BENEFIT-COST ANALYSIS OF THE YAKIMA BASIN INTEGRATED PLAN PROJECTS

REPORT TO THE WASHINGTON STATE LEGISLATURE

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Executive Summary

The Yakima River Basin lies in semi-arid south central Washington and supports a growing population as well as $3 billion agricultural industry that is heavily dependent on irrigation for production. The river system historically supported large runs of salmon and steelhead, but a variety of stressors both internal and external to the basin have reduced those populations substantially since the early 20th century. A reservoir system supplies water through the operation of five reservoirs with a combined storage totaling just over a million acre-feet (af). Stream flow is primarily derived from the spring snowmelt runoff. Precipitation in this area is winter-dominant, and is stored in the snowpack as a natural but seasonally declining reservoir for spring and summer water use. Water rights in the basin are over-appropriated such that a number of droughts in the last few decades have led to curtailment of water to junior water rights holders.

Historical drought impacts, concerns over the effects of climate change on snowpack, the potential for increasing anadromous fish abundance in the basin, and future municipal water demands have been the impetus for the development of the Yakima River Basin Integrated Water Resource Management Plan ("IP"). The IP includes the following elements:

- Reservoir Fish Passage
- Fish Habitat Enhancement
- Modifying Existing Structures and Operations
- Surface Storage
- Market-Based Reallocation
- Groundwater Storage
- Enhanced Water Conservation

Fish passage projects, habitat enhancements, and instream flow augmentation are designed to support increases in salmon, steelhead, and other fish populations in the basin. Proposed infrastructure and water market development are intended to mitigate instream and out-of-stream drought impacts through increased storage and improved water trading, respectively. In particular, the surface water and groundwater storage projects would increase cumulative water storage by 500,000 af for a total of 1.5 million af in the basin.

Many analyses of the IP and its components have been published to date. One of them, the "Four Accounts analysis" (2012), compares the net benefits of the IP as a whole against a no-IP alternative, and reports benefits ranging from $6.2 billion to $8.6 billion, and costs ranging from $2.7 billion to $4.4 billion. The reported Benefit/Cost (B/C) ratios are 1.4 and above, suggesting that the benefits of the IP as a whole outweigh its costs in aggregate net present value. These B/C results are provided for the full proposed implementation of the IP, but with limited exceptions, existing studies do not provide estimates of the net benefits of the individual components of the IP.

Section 5057 of the State of Washington Capital Budget for 2013 charges the State of Washington Water Research Center "to prepare separate benefit-cost [B-C] analyses for each of the projects proposed in the 2012 Yakima River basin water resource management plan [IP]". It further stipulates that "To the greatest extent possible, the center must use information from existing studies, supplemented by primary research, to measure and evaluate each project's benefits and costs." This report is in response to and framed by this charge.

Existing hydrologic and water management models of the Yakima River basin are used to examine the impact of proposed IP water storage projects, conservation, and proposed instream flows on drought impacts under a limited set of climate scenarios. A crop production model is used to assess the potential economic impact of IP projects and water market development on the economic risk of water curtailment. Municipalities in the basin are slated to receive water rights for future population growth under the IP, and these benefits to municipalities are estimated. The net benefits of fish passage for the five reservoirs in the basin, proposed IP instream flows, and habitat restoration in the basin for salmon and trout are assessed.

Because each of the proposed IP projects would operate within the Yakima Basin hydrologic system, there are extensive interdependencies among projects, so that the benefits of one project are often dependent on the implementation status of other projects. We show that the value of any given water storage projects is highest when no other water storage project is implemented, and that water market development also affects the value of water storage projects. The economic tradeoffs between instream flows for fish and out-of-stream water uses are also dependent on these factors. Selected results include the following:

- *A snapshot of IP benefit estimates for moderate climate, water market, and baseline fish scenarios.*
    - Agricultural irrigation benefits: $117 million.
    - Municipal and domestic benefits: $32 million.
    - Fish benefits: $1 to $2 billion.
- *When implemented together as part of the IP, the major water storage projects as a group do not pass a B-C test.* Net present value for out-of-stream benefits (NB) from the IP range from -$2.2 to -$2.7 billion (B/C ratios from 0.02 to 0.20) depending on market and climate assumptions. Estimated benefits of proposed instream flow increases cannot make up for this shortfall.
- *No individual water storage project provides positive net benefits for out-of-stream uses when implemented as part of the full IP, even under the most adverse climate and restrictive market conditions.*
- *Net benefits for out-of-stream use of individual water storage projects implemented with no other projects implemented are negative, with some exceptions under the most adverse climate and water market conditions.* Based on moderate climate and market outcomes, storage infrastructure projects implemented alone and without proposed IP instream flow augmentation result in the following estimated out-of-stream net present value and B/C ratios, none of which passes a B-C test:
    - Bumping Lake Expansion: NB=-$371 million; B/C ratio of 0.18.
    - Cle Elum Pool raise: NB= -$6 million; B/C ratio of 0.62. Under the most adverse climate scenario and moderate market conditions, NB=$5 million with a B/C ratio is 1.35. It is also the most likely of the storage projects to satisfy a B-C test under moderate climate based on the sum of out-of-stream and instream use value.
    - Keechelus to Kachess Conveyance: NB= -$110 million; B/C ratio of 0.20.

- o Kachess Drought Relief Pumping Plant: NB= -$107 million; B/C ratio of 0.46. Under the most adverse climate considered, Keechelus to Kachess Conveyance and Kachess Drought Relief Pumping Plant together provide net benefits of $6 million and a B/C ratio of 1.02.
    - o Passive Aquifer Storage and Recovery: NB=-$82 million; B/C ratio of 0.35.
    - o Wymer Dam and Reservoir: NB= -$1,217 million; B/C ratio of 0.09.
    - o Due to diminishing economic returns to water in the basin, increasing the number of IP storage projects reduces the value of each water storage project implemented.
- *Instream flow benefits are insufficient to support the full suite of IP water storage projects given the net benefit shortfall in out-of-stream benefits, but proposed instream flows may be supportable through market purchases.*
    - o Purchases of senior water rights to implement proposed IP instream flows would be less expensive than providing instream flows via IP storage infrastructure, with estimated costs ranging from $85 million to $500 million depending on water market and climate conditions.
    - o Because of its low cost, Cle Elum pool raise is most likely to satisfy a B-C test under moderate climate based on the sum of estimated out-of-stream and instream benefits.
- *Reservoir fish passage projects are likely to provide positive net benefits through their pivotal role in supporting wild sockeye reintroduction into the basin.* Fish passage is estimated to provide benefits ranging from about $0.95 to $1.7 billion and cost a total of $0.35 billion for all fish passage projects, which provide B/C ratios ranging from 2.7 to 4.9 for the individual fish Passage projects.
- *Fish habitat restoration is unlikely to satisfy a B-C test.* Results for the net benefits of instream flow purchases and restoration investment together range from about $48 million to $294 million, which fall below their estimated combined costs of $450 million. IP restoration costs are estimated at $338 million, so our results suggest that restoration does not satisfy a B-C test. However, insufficient evidence exists to estimate the contribution of habitat restoration to fish passage productivity, which may affect the value of restoration.
- *Water markets show potential for reducing the impacts of basin-wide curtailment.* We estimate that potential net gains from trade net of estimated transaction costs range between $216 million and $1.4 billion depending on climate, the extent of market development, and the extent of IP development. We show that markets act as a substitute for IP water storage infrastructure in that more active markets reduce the value of IP water storage infrastructure.

This report is not intended as a review of prior benefit-cost assessments of the IP, but it does utilize and extend existing IP analyses, and sheds some light on the sources and accuracy of previous B-C estimates. The Four Accounts analysis estimates agricultural benefits of 0.8 billion, municipal benefits of 0.4 billion, fish benefits ranging from $5 to $7.4 billion, and costs ranging from $2.7 billion to $4.4 billion, which together provide positive net benefits and B/C ratios of 1.4 and higher. Our estimated benefits are lower for each category for a host of reasons. Notably, the assumed climate regime has substantial consequences for agricultural benefits, and the baseline salmonid abundance in the Columbia River Basin has important consequences for fish benefits.

Despite differences in results, there are important similarities in our findings. Fish passage projects alone comprise a small percentage of median IP costs but provide about 75% to 80% of the estimated benefits of the IP. In contrast, IP investments for instream and out-of-stream uses account for about 66% of median costs but provide a small fraction of benefits, although this breakdown is not explicit in the Four Accounts analysis. This distribution of costs and benefits drives the strong results for fish passage.

In accordance to the legislative charge, this report focuses sharply on Benefit-Cost analysis to assess the economic efficacy of individual projects. It does not include an economic *impact analysis* to assess the indirect economic impact of IP investments on the local economy or the statewide impacts of the potential use of state funds to support the IP. Nor does this report cover costs and benefits from ongoing, non-IP programs within the basin whose outcomes may impact IP benefit metrics, such as fish translocation or hatchery operations.

Due to data limitations, the majority of the results are based on simulation methods rather than statistical analysis, though statistical analysis is provided when feasible and useful. The consequence is that the majority of our results do not lend themselves to statistical confidence assessment, although robustness analyses are performed. Many necessary tradeoffs were made with respect to modeling approaches due to the dimensionality and scope of this research mandate. As is always true of modelling exercises, refinements are certainly possible and may provide more precision and accuracy for various aspects of this analysis.

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I. Introduction

The Yakima River Basin Integrated Water Resource Management Plan (IP) is a water management plan for Yakima River Basin of South-central Washington State that has arisen out of the Yakima River Basin Water Enhancement Project (YRBWEP), which has been in development over several decades (HDR Engineering et al. 2012). The IP includes the following elements (State of Washington Department of Ecology 2013a):

- Reservoir Fish Passage
- Fish Habitat Enhancement
- Modifying Existing Structures and Operations
- Surface Storage
- Market-Based Reallocation
- Groundwater Storage
- Enhanced Water Conservation

These elements are categories of more specific projects identified as component parts of the integrated plan. For example, there are six fish passage projects, one for each existing above-ground dams managed as a part of the existing Yakima Basin Project, there are several surface and groundwater storage projects.

An extensive legislative history and body of research has developed in relation to individual components of the IP and YRBWEP since the 1970s, much of it described and accessible from the U.S. Bureau of Reclamation Yakima River Basin Water Enhancement Project Columbia-Cascades Area Office website http://www.usbr.gov/pn/programs/yrbwep/2011integratedplan/ (U.S. Department of the Interior Bureau of Reclamation 2013).

A Benefit-Cost analysis (referred to from here on as the *Four Accounts analysis*) has been published, which provides estimates of value of the IP as a whole against a "no action" alternative (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012). It reports net present value benefit and cost estimates of $6.2 to $8.6 billion and $2.7 to $4.4 billion, respectively, provide B/C ratios ranging above 1.4, suggesting that benefits outweigh the costs in aggregate present value terms (Table 2 and Figure 2, Four Accounts analysis).[1]

Estimated costs of implementing the IP have been reported more or less on a project by project basis. For example, Fish passage at Lake Cle Elum Dam is estimated to cost $81.5 million in present-value terms, and Wymer Dam (which would be a new dam and reservoir on Lmuma Creek) is estimated to cost $1,330 million in present value terms (HDR Engineering, Inc. 2012, page 8). While project-specific cost estimates have been reported, project-specific benefits have not been

[1] Throughout this report, we use "B/C" specifically to represent the ratio of benefits over costs. The term "B-C" will be used to represent benefit-cost analysis in general, or net benefits in particular (that is, the benefits minus the costs).

reported for most of the projects in the IP, so project-specific benefit-cost assessment as mandated for this report is not possible without additional analysis.

A. Objective of this study

The objective of this analysis is to perform benefit-cost analyses for the individual component projects of the integrated plan. Section 5057 of the State of Washington Capital Budget for 2013 charges the State of Washington Water Research Center "to prepare separate benefit-cost analyses for each of the projects proposed in the 2012 Yakima river basin integrated water resources management plan (Yakima integrated plan)." Further, "[t]o the greatest extent possible, the center must use information from existing studies, supplemented by primary research, to measure and evaluate each project's benefits and costs." Finally, "The center must measure and report the economic benefits of each project on a disaggregated basis, so that it is clear the extent to which an individual project is expected to result in increases in fish populations, increases in the reliability of irrigation water during severe drought years, and improvements in municipal and domestic water supply." This report is in response to this charge.[2]

B. Analytical framework

Analysis of the impacts of such a diverse set of projects in an interconnected environment such as the Yakima River Basin requires a suite of analytical tools, applied with recognition that the impacts of each project may be dependent on the implementation of other projects in the IP. Our analytical framework to examine the impacts of IP projects, operations, and market developments on drought risk to agriculture, municipalities, and fish abundance includes the following elements:

- RiverWare™ hydrological model, modified specifically for the Yakima River basin and parameterized for IP projects and operations,
- An agricultural crop production model to estimate the value of water use and the cost of curtailment in terms of agricultural production,
- A water market simulation model,
- A model for estimating municipal benefits,
- Models for estimating the impact of fish passage, instream flows, and habitat restoration,
- A model for estimating the economic value of fish abundance changes due to IP projects.

For each of these modeling components we rely heavily on the models that have already been developed for assessing various aspects of the IP. However, we modify these models as necessary in part because the objectives of this project are different than preceding research efforts, and in some cases we make modifications based on additional methodological and empirical grounds. In these

[2]Benefit-Cost analysis is a required for federal water resource planning and funding. The Principles and Guidelines for Water and Land Related Resources Implementation Studies (P&G) guides Federal evaluation of proposed water resource development projects (U.S. Water Resources Council 1983). The analysis in this report is generally consistent with these guidelines. The methods in this report are also generally consistent with the draft "Updated Principles and Guidelines" (Council on Environmental Quality 2013). However, our primary strategy for research is based primarily on our mandate from the Washington State Legislature.

cases we explain these changes in relation to the original models upon which we draw in hopes to better place our results in the context of prior reports.

C. Overview of results

As a point of comparison, a summary of reported aggregate benefits reported in the Four Accounts analysis is useful. The Four Accounts reports estimates benefits of the IP to range from $6.2 to $8.6 billion. Of this, $5.0 to 7.4 billion are attributed to forecasted improvements in fish populations (primarily salmon and steelhead), $0.8 billion to agricultural irrigation benefits, and $0.4 billion to municipal and domestic water supply benefits. The estimated costs for the IP reported in the Four Accounts analysis range from $2.7 billion to $4.4 billion.

For a host of reasons explained in this report, our range of benefit estimates are lower for all three categories of benefits. A snapshot of results representing moderate climate change, water market, and baseline fish conditions are

- Agricultural irrigation benefits: $100 million.
- Municipal and domestic benefits: $30 million.
- Fish benefits: $1 to $2 billion.

While these results are informative, our legislative mandate is to provide B-C analysis for each of the listed projects in the IP. Our results show the following:

- All individual fish passage projects are likely to positive estimated net benefits.
- All water storage and conservation projects fail to pass a benefit-cost test for out-of-stream uses, with limited exceptions under most adverse of the climate scenarios we consider.
- The net benefits of proposed instream flows for fish are negative when provided via implementation of IP storage, which is to say that instream flow benefits do not appear to be sufficient to make up for the shortfall in net benefits for out-of-stream uses.
- The costs of providing proposed IP instream flows are likely to be substantially lower if acquired via a (heretofore underdeveloped) market for instream flows. However, the net benefit of such transactions for the proposed IP instream flow augmentation is ambiguous due to uncertainty surrounding their impact on fish abundance.
- Water market development shows promise as a way to mitigate the impact of out-of-stream curtailment, and these benefits increase with more adverse climate.

D. Scope and limitations of this report

The scope of this report as defined by its underlying legislative mandate is in some ways expansive, and in many ways narrow. First, due to the number of projects within the IP and the complexity of the problem, we examine only the projects as defined by the Yakima River Basin Watershed Enhancement Project Workgroup (YRBWEP), the US Bureau of Reclamation (Reclamation), Washington State Department of Ecology (Ecology), and the private consulting firms who have been involved in the design of IP proposal and implementation. We do not examine any other design possibilities.

Second, our legislative charge explicitly calls for *benefit-cost analyses* of the component parts of the integrated plan. It is not uncommon for *economic impact analysis* to be carried out to assess indirect economic impacts of infrastructure projects on the regional or national economy, including, for example, impacts on job availability and employment, regional or national production and income, and/or the same types of economic impacts on the State economy that could result from the potential use of state funds to support IP projects. Economic impact analysis and benefit-cost analysis are distinct analyses that provide different information. Our legislative charge does not call for an economic impact analysis of the integrated plan, and we do not carry out such analysis. This analysis specifically focuses on the direct benefits and costs of the IP projects.

Third, an extensive amount of research has been carried out over the last 30 years working toward additional water storage infrastructure and fish habitat and conservation improvements. As charged in the enabling legislation, the analysis in this report relies heavily on research and modeling infrastructure that now exists from this extended effort. We owe a great deal of gratitude to HDR Engineering, ECONorthwest, Reclamation, and Ecology as well as other firms who have openly shared the models that they have been developing for the Yakima Basin and the Integrated Plan projects. That said, our legislative charge requires us to answer a set of questions that differ in many respects than those addressed in the existing body of literature, and we modify some aspects of the existing analyses on methodological and empirical grounds. We are indebted to those listed above and others for their contributions and prior work, but this research team, and the Project Lead specifically, accepts full responsibility for any shortcomings or errors in this report.

The large set of projects and potential benefits that we are examining requires a balance between expansive and exhaustive analysis versus clarity of results. We therefore limit our analysis in several ways. First, we examine only a subset of the combinations of projects, and choose our focus to best illustrate the range of possible outcomes. That said, due to the large number combinations of outcomes, we rely on the outcomes of these combinations themselves to provide some sense of robustness. Beyond this, analysis of variance in certain parts of the analysis, especially simulations, is limited. When we have statistical results to convey, we do so to shed light on the substantial uncertainty surrounding the impact outcomes. There are myriad assumptions implicit in each of the models, and the validity of the results is dependent on the validity of these underlying assumptions. We attempt to be clear about the most consequential assumptions underlying our results.

While we examine the impacts of various market and climate scenarios, we do not as a matter of course predict which of these scenarios are most likely within the range that we consider. For market outcomes, this is in part because water market development is actually part of the proposed IP. For climate outcomes, even the Intergovernmental Panel on Climate Change avoids making statements about the likelihood of one simulated climate scenario over another. What we do instead is report on the variation in outcomes within the domain of future market and climate outcomes. In terms of fish impacts, we would like to have been able to address a number of potential environmental and management realities in the Yakima basin that are likely to affect IP outcomes, including the spatial structure in water temperature variability, short-term fluctuations in ocean conditions and its effect on fish survival, multi-species, multi-objective hatchery operation decisions, and out of basin management that affects in-basin fish abundance. Unfortunately, the requisite data and information bases to address these issues are either unavailable, unknowable, or outside the mandate of the Legislative charge. More detailed discussion the weaknesses of the individual model frameworks are discussed in their respective sections.

Section II provides background of the Yakima Basin and descriptions of the individual projects examined; Section III describes the methods used in the analysis as well as methodological background and data that we rely on from previous studies; Section IV provides results for agricultural irrigation and municipal benefits and the opportunity cost of instream flows, fish benefit discussion, and individual project summaries. Section V concludes. An appendix provides additional background and technical analysis.

II. Context and IP project descriptions

The existing Yakima River reservoir system supplies water through the operation of five reservoirs with cumulative storage of 1.07 million af, which is about 30% of mean annual river flow. Runoff is derived mostly from winter precipitation in the Cascade Mountains, much of which is stored as snowpack (Vano et al. 2010a) . The largest use of water in the Basin is for irrigated agriculture, covering about 464,000 irrigated acres based on about 2.5 million af of irrigation water rights (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012). The primary source of water for this purpose is the federal Yakima Irrigation Project operated by the U.S. Bureau of Reclamation. The Yakima Project includes six irrigation divisions holding about 2 million af of water entitlements, and additional water is also supplied from non-federal diversions of surface water groundwater (HDR Engineering and Anchor QEA 2011). Figure 2 provides another graphic of the Yakima River Basin with a focus on the hydrologic system, the major water storage projects proposed under the IP, and the major irrigation districts.

Several droughts over the last 20 years have led to irrigation curtailments. Because of the characteristics of their water rights, three of the irrigation districts, Kittitas Reclamation District (KRD), Roza Irrigation District (Roza), and Wapato Irrigation Project (WIP) hold about 96% of the proratable water entitlements among the districts (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012), are subject to curtailment of irrigation water during droughts more than the other districts in the Basin. They are therefore among the primary beneficiaries of the water storage components of the IP. Municipal and domestic water use in the basin is also affected by water scarcity. Municipal water rights are primarily junior, and may be (and in limited cases have been) subject to water curtailment during drought, and residential development in part of the basin is required to mitigate new groundwater development with the purchase of surface water rights due to concerns about surface/groundwater interaction (Washington State Department of Ecology 2010). Benefits to municipalities of the IP include new (presumably uninterruptible) water supply of 50,000 acre feet per year to support municipal water demand growth in the Yakima River basin

(HDR Engineering and Anchor QEA 2011). In all, the proposed water storage projects are designed to provide approximately 500,000 af of additional storage to the basin, for a total of 1.5 million af of storage.

The Yakima River historically supported large anadromous salmonid populations, with runs estimated at 300,000 to 960,000 fish per year in the 1880s. Since then anadromous fish abundance has declined substantially, and three salmon species have be substantively extirpated from the basin – sockeye, summer chinook, and coho, and Steelhead and bull trout are listed as threatened under the Federal Endangered Species Act (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). Reasons for the decline in these fisheries include the construction of storage dams in the Basin, the Columbia River dams, irrigation diversions that have altered stream flow, and numerous other factors (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012).

