo, 2008a). Additionally, problems in human social systems threaten global freshwater health. For example, conflicts over transboundary flows, limited knowledge of complex, heterogeneous and interconnected ecosystem properties, and issues concerning cross-generational equity pose further threats to already stressed freshwater ecosystems (Chapin, *et al.*, 2010).

As demonstrated, global-scale changes to climate, land use and human populations also represent long-term forces that may prove to be primary determinants of the future state of freshwater ecosystems (Postel, 2005). Clearly, the aforementioned long-term drivers of ecosystem change may exacerbate the problem of aquatic species loss (e.g., Mantua, *et al.*, 2009; Beechie, 2009). These findings represent a call to action and there is limited in which to improve our management methods (Poff, 1992).

However, this thesis serves as evidence that the tools and data necessary for improved restoration planning and implementation are currently available. Natural resource managers, from State and Federal Agency officials, to non-profit managers should engage in integrated, long-term planning that is aligned with the time scale of the flow regimes, disturbance regimes and biogeochemical cycles of the resources they manage (Chapin, *et al*., 2010).

As mentioned earlier in this document, several other researchers are currently attempting to integrate long-term planning and decision-support into natural resource management. For example, a research group at the University of Montana’s Flathead Lake Biological Station (FLBS) examined salmonid habitat and forecasted flows for all salmon bearing rivers in the Northern Pacific Rim (Stanford, *et al.* 2010). The FLBS study covers an expansive area and provides managers with the opportunity to assess the impacts of long-term climate change on large-scale and interconnected aquatic ecosystems. Unlike many other studies of its kind, the FLBS study includes a very useful examination of physical habitat area for salmonids along with instream temperature projections.

The spatially and intellectually comprehensive information included in the FLBS study may prove valuable for long-term conservation planning for listed salmonid species. However, in order to bring the findings of studies such as the FLBS study to bear on the pressing issues that our water resources currently face, there are several important steps that many managers have yet to take. For example, managers and planners should integrating scientific hypotheses and policy questions in such a way that they can gain knowledge of both the ecosystems they operate in and the policy options that are most appropriate for their given set of governance circumstances (Lee, 1993). Although these are not novel concepts (Holling, 1978; Holling 1995, Gunderson, 2006), they are not widely practiced. However, there is mounting evidence that if managers strategically plan for their implementation process, organize their data using models, communicate their logic in unambiguous terms and maximize opportunities for learning, they will be better equipped to navigate both present and future water resource challenges.

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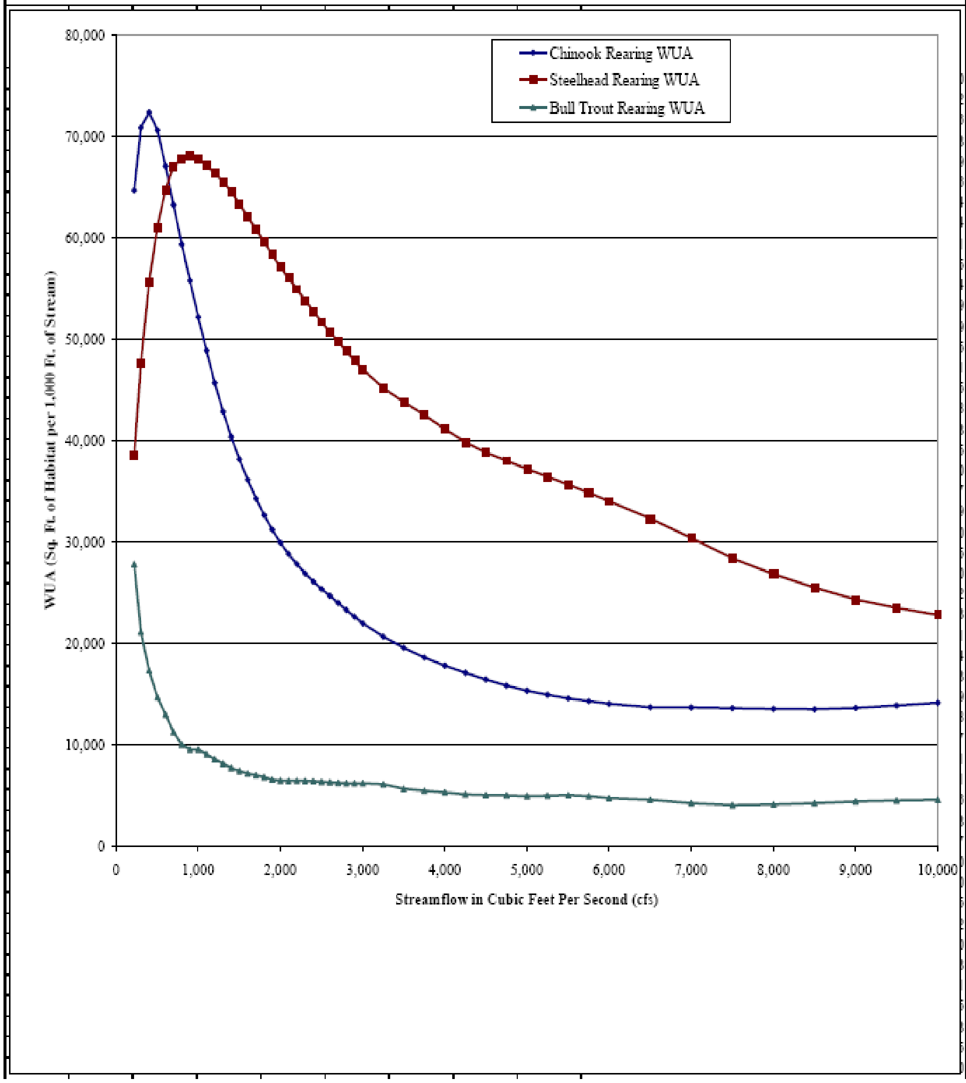
Appendices

Appendix A. Weighted Usable Area (WUA) estimates from the Wenatchee Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. These WUA estimates are for rearing Chinook, Steelhead and Bull Trout.

Figure 3.1-1 Wenatchee River Reach 1: Fish Habitat (WUA) vs. Flow.

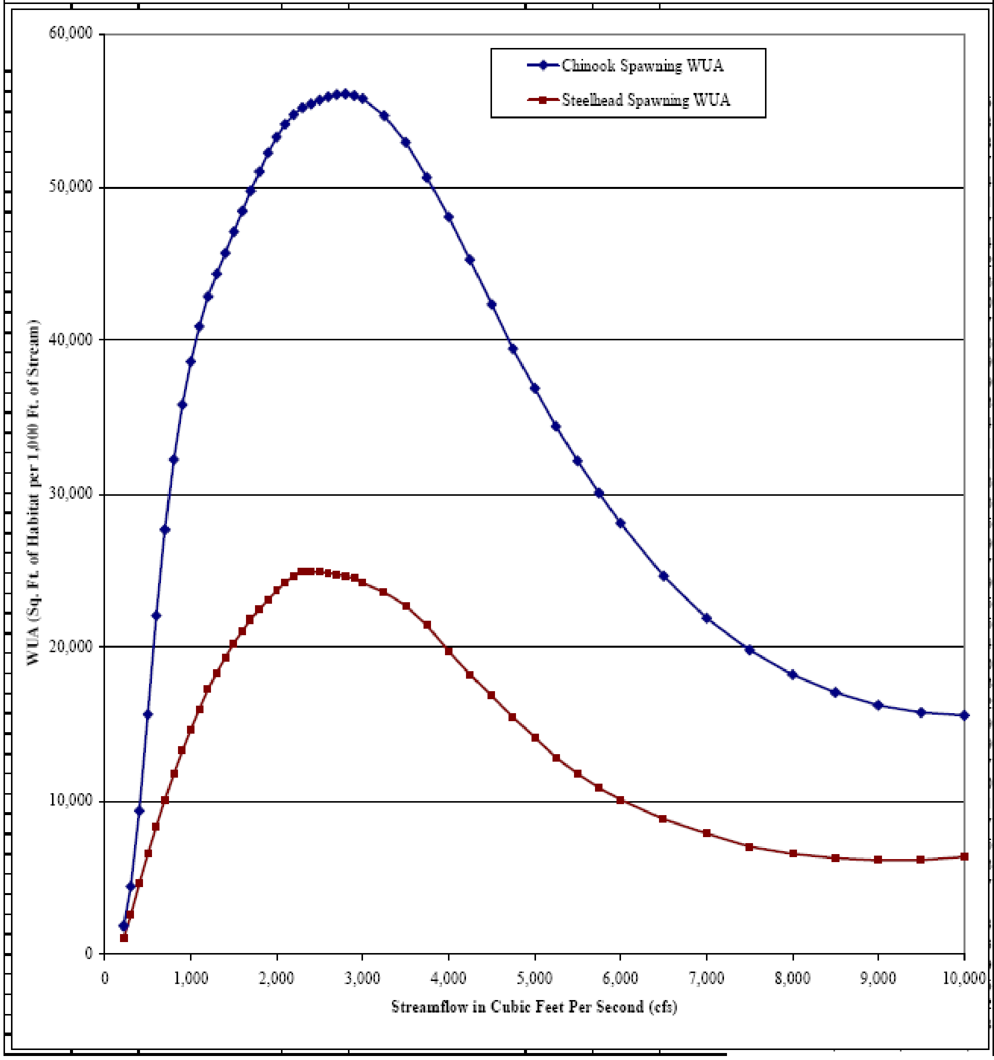


Percent of Peak Habitat vs Flow

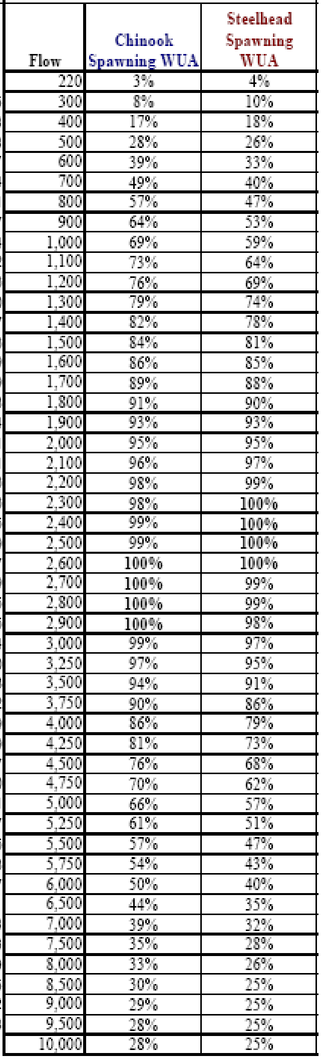
Flow	Chinook Rearing WUA	Steelhead Rearing WUA	Bull Trout Rearing WUA
220	89%	57%	**100%**
300	98%	70%	76%
400	**100%**	82%	62%
500	98%	90%	53%
600	93%	95%	47%
700	87%	99%	40%
800	82%	**100%**	36%
900	77%	**100%**	34%
1,000	72%	**100%**	34%
1,100	68%	99%	32%
1,200	63%	97%	31%
1,300	59%	96%	29%
1,400	56%	95%	28%
1,500	53%	93%	27%
1,600	50%	91%	26%
1,700	47%	89%	25%
1,800	45%	88%	24%
1,900	43%	86%	24%
2,000	41%	84%	23%
2,100	40%	82%	23%
2,200	38%	81%	23%
2,300	37%	79%	23%
2,400	36%	78%	23%
2,500	35%	76%	23%
2,600	34%	75%	23%
2,700	33%	73%	22%
2,800	32%	72%	22%
2,900	31%	70%	22%
3,000	30%	69%	22%
3,250	29%	66%	22%
3,500	27%	64%	20%
3,750	26%	62%	19%
4,000	25%	60%	19%
4,250	24%	59%	18%
4,500	23%	57%	18%
4,750	22%	56%	18%
5,000	21%	55%	18%
5,250	21%	54%	18%
5,500	20%	52%	18%
5,750	20%	51%	18%
6,000	19%	50%	17%
6,500	19%	47%	16%
7,000	19%	45%	15%
7,500	19%	42%	14%
8,000	19%	39%	15%
8,500	19%	37%	15%
9,000	19%	36%	16%
9,500	19%	34%	16%
10,000	19%	33%	16%

Appendix B. Weighted Usable Area (WUA) estimates from the Wenatchee Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. These WUA estimates are for spawning Chinook and Steelhead.