The Yakima Basin Integrated Plan (IP) has developed by a workgroup including the U.S. Bureau of Reclamation, Washington State Department of Ecology, the Yakama Nation and various Yakima river basin stakeholders, with a goal to "protect, mitigate, and enhance fish and wildlife habitat; provide increased operational flexibility to manage instream flows to meet ecological objectives, and improve the reliability of the water supply for irrigation, municipal supply and domestic uses" (HDR Engineering et al. 2012). Section II.A provides an overview of IP projects developed by the Washington State Department of Ecology. The IP includes fish passage at the five major dams designed to open up habitat above the dams. Proposed instream flow augmentation and habitat restoration are designed to provide additional fish abundance benefits as well (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011).

This is meant only as a brief overview for context. Numerous other articles and reports are accessible for more extensive background on the basin and water related issues (including, but not limited to HDR Engineering et al. 2012; U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012; HDR Engineering Inc. et al. 2011). For extensive archives of reports, see the U.S. Bureau of Reclamation's Yakima River Basin Water Enhancement Project webpage at http://www.usbr.gov/pn/programs/yrbwep/2011 integratedplan/ and Washington State Department of Ecology's Yakima Basin Integrated Water Resource Management Plan website at http://www.ecy.wa.gov/programs/wr/cwp/ybip.html.

A. Summary of projects

The Integrated Plan consists of the following elements: (A) water storage, (B) conservation, (C) water operational changes, (D) water marketing, and (E) fish passage and habitat improvements. However, the projects included within each are variously named in existing reports, and the listed projects are in many cases categories of projects (e.g. "municipal conservation" and "agricultural conservation" represent sets of activities to reduce consumptive use or loss from municipal and agricultural water diversions). Further, project names used by the YRBWEP have changed for some of the projects. As such, we found that modest reclassification (within the spirit of the legislation) to be useful, so the projects specified in the legislation were grouped by element as follows:

1) Reservoir fish passage
   a) Kachess fish passage
   b) Box canyon creek fish passage
   c) Keechelus fish passage
   d) Tieton (Rimrock) fish passage
   e) Cle Elum fish passage
   f) Clear Lake fish passage
2) Tributary/mainstem fish habitat enhancement
3) Surface storage
   a) Wymer reservoir
   b) Bumping reservoir enlargement
   c) Cle Elum pool raise
   d) Kachess drought relief pumping station
4) Groundwater storage
   a) Shallow groundwater recharge
   b) Aquifer storage and recovery
5) Enhanced water conservation
   a) Agricultural conservation
   b) Municipal conservation
6) Modifications to existing structures and operations
   a) Subordination of power generation (Roza and Chandler)
   b) Keechelus to Kachess conveyance
7) Market-based reallocation

Despite some reclassification, elements of the IP have remained fundamentally unchanged since being tasked by the Legislature to provide benefit costs analyses for individual project components (Washington State Legislature 2013a). Individual projects continue to be refined, studied, and otherwise informed by stakeholder discussions as reflected in the Yakima River Basin Study (HDR Engineering Inc. et al. 2011), Yakima River Basin Final Programmatic Environmental Impact Statement (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012), technical memoranda for individual project components, and YBIP Workgroup meeting minutes and presentations. Where discrepancies exist, the following project descriptions are consistent with the Yakima Basin Riverware model (YAKRW) as implemented by HDR Engineering and Ancho QEA (2011) and its updated operational rules (HDR Engineering, Inc. 2014).

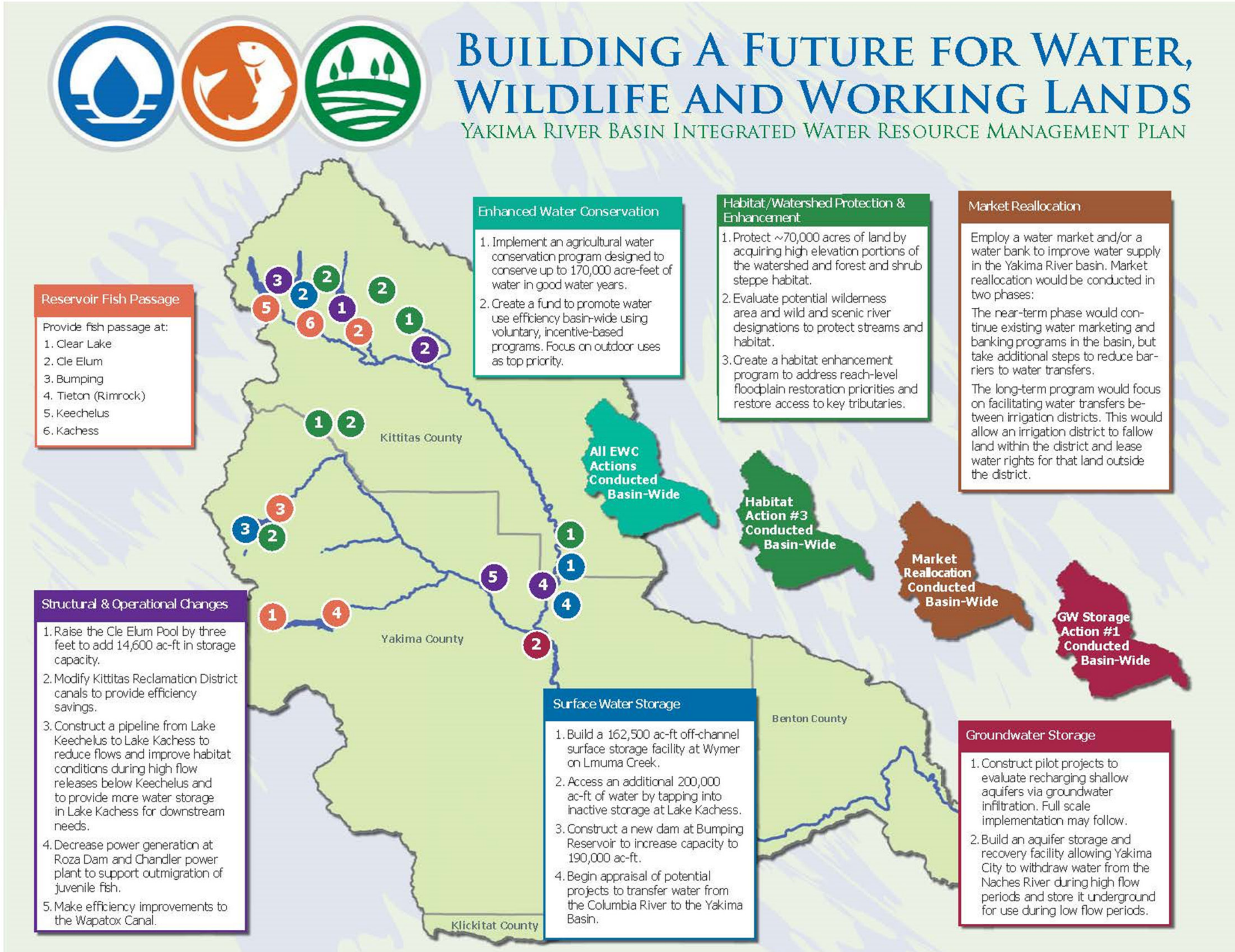
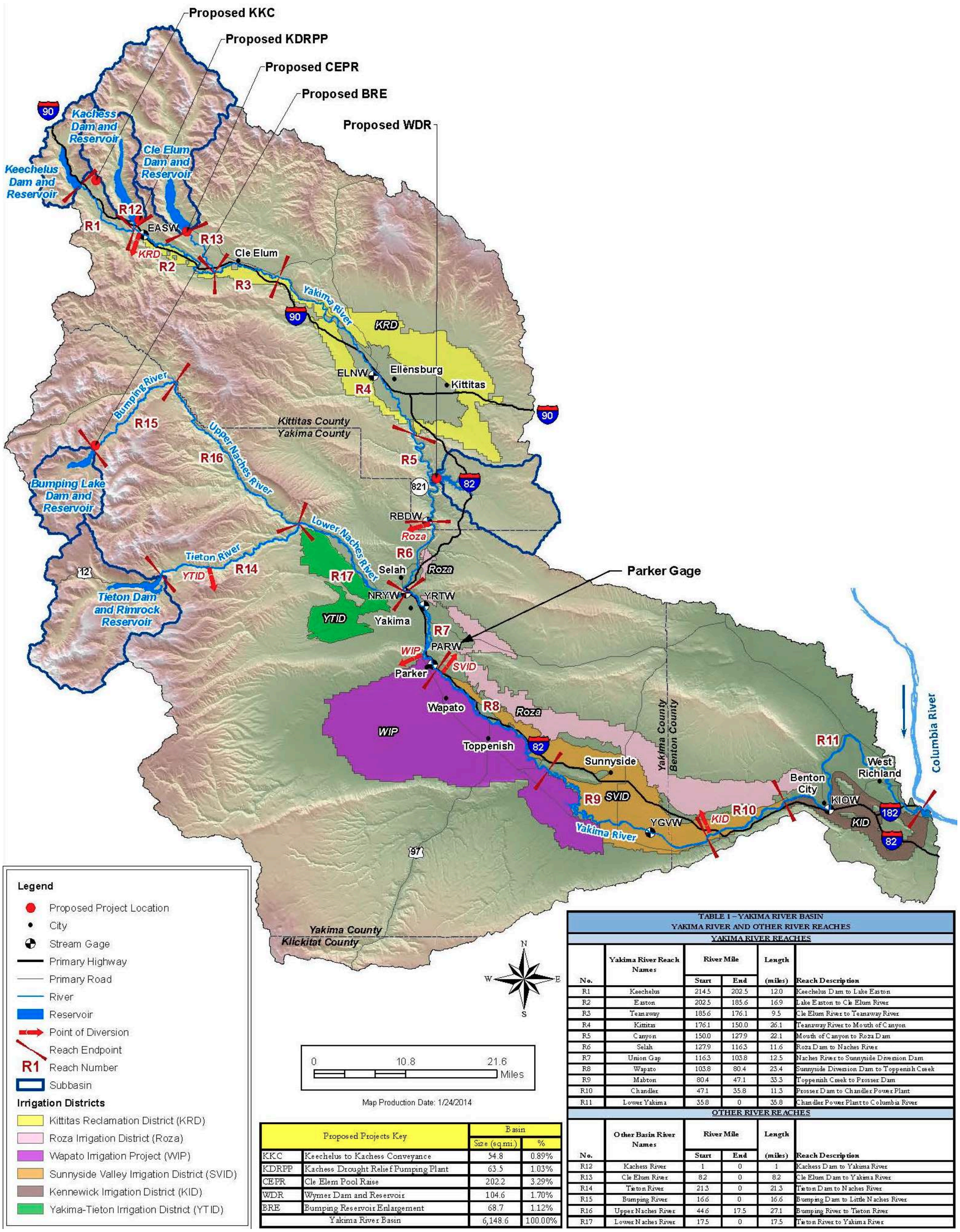


Figure 1: Description and general locations of IP projects (source: http://www.ecy.wa.gov/programs/wr/cwp/ybip.html. Also available in The Yakima River Basin Integrated Water Resource Management Plan Final Programmatic Environmental Impact Statement (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012))



Proposed Projects Key		Basin	
		Size (sq.mi.)	%
KKC	Keechelus to Kachess Conveyance	54.8	0.89%
KDRPP	Kachess Drought Relief Pumping Plant	63.5	1.03%
CEPR	Cle Elem Pool Raise	202.2	3.29%
WDR	Wymer Dam and Reservoir	104.6	1.70%
BRE	Bumping Reservoir Enlargement	68.7	1.12%
Yakima River Basin		6,148.6	100.00%

TABLE 1 – YAKIMA RIVER BASIN
YAKIMA RIVER AND OTHER RIVER REACHES

YAKIMA RIVER REACHES					
	Yakima River Reach Names	River Mile		Length	
No.		Start	End	(miles)	Reach Description
R1	Keechelus	214.5	202.5	12.0	Keechelus Dam to Lake Easton
R2	Easton	202.5	185.6	16.9	Lake Easton to Cle Elum River
R3	Teanaway	185.6	176.1	9.5	Cle Elum River to Teanaway River
R4	Kittitas	176.1	150.0	26.1	Teanaway River to Mouth of Canyon
R5	Canyon	150.0	127.9	22.1	Mouth of Canyon to Roza Dam
R6	Selah	127.9	116.3	11.6	Roza Dam to Naches River
R7	Union Gap	116.3	103.8	12.5	Naches River to Sunnyside Diversion Dam
R8	Wapato	103.8	80.4	23.4	Sunnyside Diversion Dam to Toppenish Creek
R9	Mabton	80.4	47.1	33.3	Toppenish Creek to Prosser Dam
R10	Chandler	47.1	35.8	11.3	Prosser Dam to Chandler Power Plant
R11	Lower Yakima	35.8	0	35.8	Chandler Power Plant to Columbia River
OTHER RIVER REACHES					
	Other Basin River Names	River Mile		Length	
No.		Start	End	(miles)	Reach Description
R12	Kachess River	1	0	1	Kachess Dam to Yakima River
R13	Cle Elum River	8.2	0	8.2	Cle Elum Dam to Yakima River
R14	Tieton River	21.3	0	21.3	Tieton Dam to Naches River
R15	Bumping River	16.6	0	16.6	Bumping Dam to Little Naches River
R16	Upper Naches River	44.6	17.5	27.1	Bumping River to Tieton River
R17	Lower Naches River	17.5	0	17.5	Tieton River to Yakima River

Figure 2: Yakima Basin and Integrated Plan water projects. Map and content courtesy of HDR Engineering, Inc.

B. Water storage projects

Wymer Reservoir. Located in Lmuma Creek eight miles upstream from the Roza Diversion Dam, Wymer Reservoir will provide 162,500 af in new water storage. A portion (82,500 af) would be used to improve annual instream flows for fish with the remaining 80,000 af reserved for irrigation needs (Operational Guidelines Committee 2013; Lynch 2013). There are two alternatives for releasing water from Wymer. The Riverware model assumes that water would be released directly below the dam in accordance with the "Wymer 1" alternative (HDR Engineering, Inc. 2014). Construction would include a new pump station at Thorp, a new pipeline connecting the pump station to the upgraded KRD Canal system, and a new intake tunnel to deliver water to the Wymer reservoir (HDR Engineering Inc. et al. 2011, 43; U.S. Bureau of Reclamation 2011b). An alternative plan for Wymer releases could include a new pump station on the Yakima River upstream of Lmuma Creek and a new pipeline that would convey water between the pump station and the reservoir (HDR Engineering 2012). Major components of Wymer reservoir originally outlined in a 2007 technical memorandum (U.S. Bureau of Reclamation 2011b; HDR Engineering Inc. et al. 2011) have since been updated to reflect modifications to the proposed power plant and revised construction cost estimates (HDR Engineering Inc. 2014). An additional technical memorandum quantifies the impact of Wymer releases on instream flow temperature (YRBWEP Workgroup 2013c), an important component of water quality affecting salmon survival. Results from the Riverware model suggests that Wymer releases have the potential to decrease downstream river temperature significantly in the summer and increase temperatures in the mid-fall period (Anchor QEA, 2014).

Previous benefit costs analyses of Wymer Reservoir were conducted as part of the Yakima River Basin Water Storage and Feasibility Study (2008b). Reclamation found that alternative versions of Wymer Reservoir – with and without a pump exchange on the Yakima River – had benefit-cost ratios less than 0.08 and 0.33, respectively (U.S. Bureau of Reclamation 2008b, 6).

Kachess Drought Relief Pumping Station (KDRPP). The construction of a new pumping plant would provide access to an additional 200,000 af in drought years. Water supplies would be used by irrigators during years when supplies fall below 70% of proratable entitlements (Operational Guidelines Committee 2013), because "the capacity for transferring Lake Kachess water to the Yakima River…was established based on the need to convey the additional 200,000 af of water over an approximately four-to-six month irrigation season" (U.S. Bureau of Reclamation, Washington State Department of Ecology, and Prepared by HDR Engineering, Inc and Anchor QEA 2011, 2). However, drought relief water would also be available to municipal and domestic water users (U.S. Bureau of Reclamation and Washington State Department of Ecology 2014). It is expected that the drought relief water supply, currently stored but considered inactive, would be made available three out of every 10 years throughout the IP's 100-year planning horizon (U.S. Bureau of Reclamation and prepared by HDR Engineering Inc 2013).

Aquifer Storage (ASR). Previous analysis of the Yakima Basin's groundwater storage capacity suggest that underground storage is a feasible alternative in the Yakima Basin (Golder Associates 2001). The IP provides for both passive and active aquifer storage and recovery projects (ASR).

The 2011 appraisal-level study explains that water for shallow aquifer recharge, or groundwater infiltration, would be applied to spreading areas like ponds and canals, each of which would be roughly 2-10 acres in size (2011). This infiltrated water would reduce the volume of water required from reservoir releases, supplementing the total water supply available (TWSA) and base flows in the Yakima River during low-water seasons (U.S. Bureau of Reclamation, Washington State Department of Ecology, and Prepared by Golder Associates, Inc and HDR Engineering, Inc 2011). Between 160 and 500 acres of infiltration area would be required to store 100,000 af (Golder Associates and Washington State Department of Ecology 2009), the annual average that could be made available for other uses (Reclamation and Ecology 2011n). Data collection and modelling efforts are currently underway to refine the timing of well injection and removal processes (YRBWEP Workgroup 2014b) at various test sites throughout the Yakima Basin (YRBWEP Workgroup 2014c).

Ahtanum ASR. The city of Yakima is proposing an active aquifer storage and recovery project described in Golder Associates (2014). This project is parameterized as part of the future municipal and industrial specification option in the YAKRW model. We incorporate it as a component of their baseline scenario. The city would divert and treat 5,000-10,000 af from the Naches River during winter, store the excess water underground, and recover the water reserves during the summer (HDR Engineering Inc. et al. 2011, 45). When completed the recovery wells, operating at a 3000 gallons-per-minute (gmp) capacity, would meet 100% of the city's peak demand. The project would also provide streamflow benefits, especially between the months of April and September (Golder Associates and Washington State Department of Ecology 2009), because a small amount of seepage (8% over one year and 40% over ten years) would supplement TWSA. (Golder Associates 2014). Given that this ASR project is not a named part of the IP, we do not provide a benefit-cost assessment of it.

Cle Elum Pool Raise (CEPR). Modifications to the radial gates at Cle Elum dam would allow water resource managers to raise the pool level by 3 feet, increasing total storage capacity by 14,600 af (HDR Engineering Inc. et al. 2011, 37). The additional water supply would be used for fisheries benefits (Operational Guidelines Committee 2013) in accordance with YRBWEP authorizing legislation (United States Congress 1994). A new release in the amount of 30,000 af would improve winter fish flows; the magnitude of spring releases have not been finalized (Lynch 2013).

Bumping Reservoir Enlargement (Bumping) The proposed Bumping Reservoir expansion would be smaller than those previously considered (United States Bureau of Reclamation 1979). The IP would expand Bumping Reservoir by building a new dam 4,500 feet downstream of the existing dam, expanding storage capacity from 33,700 af to 190,000 af (HDR Engineering 2012). A June 2013 presentation by the Operational Guidelines Workgroup Committee suggests how additional water supplies would be allocated among instream, flood control and irrigation needs. Winter and spring releases in the amount of 10,000 af and 32,000 af, respectively, would supplement instream flows. At least 34,000 af would be available for flood control at all times, and 34,000 af would augment TWSA (Lynch 2013).

C. Conservation

Agricultural water conservation measures include lining or piping existing canals, automating canals, constructing re-regulating reservoirs on irrigation canals, improving water measurement and accounting systems, and voluntary on-farm water conservation improvements, as well as other measures (HDR Engineering Inc. et al. 2011). The YRBWEP Conservation Advisory Group is tasked with establishing a prioritized list of projects and making selections on the basis of detailed feasibility studies (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). RiverWare model guidelines identify the specific set of agricultural conservation projects reflected in the benefit-cost estimates (HDR Engineering, Inc. and Anchor QEA 2011; HDR Engineering, Inc. 2014). It is estimated that these projects would affect the control and distribution of 171,700 af of irrigation water in full water years, though this does not represent net water savings because reducing proximate water loss will reduce instream flows downstream. A portion of the water savings could be placed into the State Trust Water Rights Program to serve instream needs (YRBWEP Workgroup 2013a), but this is not accounted for in the YAKRW guidelines. The conservation savings estimates exclude conserved water that would result from projects that have been previously planned under YRBWEP (HDR Engineering, Inc. 2014).

Under the IP *municipal conservation program*, educational measures and incentive-based actions to achieve municipal and domestic conservation estimates set forth in the Integrated Plan (HDR Engineering Inc. et al. 2011, 58). Average municipal conservation savings under the Integrated Plan are estimated to be 22,100 af annually in total water use (HDR Engineering, Inc. 2011). Of this 7,600 af/year will be consumptive use savings. It is assumed that 60% of these annual savings will be accrued by 2030, and 100 percent by 2060. Examples of incentive-based actions currently under consideration include investing in infrastructure improvements to reduce leakage, distributing more water efficient equipment (appliances, shower heads), funding public education programs, and changing indoor plumbing codes and water rate structures (HDR Engineering, Inc. 2011).

D. Water operations

Power Subordination at Roza and Chandler. Water supply use for hydropower production at the Roza and Chandler power plants will be decreased in order to provide more water instream for local fisheries. The IP assumes that the Roza plant will not produce power in April and May and that the Chandler plant would stop production in April, May and June. This level of subordination would result in 25,000 MWH of foregone annual power production (U.S. Bureau of Reclamation 2011d). The precise decrease in power production is under discussion, and actual levels of subordination would be determined by a management team that would provide recommendations on an annual basis (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012, 5–17).