Figure 3.1-5 Wenatchee River Reach 1: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow



Flow	Chinook Spawning WUA	Steelhead Spawning WUA
220	3%	4%
300	8%	10%
400	17%	18%
500	28%	26%
600	39%	33%
700	49%	40%
800	57%	47%
900	64%	53%
1,000	69%	59%
1,100	73%	64%
1,200	76%	69%
1,300	79%	74%
1,400	82%	78%
1,500	84%	81%
1,600	86%	85%
1,700	89%	88%
1,800	91%	90%
1,900	93%	93%
2,000	95%	95%
2,100	96%	97%
2,200	98%	99%
2,300	98%	100%
2,400	99%	100%
2,500	99%	100%
2,600	100%	100%
2,700	100%	99%
2,800	100%	99%
2,900	100%	98%
3,000	99%	97%
3,250	97%	95%
3,500	94%	91%
3,750	90%	86%
4,000	86%	79%
4,250	81%	73%
4,500	76%	68%
4,750	70%	62%
5,000	66%	57%
5,250	61%	51%
5,500	57%	47%
5,750	54%	43%
6,000	50%	40%
6,500	44%	35%
7,000	39%	32%
7,500	35%	28%
8,000	33%	26%
8,500	30%	25%
9,000	29%	25%
9,500	28%	25%
10,000	28%	25%

Appendix C. Weighted Usable Area (WUA) estimates from the Wenatchee Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. These WUA estimates show the relationship between stream flow and available instream habitat for Chinook, Steelhead nad Bull Trout.

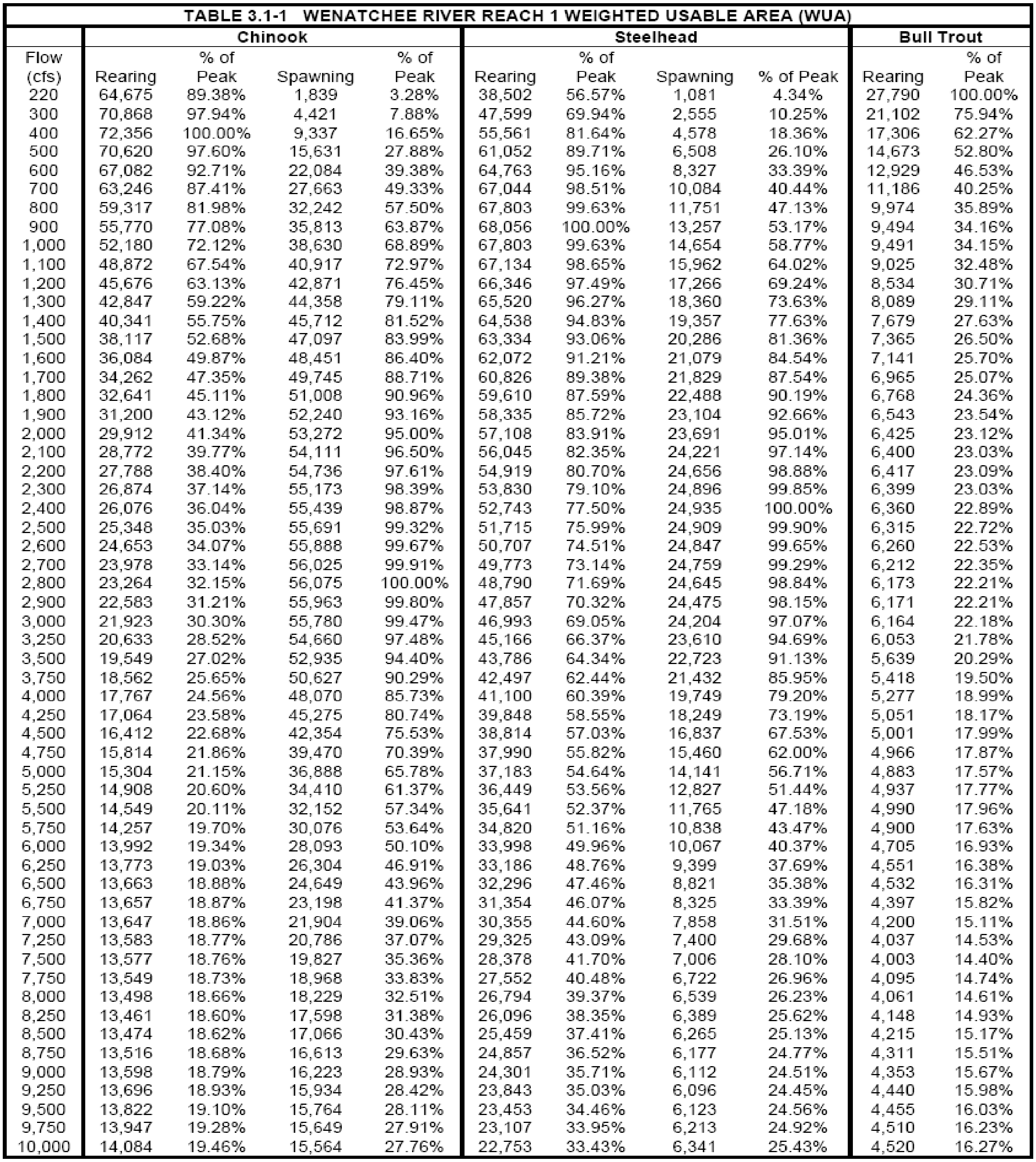


TABLE 3.1-1 WENATCHEE RIVER REACH 1 WEIGHTED USABLE AREA (WUA)

	Chinook				Steelhead				Bull Trout	
Flow (cfs)	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak
220	64,675	89.38%	1,839	3.28%	38,502	56.57%	1,081	4.34%	27,790	100.00%
300	70,868	97.94%	4,421	7.88%	47,599	69.94%	2,555	10.25%	21,102	75.94%
400	72,356	100.00%	9,337	16.65%	55,561	81.64%	4,578	18.36%	17,306	62.27%
500	70,620	97.60%	15,631	27.88%	61,052	89.71%	6,508	26.10%	14,673	52.80%
600	67,082	92.71%	22,084	39.38%	64,763	95.16%	8,327	33.39%	12,929	46.53%
700	63,246	87.41%	27,663	49.33%	67,044	98.51%	10,084	40.44%	11,186	40.25%
800	59,317	81.98%	32,242	57.50%	67,803	99.63%	11,751	47.13%	9,974	35.89%
900	55,770	77.08%	35,813	63.87%	68,056	100.00%	13,257	53.17%	9,494	34.16%
1,000	52,180	72.12%	38,630	68.89%	67,803	99.63%	14,654	58.77%	9,491	34.15%
1,100	48,872	67.54%	40,917	72.97%	67,134	98.65%	15,962	64.02%	9,025	32.48%
1,200	45,676	63.13%	42,871	76.45%	66,346	97.49%	17,266	69.24%	8,534	30.71%
1,300	42,847	59.22%	44,358	79.11%	65,520	96.27%	18,360	73.63%	8,089	29.11%
1,400	40,341	55.75%	45,712	81.52%	64,538	94.83%	19,357	77.63%	7,679	27.63%
1,500	38,117	52.68%	47,097	83.99%	63,334	93.06%	20,286	81.36%	7,365	26.50%
1,600	36,084	49.87%	48,451	86.40%	62,072	91.21%	21,079	84.54%	7,141	25.70%
1,700	34,262	47.35%	49,745	88.71%	60,826	89.38%	21,829	87.54%	6,965	25.07%
1,800	32,641	45.11%	51,008	90.96%	59,610	87.59%	22,488	90.19%	6,768	24.36%
1,900	31,200	43.12%	52,240	93.16%	58,335	85.72%	23,104	92.66%	6,543	23.54%
2,000	29,912	41.34%	53,272	95.00%	57,108	83.91%	23,691	95.01%	6,425	23.12%
2,100	28,772	39.77%	54,111	96.50%	56,045	82.35%	24,221	97.14%	6,400	23.03%
2,200	27,788	38.40%	54,736	97.61%	54,919	80.70%	24,656	98.88%	6,417	23.09%
2,300	26,874	37.14%	55,173	98.39%	53,830	79.10%	24,896	99.85%	6,399	23.03%
2,400	26,076	36.04%	55,439	98.87%	52,743	77.50%	24,935	100.00%	6,360	22.89%
2,500	25,348	35.03%	55,691	99.32%	51,715	75.99%	24,909	99.90%	6,315	22.72%
2,600	24,653	34.07%	55,888	99.67%	50,707	74.51%	24,847	99.65%	6,260	22.53%
2,700	23,978	33.14%	56,025	99.91%	49,773	73.14%	24,759	99.29%	6,212	22.35%
2,800	23,264	32.15%	56,075	100.00%	48,790	71.69%	24,645	98.84%	6,173	22.21%
2,900	22,583	31.21%	55,963	99.80%	47,857	70.32%	24,475	98.15%	6,171	22.21%
3,000	21,923	30.30%	55,780	99.47%	46,993	69.05%	24,204	97.07%	6,164	22.18%
3,250	20,633	28.52%	54,660	97.48%	45,166	66.37%	23,610	94.69%	6,053	21.78%
3,500	19,549	27.02%	52,935	94.40%	43,786	64.34%	22,723	91.13%	5,639	20.29%
3,750	18,562	25.65%	50,627	90.29%	42,497	62.44%	21,432	85.95%	5,418	19.50%
4,000	17,767	24.56%	48,070	85.73%	41,100	60.39%	19,749	79.20%	5,277	18.99%
4,250	17,064	23.58%	45,275	80.74%	39,848	58.55%	18,249	73.19%	5,051	18.17%
4,500	16,412	22.68%	42,354	75.53%	38,814	57.03%	16,837	67.53%	5,001	17.99%
4,750	15,814	21.86%	39,470	70.39%	37,990	55.82%	15,460	62.00%	4,966	17.87%
5,000	15,304	21.15%	36,888	65.78%	37,183	54.64%	14,141	56.71%	4,883	17.57%
5,250	14,908	20.60%	34,410	61.37%	36,449	53.56%	12,827	51.44%	4,937	17.77%
5,500	14,549	20.11%	32,152	57.34%	35,641	52.37%	11,765	47.18%	4,990	17.96%
5,750	14,257	19.70%	30,076	53.64%	34,820	51.16%	10,838	43.47%	4,900	17.63%
6,000	13,992	19.34%	28,093	50.10%	33,998	49.96%	10,067	40.37%	4,705	16.93%
6,250	13,773	19.03%	26,304	46.91%	33,186	48.76%	9,399	37.69%	4,551	16.38%
6,500	13,663	18.88%	24,649	43.96%	32,296	47.46%	8,821	35.38%	4,532	16.31%
6,750	13,657	18.87%	23,198	41.37%	31,354	46.07%	8,325	33.39%	4,397	15.82%
7,000	13,647	18.86%	21,904	39.06%	30,355	44.60%	7,858	31.51%	4,200	15.11%
7,250	13,583	18.77%	20,786	37.07%	29,325	43.09%	7,400	29.68%	4,037	14.53%
7,500	13,577	18.76%	19,827	35.36%	28,378	41.70%	7,006	28.10%	4,003	14.40%
7,750	13,549	18.73%	18,968	33.83%	27,552	40.48%	6,722	26.96%	4,095	14.74%
8,000	13,498	18.66%	18,229	32.51%	26,794	39.37%	6,539	26.23%	4,061	14.61%
8,250	13,461	18.60%	17,598	31.38%	26,096	38.35%	6,389	25.62%	4,148	14.93%
8,500	13,474	18.62%	17,066	30.43%	25,459	37.41%	6,265	25.13%	4,215	15.17%
8,750	13,516	18.68%	16,613	29.63%	24,857	36.52%	6,177	24.77%	4,311	15.51%
9,000	13,598	18.79%	16,223	28.93%	24,301	35.71%	6,112	24.51%	4,353	15.67%
9,250	13,696	18.93%	15,934	28.42%	23,843	35.03%	6,096	24.45%	4,440	15.98%
9,500	13,822	19.10%	15,764	28.11%	23,453	34.46%	6,123	24.56%	4,455	16.03%
9,750	13,947	19.28%	15,649	27.91%	23,107	33.95%	6,213	24.92%	4,510	16.23%
10,000	14,084	19.46%	15,564	27.76%	22,753	33.43%	6,341	25.43%	4,520	16.27%

Appendix D. Weighted Usable Area (WUA) estimates from the Yakima Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. These WUA estimates show the relationship between stream flow and available instream habitat for Chinook, Steelhead and Bull Trout.