Keechelus to Kachess Conveyance (KKC). A new conveyance between Keechelus and Kachess Reservoirs would help moderate Upper Yakima River fish flows and make the process of refilling Kachess more efficient (U.S. Bureau of Reclamation 2011c). The conveyance would capture excess runoff in the Keechelus Reservoir drainage basin and store the water in the Kachess Reservoir (U.S. Bureau of Reclamation and Washington State Department of Ecology 2014). While the preferred method for the conveyance is either of two tunnel alternatives ranging in length from 17,000 to 19,000 feet (YRBWEP Workgroup 2013b), the model assumed that the conveyance would take the form of a shorter pipeline consistent with the YAKRW model (HDR Engineering, Inc. 2014; HDR Engineering, Inc. 2014) . The conveyance would provide the most benefits in drought years, but transfers between the two reservoirs would be made in all years. The YBIP model simulated average transfers of 92,182 af in annual conveyances from Keechelus to Kachess based on actual flows from 1981-2003 with a fully implemented Integrated Plan (YRBWEP Workgroup 2012, 8–9). Note that this included simulated transfers of 43,565 af and 55,806 af in the 2001 and 2005 severe drought years, respectively. YAKRW modelling guidelines assume that conveyances occur if Keechelus storage exceeds minimum target pool levels, which vary throughout the year. Transfers serve to increase the additional storage capacity of Keechelus and decrease additional storage capacity of Kachess by the amount of water transferred. Project goals could be accomplished through average flows of 400 cubic feet per second (cfs) (U.S. Bureau of Reclamation and Washington State Department of Ecology 2014).

Water Marketing. Water marketing programs facilitate the reallocation of water from willing sellers to willing buyers. The benefits from water marketing are the result of the increased productivity of water, namely the substitution of lower-valued uses for higher-valued uses. Despite a budgeted capital cost of $2.1 million and annual O&M costs of $212,000 (HDR Engineering et al. 2012, 18), there is no detail in the IP regarding which actions are envisioned in the water marketing component, nor how proposed changes would differ from current market infrastructure and conditions. Although the Framework for Implementation document discusses some of the barriers to water markets (pg. 46), the IP's planning documents and technical appendices only make generic references to how these barriers would be surmounted (i.e. building trust, increasing the transparency of information; a document compiling all of the detailed quotes from these documents regarding water markets is available on request). The Technical Appendix on water marketing (U.S. Bureau of Reclamation, ECONorthwest, and State of Washington Department of Ecology 2011) describes a number of assumptions about the potential for markets, but does not describe what legislative, regulatory or operational changes would lead to these outcomes. The only reference we have found to specific actions is in response to comment letter 28 on the IP's EIS, where the agencies report that:

"Details about the Market Reallocation Element can be found in the Ecology's 2009 Integrated Water Resource Management Alternative Final EIS and its supporting documents and in the "*Market- based Reallocation of Water Technical Memorandum*" (Reclamation and Ecology, 2011j). Ecology considered a wide range of marketing options and the Integrated Plan proposes the removal of legal barriers to implementing an open water marketing system. A rotation fallow program is included in the Long-Term Option for the Market Reallocation Element." (pg. CR-231)

Ecology's 2009 Alternative Final EIS pertained to a program that is a precursor to the current IP; it is not part of the current set of IP planning documents. Nonetheless, we make the assumption that the actions proposed in Ecology's 2009 Alternative Final EIS (Washington State Department of

Ecology 2009), and the 2009 Technical Appendix on water marketing (Mary McCrea and Ernest Niemi 2009) are the basis for the specific actions of the water marketing component. As such, the recommended options for the near term would include expanding the jurisdiction of the Yakima Superior Court to handle both permanent and temporary transfers, and seeking funding from the Legislature to support this work (Washington State Department of Ecology 2009, 2–63). Further funding would be necessary to support the Superior Court in this work after the *Acquavella* adjudication is completed. Ecology would also explore the possibility of temporary approval of permanent transfers that were "unlikely to result in an impairment." None of the documents describe specifically how this change would lead to the increased use of markets assumed in the 2011 Technical Report on markets.

The "long-term" option would involve market transfers between irrigation districts who participate in voluntary fallowing, but again no detailed changes are specified. This long-term scenario is not a guaranteed outcome in the IP documents. Ecology's 2009 EIS points out that irrigation districts can act as a barrier to water markets by preventing transfers outside the district (pg. 2-59), and stresses that the participation of districts in the long term option would be voluntary - "if they so desired" (pg. 2-64). Furthermore, the IP's 2011 Technical Report describes limits on water markets that are weakly justified, most notably limiting out-of-district transfers to 10% of the district's water supply.

Proposed instream flow changes under the IP. Instream flow augmentation as proposed under the IP is primarily intended to promote abundance of (primarily) anadromous fish in the basin. Table 5-3 in the Final Programmatic Environmental Impact Statement for the IP (FPEIS) shows flow augmentation objectives for each river reach, and provides a categorical assessment of the degree to which these flow goals are successfully met (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). As described in the FPEIS, the additional flows used to augment current instream conditions would be partially obtained from the new storage projects and agricultural water conservation measures, in part at the expense of out-of-stream uses; as well as by diverting less water for power production at Roza and Chandler power plants.

E. Fish passage and habitat

The IP's estimated impact on future fish populations are justified by the proposed fish passage projects at Cle Elum Reservoir, Wymer Reservoir, Keechelus Reservoir, Kachess Reservoir, Tieton reservoir, Clear Creek Dam and Box Canyon Creek. Fish benefit estimates presented in the Four Accounts analysis (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012) reflect estimated increases in adult salmon populations that result from simulated instream flows (HDR Engineering, Inc. and Anchor QEA 2011) and different combinations of individual projects (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011). The IP estimates fish passage benefits by comparing expected fish populations under an IP that is fully implemented with fish passage components ("Restoration + Passage") to fish populations under the same IP, but without fish passage components ("Restoration" only) (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011). Previous studies have estimated the effect of fish passage projects on basin fish populations at a limited number of individual reservoir sites

(Ackerman, Cramer, and Carlson 2002; U.S. Bureau of Reclamation 2008a). Fish passage projects have the potential to make upstream habitat accessible for spawning six to eight miles above Bumping, 0.8 miles above Kachess, 34.8 miles above Tieton, 13.8 miles above Keechelus, 29.4 miles above Cle Elum, 1.6 miles in Box Canyon Creek, and 2 miles above Clear Lake Dam (U.S. Bureau of Reclamation 2011a; U.S. Bureau of Reclamation 2003).

Cle Elum and Bumping Reservoirs. Cle Elum has been singled out as particularly important for the reintroduction of sockeye (U.S. Bureau of Reclamation 2011a; Yakima Basin Fish and Wildlife Recovery Board 2004; HDR Engineering Inc. et al. 2011). The proposed Cle Elum fish passage facilities would include a helix bypass conduit for juvenile fish and a fish ladder leading to a separate collection site where adult fish are trapped and hauled upstream via tanker truck (HDR Engineering Inc. et al. 2011; HDR Engineering 2012). A series of schematics are shown in the project-specific Technical Memorandum (U.S. Department of the Interior Bureau of Reclamation 2011)- the design of the helix conduit is currently being refined (YRBWEP Workgroup 2014b). The final design for the fish passage facilities at Cle Elum was 30% complete as of March 2014 (YRBWEP Workgroup 2014b) with a 60% final design review scheduled for July 2014 (YRBWEP Workgroup 2014a), though this final design update is not yet published to our knowledge. Fish passage facilities at Bumping dam may be similar to those at Cle Elum (HDR Engineering Inc. et al. 2011)

Keechelus, Kachess and Tieton (Rimrock) Reservoirs. As described in Volume 1 of the Proposed Integrated Water Resource Management Plan, upstream and downstream fish passage would be installed at the Keechelus, Kachess and Tieton Reservoirs (HDR Engineering Inc. et al. 2011). While construction details are "subject to further evaluation of alternatives to determine the most feasible approach" (2011, 34), project development is scheduled to proceed similarly at each site. Following a three year study period, two subsequent years for environmental review and permitting, and a three year construction window, it is expected that fish passage construction will be completed by the end of 2023 (HDR Engineering Inc. et al. 2011, 61). While each fish passage facility would benefit a variety of species, the passage at Tieton Reservoir is anticipated to also connect bull trout populations with those in the Naches Basin, and enhance the ability of steelhead to colonize tributaries to Rimrock Reservoir (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012).

Box Canyon Creek & Clear Lake Dam. Fish passage improvements at Box Canyon Creek and Clear Lake Dam are important for upstream bull trout populations. YBIP actions in Box Canyon Creek would expand the amount of accessible habitat as well as enhance the quality of existing shoreline habitat for fish (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). The proposed improvements at Box Canyon Creek complement the Kachess Drought Relief Pumping Plant project, which would lower creek flows in severe drought years (HDR Engineering Inc. et al. 2011). The Clear Lake dam is located upstream of Tieton Reservoir. The proposed fish passage improvements would overcome the limitations of the current fish ladders, promoting upstream fish migration and enhance the value of fish passage improvements at Tieton (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012).

Habitat Improvements. This component of the YBIP contains an extensive fish habitat enhancement program that aims to restore critical habitat, augment instream flows and remove additional barriers to fish passage. Habitat improvements would occur throughout the mainstem of the Yakima River and on tributaries in the middle and upper reaches of the Yakima basin. Consequent to much of the decision making for design and prioritization of habitat management actions being decentralized and vested with local agents, as per for example the Washington State Salmon Recovery Act of 1998, a single detailed list of management actions is not at hand. Prioritized lists of currently planned and "in-process" projects (YRBWEP Workgroup 2013a), subsets of the entire IP, are maintained by the Habitat Subcommittee, who is formally tasked with prioritizing projects that are: "1) scientifically defensible; 2) synergistic with other projects and funding sources; 3) expand on the Yakama Nation, Kittitas, and Yakima County floodplain restoration efforts; 4) improve bull trout populations in relation to the KKC and KDRPP projects; 5) enhance watershed protections for fish and water supply; and 6) support other elements of the Integrated Plan" (YRBWEP Workgroup 2014a, 6). In order to prioritize habitat enhancement actions, Reclamation and Ecology have set up a coordinating group similar to YRBWEP's Conservation Advisory Group (HDR Engineering Inc. et al. 2011). Future habitat enhancement would build on past work by other stakeholder groups in the Yakima Basin. In particular, YBIP would rely on strategies identified in the Yakima Subbasin Plan (Yakima Basin Fish and Wildlife Recovery Board 2004) and complete most of the priority action types described in the Yakima Steelhead Recovery Plan (Ch. 5.5, Yakima Basin Fish and Wildlife Recovery Board 2009), as stated in the Final Programmatic Environmental Impact Statement (2012). A variety of conservation projects have already been completed in the upper basin near Manatash Creek and the Teanaway River. These upper basin projects contribute to the 553 total known restoration actions to improve fish habitat completed (and 36 additional, as yet incomplete projects) in the Yakima basin since 1989 (Pacific Northwest Salmon Habitat Project Database, accessed 9/16/2014; Katz et al. 2007a; Barnas and Katz 2010).

III. Methods

The legislative mandate (Washington State Legislature 2013, p180) calls for project-specific benefit-cost analyses for individual YBIP projects, which requires modeling the Yakima Basin hydrological system with and without specific projects such that the economic outcomes of each scenario in terms of irrigated agriculture, municipal water availability, and fish populations may be compared. The physical and economic outcomes of the YBIP projects are the results of complex interactions between the natural ecosystem, the built infrastructure, infrastructure operations, water use, and economic factors. To carry out our legislative charge, a suite of modeling approaches is used to represent different components of this complex system. The legislative mandate also explicitly requires that existing YBIP data and study findings be utilized to the greatest extent possible (see U.S. Department of the Interior Bureau of Reclamation 2013, for examples). We therefore use those available models, data and other information provided in these studies directly as a starting point, or at a minimum, as a frame of reference for this research.

While the legislation calls for benefit-cost estimates for each project in the IP, it is likely that the net benefits on one project are dependent on whether another project in the plan is implemented. This economic interdependence does not mean that projects cannot be implemented or assessed separately from each other. Indeed, this study assesses the benefits and costs of individual projects. that the economic outcomes are for one project depend on the status of the other, and so the benefit-cost assessment for each project is *conditional* on the status of the other project, and must be interpreted as such. This condition is also often referred to as economic *non-separability*, which again does not mean that the project are not implementable separately, but that the benefits and/or costs of each project depends on (cannot be separated unconditionally from) other projects.

There are several sources of economic interdependence in outcomes: 1) Technical complementarity and/or substitutability across projects, 2) Diminishing marginal productivity across projects, and 3) Diminishing marginal value of impacts. Technical complementarity or substitutability occurs when the productivity of a project is dependent on the implementation of another project. Within the IP, this may pertain to fish habitat and fish passage productivity and water availability and distribution. For example, the effectiveness of fish passage at Cle Elum dam may be enhanced by increasing minimum allowable instream flows during low-water periods (but this does not mean that one cannot or necessarily should not be implemented without the other). In contrast, water allocation benefits through facilitated water market transactions may be reduced if water storage is increased because gains from trade between senior and junior water rights holders will be lower with reduced curtailment risk. Diminishing marginal productivity and diminishing marginal value are important in cases where a project augments the outcome of another project, and is important to examine in cases where additional water storage and fish habitat or passage projects are considered. For example, irrigators have recognized that the marginal impact of minor diversion curtailments have minimal economic impact, but that major curtailments have larger marginal impacts, suggesting diminishing marginal productivity of irrigation water (HDR Engineering and Anchor QEA 2011). For increases in fish production, diminishing marginal value of fish populations was considered in the Four Accounts analysis of the IP (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012).

These three types of non-separability across projects suggest that the net benefits of any proposed project depends, to some extent, on the implementation of other portions of the IP. However, the number of possible combinations of projects is very large (2^n possible combinations of n projects), so we limit the number of conditional analyses by balancing the likely magnitude of conditionality effects with the costs of the analysis (e.g. computation and coding time, clarity in results). For instance, the implementation status of fish passage projects will have little effect on water storage outcomes, so we treat these two categories of projects separately.

In this section we provide an overview of the modeling framework used in the analysis, a detailed description of the component models, and describe how benefits and costs are calculated and aggregated.

A. Modeling overview

This modeling framework incorporates several components, including a hydrological model that accounts for both snowpack and rainfall when quantifying the total water available for out-of-stream use and instream flow requirements within the basin; agricultural and municipal water demand/value models for estimating the economic cost of curtailments; fish impact assessments that examine the suitability of instream flows and habitat access and quality; fish value estimates as a function of fish populations, as well as other factors such as the predicted cost of lost hydroelectric power to provide instream flows.

Figure 3 is a modeling overview that describes the general relationship between data inputs and outputs at each stage of analysis for one IP scenario. A ***scenario*** is defined for this report as one specific combination of IP infrastructure projects in conjunction with one set of proposed operations. For example, one of the water storage scenarios considered in this report is the implementation of (a) the Keechelus to Kachess conveyance project, (b) the Kachess Drought Relief Pumping Plant, and (c) the Cle Elum Pool Raise (all others unbuilt), along with (d) operations to implement augmented instream flows. If any of these elements are changed, it would represent a different scenario. The can be interpreted to represent short time-frames (e.g. one year) or longer time frames and is explained as follows (from left to right):

(1) Information inputs (grey) including (1a) inflows into the hydrological system (denoted "Weather"), (1b) a specific set of IP water storage projects and (1c) proposed operations, along with (1d) IP habitat project scenarios. Scenarios on which we report are presented in Table 1.
(2) Costs of building and operating associated with each scenario project (green).
(3) Two models (yellow) relating inputs in (1) to physical outcomes:
   (a) A hydrologic model that quantifies the total water supply available in the basin (TWSA) based on water inflows, and the distribution of water as a function of YBIP projects considered and their operations. We utilize the YAKRW implementation of RiverWare, developed initially by USBR and parameterized for YBIP by HDR Engineering, Inc.
   (b) A fish habitat model that assesses potential fish abundance as a function of spawning habitat made available by fish passage projects, instream flow augmentation and fish habitat restoration activities.

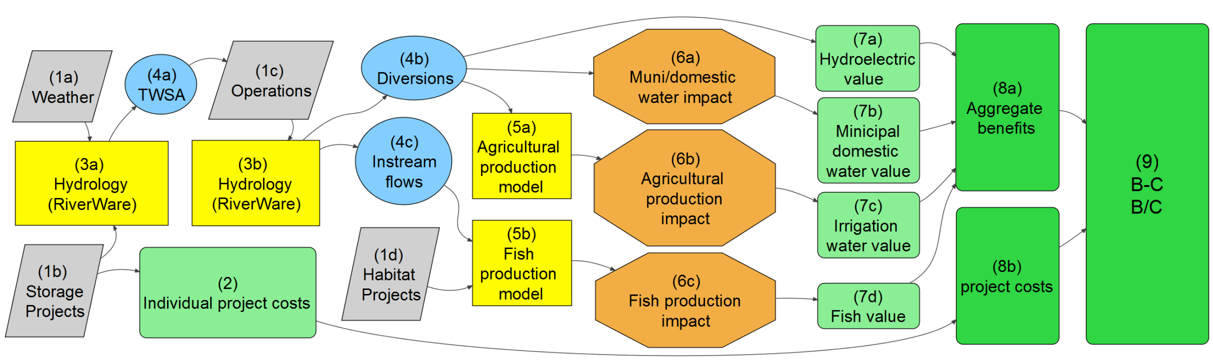


Figure 3: Schematic overview of the model framework for one YBIP scenario.

(4) Hydrologic modeling outputs (blue) including (4a) estimates of the total water supply available (TWSA) in the basin for any given season, which is distributed through operations (1c) as out-of-stream water in the form of (4b) diversions to the various water-rights holders and (4c) instream flows.
(5) Benefits gained from a distribution of TWSA among competing uses (yellow) including:
    (a) An agricultural production model relating water availability, in the form of proration and curtailment relative to entitlements non-drought-year water use, to irrigated agricultural production in the basin.
    (b) A municipal benefit analysis relating the benefits of IP infrastructure and water market development to current and future municipal water users
    (c) A fish productivity analysis relating instream flows (4c) and fish habitat (1d) to fish population impacts (6c).
(6) Outputs from the agriculture, municipal/domestic, and fish production models (orange) including crop production values as a function of water proration rates defined by a given climate and IP scenario, water provided to municipalities as part of the proposed IP, and changes in fish populations due to IP habitat and instream flow modifications.
(7) Economic value of the availability or curtailment of municipal water, irrigation water, instream flows, and hydroelectric flows (green) as estimated by relating the marginal value of water for uses to the physical impacts in (6).
(8) Benefits and costs (green) that are aggregated, discounted, and characterized as statistical expectations when appropriate to provide summary statistics for a given scenario.
(9) Aggregate expected net present value estimates (green) for both benefits and costs of a given scenario when compared against the baseline (future without any YBIP implantation) or another scenario.

The availability and distribution of water among competing uses hinges on the risk of curtailment of water rights during drought years. In this work, variability in water availability is simulated from historical data (1925-2009) and three future climate change scenarios using the YAKRW RiverWare model (HDR Engineering, Inc. and Anchor QEA 2011). The hydrologic output (4a and 4b in Figure 3) is used to generate empirical probability distributions over water curtailments and annualized economic impacts, which in turn is the basis for estimating the expected net present value of reducing curtailments in a given year, which is then the basis for calculating the expected net present value of these impacts over the 100 year planning horizon. This process is illustrated in Figure 4. Present value calculations rely on a 4% discount rate to be consistent with the Four Accounts analysis and its supporting reports, although a brief examination of the implications of a lower interest rate of 3.5% to be consistent with current federal water resources planning requirements (U.S. Bureau of Reclamation 2013).

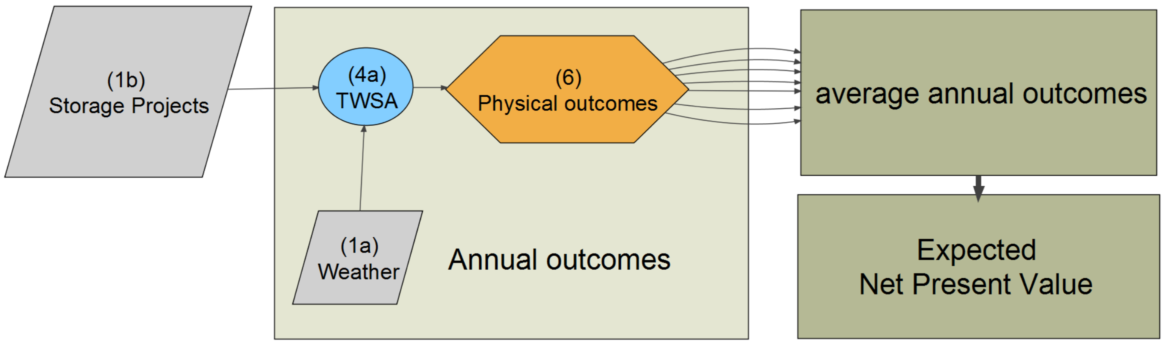


Figure 4: Generating average annual outcomes and expected net present value from annual modeling outcomes

One important difference between previous reports and this analysis centers on how the connection between fish impacts versus agricultural and municipal impacts of IP scenarios are characterized. Ideally, a complete integration of fish, agricultural, municipal, and other impacts would be used as a definitive benefit-cost metric for policy decisions. However, due to various data deficiencies, there is a large difference in the precision and confidence placed on fish impact estimates versus agricultural and municipal impacts. To compensate, instream and out-of-stream scenarios are assessed independently to the extent necessary, and jointly when possible.

Despite the high level of uncertainty associated with benefits from instream flows for fish populations, two types of information can be derived from any given IP scenario based solely on out-of-stream benefits. One type utilizes the B-C metric, calculating the value that fish must accrue (i.e. the "break-even" value) given the estimated out-of-stream value and cost of implementation for a proposed scenario. The other type uses the cost of providing those instream flows as estimated in terms of foregone out-of-stream beneficial uses. There is a direct economic trade-off between the benefits from diversion (out-of-stream) and the costs in terms of fish impacts. As such, the opportunity cost of providing instream flows is the foregone agricultural and municipal benefits that could accrue were instream flows allocated for out-of-stream use. Figure 5 illustrates this trade-off. For any given set of IP water storage and habitat projects, a restriction on diversions to increase instream flows leads to smaller out-of-stream benefits. The difference in the size of out-of-stream use value (6a-b) on the left compared to the right is symbolic of this trade-off. Therefore even if fish benefits cannot be confidently estimated, this trade-off can still serve as the basis for calculating the opportunity cost of instream flows in terms of foregone out-of-stream uses. These opportunity costs can be compared to the costs of providing instream flow augmentation through augmenting dry-season water availability through IP water storage infrastructure.