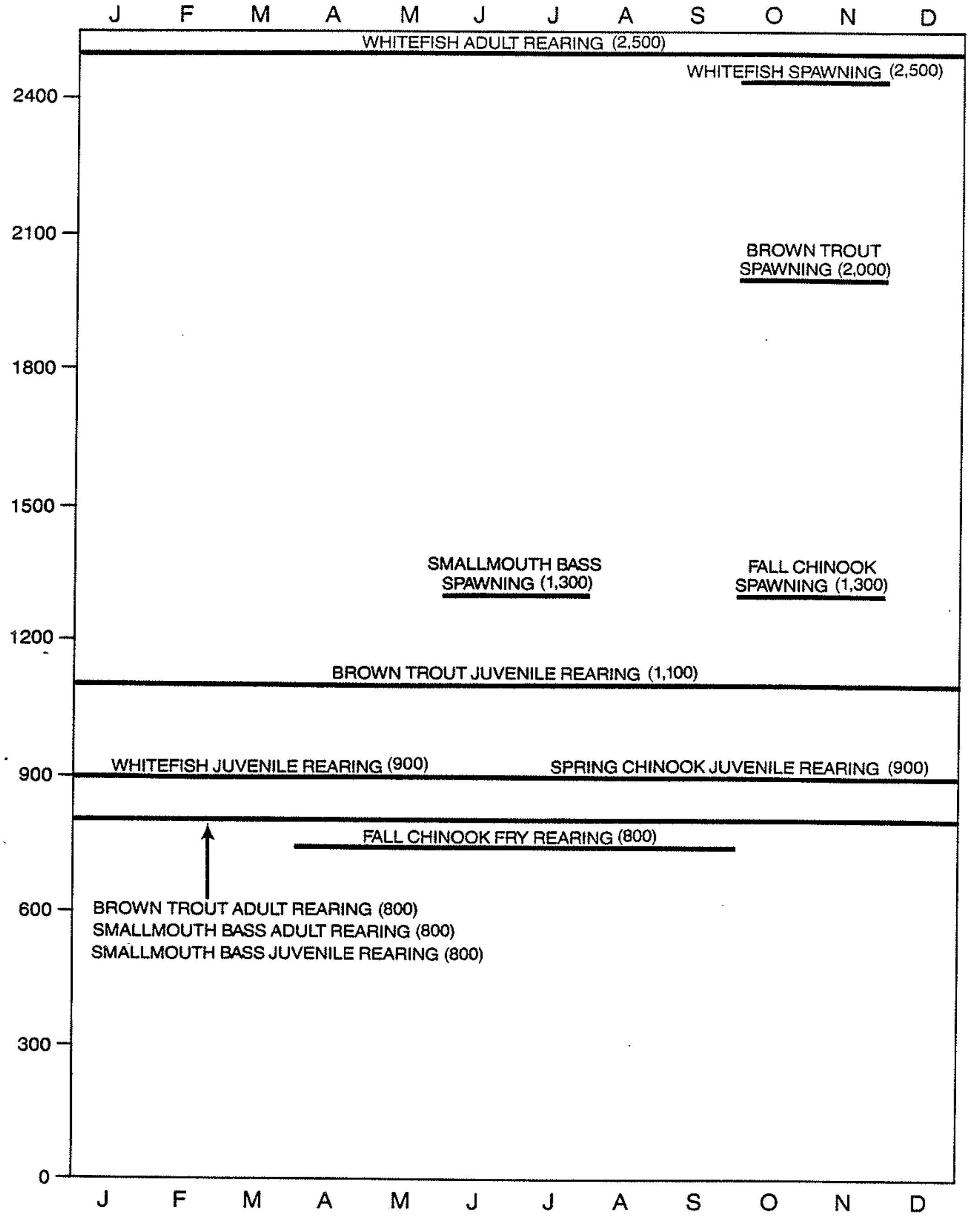


Figure A-9. Yakima River mouth to Horn Rapids Diversion Dam, optimum flows and time of occurrence of important species and life stages.

Appendix E. Weighted Usable Area (WUA) estimates from the Okanogan Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. These WUA estimates show the optimum discharges for each species and life stage present at the site.