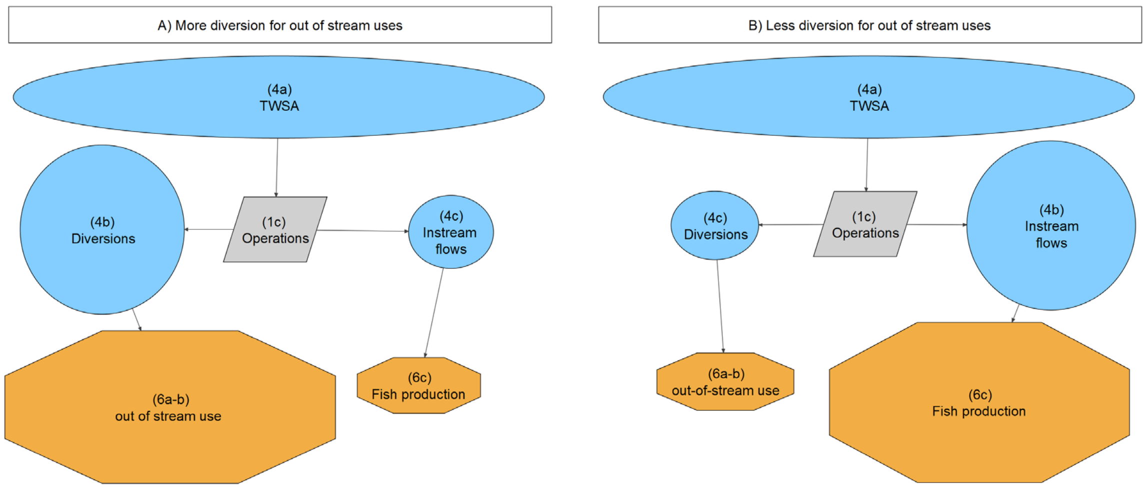


Figure 5: Trade-offs between diversions for out-of-stream beneficial uses and instream flows for fish benefits.

Fish abundance and its economic value follow from three categories of IP activities: instream flows (as discussed above), fish habitat restoration, and fish passage. Each of these categories of activities impact fish in different ways (Figure 6). The way in which fish passage in particular impacts fish abundance differs substantially from instream flow and restoration changes, and is modeled very differently. Again we use existing studies that form the foundation of the Four Accounts analysis as our starting point (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). Sockeye salmon is the primary beneficiary of fish passage, and also the single most important contributor to IP benefits as estimated in the Four Accounts analysis. They require lake/reservoir access for reproduction, and were therefore essentially extirpated from the Yakima Basin when the existing dams were completed in the early 1900s. Estimates of sockeye abundance potential in the basin were generated using a model based on lake/reservoir size and subsequent survival rates conditional on fish passage. We assess the estimates used in the Four Accounts analysis in light of additional data on sockeye potential in the basin, and infer potential contributions of the various fish passage based on their relative size. Instream flow and restoration activity impacts were estimated in previous studies for the IP using an entirely different method, and were estimated together in such a way that it is difficult to discern their relative impacts. We perform empirical analysis on a newly created dataset for the basin to assess the estimates relied

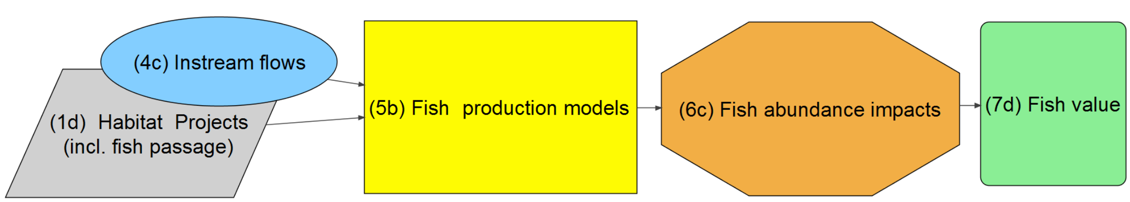


Figure 6: Fish abundance and fish value.

upon in the Four Accounts analysis, and we make use of available information to discern to the extent possible the relative potential contributions of instream flow augmentation and habitat restoration.

To place a value on fish, the Four Accounts analysis utilizes a combination of stated preference and benefits transfer methods, both of which are commonly used in non-market valuation estimation. We rely substantially on the analysis presented in the Four Accounts analysis for fish values but assess its veracity and the potential implications.

The remaining subsections and their associated appendix content describe in detail the methods used in the analysis. It should be noted at the outset however that where we rely directly on existing models we will cite the supporting documentation and rely on it heavily as a reference.

B. Hydrologic modeling

For the analysis of instream and out-of-stream benefits from water storage, this report relies on the hydrologic model RiverWare™ and modifications of it developed by various research teams to represent the Yakima Basin and the specific hydrologic effects of the water storage projects and operations proposed in the YBIP. We also rely on the Variable Infiltration Capacity (VIC) model for future climate regime inflow data. We provide a brief description of the models and the specific YBIP scenarios that we use as a basis for analysis.

1. RiverWare (RW) and Yakima RiverWare (YAKRW)

RiverWare (RW) is a general multi-objective modeling tool. It can handle complex river systems with multiple reservoirs and diversions and with different operation objectives (Zagona et al. 2001). First developed in 1994, RiverWare is collaboration between the Bureau of Reclamation, the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado and the Tennessee Valley Authority.

RiverWare provides a graphical interface with an object-oriented modeling framework. Different objects can be schematically drawn in RW and rules and policies corresponding to each can be defined by the user. The primary objects in RW represent river reaches, canals, reservoirs, diversions, etc. (Carron, Zagona, and Fulp 2000). These objects are connected in a network that represents water flow between objects. RW has been parameterized to simulate different river basins such as the Colorado River (Fulp and Harkins 2001), and the Truckee-Carson River system (Coors 2006) as well as the Yakima Basin.

YAKRW is a daily time-step reservoir and river operation computer model of the Yakima Basin Project developed using the RiverWare software (HDR Engineering Inc. et al. 2011, 109).

YAKRW (Mastin and Vaccaro 2002) is used to apply detailed information about operation rules of dams and diversions, water rights and other basin characteristics within the RiverWare software. YAKRW was first introduced by USBR's Yakima Field Office and the Upper Columbia Area Office as a component of the Watershed and Rivers System Management Program (WARSMP) (U.S.B.R., 2011). YAKRW was modified and used in the Yakima River Basin Water Storage Feasibility Study

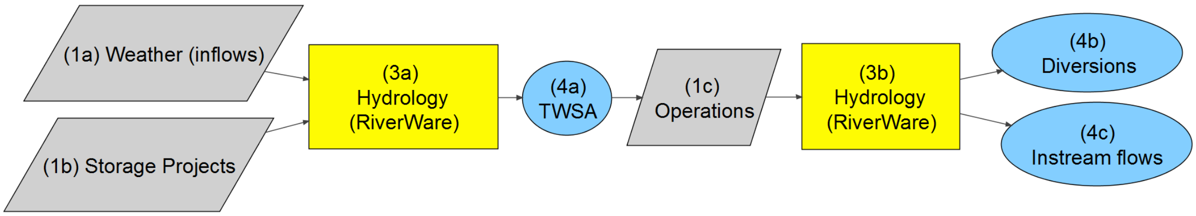


Figure 7: Schematic of YAKRW modeling process. (TWSA is total water supply available.)

(USBR 2008) to assess the effectiveness of different proposed alternative actions on Yakima River Basin water availability and environmental conditions.

HDR received a modified version of YAKRW that could handle climate change scenarios from Reclamation's Technical Service Center (TSC). This group was also responsible for further modifying the TSC model for options proposed in the integrated water resource management plan (U.S. Bureau of Reclamation, Washington State Department of Ecology, and Prepared by HDR Engineering, Inc. & Anchor QEA 2011, 46). HDR has also implemented within YAKRW anticipated future demand and potential conservation scenarios in the basin.

2. *YAKRW inputs and outputs*

YAKRW is parameterized to represent the hydrologic behavior of the Yakima Basin conditional on water inflows into the system, water storage characteristics, and operations. Figure 7 provides a schematic of the YAKRW modeling process.[3] The numbered items in the figure correspond to those in Figure 3 representing the overall modeling process.

For purposes of this analysis, operational inputs to YAKRW for a single simulation run include:

1) The choice among one of four climate regimes (historical and three simulated future regimes), which implement specific inflows ((1a) in Figure 1 and described below) on a daily time-step.
2) The choice of integrated plan (IP) infrastructure project(s) implemented (1b). These are parameterized as modules within YAKRW, and are implemented with parameter switches.
3) Specific operations scenarios in the form of dam spill and diversions. The only operations that we directly manage are via a module that either implements (or not) the proposed IP instream flows.

YAKRW provides extensive output on a daily time-step for a given simulation run. We use three variables from the YAKRW output in our analysis: Total Water Supply Available (TWSA), the daily simulated basin-wide proration level, and the date.[4] Both the TWSA and the proration rate represent the basin as a whole. TWSA represents the sum of the total water in reservoir storage, the

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[33]The linear configuration of Figure 7 is slightly misleading, because TWSA can be affected to some degree by water storage carry-over from the prior year, which is operations-dependent.

[4] The variable names for TWSA, the daily proration rate, and date outputted from YAKRW are TWSA PARW DataDaily TWSA, TWSA PARW_DataDaily Proration Level, and Run0, respectively.

expected runoff through the remainder of water year, and the expected return flows from diversions. Calculations begin on April 1 of each year and are updated throughout the irrigation season (HDR Engineering, Inc. 2014). District-specific proration rates depend on their individual shares of proratable and non-proratable rights as described in Section III.C.1.a.

Four climate scenarios are used in this analysis, one based on historical outcomes, and three others representing potential future climate change outcomes (described in more detail below). The historical climate regime used for the analysis of IP projects spans the years 1925 - 2009 (85 annual observations per scenario).[5] However, when comparing historical conditions to those in our three future climate conditions, we use the period of record spanning 1925 - 2006 (82 annual observations per scenario). The disparity in the periods of record used arises from differences in how future climate data were generated. This disparity and the climate scenarios in general are described in more detail later in this section.

A primary limitation of the YAKRW model is that it does not capture interactions between the river system and the hydrologic cycle in a sophisticated way. YAKRW is a river management model that takes surface water inflows at a few key locations. Return flows are assigned as a percentage of water diversion and there are similarly simplistic ways of handling surface-groundwater interactions. Land surface hydrology is heavily impacted by climate change through changes in evapotranspiration and crop water demands, which impacts infiltration, return flows, and groundwater recharge. YAKRW's simplistic handling of hydrologic processes is a weakness that is most relevant when running the model under scenarios of change, particularly if inflows and return flows rates are altered, as they would be under climate change. Thus, along with the substantial uncertainty that exists about which climate scenario might best represent future states of the world, YAKRW suffers from increased modeling error under these conditions also.

3. *YAKRW output use and post-processing*

The outputs from YAKRW are used to populate an annual crop production model. However, because irrigation district water entitlements occur on a monthly basis and YAKRW model outputs are given in a daily time-step, data are translated first to a monthly then an annual time-step in two stages. Hydrologic outputs are first aggregated to monthly values to conform to the monthly data available for irrigation district water entitlements. Using district-specific water entitlement data, district-level proration are then calculated based on each district's share of proratable rights and the monthly mean basin-wide proration rate (calculated as the monthly mean of the YAKRW daily proration rates). This allows the volume of water available for irrigation to be calculated on a monthly basis. Monthly data for irrigation seasons are then aggregated to an annual time-step, which provides the mean proration rate for the irrigation district and the associated water available for irrigation (the sum of water available by month and district, subject to entitlements and proration). The annual hydrologic outputs from YAKRW for each specific IP project

[5] The original observed flow data under which the scenarios were modeled represent conditions that occurred historically from 1981 through 2005 (HDR Engineering Inc. et al. 2011, 65) but HDR recently has extended this period from 1924 to 2009.

implementation and climate regime scenario are then used as inputs in the crop production model described in Section III.C.1.

One of the fundamental differences between the Four Accounts report and the current analysis is the use of YAKRW to provide curtailment data (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012). Instead of using the history of proration/curtailment and climate variances as we do, the Four Accounts analysis assumes just two types of curtailment outcomes: no curtailment (proration rate = 100%), and severe drought which is defined as a basin-wide curtailment of proratable rights of 70% (proration rate = 30%). The implications of this difference are discussed in some detail in Section IV.A.

4. YAKRW scenarios used in this analysis

To assess the economic benefits of incremental changes in water storage capacity within the Yakima River Basin, YAKRW provided the TWSA and curtailment data used for numerous IP storage scenarios. The outputs from these runs are then used to simulate agricultural productivity. Each scenario outcome is compared to appropriate baseline scenarios. Comparing scenarios with different agricultural production values allows us to estimate the economic impact of different IP projects. The full set of scenarios used is described in Table 1. See Section II for a more detailed description of the projects implemented in YAKRW. Each of these scenarios can be applied to any climate scenario (detailed in Table 1).

In the analysis, there are two primary baseline scenarios of interest for modeling purposes. The "Base" scenario describes a case with no IP projects.[6] We also use the full IP scenario as a base to estimate the value (cost) of excluding a project when the IP is otherwise fully implemented. These two sets of comparisons are included because, as evident in the results of section IV.F, implementing a project alone without other IP storage projects provides benefits that are different (and in all cases greater) than when the project is implemented along with other storage projects. Also worth noting is the one set of scenarios that indicates whether or not the proposed IP instream flows are implemented (Base + Instream). This scenario differs from the other scenarios described in Table 1 in two ways, 1) it represents an operations change instead of an infrastructure investment, and 2) in contrast to storage projects, implementing the (augmented) proposed instream flows reduces water for out-of-stream uses.

[6] The "Base" scenario modeled in YAKRW to include projects underway in the basin but not considered part of the IP.

Table 1: Project Scenarios. Each scenario is applicable to any climate regime.

Name	Description
Base	HDR scenario 7.1. No IP projects, includes Future M&I demand, Yakima (Ahtanum) ASR, non-IP conservation Project (HDR Engineering, Inc. 2013).
Baseline plus one project only	
Base+Bumping	Baseline plus Bumping Lake expansion only
Base+CEPR	Baseline plus Cle Elum Pool Raise (CEPR) only
Base+Conservation	Baseline plus IP agricultural water conservation measures (Conserv)
Base+ASR[1]	Baseline plus passive groundwater recharge at Thorp + WIP only
Base+KKC	Baseline plus Keechelus to Kachess Conveyance (KKC) only
Base+KDRPP	Baseline plus Kachess Drought Relief Pumping Plant (KDRPP) only
Base+KKC&KDRPP[2]	Baseline plus KKC + KDRPP only
Base+Wymer	Baseline plus Wymer Dam and reservoir only
Base+Instream	Baseline plus proposed IP instream flows implemented only
Full IP with project exclusion	
IP	Full IP: HDR scenario 7.8 (HDR Engineering, Inc. 2013).
IP-Bumping	IP excluding Bumping Lake expansion only
IP-Conservation	IP excluding IP agricultural water conservation measures (Conserv)
IP-CEPR	IP excluding Cle Elum Pool Raise (CEPR) only
IP-ASR	IP excluding passive groundwater recharge at Thorp + WIP only
IP-KKC	IP excluding Keechelus to Kachess Conveyance (KKC) only
IP-KDRPP	IP excluding Kachess Drought Relief Pumping Plant (KDRPP) only
IP-KKC&KDRPP[1]	IP excluding KKC + KDRPP only
IP-Wymer	IP excluding Wymer Dam and reservoir only
IP-Instream	IP excluding proposed IP instream flows

1ASR for YAKRW runs does not pertain to the Ahtanum ASR; only Thorpe and WIP passive Aquifer Storage and Recovery.
2 KKC and KDRPP may be treated and pursued by IP developers as one project. It is therefore considered as a pair here.

Note that in the Base scenario (HDR 7.1), future municipal, industrial, and domestic water demand (M&I) for the year 2040 is applied to the upper Yakima River using data described by (HDR Engineering and Anchor QEA 2011, 31–32.). Furthermore, The City of Yakima is assumed to implement the Ahtanum Valley ASR project (not part of the IP) as described in HDR Engineering, Inc. (2014) and Golder Associates (2014) and briefly summarized in Section II.A. Together, these two components of the Base case (as well as the scenarios to which the base case are compared) represent the assumption that IP water will be provided to municipalities based on future population and water demand growth needs. This assumption implies that these municipal demands are met using water available for other instream and out-of-stream uses, and allows for the estimation of municipal benefits in Section IV.A.2 without double-counting water.

In addition to the scenarios above, we also include results for a series of sequenced project scenarios being developed by HDR Engineering representing the proposed plan for implementation. These scenarios are summarized in (HDR Engineering, Inc. 2013).

Table 2: HDR sequenced implementation Project scenarios (HDR Engineering, Inc. 2013)

Scenario name	Description
HDR 7.1	Base in Table 1
HDR 7.2	HDR 7.1 + GW + Conserv ["Non-storage" scenario]
HDR 7.3	HDR 7.2 + KKC [Add KKC]
HDR 7.4	HDR 7.3 +KDRPP [Add KDRPP]
HDR 7.5	HDR 7.4 + CEPR [Add CEPR]
HDR 7.6	HDR 7.5 + Wymer [Add Wymer]
HDR 7.7	HDR 7.6 + Bumping [Add bumping]

5. Climate scenarios

The historical flow data used as an input to YAKRW represents a naturalized flow regime. This historical regime corresponds to flows that would have occurred in the absence of any anthropogenic changes in the basin or river. The observed flow was developed by the U.S.B.R. by taking into account detailed information related to diversions, reservoirs, and dam operations. In YAKRW, the future flow data are taken from Brekke (2010). The scenarios associated with these future flow data are from the Third Climate Model Intercomparison Project (CMIP3). The scenarios are from the Third Climate Model Intercomparison Project (CMIP3).

All climate change results are generated using the Variable Infiltration Capacity (VIC) model (Liang et al. 1994): a distributed hydrologic model that simulates continuous water and energy balances at daily or sub-daily time-steps. The model has been validated and used in number of different studies to project future hydrologic conditions over the Columbia and Yakima River basins (Elsner et al. 2010; Hamlet and Lettenmaier 1999; Vano et al. 2010b; Yorgey, G et al. 2011; Barnett, Adam, and Lettenmaier 2005; Mote et al. 2005). The Period of Record (POR) for VIC-generated flows available in the YAKRW model is 1915-2006.

The forcing data used to run the VIC model are available in 1/16 degree resolution over the Pacific Northwest region (Elsner et al. 2010). Downscaling of the meteorological data was done using the hybrid-delta change approach (Mote and Jr 2010; Elsner et al. 2010). Future climate data represent the climatological condition of year the 2040 by adjusting the statistics of the historical period (1915-2006) to capture changes in precipitation and temperature as projected by the Global Climate Models (GCMs) for each of the scenarios in Table 3. Therefore, there are 92 years of different climate realizations for the year 2040; although, to avoid issues related to spin-up of the hydrologic model, we did not include the first 10 years of data in our analysis. When comparing historical and future climate results, it is important to use a consistent baseline period. Therefore, the POR for our climate change impact scenarios is 1925-2006.

Table 3: Climate scenario description and summary.

Scenario	Climate Model	Emission scenario	RMJOC label	Average Temperature change	Average precipitation change	Annual reservoir inflow
Historical	Historically Based	Historically Based	–	0	0	1.66 MAF
Less Adverse	CGCM3.1 [HADCM]	B1	LW/W: Low Warming	+1.3 °C	+11.5%	1.86 MAF
Moderate Scenario	HADCM	B1	C: Central Change	+1.7 °C	+3.7%	1.48 MAF
More Adverse	HADGEM1 [HADGEM]	A1B	MW/D: More Warming	+2.8 °C	-2.5%	1.38 MAF

*RMJOC : Reservoir Management Joint Operation Committee

To retain consistency with earlier HDR reports, we utilized the three CMIP3 climate scenarios described in Table 3, which provided the basis of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). However, it is important to mention that the more up-to-date CMIP5 scenarios are currently available as part of the Fifth Assessment Report (ASR5) of the IPCC (Rogelj, Meinshausen, and Knutti 2012). Rogelj et al., (2012) compared CMIP3 and CMIP5 scenarios and found that the greenhouse gas (GHG) concentrations used in CMIP5 represent a higher range of possible outcomes related to temperature as well as higher temperatures on average. Therefore, application of the more updated CMIP5 scenarios may result in more adverse effects. This question will be addressed in subsequent studies. Finally, it is important to mention that it is beyond the scope of the AR4 Working Groups to assess the likelihood of emission scenarios, as there is no widely accepted method of assigning probabilities to them (Nakicenovic and Swart 2000; Webster et al. 2002).

C. Out-of-stream impacts of IP projects

Out-of-stream benefits of the IP are primarily in the form of the value of agricultural production due to irrigation, and benefits to municipalities of being provided water for future water demand growth. Methods for water market analysis are also summarized in this section.

1. Water for agriculture

The benefits for agriculture from the IP water storage projects accrue during droughts when irrigated farmers are permitted to use more water than they would without the IP storage. As such, the additional storage increases water availability during the irrigation season. The benefit to agriculture for a given drought year is measured as the difference between total net revenues generated from agriculture without the IP project(s) (less water available, more severe curtailment) compared to total net revenues with the IP project(s).

The risk of curtailment over time in part determines the distribution of irrigation water and agricultural production value over time. This information can then be used to calculate the average agricultural production value (expected value) for a given IP scenario, as well as the net present value of an IP project scenario relative to a baseline.

While prorated entitlements are the basis for estimating the volume of water available for irrigation in any district, water market transactions in the form leases or purchases can in principle move available water to higher valued crops both within and/or across districts. This decreases the impacts of curtailment and affects the aggregate value of agricultural production for a given basin-wide curtailment.