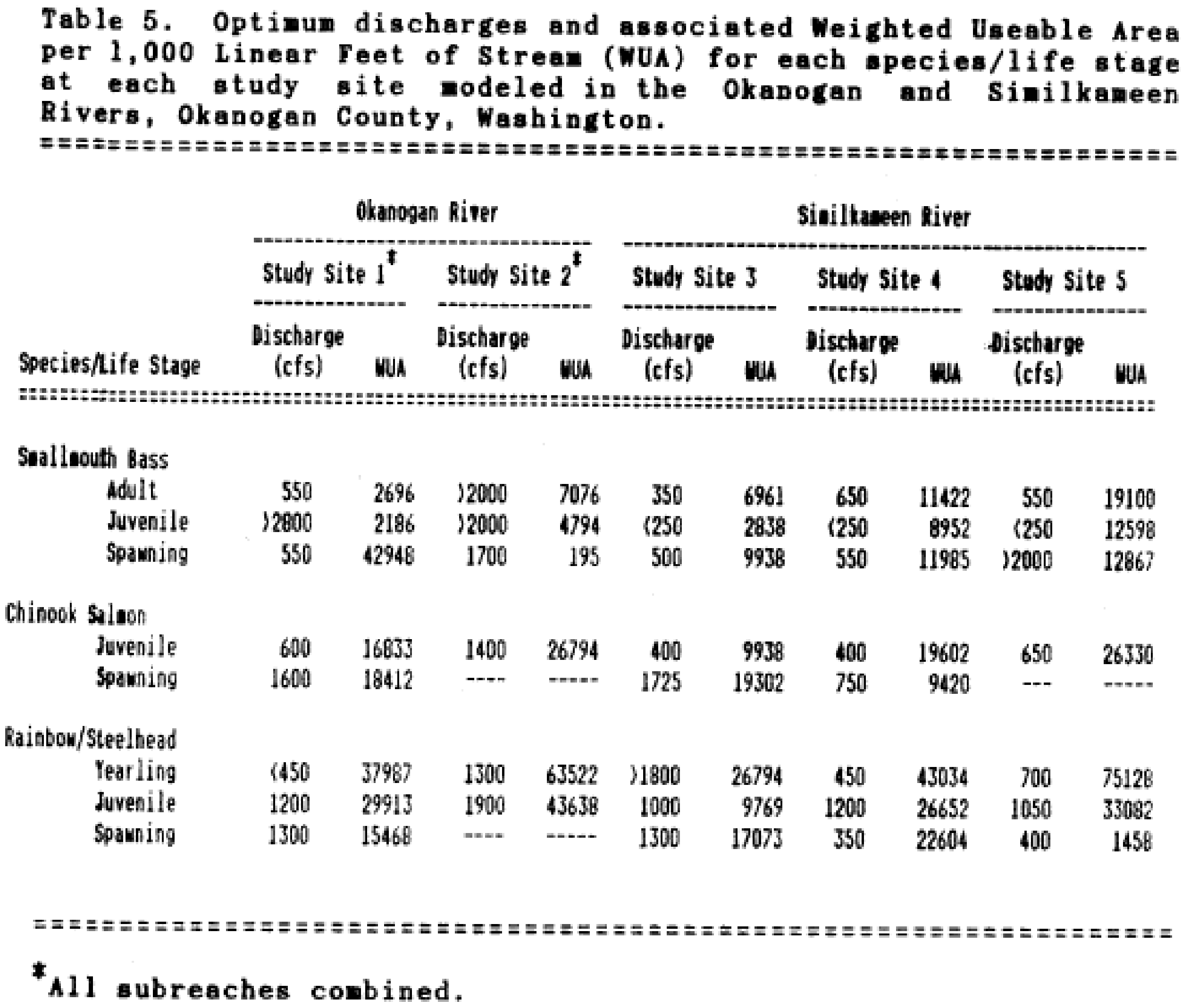


Table 5. Optimum discharges and associated Weighted Useable Area per 1,000 Linear Feet of Stream (WUA) for each species/life stage at each study site modeled in the Okanogan and Similkameen Rivers, Okanogan County, Washington.

	Okanogan River				Similkameen River					
	Study Site 1*		Study Site 2*		Study Site 3		Study Site 4		Study Site 5	
Species/Life Stage	Discharge (cfs)	WUA	Discharge (cfs)	WUA	Discharge (cfs)	WUA	Discharge (cfs)	WUA	Discharge (cfs)	WUA
Smallmouth Bass										
Adult	550	2696	>2000	7076	350	6961	650	11422	550	19100
Juvenile	>2800	2186	>2000	4794	<250	2838	<250	8952	<250	12598
Spawning	550	42948	1700	195	500	9938	550	11985	>2000	12867
Chinook Salmon										
Juvenile	600	16833	1400	26794	400	9938	400	19602	650	26330
Spawning	1600	18412	----	-----	1725	19302	750	9420	---	-----
Rainbow/Steelhead										
Yearling	<450	37987	1300	63522	>1800	26794	450	43034	700	75128
Juvenile	1200	29913	1900	43638	1000	9769	1200	26652	1050	33082
Spawning	1300	15468	----	-----	1300	17073	350	22604	400	1458

*All subreaches combined.

Appendix F. Weighted Usable Area (WUA) estimates from the Okanogan Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. Composite habitat versus flow results for the Okanogan River.

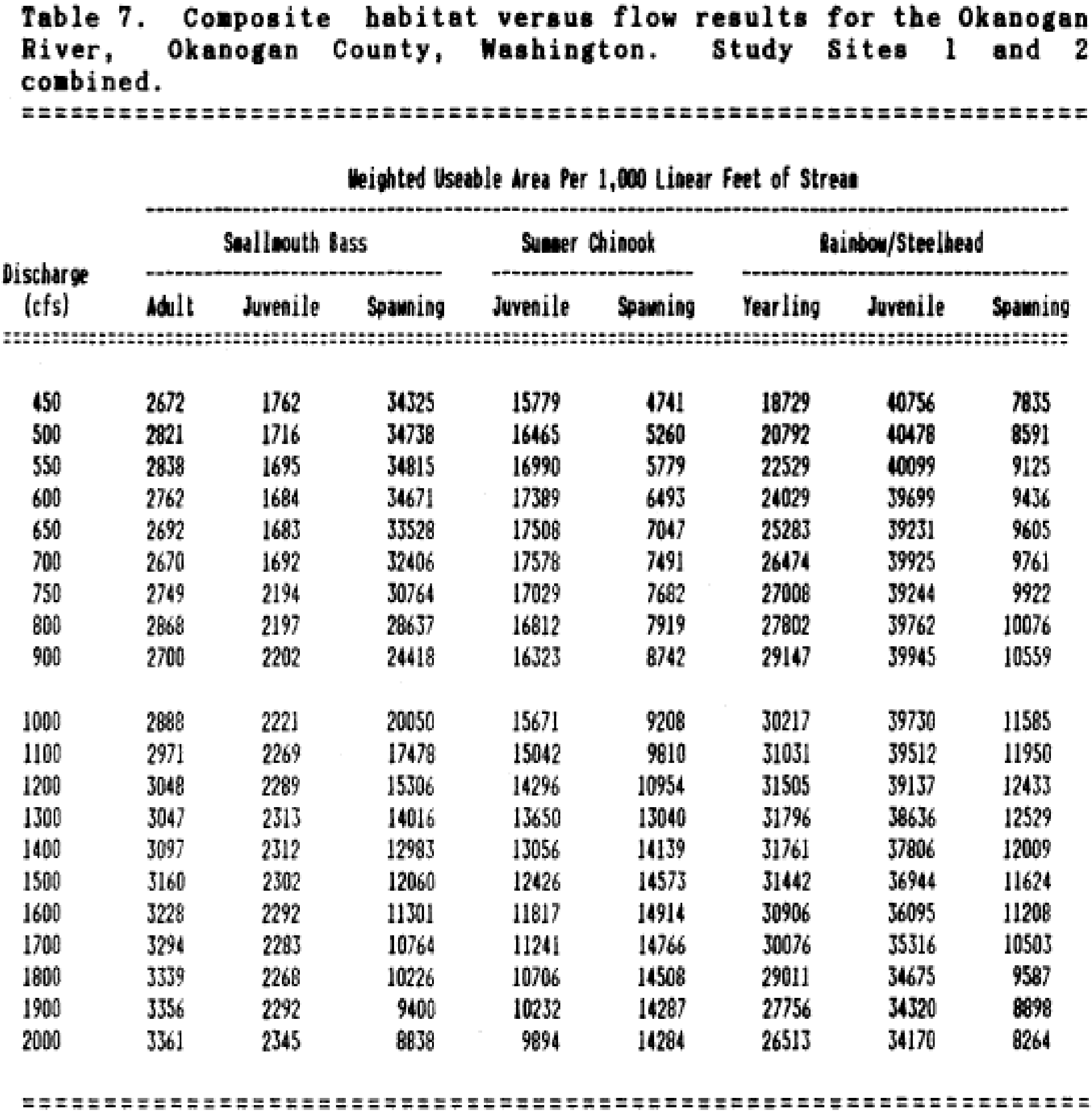


Table 7. Composite habitat versus flow results for the Okanogan River, Okanogan County, Washington. Study Sites 1 and 2 combined.

	Weighted Useable Area Per 1,000 Linear Feet of Stream							
	Smallmouth Bass			Summer Chinook		Rainbow/Steelhead		
Discharge (cfs)	Adult	Juvenile	Spawning	Juvenile	Spawning	Yearling	Juvenile	Spawning
450	2672	1762	34325	15779	4741	18729	40756	7835
500	2821	1716	34738	16465	5260	20792	40478	8591
550	2838	1695	34815	16990	5779	22529	40099	9125
600	2762	1684	34671	17389	6493	24029	39699	9436
650	2692	1683	33528	17508	7047	25283	39231	9605
700	2670	1692	32406	17578	7491	26474	39925	9761
750	2749	2194	30764	17029	7682	27008	39244	9922
800	2868	2197	28637	16812	7919	27802	39762	10076
900	2700	2202	24418	16323	8742	29147	39945	10559
1000	2888	2221	20050	15671	9208	30217	39730	11585
1100	2971	2269	17478	15042	9810	31031	39512	11950
1200	3048	2289	15306	14296	10954	31505	39137	12433
1300	3047	2313	14016	13650	13040	31796	38636	12529
1400	3097	2312	12983	13056	14139	31761	37806	12009
1500	3160	2302	12060	12426	14573	31442	36944	11624
1600	3228	2292	11301	11817	14914	30906	36095	11208
1700	3294	2283	10764	11241	14766	30076	35316	10503
1800	3339	2268	10226	10706	14508	29011	34675	9587
1900	3356	2292	9400	10232	14287	27756	34320	8898
2000	3361	2345	8838	9894	14284	26513	34170	8264

Appendix G. Weighted Usable Area (WUA) estimates from the Okanogan Instream Flow Incremental Methodology Basin Study. Estimates from the site nearest the mainstem of the Columbia. These WUA estimates show the optimum discharges for each species and life stage present at the site.