To measure the value of additional storage projects in terms of agricultural irrigation benefits, we follow the following procedure:

1) We relate annualized basin-wide curtailments from YAKRW simulations (See sections III. B.2 and 3) for a given IP/climate scenario to irrigation district curtailment rates based on district entitlements. This provides the volume of prorated water available to a district based on their entitlements and the basin-wide proration rate for the year.
2) We relate the volume of available water in a district to the value of agricultural production. This relationship represents the *marginal value of water* for crop production (also known as the *inverse demand function*).
3) Given district-specific proration rates and marginal value functions, we calculate annual values of agricultural production for each district for the simulation period. The value of production depends on how water is used (distributed across crops) within and across districts. Three different market regimes are simulated, which affect the relative impact of proration in the basin. Thus, we generate annual production values for a given IP/climate/market scenario.
4) The average annual production value for a given IP/climate/market scenario is used to calculate the expected net present value of agricultural production over 100 years assuming a discount rate of 4% (again, in keeping with the existing YBIP literature).
5) Differences in the net present value of production across any pair of IP scenarios represents the difference in benefits of one scenario compared to the other, and can be compared to the difference in the cost of implementing these scenarios.

To begin, we describe the irrigation districts and their water entitlements. Construction of the marginal value of water functions (by district) is described next, followed by an explanation of how the market scenarios are defined and implemented, and how they affect aggregate market production value. The process of aggregating annual values into expected net present values for a given project/climate/market scenario is then discussed, followed by a brief description of how these net present values are used to assess the expected net present value of benefits from IP project(s) relative to base cases.

a. *Irrigation districts and their water rights*

Water rights in the Yakima Basin are defined in terms of seniority and are grouped into four categories for this analysis. A majority of water rights in the Yakima basin are held by irrigation districts whose rights were defined by a 1945 Consent Decree and can be categorized as either non-proratable or proratable based on their status as of May 1905. In drought years, proratable rights in the basin are curtailed by the same proportion based on a basin-wide proration rate. Water rights acquired prior to 1905 are senior to non-proratable rights. Water rights acquired after the 1945 consent decree we will call junior water rights. Virtually all municipal water rights are junior rights.

As described in the Four Accounts analysis, five irrigation districts account for the majority of water rights in the basin that may be directly or indirectly affected by the development of additional storage in the basin; Roza Irrigation District (Roza), Wapato Irrigation Project (WIP), Kittitas Reclamation District (KRD), Sunnyside Valley Irrigation District (SVID), and Yakima Tieton Irrigation District (YTID). All of these districts have proratable and/or non-proratable rights. Some of these districts, such as Roza and KRD, are directly affected by curtailment because 100% of their water rights are proratable and therefore subject to curtailment in dry years. Others face substantially less curtailment risk, such as YTID and SVID, as they hold a higher proportion of non-proratable rights. SVID has sold water in past droughts (e.g. 2006) to Roza.

Because we are charged with examining the benefits of improving water markets (i.e. facilitating gains from trade), we include an additional set of senior water rights owners in Kittitas County (Ecology subbasins 1-15) who we categorize as Kittitas Senior (KSR). They are not part of a single irrigation district, though we will refer to them as a district simply as a shorthand reference along with the other districts. As a group these are senior water rights and so do not face any substantive risk of water curtailment. However, they may be well positioned to participate in water markets during drought years, and so we include them for their role in market simulations. Table 4 provides information about these irrigation districts.

Table 4. District level entitlement, water use, and profit.

District	Entitlement (af)	% Proratable Rights	Average water use in non-drought year (af)	Total profit in non-drought year ($)
Roza Irrigation District (Roza)	393,000	100	322,496	130,284,737
Wapato Irrigation Project (WIP)	655,613	53	565,949	144,712,511
Kittitas Reclamation District (KRD)	336,000	100	287,369	31,782,923
Sunnyside Valley Irr. District (SVID)	447,422	35	430,411	129,077,002
Yakima Tieton Irrigation District (YTID)	106,290	33	78,776	41,753,411
Kittitas Senior Right holders (KSR).[1]	222,925	0	190,429	20,011,692

[1]KSR is not a single irrigation district. It is an aggregation of smaller districts and senior water rights holders in Upper Kittitas County as described in this section. Source for all but KSR data: (HDR Engineering and Anchor QEA 2011). The source for KSR data is Cook and Rabotyagov (2014).

There are a few characteristics of these districts that are worth noting. Firstly, the average water use in non-drought years tends to be lower than the entitlement for each district. Indeed, due to changes in irrigation technology, and to a lesser extent crop mix, non-drought water use has declined relatively steadily over the last few decades.

Secondly, a district's share of proratable rights defines its proration rate for any given basin-wide proration. If a share of its rights are non-proratable, their district-level proration rate will be higher than the basin-wide proration rate (hence their curtailment requirement will be lower than the basin-wide curtailment rate).[7] Some districts have a mix of proratable and non-proratable rights based on the historical water rights of the landowners within the basin. In these districts, curtailment requirements are applied equally across all shareholders in the district- each is curtailed by the same amount (though shareholders may in principle purchase or sell water which would lead to differences in water entitlements after a sale). These characteristics, as well as their location within the basin (discussed below) will affect how outcomes are calculated, in turn affecting the degree to which IP projects impact irrigation water availability in these districts.

b. *The value of water for agricultural production by district*

The methodological approach used in this study to estimate the benefits to agriculture from the individual YBIP projects builds on the spreadsheet model (Scott et al. (2004) used in the Four Accounts. A number of modeling capabilities are added to this previous work and detailed in Appendix VII.A. These changes allow for greater flexibility in implementing and designing scenarios.

The model uses three sets of information to estimate the value of agricultural production as a function of water availability:

1) Net revenue per acre by crop ($/acre)
2) Water use requirement for each crop/irrigation district combination (af/acre)
3) Acres by crop type for each irrigation district (acres),

The data for these categories are provided in Table 5. With the exception of Kittitas Senior (KSR), these data are taken directly from assumptions used in the Four Accounts analysis.

A useful way to understand the value of water for crop production is in terms of net revenue per af of water ($/af) as a function of water use (in af). Net revenue per af for a crop is calculated by dividing net revenue per acre (1) by the crops water requirement (2): $\$/af = \left(\frac{\$/acre}{af/acre}\right)$. The number of af of water used to grow a crop in a district is water use per acre (2) times the number of acres of that crop planted in the district: $af = \frac{af}{acre} \times acres$.

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[7] A district's proration rate can be calculated as $\mathrm{p_d} = (\mathrm{E}(1 - \mathrm{s}) + \mathrm{p\ E\ s})/\mathrm{E}$, where E is the total entitlement, p is the basin-wide proration rate, s is the district's non-proratable entitlement. For example, if the basin-wide proration rate is 0.3 (70% curtailment), then the proration rate for WIP for example is $p_{WIP} = \frac{655{,}613\times(1-0.53)+0.3\times 655{,}613\times 0.53}{655{,}613} = 0.63$, which means that if the basinwide curtailment rate is 70% (proration rate of 30%), WIP's district proration rate is 63%.

Table 5. Crop by district values for net revenue per acre, water use per acre, and total acres.

		Af/ acre						Acres					
Crop Group	Net Revenue $/ac	Roza	WIP	KRD	SVID	YTID	KSR	Roza	WIP	KRD	SVID	YTID	KSR
Alfalfa	678	4.7	6	5	4.8	3.1	5	2,878	12,939	1,778	12,219	124	1,800
Apples	2,248	5.6	7	6	6	3.7	6	23,969	10,445	548	6,720	17,288	6
Asparagus	238	4.2	5	0	4.4	0	0	635	1,831	0	2,657	0	0
Concord	1,509	3.3	4.7	0	3.8	0	0	11,913	4,954	0	20,784	0	0
Hops	3,481	3.4	4.3	0	3.7	0	0	3,540	15,350	0	10,955	0	0
Mint	804	4.9	6.1	0	5.1	0	0	578	9,424	0	1,770	0	411
Miscell.	785	3.9	5	4.7	4	3.3	4.7	3,613	24,017	81	21,050	355	95
Other Grain	3	3	4	4.6	3.2	2.1	4.6	2,670	662	1,963	3,246	21	2,182
Other Hay	240	4.8	6.2	5.5	5	3.2	5.5	431	3,204	4,971	3,719	1,058	3,077
Other Tree	833	5.5	6.7	5.3	5.8	3.6	5.3	8,797	3,211	256	9,534	2,729	1
Other Veg	5,422	2.5	4.1	4.1	3	0	4.1	270	3,286	6	525	0	6
Pasture	479	3.8	4.8	4.5	3.7	0	4.5	62	1,960	13,129	1,141	0	18,032
Potatoes	1,155	4.2	5.1	4.3	0	0	4.3	72	1,161	89	0	0	0
Sweet Corn	436	3.1	3.3	3.1	2.8	0	3.1	173	912	1,368	39	0	408
Timothy	701	0	6.4	5.6	0	0	5.6	0	126	29,607	0	0	12,468
Wheat	40	3	4	4.4	3.2	0	4.4	1,333	15,621	1,710	2,892	0	386
Wine	2,630	3.3	4.7	3.1	3.8	2.1	3.1	11,998	12	10	1,992	0	9

Figure 8 shows revenues ($/af) as a function of water use for the specific crop acreage allocation in the Kittitas Reclamation District (KRD). There are three distinct features in this figure. First, the flat line shows the average value of water across all acres in the district. Second, a step-function reflects the value per acre-foot of irrigation, from highest (left) to lowest (right), for each crop considered. This step function is approximated by a continuous, decreasing curve (curved line) for market impact analyses. The methodology for converting step functions to continuous functions for modeling irrigation water use was developed by (Burt 1964).

As arranged, the step-function in Figure 8 and its continuous counterpart (the curved function) can also be interpreted as an inverse demand function. In this case, the inverse demand function represents the marginal value of water for different volumes of available water assuming that water is applied to its highest valued use first, and then to crops with lower values as more water becomes available.[8] Conversely, if water is curtailed and crops are *selectively fallowed* sequentially from lowest- to highest valued uses, the functions represent the marginal cost of irrigation curtailment in terms of lost agricultural production value per aft removed. Analogously, the flat line represents the average value of water across crop acreage in the district and reflects the marginal cost of water reductions if fallowing occurs *proportionally* across all crop acres regardless of the relative value of water. The distinction between proportional and selective fallowing will be important for understanding the

[8] Furthermore, the areas under these curves between any two water use levels can be interpreted as the difference in total production value between the two points.

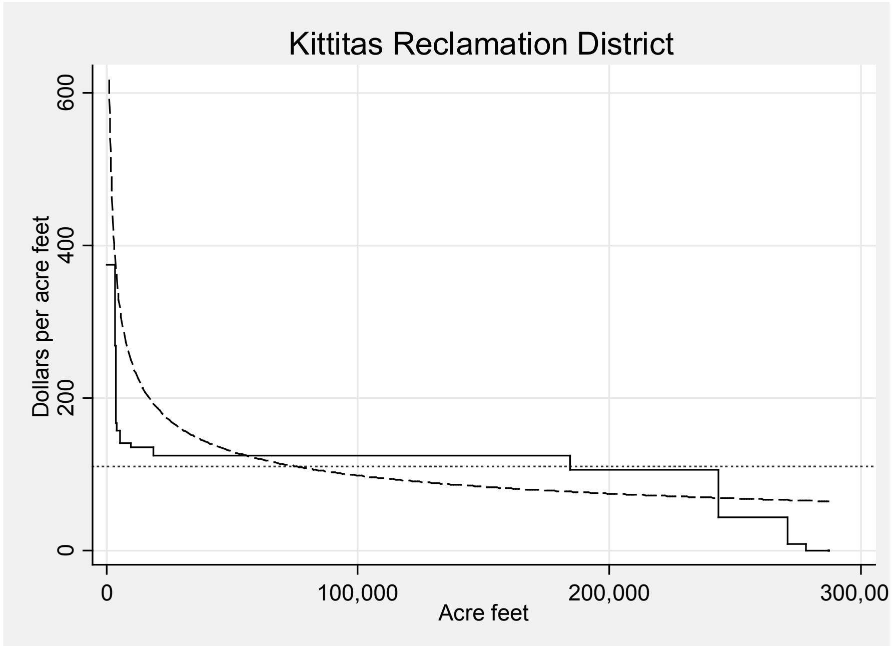

Figure 8: Water value curve for Kittitas Reclamation District.

potential impact of water market performance in the basin. Before describing the impacts of water market simulations, several limitations of this method for assessing water value and water curtailment impacts should be discussed.

Deficit irrigation and other management decisions: An important assumption made in the model developed by (Scott et al. 2004) that is commonly applied when modeling drought impacts is that a reduced water budget is met only through fallowing (R. Howitt et al. 2014). This assumption prohibits what is often referred to as deficit irrigation where the volume of water applied is less than the level required for maximum yield. The result of this assumption is that the production relationships between water, land, and crops are in fixed-proportions, and thus the number of acres that are chosen to fallow for each crop directly determines how much water is used for each crop. Assuming/allowing no deficit irrigation or other management options leads to overestimation of curtailment impacts to the extent crop producers actually do choose to deficit irrigate and overestimates the marginal value of irrigation water (D. J. Bernardo et al. 1988; D. Bernardo et al. 1987). This in turn suggests that the actual inverse demand curves (read from right to left as the cost of curtail) would be flatter than estimated.

Multi-year impacts of irrigation curtailment: Another simplifying assumption underlying this model is that the impact of irrigation curtailment spans only one year. For crops that are not replanted every year, such as tree-fruit and timothy hay, deficit or no irrigation in one year can negatively affect yield in subsequent years. To the extent that this is true, assuming the impacts of irrigation curtailment are reset on a yearly basis will lead to underestimation of the true impacts of curtailment.

Crop mix: The model assumes a fixed and unchanging mix of crops and crop acreage (shown in Table 5). In reality, producers not only change their crop mix during crop rotations, but also have the capacity to change their crop mix in response to changes in the economic or physical environment, which includes irrigation curtailment risk. If curtailment risk changes due to IP project implementation or climate change, for example, producers have the capacity across one or more years to change their crop mix to mitigate the effects of these risks. However, assuming a fixed crop mix may lead to an over- or under-estimation of curtailment impacts over the long term, depending on the situation. For instance, if the IP reduces curtailment risk relative to the status quo, crop substitution toward more water-dependent crops may increase the value of the IP. On the other hand, if climate change leads to increases in curtailment (as in some of the scenarios we consider), these impacts may be mitigated by crop substitution. In the most extreme cases considered, producers switching from simple fallowing to dryland crops will also mitigate the impacts of curtailment risk.

Differences in production costs and irrigation efficiency across districts: The net revenue in $/af in Table 5 are assumed to be the same across districts. This implicitly assumes that production costs, irrigation efficiency --- and therefore consumptive use rates, and other production factors are the same across districts. This simplifying assumption is discussed in the Four Accounts analysis, and so will not be reviewed in detail here, except to say that it is likely that intra-district variation in these factors for a given crop is likely to be larger than average differences across districts for a given crop, so this assumption likely would not have a substantial impact on outcomes. The consequence of assuming that consumptive use rates are the same across districts implies that water trading based on diversions across and within districts is equivalent to trading based on consumptive use. There are most likely larger differences in consumptive use between agricultural irrigation and municipal use. This is addressed in the discussion of municipal benefits (Sections III.C.3 and IV.C).

These simplifying assumptions, as well as others, create countervailing and offsetting biases in our water value function estimates. However, when considered together, it is unclear which direction the aggregate bias would be on our marginal value (inverse demand) functions.

c. *The impact of curtailment risk on expected future agricultural production*

The above description relates an annual water availability and curtailment outcome to the marginal value of water in terms of agricultural production value of crops by district. The impact of the risk of water curtailment on agricultural production value are summarized by the following two steps:

1) Simulation of market transactions that can lead to reallocation of water among competing uses in the event of curtailment,
2) Estimation of future expected annual value of production in the face of curtailment risk, and the net present value of the stream of annual expected outcomes over the planning horizon.

Figure 9 illustrates the relationship between annual and expected future water outcomes. Climate regimes and IP scenarios (including operations) define the TWSA, instream flows and basin-wide curtailment outcomes as simulated by YAKRW, and water entitlements define the district-level curtailment rates. After district-level curtailment requirements are set, water market transactions ---

modeled as leases in response to short-term curtailments --- may then be used to reallocate water to alternative uses. Reallocation affects both district-level and aggregate production values for any basin-wide curtailment rate.

Using the annual production values for each irrigation district, the expected future outcomes and the expected net present value of agricultural production for a given IP scenario/climate /market combination are calculated. These present values are the basis for assessing the value of IP projects.

In this analysis, three different water market scenarios are considered: "no trade", "intra-district trade", and "full trade". Each scenario is described in detail below, including the methodology for calculating the expected net present value of production for agricultural irrigation, and the steps followed for comparing scenarios.

The relationship between the basin-wide and district-level curtailment risk includes an important caveat. Many producers have access to supplemental well rights in the event of curtailment. For these producers, groundwater may be substituted for their proratable or junior water rights in drought years if emergency withdrawals are authorized. This will reduce the impact of curtailment and increase the likelihood that our estimates of curtailment impacts, and the value of IP storage projects, are overestimated.

(1) *The expected net present value of IP projects*

As described in Section III.B, for each simulation run, YAKRW uses specific IP projects and climate regime scenarios to simulate annual basin-wide curtailment rates (after post-processing) for an 85 year period (82 years for future climate runs). The distribution of these annual curtailment rates differ depending on project and climate scenarios selected. For example, Table 9 in Section IV.A illustrates that the probability of curtailment (proration less than 100%) and the average curtailment rate increases with increasingly adverse future climate scenarios. Water allocations rights for each district, represented by district-level curtailment rates, are then defined by their total entitlements and share of proratable rights.

After curtailment rates are announced, water is reallocated via leases within and across districts, water is applied to crops, and district-level and aggregate agricultural production value is generated. However, for any given curtailment, the district-level and aggregate value of production also depends on the market scenario as well. In short, YAKRW provides annual curtailment rates, and the water value function links curtailments to agricultural production value for a given market

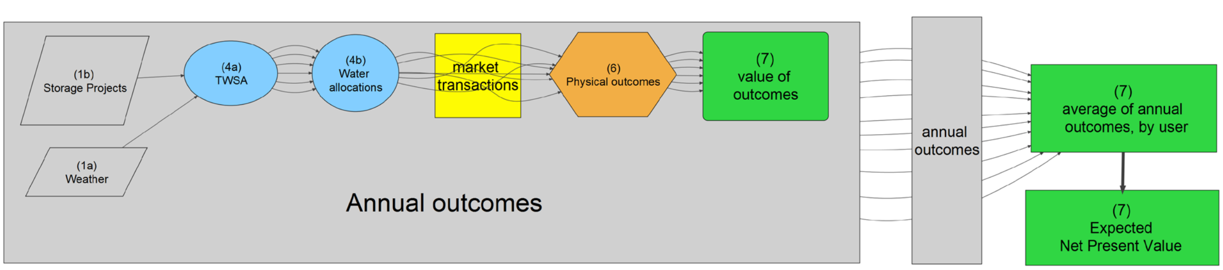

Figure 9: Annual outcomes as a basis for net present value calculations

scenario, by district.

Once the annual production value is simulated for each district based on a chosen IP/climate/market scenario, the district production values are summed as $V_t(X) = \sum_{i=1}^{m} V_{it}(X)$, where V_{it} is the district-level production value and X is an index that represents a given IP/climate/market scenario (Figure 9). The expected value of future agricultural production is estimated as the average production value across all years in the sample:

$$EV(X) = \frac{1}{T}\sum_{t=1}^{T} V_t(X),$$

where T is the number of years in the simulation sample (85 for the historical climate regime and 82 for future climate simulations). Using this value as the expected agricultural production value for each year over the 100 year planning horizon for the IP, the expected net present value of this 100 year annuity can be calculated as

$$ENPV(X) = \sum_{t=0}^{99} \frac{EV(X)}{(1+r)^t} = d \times EV(X)$$

where $d = \sum_{t=0}^{99} \frac{1}{(1+r)^t} = \left(1 - (1+r)^{(-100)}\right)/r$, and r is the discount (interest) rate. To be consistent with the Four Account analysis, we assume a 4% interest rate $(\mathrm{r} = 0.04)$, which implies $\mathrm{d} = 24.505$.[9] However, the current Federal rules for water resource planning require an interest rate of 3.5%, which provides $d = 27.655$, which leads to a present value 13% higher than with r=4%. We provide comparisons for a few of our results, but the qualitative implications in terms of B-C results remain unchanged in all cases we examine.

(2) *Calculating IP project benefits*

The benefits received from an IP scenario can be estimated by comparing the expected net present value, $ENPV(X)$, against an appropriate baseline. As an example, suppose we want to estimate the benefits accrue for a scenario in which only the Wymer Dam is implemented, assuming the historical climate regime and an intermediate trade scenario that assumes intra-district trading only. Benefits are quantified by comparing the described scenario (Wymer Only, historical climate, intra-district trade), denoted here as X_1, with the appropriate baseline (no IP projects implemented, historical

[9] Climate regimes correspond to CMIP3 forecasts for 2040 and are implemented for tractability as stationary for the entire planning horizon. However, climate forecasts show a drift in the distribution of curtailment rates and the distribution mean. The consequence of this stationarity for our estimates is that near-term impacts are biased upward until 2040, and then biased downward thereafter. Because temporally distant values are discounted in present value calculations, this is may lead to an overestimate of the impact of climate change in expected net present value terms. A coarse estimate of this bias can be developed by linearly interpolating EV(X) (X representing a specific IP/trade scenario) from the historical to future climate between 2015 and 2040 and extrapolating through 2114, calculating ENPV(X), and comparing this value to the ENPV(X) that we report. ENPV(X) based on this linear progression are 91% of our estimates, suggesting that we overestimate ENPV(X) for any future climate regime by about 10% to the extent that such a linear interpolation is valid (which we do not claim to be the case).

climate, and intra-district trade), denoted as X_0, where "Base" means that no IP projects are implemented. The net present value of adding Wymer is:

$$\Delta_{01}ENPV = ENPV(X_1) - ENPV(X_0).$$

The above example represents the net value of agricultural production that additional Wymer storage provides assuming no other part of the IP is implemented. In an alternate example, the described scenario could be compared to the Full IP implementation with the exclusion of one project. If the project excluded were Wymer, the relevant comparison would be X_0=(IP excluding Wymer, historical climate, intra-district trade) against X_1=(Full IP, historical climate, intra-district trade). In this case, $\Delta_{01}ENPV$ would represent the incremental benefits of Wymer conditional on all other IP components implemented.

With six water storage projects under consideration, there are about $(6-1)^2 = 25$ different project comparisons against a baseline. When assessed across the three climate and three market scenarios, the number of potential scenarios to compare increases to $(5 \times 3 \times 3)^2 = 2025$ scenarios to compare. We choose a limited set of these to convey the breadth of possible outcomes.

(3) *B/C and B-C estimates*

Cost estimates are described in their own section below. Once the expected net present value of benefits and costs are calculated, they are compared in two ways. Let B denote the expected net present value of benefits, and C denote the comparable costs. The benefit-cost ratio is the ratio of benefits over costs and is denoted B/C. The B/C ratio can be interpreted as the benefits per dollar of cost expenditures. A B/C ratio greater than one indicates that benefits are larger than the costs, a B/C ratio equaling one indicates that the benefits exactly equal the costs, and a B/C ratio less than one indicates that costs are larger than benefits. Net benefits are benefits minus costs B-C, and represent the value of a project minus its costs. B-C is zero if benefits equal costs, positive if benefits are larger than costs, and negative when costs are larger than benefits. Throughout this report, we use B/C to represent the benefit-cost ratio, and B-C to represent net benefits. B/C will always be greater than 0 if B-C is positive; it will equal one if B-C is zero, and will be between zero and 1 if B-C is negative. At various points in the report we refer to the "B-C criterion". This criterion, in our usage, is satisfied if B-C is positive and B/C is greater than one.

2. Water markets

The water marginal value functions for each district described in the previous section (and Appendix VII.A) show the relationship between water use, curtailment by fallowing, and agricultural production value. The economic impact of curtailment depends on how fallowing decisions are made, which depends in part on how much flexibility irrigators have to move water between crops which in turn depends in part on the effectiveness of markets to allow water reallocation across crops within a district and across districts. While we use the Four Accounts analysis as a starting point for our analysis, there are substantial differences in the way we approach market assessment, in part due to the difference in the focus of the report. Appendix VII.B provides an overview of the Four Accounts analysis and how our analysis differs.

To examine the impact of curtailments with and without market activity, we define three market regimes that provide useful benchmarks against which not only the gains from trade, but the economic impact of IP projects under different market conditions, may be assessed. The three market regimes that we consider are:

- No water trading
- Intra-district water trading
- Full trading: both intra- and inter-district trading

The no trading regime imposes the restriction that when water is curtailed during a drought, all crops are curtailed in the same proportion. The intra-district trading regime allows frictionless, efficient water distribution within irrigation districts, but no trading across districts. Full trading allows both intra- and inter-district trading such that water is distributed efficiently to its highest valued uses across districts, with some cross-district trade limitations described below.

To implement Full Trading, inverse demand curves (marginal value functions) and proportional curtailment values were estimated for all five irrigation districts included in the study, as well as the Kittitas Senior water rights holders as described in Section III.C.1 and in more detail in Appendix VII.A.

a. *No Trading and proportional fallowing*

Proportional fallowing within (and across) districts is a process whereby acres allocated to each crop are fallowed in proportion to the curtailment rate faced by the irrigation district. Consequently, the cost of one af of curtailment is equal to the area-weighted, mean marginal value of water for the crops grown in that district. Calculation of this value is straightforward: it can be calculated as the total net revenue in a non-drought year divided by the number of af of water used in a non-drought year (which on average is less than full entitlement for the districts in this analysis). The values required for the Roza district are shown here to illustrate this calculation:

- Roza entitlement: 393,000 aft
- Roza's maximum water use in non-drought year: 322,495 af
- Roza's total net revenue in non-drought year: $130,284,737

The constant marginal value of water can be calculated as total net revenue divided by water use in a non-drought year. For Roza this is ($130,284,737/acre)/(322,495 af/acre) = $403.99/af.

The analogous values for Wapato, Kittitas, and Sunnyside are $255.7/af, $110.60/af, and $299.89/af, respectively. Table 6 includes these marginal water values under proportional curtailment rounded to the nearest dollar. Note that the marginal value of water is constant regardless of the level of curtailment within each district, but is different across districts depending on their crop mix.

Table 6: The marginal value of water under proportional curtailment.

District	Acre-weighted marginal value of water ($/af)
Roza	404
WIP	256
KRD	111
SVID	300
YTID	530
KSR	106

Proportional curtailment is a behavior implied by the most restrictive assumption about trade. It is consistent with the assumption that there is no trade among irrigators within or across districts in the face of curtailment, and that individual irrigators cannot selectively move water from lower to higher valued uses within their own enterprise by "trading with themselves".

The economic impact of curtailment is at its highest under proportional fallowing. Further, because intra-enterprise and intra-district trading does occur, the proportional fallowing "no trade" regime represents an outer bound on both actual trading outcomes and the costs of curtailment. Drought impacts decrease as restrictions on water moving from low to high valued uses decrease.

b. *Intra-district trading only*

In contrast to proportional fallowing, the "intra-district trading" scenario assumes that water is reallocated from low to high value uses without restriction within a district, but that no water is traded between districts. This type of scenario is illustrated using the SVID the blue (steeper) inverse water demand curve in Figure 10, which represents the profit generated per unit volume of additional water for the district. Suppose 100,000 af of water were available to SVID. The district would generate approximately $250 in additional profit by having one additional af of water available (equal to the height of the curve at 100,000 af). The decrease in the marginal value along the x-axis from left to right occurs because the crop acreages are ordered from highest (left) to lowest (right) value. Under a particular drought scenario, the district receives a particular volume of water allotted based on their entitlement and share of proratable rights (say 100,000 af), and the total value of production is equal to the area under the inverse demand curve between 0 af and the amount available (100,000 af).

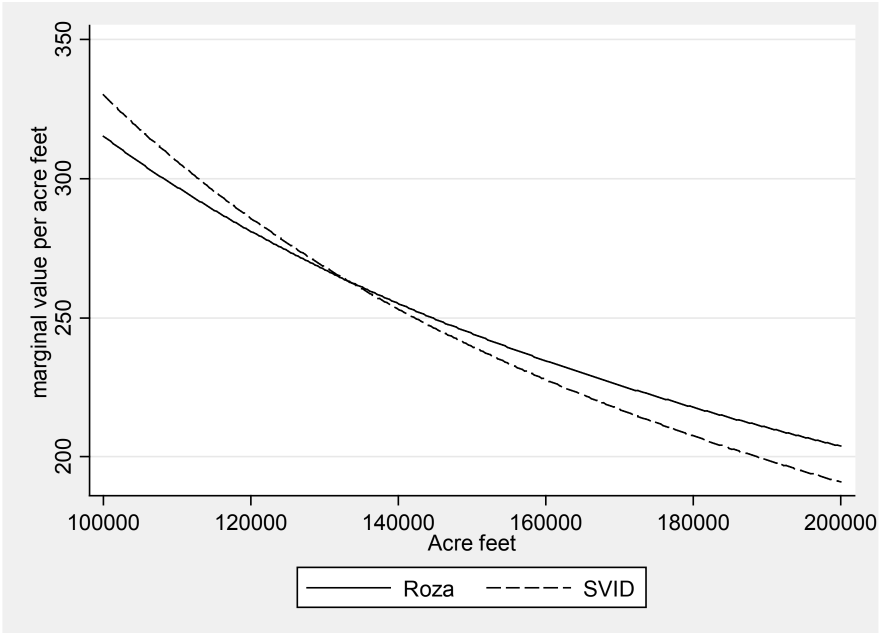

Figure 10. Water value curves for Roza and SVID.

When intra-district trading is possible, the cost of a drought is less than when proportional fallowing is assumed. This occurs because intra-district trading promotes two types of drought mitigation. First, crop diversity at the farm level allows each grower with multiple crops to fallow their low value crops in favor of irrigating their higher value crops. While technically this is not a trade between two farms, it can be thought of as "on-farm trading". Second, farms within an irrigation district can contract to buy and sell water across farms. By assuming perfect selective fallowing within districts, there is frictionless, unrestricted trading within a district. From a legal perspective, this type of trading is feasible because legislation allows place-of-use changes within districts without regulatory oversight (RCW 90.03.383 sect 3). However, there are numerous factors that could limit trading relative to this upper bound, including but not limited to:

- Poor information on potential trades and transaction costs that limit willingness to trade. For example, Yakima Tieton Irrigation District charges a $150 fee for all intra-district transfers + another $20-$50 for connection changes + mandatory escrow fees payable to a third party provider of an unspecified amount (http://www.yakimatietonirrigation.com/water-transfer-guidelines.html).
- Irrigation timing conflicts such that moving water from low- to high-value uses is constrained by differences in the appropriate timing of irrigation across crops.
- Infrastructure constraints that may limit actual transfer of water among two potential buyers.

The process of selective fallowing through implied intra-district trading as described here represents the upper bound on trade within a district, which in turn provides the lowest possible impact of curtailment on agricultural production value given no out-of-district trading.

c. *Intra-district and Inter-district Trading*

When inter-district trading is also possible, water can be moved from low to high value crops across districts as well via water trading, leading to additional reductions in curtailment impacts. To provide a sense of how water is reallocated during inter-district trading, the water value curves for Roza and SVID are overlaid in Figure 10. Using an economic optimization model, the volume of water that can be allocated across districts to maximize the total combined profit of the two districts can be calculated. Implicit trading occurs when the value of the last af of water that one district receives is worth less than the last af received by another district. Water is traded toward higher value uses at the margin, until the marginal value of water is equal across all uses. The point where the marginal value functions cross in Figure 10 illustrates such a point when the marginal value of water is equal across the districts.[10] Historically, water has been traded between SVID and Roza because SVID has a higher share of non-proratable rights. This means that SVID has access to more water than Roza for a given drought level, and is further to the right on their water value curves. Water trading from SVID to Roza is therefore more likely because the inverse demand curve (marginal value curve) for Roza is higher than that for the SVID for all but the largest curtailments (available water below about 25,000 af).

d. *Market constraints and frictions as context for interpreting market simulation results*

The market model described above represents frictionless trading regimes for both intra- and inter-district trading, and provides the upper bound on possible water market performance among the districts as trading partners. There are several constraints that we impose on the trading model. In the case of inter-district trading, we assume that WIP and YTID do not trade between districts. We impose this constraint on WIP because it retains institutional limitations that are likely to limit its market participation in the intermediate, and potentially even in the long run (Ross 2014; U.S. General Accounting Office 1997). We preclude YTID from trading because, hydrologically-speaking, it is relatively isolated in such a way to limit water sales, and because its crop values and non-proratable status limits its incentive to buy. Another constraint to be cognizant of is the potential for third-party effects of transactions, especially in the case of transactions between downstream sellers and upstream buyers, which can negatively impact instream flows (and therefore also the diversion capacity of other water rights holders) between the transactants. For the irrigation districts among which we allow active trading, however, the idiosyncrasies of the irrigation districts considered here generally preclude this from happening. In particular, we would be concerned about KRD buying from SVID for this reason, but the crop mix and associated water value functions essentially preclude it from happening. Although our market model is not spatially explicit, the simulated trading outcomes are such that the KRD does not buy from SVID. In this simulated trading environment, KRD only buys if curtailment reaches above 90%, at which point Kittitas Senior sells more than enough water to cover KRD purchases.

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[10] This trading outcome occurs regardless of a district's initial endowment as long as the differences in production value across districts are not too great such that the marginal value curves do not cross within the constraints of total available water (i.e. a corner solution).

There are also many constraints on water markets that are “soft” over the long-term, diminishing or disappearing if and when market development occurs. Here, we discuss five important soft constraints that would lower the impact and value of market-based reallocation, making our results overly-optimistic in terms of market performance.

First, water right transfers involve real economic resources in applicant time, Department of Ecology and Superior Court staff time, financial outlays on consultants and attorneys, etc. A transaction between a seller who was earning $50 per af of water and a buyer who would earn $150 per af would not occur if the transaction costs are $100 per af or higher. These transaction costs, particularly the long review times, are identified as a barrier to water markets in the IP. A number of studies have examined water market transaction costs (Colby, Crandall, and Bush 1993; Colby 1990a) and have found that in some cases they can add approximately one-third to the purchase price (McCann et al. 2005). Surveying public/administrative transaction costs for environmental purchases in several states and basins, Garrick and Aylward (2012) identified the public administrative costs to be on the order of $6/af in the Yakima Basin. We do not have an estimate for the private transaction costs (e.g. time, lawyer fees, specialized water right examiner fees). While we do not model transaction costs explicitly in our simulations, we would again note that transaction costs should decrease market activity increases and transfers become more standardized.

Second, although the Yakima Adjudication has clarified the status of rights in the basin, there may remain some legal uncertainty for an individual interested in selling or leasing water. If Ecology or the Water Transfer Workgroup examine their right for a possible transfer and find that the water has not been put to beneficial use, the right could be at risk of curtailment. This report is a public record, and Ecology has noted that this may be an impediment to sellers coming forward (McCrea and Niemi 2007; Clifford 2012). The non-profit Washington Water Trust is one of the few organizations that can provide confidential initial reviews of a water right’s validity. Although several options to avoid this problem were discussed in Ecology's 2009 EIS, none were carried forward as recommended options. Furthermore, although the Washington State Department of Ecology has successfully used its Trust Water Right program for a number of years, there is anecdotal evidence that many still believe a temporary transfer would endanger their water right. The growing mitigation market in the upper Kittitas valley is evidence, though, that the legal issues are not insurmountable, at least for transactions between "senior” Kittitas sellers and domestic buyers.

Third, our estimate of the net revenue per acre may understate the value that growers place on their ability to farm as a livelihood and their feeling of contributing to the local farm economy. Previous research has documented a reluctance to transfer water out of agriculture among farmers in the Yakima Basin (Lovrich et al. 2004), Northeast Washington State (MacDonnell 2008) and the Western United States more generally (Western States Water Council 2008). Farmers may be concerned about lost wages in the farm economy and reduced control over the use of water. Potential risks to the farm economy are larger to the extent that local economies are less diversified and where water use is disproportionately reliant on irrigated agriculture and where transfers would fallow more irrigated acres (Hanak 2003) (NRC 1990). Cook and Rabotyagov (2014) find that farmers in the upper Kittitas preferred split-season leases over full-season lease agreements that would fallow land for an entire irrigation season. Our treatment of silage corn for dairies may also understate its value; given the high transport costs it is uneconomical to import silage corn from distances greater than 8 miles (van Gundy, R. pers. Comm.). Similarly, the net revenue estimates used in the Four Accounts and here for hay and timothy hay may underestimate the revenue lost when a hay stand is fallowed in the middle of its 4-year rotation period. The stand will not return to its full productivity the following year, so foregone revenues may be double our estimates. An upper bound estimate would be the costs to re-establish the stand.

Fourth, although the mitigation market has grown in recent years, the market is still "thin" (in the parlance of economics) and sellers may be concerned about their ability to negotiate a fair price. They must have a clear knowledge of their own opportunity costs (foregone net revenues) for a short-term lease, and for longer-term leases or sales, must project those net revenues into a future with increasing supply variability (Scott et al. 2004). Irrigators may also be reluctant to sell water for instream flows if they question whether contract enforcement will be effective in securing benefits for fisheries rather than downstream water users (Lovrich et al. 2004).

For long-term leases or sales, the separation of water from land and its appraisal is another concern. Clifford observes that "many landowners are uncomfortable separating their water right from their land… Landowners are concerned about the effect the loss of the water right could have on the value and future use of the land" (Clifford 2012, 11). The fact that Ecology cannot purchase land and water together can make it more difficult for the state to participate as a buyer in local water markets. While Reclamation, unlike Ecology, can purchase bundled land and water, federal acquisition rules require Reclamation to estimate a single (combined) value of land and water in purchases of real property (Linne, Kane, and Dell 2000, A–19). Doing so typically results in lower water right valuations than if water rights were valued separately from land (Clifford 2012). The acquisition rules can serve as a deterrent to price negotiations in public water purchases to the extent that Reclamation acts as a buyer or seller. Reclamation is limited to "just compensation," or "fair market value" (Code of Federal Regulations [CFR] sec 24.103) that is lower than private sector appraisers commonly estimate at the request of potential sellers. Additionally, there may exist contractual restrictions on change of use for federal project water --- which describes the water held by the large irrigation districts in the Yakima Basin. Sales from agriculture to municipalities or for instream flows may call for legislative action to facilitate, as was the case for California (e.g. the Central Valley Improvement Act, 1992, Sec 3405.[11] As another example, the California water code also was also modified to allow the sale of conserved federal water to municipalities.[12] This legal issue may be pertinent in the Yakima basin, because irrigation diversions in full-water years have steadily declined below full entitlement over the last few decades.

Although irrigators in our "senior" Kittitas group do have the legal ability to lease or sell their water rights, individual irrigators in federal irrigation districts do not have the same capacity for doing so. Irrigation districts – with some exceptions – have generally been less enthusiastic about the role of

[11] See http://www.usbr.gov/mp/cvpia/title_34/public_law_complete.html.

[12] See http://www.sdcwa.org/quantification-settlement-agreement.

water markets and less likely to participate (Ghimire and Griffin 2014). In the State of Washington, irrigation districts may sell water to any user outside the district "on such terms and conditions as the Board of Directors shall determine" (RCW 90.03.380). What might prevent more transactions between irrigation districts? Transfers outside of a district may hinder the operational ability of the district to meet its obligation to deliver water to its customers (for example, those customers who did not wish to participate in a voluntary fallowing program). Indeed, a district's justification for blocking transfers is strengthened to the extent that a proposed transfer would "adversely affect the ability to deliver water to other landowners or impair the financial integrity of the districts" (RCW 90.03.115). The IP models cap out-of-district trades at 10% of a district's supply on these grounds, but provide no further guidance on why this number was chosen.

Finally, where the new place of use is located in a different county than the point of diversion, the Board of County Commissioners in the originating County must be notified (RCW 90.03.380.10) in addition to the normal public comment period. County Commissioners in some Northeast Washington Counties have shown increasing interest in restricting the amount of water transferred out of a county of origin through limits and taxes on exported water (MacDonnell 2008). While no such restriction currently exists in the Yakima Basin, it is conceivable that Kittitas County might consider such a regulation in the future. Should such a rule be implemented, it could take the form of weed management and re-vegetation requirements for fallowed lands. Alternatively, the rule could require annual compensation payable to the purchasing county for a period of 20 years to offset lost property tax revenues or take the form of a fixed fee per af of water transferred (MacDonnell 2008).

The discussion above pertains the extent to which our estimates (and those of the Four Accounts analysis) of the benefits of market-based reallocation are overly-optimistic. There remains the question of precisely what actions the Integrated Plan will undertake to achieve the increased market-based allocation results in the Four Accounts. As discussed in Section II (Project Descriptions), we can find no references to proposed legal or administrative changes, and essentially no basis for the estimated costs reported in the Four Accounts analysis associated with this element of the Integrated Plan.

3. Water for municipal and domestic use

Our analysis of municipal benefits takes the Four Accounts analysis (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012; HDR Engineering and Anchor QEA 2011) as a starting point. We take their assumptions of population growth and related water demand increases as given. We use our interpretation of their methods as a starting point for our analysis, but with modifications where warranted. These modifications fall under three categories: 1) correcting methods where we believe values were arrived at incorrectly relative to Four Accounts stated approach, 2) introducing changes to methodology that we believe represent improvements to the approach used in the Four Accounts study, and (3) applying of alternative price scenarios that are within a reasonable domain of future outcomes.

a. *Summary of Four Accounts Analysis for municipal benefits*

Municipal benefits come from two sources in the Four Accounts analysis (1) benefits from the provision of new IP-based proratable summer water entitlements to municipalities to cover demand increases from population growth, and (2) benefits from the IP for providing water security against curtailment of (junior) groundwater rights that municipalities in the basins relied upon. Below we summarize our interpretation of the methods used in the Four Accounts analysis.

For the demand growth component of the Four Accounts analysis, the benefits of the IP stem from their assumptions that (1) entitlements to summer water from IP storage development would be allocated to municipalities and domestic uses to cover all of their development needs for the next 100 years at zero cost to municipalities, and (2) in the absence of the IP these municipalities and domestic users would have to purchase senior water rights to provide water for all growth.[13]

To estimate the cost of new water for population-based demand growth (under the no IP scenario), the Four Accounts analysis assumes that new municipal and domestic water use beyond 2020 would be purchased annually. The cost per af of water is assumed to be a wholesale municipal water price of $258 per af. While these annual purchases are described as wholesale water purchases, they can be usefully thought of as water leases to distinguish them from permanent purchases of water rights.[14] The amount of water purchased increases annually to cover forecasted population and water demand growth in the basin. The net present value of this accumulating set of annual water purchases is then interpreted as the cost to municipal and domestic users of not implementing the IP, and therefore the benefits of implementing it. The estimated benefit arrived at for this component of the municipal/domestic analysis is $115 million, which we have replicated within rounding error of <$1 million.

For the water security component, the Four Accounts analysis assumes that current groundwater rights will be curtailed during drought, and that the IP will improve markets to allow municipalities to replace their current junior groundwater rights with senior water rights. Benefits of the IP arise entirely from presumed IP improvements to water markets that allow groundwater users to replace their junior water rights by purchasing senior water rights. To estimate these values, groundwater users are assumed to purchase senior water rights at $2,500/af per year from owners of senior agricultural irrigation water rights holders, for whom the opportunity cost of this water is assumed to be $1,000, providing net gains from trade of $1,500 per af. Their estimated benefits for water security for existing rights is $280 million, which we have been able to replicate within rounding error of < $30,000. Adding up their two estimates provides $395 million, or about $0.4 billion, which they report as the benefits of the IP received by the municipal and domestic water use sector.