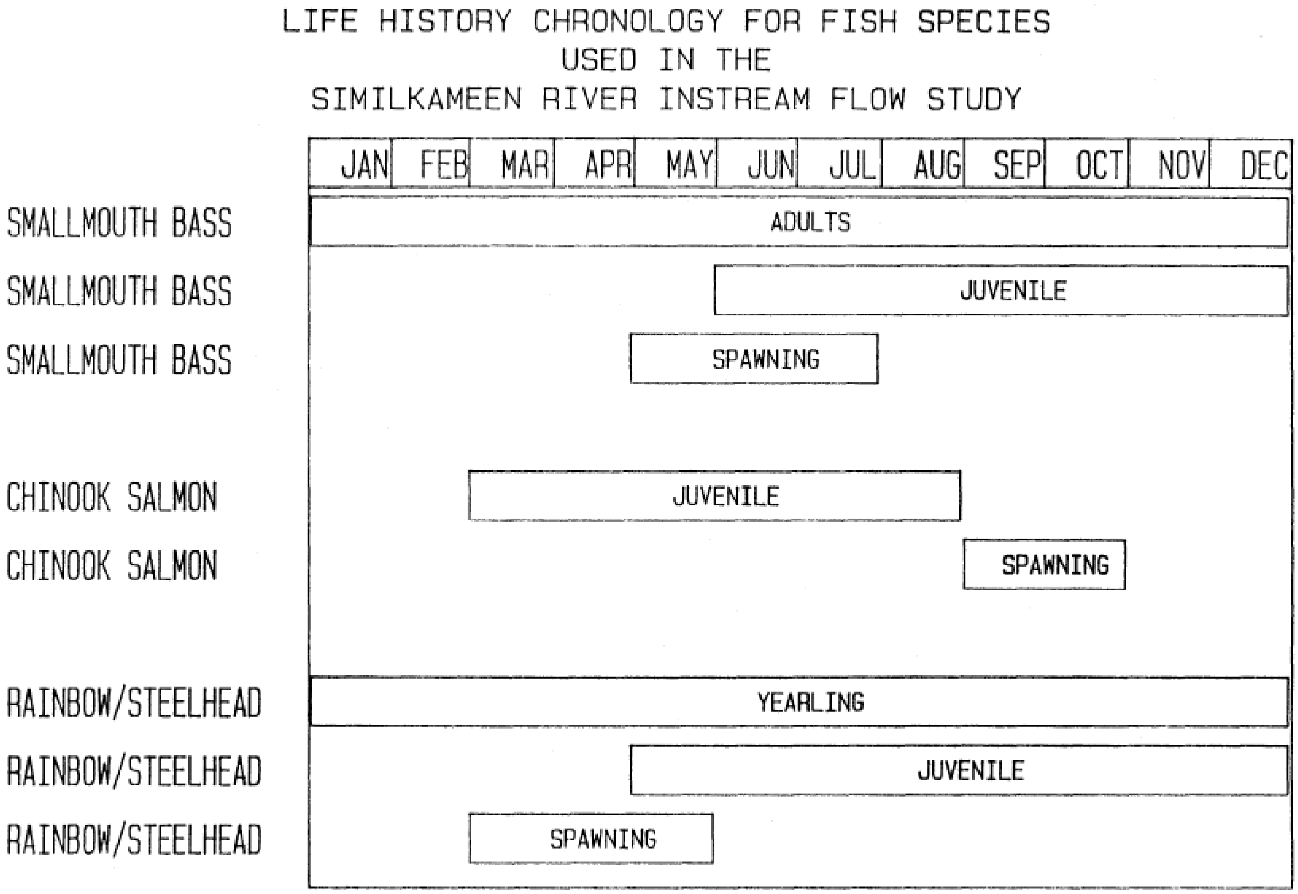


Fig. 12.

Appendix H. Monthly water use (in cubic meters) in the Okanogan sub-basin. Water uses include reported agricultural water use, losses due to crop evapotranspiration, municipal and domestic water use and commercial and industrial water use.

Month of Year	Monthly Ag Water Use	Losses Due to Crop ET	M&D Water Use	Comm/Ind Water Use
1	0.00	0.00	540,616.06	814,877.45
2	0.00	0.00	540,616.06	814,877.45
3	0.00	0.00	1,081,232.12	1,246,283.16
4	18,764,343.99	13,851,688.16	1,081,232.12	1,246,283.16
5	25,114,618.17	18,539,409.60	1,081,232.12	1,246,283.16
6	28,791,092.69	21,253,353.59	1,621,848.18	1,485,953.00
7	31,797,838.38	23,472,909.13	1,621,848.18	1,485,953.00
8	28,670,021.41	21,163,979.74	1,621,848.18	1,485,953.00
9	21,613,782.27	15,955,120.63	1,081,232.12	1,246,283.16
10	15,367,527.09	11,344,185.18	1,081,232.12	1,246,283.16
11	0.00	0.00	1,081,232.12	1,246,283.16
12	0.00	0.00	540,616.06	814,877.45

Appendix I. Monthly water use (in cubic meters) in the Methow sub-basin. Water uses include reported agricultural water use, losses due to crop evapotranspiration, municipal and domestic water use and commercial and industrial water use.

Month of Year	Monthly Ag Water Use	Losses Due to Crop ET	M&D Water Use	Comm/Ind Water Use
1	0.00	0.00	59,891.01	3,874,687.22
2	0.00	0.00	59,891.01	3,874,687.22
3	0.00	0.00	119,782.01	5,925,992.22
4	7,403,277.75	5,932,053.62	119,782.01	5,925,992.22
5	10,037,397.30	8,042,704.99	119,782.01	5,925,992.22
6	11,408,401.84	9,141,255.22	179,673.02	7,065,606.11
7	12,892,617.01	10,330,518.18	179,673.02	7,065,606.11
8	11,613,905.73	9,305,920.14	179,673.02	7,065,606.11
9	8,682,539.49	6,957,092.72	119,782.01	5,925,992.22
10	6,338,694.19	5,079,030.54	119,782.01	5,925,992.22
11	0.00	0.00	119,782.01	5,925,992.22
12	0.00	0.00	59,891.01	3,874,687.22

Appendix J. Monthly water use (in cubic meters) in the Wenatchee sub-basin. Water uses include reported agricultural water use, losses due to crop evapotranspiration, municipal and domestic water use and commercial and industrial water use.

Month of Year	Monthly Ag Water Use	Losses Due to Crop ET	M&D Water Use	Comm/Ind Water Use
1	0.00	0.00	279,846.12	3,874,687.22
2	0.00	0.00	553,029.24	3,874,687.22
3	0.00	0.00	553,029.24	5,925,992.22
4	10,677,740.28	8,704,310.35	553,029.24	5,925,992.22
5	14,476,928.33	11,801,343.15	832,875.37	5,925,992.22
6	16,454,326.85	13,413,284.44	832,875.37	7,065,606.11
7	18,595,008.94	15,158,331.69	832,875.37	7,065,606.11
8	16,750,724.91	13,654,903.05	553,029.24	7,065,606.11
9	12,522,818.23	10,208,386.19	553,029.24	5,925,992.22
10	9,142,292.45	7,452,639.67	553,029.24	5,925,992.22
11	0.00	0.00	279,846.12	5,925,992.22
12	0.00	0.00	279,846.12	3,874,687.22

Appendix K. Monthly water use (in cubic meters) in the Yakima sub-basin. Water uses include reported agricultural water use, losses due to crop evapotranspiration, municipal and domestic water use and commercial and industrial water use.

Month of Year	Monthly Ag Water Use	Losses Due to Crop ET	M&D Water Use	Comm/Ind Water Use
1	0.00	0.00	5,946,570.89	2,050,125.67
2	0.00	0.00	5,946,570.89	2,050,125.67
3	0.00	0.00	11,893,141.79	3,135,486.32
4	391,846,898.51	232,049,001.01	11,893,141.79	3,135,486.32
5	520,049,464.29	307,969,666.53	11,893,141.79	3,135,486.32
6	583,828,167.04	345,738,969.58	17,839,712.68	3,738,464.46
7	652,131,370.51	386,187,650.40	17,839,712.68	3,738,464.46
8	588,344,289.06	348,413,385.54	17,839,712.68	3,738,464.46
9	438,960,356.94	259,949,262.57	11,893,141.79	3,135,486.32
10	320,912,781.66	190,042,311.62	11,893,141.79	3,135,486.32
11	0.00	0.00	11,893,141.79	3,135,486.32
12	0.00	0.00	5,946,570.89	2,050,125.67