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[13] While not directly pertinent to this analysis of municipal benefits, note that our results for agriculture rely on the assumption optionally implemented in HDR the implementation RiverWare YAKRW model that municipal/domestic water demand is set at projected 2040 levels(HDR Engineering, Inc. and Anchor QEA 2011, p. 31-32), which is the midpoint between the 2020 and 2060 time window assumed on the Four Accounts analysis for municipal growth.
14 In addition, to the extent that this wholesale water price includes the cost of conveyance and processing, this cost is likely to overstate the marginal opportunity cost of water, which is the marginal value of water in a quantity-constrained system.

b. *Modifications to the Four Accounts methods and assumptions*

We begin with issues that apply to both the water security component and the future demand growth component, and then examine each independently thereafter.

First, for both new demand and security for current municipal/domestic groundwater users, the analyses hinge on whether leasing or purchasing senior water rights is available for municipal and domestic use, but water prices are applied inconsistently. The Four Accounts analysis uses a price of $2500 per af as a municipal water value for water security, as explained in the Four Accounts text on page 52:

"Recent small transactions to mitigate the impacts of residential development have occurred with prices equivalent to about $30,000 per acre-foot, but information obtained during efforts by Ecology and others to expand the amount of market activity suggests the price will likely fall to about $2,500 per acre-foot (Barwin, 2012)."

The reference to mitigating new residential development and the magnitude of these values suggest that this price refers to a sale price rather than a lease price.[15] A competitive sale price for an asset such as a permanent water right can be approximated by an annual annuity. The present value of a permanent annuity A at interest rate r is $\text{PV} = A/r$. In this case, the sale price of a permanent water right in a competitive market equilibrium is PV=$2,500/af. Given a 4% interest rate, $A = PV \times r = \$2{,}500 \times 0.04 = \$100$. Thus, a permanent water right price of $2,500 is equivalent in present value terms to an annual annuity (i.e. repeated lease) of $100/af/year.[16] This value is lower than the $258/af/year used in the Four Accounts analysis to model water rights leases to satisfy population growth-based demand increases (U.S. Department of the Interior Bureau of Reclamation 2008; ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012).[17] Thus, the values for annual lease versus permanent water rights purchases are used inconsistently in the water security versus new demand components of the Four Accounts municipal/domestic benefit analysis.

For our analysis, we rely primarily on the following values either drawn or inferred from the Four Accounts municipal and domestic analysis:

- The opportunity cost of a permanent sale from agriculture is $1,000/af of water sold. This implies an annual annuity (lease) value of $40/af/year.
- A water purchase price of $2,500/af for a transfer from a representative agricultural seller to a municipal buyer for water purchased, which implies an annual annuity (lease) value of

[15] They also cite Brewer et al. (2007) in discussing water sales prices, which supports our interpretation.

[16] We are not suggesting that water sales prices will tend to exactly equal the present value of lease prices. Indeed, based on a limited dataset on western states water transfers available from UC Santa Barbara (Libecap 2014), we find that water sale prices for agriculture to urban transactions averaged $612.25/af and lease prices average 79.38/af/year, the latter of which has a present value of $1,984.67 (these prices are inflated to 2012 dollars). Analogous averages for WA, OR, and ID tend to be lower, at $434.61/af for sales and 42.61/af/year (present value $1,061.72). There are many reasons why we would not expect the present value of market lease prices treated as a perpetual annuity to equal water sales prices, including the fact that transaction costs are different between the two, uncertainty about future water availability, and other factors will affect the outcomes. What is most useful here is that the range of these values is within the ballpark of the $1,000-$2,500 sale and lease prices discussed in this section.

[17] The permanent water right purchase price corresponding to an annuity of $285 is $258/0.04=$6,450.

$100/af/year.[18] This is taken to be the cost avoided by municipalities if uninterruptible rights are received by municipalities at no cost to them under the IP.

We justify the use of these prices and price differentials instead of $258/af/year in Appendix VII.D. However, we also show in the appendix that based on the marginal value of water for agriculture, the assumed opportunity cost of water of $1,000 is if anything too low based on our simulations, and so the net gains to municipalities would be too high based on these assumptions.

As in the Four Accounts analysis, we assume that these increases in demand to 2060 will not have significant impacts on the prices of average ag-to-urban trades. This is likely not to be an egregious assumption for three reasons. Firstly, the aggregate additional consumptive water use is forecasted to grow to at 1193 af/year, reaching a total of 48,900 af/year of additional demand relative to current conditions and is a relatively small volume in relation to the 1 million non-proratable entitlements in the basin (HDR Engineering and Anchor QEA 2011, page 9, Table 1). Secondly, the assumption falls within the amount of entitlements not used in an average year by the five major districts. Finally, the demand for municipal water is price inelastic relative to that of agricultural demand, so we presume that while transaction prices may be volatile, this increase in municipal demand is likely not by itself going to impose much upward pressure on water prices in the basin, all else constant. We defer additional details of our water security and new demand analyses for the municipal benefits results in Section IV.C.

None of the above suggests that the marginal value of water to municipalities is limited to the equilibrium price of agriculture-to-municipal trades. In principle, the price negotiated between a buyer and a seller lies between the marginal willingness to accept for the seller and the marginal willingness to pay for the buyer. While estimates of the full gains from trade are unnecessary to estimate the value of IP water for new demand as a function of foregone water purchase costs, the full gains from trade would be useful for assessing the value of water security for current water users. However, we do not have sufficient information about the marginal value of water for municipalities in the basin. Nonetheless, we perform some robustness analysis in Section IV.C.1. The Appendix Section VII.D includes details of calculations, as well as the summary of a review of the non-economic foundations of the municipal demand analysis, including estimates of municipal water use and potential growth in use.

D. Fish impacts

To assess the economic value of the IP from fish abundance impacts, the impacts of these projects/operational changes on fish abundance must be estimated, and their economic value must be estimated.

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[18] While water rights are generally based on diversion rights, water transactions are generally predicated on consumptive use. Implicit in the Four Accounts accounting is that the transaction numbers that they use account, on average, for the differences in consumptive use across sectors. Generally speaking, municipal and domestic consumptive use tends to be lower than that of agriculture. The $1,500 difference in market price per af between intra-agriculture trades and trades between agriculture and municipalities is taken here to implicitly account for these differences in consumptive use rates.

1. *Fish productivity*

For the purposes of this report, actions to improve fish populations in the basin can be categorized as follows:

1) Fish passage for one or more existing dams in the basin
2) Operation changes to improve instream flow conditions for fish
3) Other fish habitat restoration

The effects of these activities are crucially dependent on the life histories of the fish species of interest. We therefore begin with background information on fish populations within the Yakima Basin in the context of the larger habitat and management in the basin, with a focus on sockeye (*Oncorhynchus nerka*), chinook (*Oncorhynchus tshawytscha*), and coho salmon (*Oncorhynchus kisutch*), and Steelhead trout (*Oncorhynchus mykiss*). These life histories inform the modeling methods used in the existing analyses as well as our reassessment of both methods and results.

2. *Fish life histories, fish passage, and restoration*

Expectations for the impacts of passage, restoration and flow are constrained by aspects of fish ecology and life history—all of which in turn have species-specific differences. The life history diversity of salmon and other highly mobile fish in the Columbia River System therefore specifies the frameworks available to evaluate the specific benefits from the YBIP. For example, the distance from the Yakima River headwaters to the Pacific Ocean is 547 river miles, and anadromous fish leaving the Yakima may travel several thousand ocean miles after they leave the mouth of the Columbia and before they return as adult spawners. The projects described in the IP however will only affect fish along approximately the first and last 200 river miles within the Yakima basin.

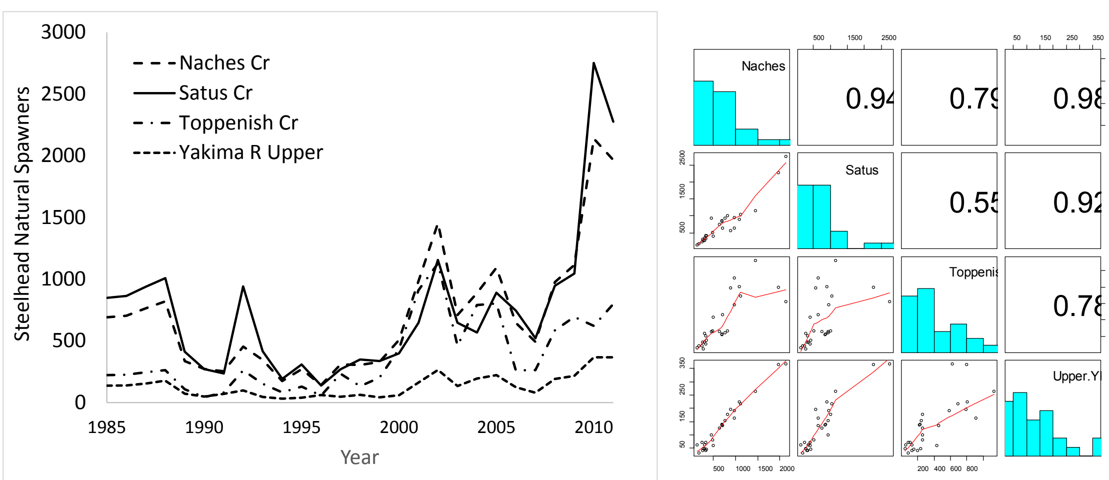

Figure 11: Time series of estimates of steelhead trout spawners in each of four identified Yakima Basin sub-populations, along with pairs plot indicating the degree of temporal cross correlation among the time series.

This has a number of consequences. Most importantly, there are a large number of potential sources of mortality occurring outside the basin, with as little as 34 - 64% of mortality occurring in the freshwater life history of anadromous salmonids (Bradford 1995). This is illustrated when we plot the time series of abundance of adult returns to different parts of the Yakima basin (Figure 11). In this case we have plotted Steelhead trout returns to the Naches, Satus, Toppenish creek and Upper Yakima River systems from 1985 to 2012 (period over which NOAA-Fisheries has published recovery data). In each case, the fish experience different habitat conditions and potential sources of mortality within each of their natal creeks, but common histories of mortality risk only occur in common areas: the lower Yakima, mainstem Columbia and Ocean systems. If habitat conditions within their discrete population areas were a principle determinant of population status, we might expect to see these times series not well correlated given the diversity of habitat among these four areas. On the right hand side of the figure are scatter plots of the correlated time series as well as their correlation coefficients. In each case, spawner correlations across tributaries are quite high and statistically significant, with the relationship between Satus creek and Toppenish creek steelhead being the weakest, but still having 30% of their variability in common. Thus, validation of the plan based entirely on adult returns means that improvements in early life survivorship due to the YBIP may be entirely successful, but out-of-basin mortality may prevent any of that success from being measurable into the future.

Another issue is that any given habitat project or flow enhancement will only be encountered by an individual fish for a matter of days in the case of an outmigrant, or perhaps hours by a returning spawner. These are very short times in the three to seven year life history to have an effect on individuals from which we would then impute a population-level effect. Therefore, all of the impacts of these projects are interpreted as changes to population-level survivorship related to a specific location or event, as they were the Four Accounts EDT forecasts. The net survivorship is the resulting cumulative probability of all the steps or life-stage transitions over the lifetime of the fish. Calculations of net survivorship are executed as a long series of multiplications of numbers between zero and one (probabilities range from 0 to 1), which culminate as a very long series for the whole life history. Consequently, even if survivorship for a specific step is high, or made high by a specific management action, the net survivorship works out close to zero. This is not a surprise when we remember that female fish may lay 3,000 to 7,000 eggs in a redd (Groot and Margolis 1991), but only two fish survive to reproduce if the population is just replacing itself. The other consequence however, is that our sensitivity to detect small changes at specific life history steps is relatively low when we are looking at a population level outcome, such as numbers of returning adult fish.

a. *The recovery paradigm*

This representation of survivorship has another important consequence: the effect of any change in survival itself is probabilistic. We cannot specify how many fish will survive passing a given dam, or other threat, we can only say what the probability of survival is, and if sufficient monitoring data exists, what the change in probability will likely be for a given management action. While we cannot predict the fate of a given fish, the probabilistic nature of survival provides a mechanism to estimate our uncertainty in any estimate.

Any forecast that is presented as a point estimate (e.g. numbers of adult fish returns) should be interpreted carefully as a number, a metric, for which there exists some probability that it will be realized in the future. Sometimes the point estimate is chosen because its probability is higher than any alternative, but sometimes it is chosen because of its position within the range of other estimates (i.e. the median, the maximum, the "best case", etc.). Regardless of the type summary metric used, however, there is some likelihood for each of the other possible outcomes (numbers of returning adults other than the point estimate presented), some of which may be very far from the point estimate. This uncertainty about any point estimate presented is not to be equated with not knowing the answer; it is part of the answer. As a consequence, the language we have to use for communicating within the framework of fish benefits is in terms of changes in fish survivorship probabilities and any value has to be communicated with its uncertainty, and the uncertainty has to be understood correctly and acknowledged. This characteristic applies to all estimates presented in this report.

It is also critical to remember that these fish are wild rather than domestic. This means that human activity can reduce the numbers of fish deterministically (harvest, habitat loss, etc.), but cannot force the production of new wild fish. The premise of a restoration enterprise is that by reducing the contribution to mortality from specific sources such as poor habitat quality a consequent increase in the number of wild fish may follow. This is not unreasonable, but these restoration mechanisms are passive, and even if the habitat alteration is successful, there may be other reasons why restoration correlates poorly with increasing numbers of fish.

If current fish abundance is below the current carrying capacity of the habitat, there may be some

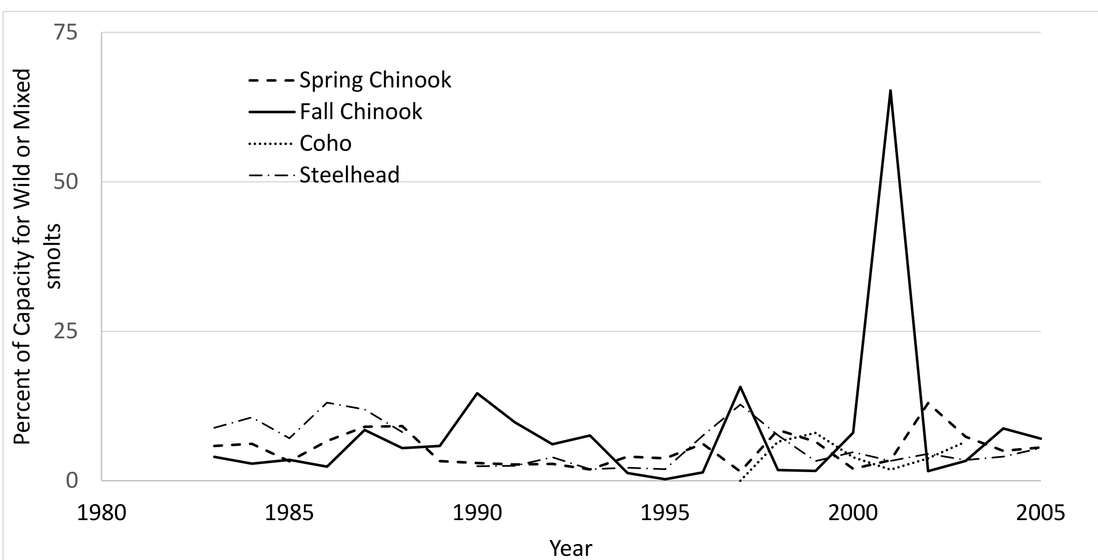

Figure 12 Estimates of smolt abundance for four species of salmonid in the Yakima basin expressed as the percent of carrying capacity based on habitat characterizations.

other factor limiting population size such that further increasing habitat capacity via restoration is unlikely to increase population size. One extreme ecological illustration is the middle fork of the Salmon river; the Frank Church Point of No Return wilderness has habitat quality unmatched anywhere in the Columbia River basin. As such, there would be no need for remedial actions to increase the quality and quantity of habitat, yet chinook salmon in this area are below carrying capacity and are listed as endangered under the Endangered Species Act (ESA).

Data available for the Yakima basin allow us to illustrate the relevance of the recovery paradigm. Figure 12 shows a time series of estimates of out-migrating smolts of various species as they pass the counting facility at the Prosser diversion dam expressed as the percentage of capacity for each species determined from habitat assessments (Fast, D. et al. 2001). In each case, the number of smolts produced generally ranges from 1-16% of habitat capacity, with the exception of fall chinook smolts in 2001 which were anomalously abundant and exceeded 65% of the estimated habitat carrying capacity. The observed rate of production suggests two things. One, that habitat conditions within the basin are not the ultimate limits to net fish production; and two, that habitat improvements alone are unlikely to produce large increases in fish abundance in the Yakima basin.

b. *Species differences*

There are important life-history and ecology differences among the fish species considered in the YBIP. The biggest difference is that while bull trout (*Salvelinus confluentus*) do move within the basin, they are not anadromous. They are also listed for protection under the Endangered Species Act so they are not commercially harvested. Bull trout are highly sensitive to water quality, requiring cold, clear water and connectivity between the main channel and the off-channel habitats that they prefer (Rieman and McIntyre 1995; Watson and Hillman 1997; U.S. Fish and Wildlife Service 2010). While bull trout are mentioned in the Fish benefits memo (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011), and it is stated that the fish benefits attributed to bull trout will be characterized by a "qualitative score card" (Section 1.3, page 2) no further mention of bull trout, in terms of related benefits or the score card, is made in the entire report. A scoring system that characterizes "Environmental Quality" is described in the Four Accounts Memo (ECONorthwest, Natural Resources Economics, and ESA 2012), and this does include information on bull trout. Although none of that information provides forecast estimates for abundance of bull trout, nor the consequent economic benefits. This is a particular challenge, since any action that would affect bull trout habitat would be subject to consultation with the US Fish and Wildlife Service under the ESA, which would be greatly facilitated by an analysis of population impacts of the potential action.

Among the anadromous species, the life histories and habitat usage of coho and chinook salmon and steelhead trout are similar in their use of stream habitat for migration, holding and spawning, and distinct from the sockeye salmon that largely use lake habitat for spawning and holding. These life-history differences are the basis for the former species' habitat associations being modeled with the Ecosystem Diagnosis and Treatment (EDT) model framework in the Four Accounts assessment, while sockeye were modeled with a reservoir surface area-habitat capacity model instead (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011). The different approaches taken with these species groups are common. Among the stream-using species, Steelhead occur in the greatest diversity of habitats and across the largest extent of habitats within the river network, with coho and chinook occurring lower in the network within a smaller number of reaches (Groot and Margolis 1991).

Sockeye are distinct from the other species in several other aspects. Principle among these differences is being almost completely extirpated from the Yakima basin in the early 20th century due to passage limitations (Gustafson et al. 1997). Dam construction eliminated access to the Kachess and Keechelus lakes in 1904, Cle Elum lake in 1905 (Bryant and Parkhurst 1950; Davidson 1953; Fulton 1970; Mullan 1986), and Bumping lake in 1910 (Davidson 1953; Fulton 1970). Thus, the reintroduction of sockeye to the Yakima under the YBIP represents a different conservation and management enterprise than the maintenance and growth of existing populations of the other stream spawning species. Consequently, the analysis of the potential fish benefits for sockeye salmon is treated differently from the other anadromous species.

Like sockeye, wild coho salmon were also largely extirpated from the Yakima basin in the early 1980's from overexploitation, and to a lesser extent habitat destruction (YSFWPB 2004; Yakima Nation 1997). Unlike sockeye, coho populations within the Yakima were being supplemented with hatchery smolts (ca. >700,000/annum) over this entire period to support harvest (Dunnigan, Bosch, and Hubble 2002). Starting in the mid 1990's these hatchery releases were recruited as a reintroduction program, intended to develop a self-sustaining wild population of coho salmon in the Yakima (Bosch et al. 2007). The coho reintroduction differs from the reintroduction of sockeye in that coho habitat quantity has been similar over this time, although quality may have changed. Thus, the coho recovery effort involves increasing fish abundance only, while the sockeye reintroduction is designed to radically increase habitat quantity over historical levels (i.e. pre-reservoirs) while increasing fish abundance.

c. *Sockeye and non-sockeye impact modeling in relation to fish passage, instream flow, and habitat restoration*

The practical implication of the difference between sockeye life histories and non-sockeye salmonid life histories is that very different models have been used to estimate the analysis of IP project impacts on the different species.

Sockeye are modeled using the "Spawner per Hectare Method" as described in the Fish Benefits Analysis Technical Memorandum (2011) and by Hubble (2012). This method relies on an understanding of the spawning capacity of lakes and assumptions about egg-to-smolt and smolt-to-adult survival rates. Because access to lakes is dependent on fish passage to the five lakes/reservoirs in the basin, and wild sockeye populations almost entirely depend on access to lakes for spawning, sockeye impacts are modeled as being entirely dependent on fish passage. While factors such as instream flow and restoration in the Yakima Basin may affect the adult survival rates in principle, these sockeye survival rates are treated as independent of IP restoration and instream flow changes.

In contrast to sockeye, the recruitment benefits to non-sockeye species focused on by previous studies (chinook, steelhead, coho) come primarily from restoration efforts and instream flow changes, and are modeled using the Yakima Basin Ecosystem Diagnosis and Treatment (EDT) model in conjunction with the All H Analyzer to provide a wild and hatchery abundance estimate (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011). The All-H Simulator is an accessory to the population process model that considers alternative management scenarios, but its outputs are dependent on the population estimates it receives from EDT.

Importantly, while these studies quantitatively distinguish between fish passage impacts and restoration impacts, they do not identify quantitative differences between instream flow contributions and other restoration contributions to non-sockeye species. This latter distinction is important for this present report because of its connection to the net benefits of water storage, to which both out-of-stream uses and instream flows may contribute.

d. *Complementary analyses and assessment*

While we use the existing analyses as a starting point for assessing the impacts of IP projects on fish populations, we can re-examine the relevance of these previous estimates in several ways. These instream or fish-based benefit estimates arise from the EDT process (described above), and are based on expectations for changes in habitat unit-based survival impacts, rather than on historical relationships between survival and habitat variability. Data on in-stream flow in the basin, the history of habitat restoration in the Yakima basin and contemporary estimates of smolt production and adult spawner abundance are available.

Smolt to Adult Return rate (SAR) is a commonly reported measure of salmonid survival, and in this case provides an index of fish survival for the part of the life history outside the Yakima basin. Relative survival over this period is anticipated to reflect in part fish condition or size as they leave the basin (Henderson and Cass 1991; Koenings, Geiger, and Hasbrouck 1993; Tipping 2011; Tomaro et al. 2012), but is also largely affected by out-of-basin mortality. The Smolt Per Adult spawner production (SPA) on the other hand is a measure of the smolts produced by adults returning at a prior time and should reflect changes in within-basin survival. It is less commonly evaluated because most analyses of salmon survival have relied on dam counts which have limited precision with respect to survival and non-tagged fish identity once outside the mainstem Columbia. Data on adult and smolt abundance were obtained from monitoring reports from the WDFW and Yakima/Klickitat Fisheries project of the Yakima Tribe. Estimates of SAR were collected but were not available in all cases (e.g. some species and some years of others). The SPA and any missing SAR values were estimated using the time series of smolt and adult abundances and an assumption of fixed age distribution within populations. The assumption of a fixed age distribution is a gross oversimplification, but lacking data for each species, it is commonly applied for developing an index of survival for these fish (e.g. Bosch et al. 2007). SAR values estimated in the source literature were found to be highly correlated with SAR estimates using a fixed age distribution assumption and the correlations were high in all cases ($r > 0.91$).

Using these time series, statistical regression models were built to predict the SAR and SPA for each species against measures of restoration project abundance, flow within the Yakima basin and spill at McNary dam on the mainstem Columbia River for the years for which data are available. These models were used to identify any measurable effects of Flow and Restoration that would allow us to better evaluate the fish benefits in the YBIP that are attributable to these management outcomes.

Habitat restoration projects are measured by the total number of projects with a completion date in the year prior to the salmon outmigration year. These "Project" data were compiled from the Pacific Northwest Salmon Habitat Project Database (PNSHP Katz et al. 2007a; updated July 2014). Restoration project data are reported as the total number of projects regardless of type, because the metadata for extent and complexity of each project are not available.

In June 2005, the U.S. district court ("the Redden Court") granted a preliminary injunction requiring National Marine Fisheries Service (NMFS), via the USACE & Bonneville Power Administration, to increase flow and spill at certain Federal Columbia River Power System (FCRPS) dams starting in the summer of 2005 and continuing to date (U.S. Court of Appeals for the Ninth Circuit - 481 F.3d 1224). The premise was that increasing the water flux through the Columbia mainstem hydropower system would improve survival of outmigrating fish. Under this injunction a set of operating rules were put in place where some dams (e.g. McNary) had spill that was a specified fraction of discharge and was therefore variable. To evaluate the potential effect of spill on Yakima Basin fish, we used the average spill for the months of May-June-July-August as the index of "Spill" for each year because these were the months with the greatest year-to-year variability and peak outmigrant numbers.

Measures of flow within the Yakima basin were reported at the USGS stream gauge at Kiona, WA (USGA Stream Gauge 12510500; http://waterdata.usgs.gov/usa/nwis/uv?site_no=12510500). Analysis of monthly average flow over the prior 25 years indicates that the greatest variance, and therefore statistical signal of year-to-year variability, occurs in the spring months. This also coincides with a large fraction of smolt outmigration (Groot and Margolis 1991). Based on this information, flow for each year is reported as the average of April-May-June (AMJ). These indices of Flow and Spill are significantly correlation ($r = 0.8$) which creates problems for linear model interpretation. Therefore, Flow was regressed on Spill, and the residuals used in the linear models are under the label "Flow". The regression results are presented in Appendix VII.E.b.

e. *Assessment of Four Accounts fish abundance methods and estimates*

Appendix Sections VII.E provides an extensive assessment of the Four Accounts fish abundance impact estimates. While the technical details are relegated to the appendix, the analysis leads to the following conclusions. First, the Four Accounts sockeye abundance impacts, especially the high-end estimates, are likely to be overly optimistic for the following reasons:

1) The range of forecasts for sockeye adult abundance in all reservoirs (escapement rather than recruitment) relied upon in the Four Accounts analysis was 73,631 to 446,903. Subsequent estimates are 112,428 to 251,310 (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). The latter high-end abundance estimate, based on a more refined modeling process that incorporates more specific ecological information, is only 56% of the initial estimate.

2) Estimates of historical sockeye runs range from 100,000 to 200,000 before the reservoirs were built. While the new lake area due to these dams would provide more spawning habitat than was available historically, the quality of this newly created habitat is unknown. Considering also the new threats and barriers faced by sockeye along their entire runs up the Columbia River and Pacific Ocean, the prospect of doubling or even quadrupling historical runs is highly speculative and uncertain.
3) High-end estimates are less likely than the low end estimates and therefore should be attributed less weight in assessing outcome likelihoods.
4) The sockeye population growth rates assumed by the Four Accounts analysis exceed marginal growth rates for comparable fish populations by a factor of 7 or more, suggesting that either fish benefits would accrue substantially more slowly (and hence provide lower present value due to discounting), or additional investment (and cost accounting) would be necessary to support population growth with hatchery fish or transplantation. The closest historical analog to potential sockeye reintroduction success is arguably the coho salmon in the Yakima, which illustrates these points.

While reintroduction of sockeye to even a modest fraction of the range relied upon in the Four Accounts analysis would be considered a major conservation success by most, the range of sockeye abundance forecasts relied upon for the economic analysis is in our assessment is overly optimistic in terms of quantity, timing, and likelihood. Having said that, the uncertainties surrounding sockeye reintroduction are so large that we cannot rule out even the higher estimates, except to say that they would, for sockeye in particular, amount to unprecedented reintroduction success.

Second, non-sockeye abundance impacts are more likely to be at the low end of the estimated range of impacts. Our limited statistical analysis and the broader literature support this conclusion, but only weakly. Non-sockeye estimates relied upon in the Four Accounts analysis are generated using a separate and very different modeling approach (EDT, as described in Section III.D) which has substantive methodological weaknesses but is commonly used. Uncertainty over these forecasts relative to the magnitude of their ranges is very large, and data do not exist to support an analysis with sufficient statistical power to say more than this.

Third, it is not possible to discern instream flow impact relative to other habitat restoration based on the existing studies, but our statistical analysis weakly suggests that instream flows have a weaker impact on abundance than do other restoration activities as a group. Appendix VII.E provides detailed discussion and analysis to support these conclusions.

3. Fish valuation

The Four Accounts analysis identifies two broad categories of economic values arising from increases in fish populations. "Use" values represent the value to commercial and recreational fisheries of harvested adult fish, as well as tribal harvest for subsistence, religious or ceremonial use. "Non-use" (sometimes called "passive use") values are a measure of what society would be willing to pay (in increased taxes, higher electricity bills, etc.) solely for the knowledge that the fish populations are improving, even if they expect never to use or come into physical contact with the resource. Because of the potential for overlap between these two categories in the process of valuation, the

Four Accounts report does not estimate use and non-use separately and add them together, but instead estimates what fraction of the total economic value is attributed to "use". The Four Accounts report estimates the total present value (use and non-use) from improved fish populations to be $5.0 - $7.4 billion, or approximately 80-85% of the total benefits from the IP. Non-use value comprises approximately 95% of the total economic value of improved fisheries (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012, 32). Because of the importance of fishery-related benefits, in this section we first briefly describe the methodology used for valuing "use" values before describing in some detail the method used for non-use values, which are based on a 1999 household mail survey. We then offer several critiques of this study and its application to the IP, arguing that the Four Accounts results are likely to be biased upward. We also provide some sensitivity analysis around the issue of non-IP related fish increases in the period 1998-2012. Because the 1999 study continues to be the best available information on how households in Washington state value increases in migratory fish, we also use this data source in our analysis.

a. *Use vs. non-use values*

Use values from harvesting adult fish are calculated using widely-accepted techniques. Values for five types of fish (coho, spring chinook, fall chinook, steelhead and sockeye) are calculated in six harvest categories (ocean commercial and sport, lower Columbia commercial and sport, Columbia tribal commercial and Yakima sport). Commercial values follow from the observed market price per fish and assume 80% of that price is profit. The analysis reasonably assumes that the increasing abundance of fish following implementation of the IP will not decrease the global market price of these fish. Recreational values, which are higher than commercial values per fish, are based on the amount of money fishermen spend to fish (e.g. equipment, licenses, travel expenses), as well as the non-financial value of the time spent traveling to site and fishing. Since many fishermen would likely spend even more to fish than they currently do, the report includes their consumer surplus, or the area under an estimated demand curve for recreational fishing. The report does not attempt to value tribal harvest for subsistence or ceremonial uses, which are described as "incalculable". These values are enumerated, though not valued economically, in Montag et al (2014).

Because "passive" uses do not reveal any behavior that can be observed through price-mediated markets, they are commonly estimated with the use of surveys. These surveys – which have been widely used and accepted in federal investment analyses for over three decades - typically present randomly-selected respondents with a hypothetical scenario where the level of some public good or service may be improved through some private cost to the respondent (e.g. higher taxes, electricity bills, water bills, or other payment vehicles). Often the respondent is told that the scenario would be implemented if a majority of respondents "vote" yes on the hypothetical referendum. Rather than observing "revealed" preferences on how salmon consumers value fish through the price they are willing to pay in the market, the survey instead observes "stated" preferences, where the values are contingent on the scenario that was presented to the respondent.

b. *The Layton, Brown and Plummer (LBP) 1999 study*

The Four Accounts analysis relies on a stated preference study conducted in 1998 for the Department of Ecology. The study was conducted by David Layton, Gardner Brown, and Mark Plummer (1999), henceforth "LBP". Although the report itself was not published in a peer-reviewed journal, results from a closely-related article relying on a subset of the data are reported in a highly-regarded, peer-reviewed economics journal (D. F. Layton 2001). The mail survey presented respondents in Washington state with four scenarios that increased populations of three groups of fish (saltwater species, freshwater species and migratory species) in two locations ("Western Washington and Puget Sound" and "Eastern Washington and the Columbia River"). Because Ecology hoped to use the survey results to evaluate the economic benefits of a wide range of programs that might improve fish populations, the survey did not provide a specific management plan for *how* the improvements might be achieved. Instead the survey said:

"The State of Washington is considering a variety of ways for improving fish populations, ranging from reductions in toxic contamination of water bodies to improvements in river flows and fish habitat. As mentioned earlier, fish populations are affected by a number of factors, including urban development, agricultural practices, timber harvesting, pollution, and hydroelectric dams. A new state program might affect some of these more than others. And in some cases, a new program would affect one region of the state differently from another, or would affect one species differently from others."

To describe the costs of the new programs, respondents are told that "new programs may directly or indirectly cost you and your household money....We want to find out more about how your household might respond to added costs such as these." Respondents were told to imagine the added costs of the program would show up as a "surcharge on your water bill (or other utility bill if you have no water bill)". It emphasized that the monthly costs would accrue each month for the next twenty years.

The survey varied the baseline "status quo" situation if no new programs were implemented. In one version, respondents were told that although fish populations had declined over the prior 20 years, they were expected to stabilize and would not decline further in the next 20 years. In a second version, the survey said that experts predicted that fish populations would decline further over the next 20 years. Respondents were given only one of these two versions. They were then asked to rank four new programs (one version shown in Figure 13) compared to the option of "no new programs". By observing these rankings, the authors statistically recover a willingness-to-pay (WTP) function for percentage improvements in each of the fish populations for the next 20 years. Importantly, this WTP function is estimated as a non-linear function such that the marginal value of improving fish populations from 2 million to 2.1 million is higher than the value of improving them from 2.5 million to 2.6 million. Specifically, the function relating annual household WTP for each of

Four Possible New Programs

	Fish Populations in 20 Years				
	No New Programs	New Programs (% increase over situation with no new programs)			
		Program 1	Program 2	Program 3	Program 4
Western Washington & Puget Sound					
Freshwater Fish	53 million	60 million (+15%)	70 million (+33%)	53 million (+0%)	55 million (+5%)
Saltwater Fish	54 million	62 million (+15%)	72 million (+33%)	108 million (+100%)	54 million (+0%)
Migratory Fish	2.5 million	2.88 million (+15%)	3.33 million (+33%)	5 million (+100%)	2.5 million (+0%)
Eastern Washington & Columbia River System					
Freshwater Fish	75 million	75 million (+0%)	79 million (+5%)	100 million (+33%)	120 million (+60%)
Migratory Fish	0.5 million	0.5 million (+0%)	0.53 million (+5%)	0.67 million (+33%)	0.9 million (+80%)
Additional Cost of Program (Monthly for 20 years)	$0	$25	$45	$4	$8

Figure 13: Four scenarios shown to respondents in one survey version of the LBP survey (replication from survey).

the 20 years and the percentage improvement (x) in migratory fish populations in "eastern Washington and the Columbia River" is[19]:

$$Annual\ WTP(2012\$) = \begin{cases} 12 * 1.377 * 2.53 * \ln(x) = 41.81 * \ln(x)\ for\ x > 5\% \\ 12 * 1.377 * 0.813 * x = 13.457x\ for\ x \leq 5\% \end{cases}$$

Applying this function to the Four Accounts-estimated increases in fish, the aggregate value of fish benefits in the Four Accounts analysis implies that the average value of one fish ranges from approximately $27,000 (for low-end fish population increase of 181,650 fish) to $15,700 (for high-end fish population increase of 472,450). These values have garnered significant attention and skepticism because they seem at first wildly implausible given that the commercial market value of one fish is on the order of $50. It is important to recognize, however, that these estimates include non-use value that is *non-rival.* That is, many people can enjoy the benefit from the good at the same

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[19] See Appendix IX.F for a more detailed explanation of how this function is derived from the LBP study. To calculate percentage improvements, one needs a baseline, and the Four Accounts assumes fish populations have not increased between 1998 and 2012, remaining constant at 2 million. This function adjusts for inflation between the survey year of 1999 and 2012, and represents the "stable" baseline treatment. The WTP function for respondents who were told that populations would continue to decline in the absence of new programs would have different parameters. This equation has a slightly different functional form for the linear portion of the function than the Four Accounts analysis, though this equation replicates their results. Again, see the appendix for more detail.

time without diminishing the benefit received by others. Rival goods, in contrast, can only be used by one person; only the person who buys the fish can eat it (a rival, "use" value). For non-rival goods, total willingness to pay increases in relation to the size of the population that values the good. These large fish value estimates stem primarily from the fact that having healthy anadromous fish populations are valued by millions of households, each of which are not directly impacting the value accrued by others. For example, assuming a population of 4.2 million households in Washington and Oregon (including projected population growth over the next 20 years), the value per fish (low end) works out to $27,000 / 4.2 million households = $0.0064 per fish per household.

Whether the LBP study is the correct benefit valuation study to use is a matter of professional judgment, and the Four Accounts analysis justifies this "benefits transfer" choice at length (see pages 12-16 of the Four Accounts report). We agree with the Four Accounts analysts that the LBP study is methodologically sound and generally consistent with modern non-market valuation approaches. The LBP study is one of several stated preference surveys valuing salmon in the Pacific Northwest (see Appendix VII.F for a survey of the existing literature), and we agree that the context and geographical scope of the LBP is the most similar to the IP. We also demonstrate in Appendix VII.F that the fish marginal value results in the study fall within the range of estimates published in the broader non-market valuation literature, although this literature focuses primarily on threatened and endangered fish. Finally, we find the application of the LBP approach to the IP in the Yakima basin via the benefits transfer methodology described in the Four Accounts analysis for the most part methodologically defensible given the available data, and consistent in general with modern non-market valuation methods.

However, we do have concerns about a) the LBP study itself and its valuation function relating fish improvements and household willingness-to-pay, and b) the way in which it is applied to the IP. These are discussed in the next section. Most of the concerns imply that the Four Accounts analysis overestimates the value of improved fish populations attributable to the IP to Washington households.

c. *Critique of the LBP study and its application to the IP*

We identify six reasons that suggest that the fish marginal value estimates as used in the Four Accounts analysis may be biased upward. In Appendix VII.F we provide more detail on each critique and our methodology in calculating the sensitivity analysis results described below.

1) Context matters in stated preference surveys eliciting non-market values. As described above, the LBP management plan for achieving fish improvements is deliberately vague. If respondents had been given the specific elements of the IP, however, it is likely that households would have reported lower average household willingness-to-pay for fish increases. In particular, we suspect that some fraction of Washington state households would object to new dams or reservoir expansions as part of the management plan given dams' controversial history and historically harmful effects on fish populations.
2) Estimates of willingness-to-pay depend critically on whether the baseline population trends are declining, flat, or increasing, and incorrect assumptions lead to a misapplication of the

LBP valuation function. Because of the nonlinear form of the LBP value function, the marginal value for a given increase in fish populations decreases as the "baseline" increases. Suppose there are two programs – A and B – and each is expected to increase fish populations by 150,000 fish per year. If only Program A is implemented, the economic value to households of having a population of 2.15 million fish would be $84.23 per year per household[20]. The same value holds if only Program B is implemented. However, suppose Program A is implemented first and increases populations to 2.15 million, and Program B is implemented fifteen years after, increasing the total population to 2.3 million fish. This new population level (a 15% increase in total) would be valued by households at $113.22 per year. According to the methodology of the LBP study, we would attribute $84.23 per household to Program A because its effects were felt first, and only $28.99 ($113.22 - $84.23) per household to Program B.

However, returning fish counts fluctuate significantly from year-to-year, and fishery scientists may not be able to estimate precisely the increase in fish populations attributable to specific programs. An analyst on Program A might reasonably ignore the effects of any prior programs (because they are lost in year-to-year noise) and assume a population of 2 million. An analyst on Program B, implemented fifteen years after Program A, might similarly ignore the observed or expected effects of Program A, and continue to assume a population of 2 million. They each conclude that benefits to the State will be $84.23 per household per year, or $168.46 combined. But the LBP study reported households are only willing to pay $113.22 per year for the combined effects of the program, so benefits would be overstated. Returning to the IP, the Four Accounts analysis assumes that the total number of returning migratory fish in the Columbia is the same 2 million that was used in the LBP study in 1998. If other fishery or habitat programs implemented in the intervening 16 years (the equivalent of Program A above) increased fish populations or can *reasonably be expected* to increase those populations, then the baseline fish population before the IP takes effect would increase from 2 million, and the corresponding economic value attributable to the IP would decline just as Program B's value declined above. These non-IP fisheries programs include the Redden Court's spill decision, ongoing water market purchases for improving instream flow, and the numerous habitat and flow improvements tallied in the PNSHP database described above. It should also be emphasized that programs implemented since 1998 *outside* the Yakima Basin count, given that LBP respondents were valuing improvements in "migratory fish" in "Eastern Washington and the Columbia River", not just yet the Yakima Basin.

To illustrate the importance of this assumption, we calculate the sensitivity of total economic benefits to Washington and Oregon households of the IP. Using a mid-range estimate of fish improvements attributable to the IP by 2042 of 200,000 fish per year, we find the total

[20] An increase of 150,000 fish represents a 7.5% increase on a base of 2 million, so the annual household WTP using the LBP formula above is 41.81*ln(7.5) = $84.23.

benefits drop from $5,243 million to $4,602 million if we assume that all other programs implemented since 1998 have increased, or will increase, fish populations in "eastern Washington and the Columbia River" by just 25,000 fish per year, a 12% drop. If non-IP programs improve populations by 50,000 fish per year, the benefits from 200,000 fish per year increase from the IP drop to $3,912 million, a 25% decline. If non-IP program increase fish by 100,000, IP benefits fall 54%. Appendix VII.E provides more detail on these calculations and present similar sensitivity calculations for a wide range of expected fish impacts of the IP[21].

3) The methods used in the LBP study to elicit fish values do not directly address the substantial uncertainty related to the potential fish impacts discussed in Appendix VII.F. Although the LBP approach is consistent with most professional stated preference surveys, a better accounting for this uncertainty in valuation methods may lead to lower valuation estimates.
4) There is no distinction in the LBP study between hatchery and wild fish. It is reasonable to assume that a substantive component of the passive-use valuation of salmon and threatened or endangered species is a conservation value, so it is likely that hatchery fish may be valued differently --- and more likely lower --- than wild populations. This issue becomes particularly important given our assessment of the need for hatchery fish to support the growth rates presumed in the Four Accounts analysis (see Section VII.F). Furthermore, the costs of the IP do not include hatchery management.
5) The Four Accounts estimates include benefits that would accrue to people outside of the State of Washington. This is entirely valid when assessing the full benefits of an investment in general. However, to the extent that the State of Washington fiscally supports the IP infrastructure investments, the benefits to Washington State residents may be of particular relevance for a comparison with the costs accrued by the State.
6) The length of the hypothetical repayment period (20 years) is long relative to standard stated preference studies, and this is likely to lead to higher stated WTP estimates than if the hypothetical repayment period were shorter.
7) The Four Accounts does not delay the onset of fish-related benefits; they begin accruing in 2012.[22] One could argue that this is not unreasonable because LBP respondents were given a patient, 20-yr timeframe to see the promised results. We adopt this assumption to be consistent with the Four Accounts.

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[21] The corresponding values for the "high-end" estimates of 472,450 fish, which we argue are implausible, are as follows: with non-IP increases of 25,000 fish per year, the benefits of the IP drop from $7,387 million to $6,543 million. With increases of 50,000 fish, benefits drop to $5,690 million; and drop to $3,957 million with non-IP increases of 100,000. If total IP costs are $4,400 million and high-end estimates hold, the project as a whole passes only if non-IP programs increased or will increase populations by 87,303 or less. If low-end IP fish increases hold, this breakeven is 24,812 fish.

[22] As discussed in the following section, we account for the construction time by assuming agricultural and municipal benefits from water storage do not begin to accrue until infrastructure construction is complete so that all projects are completed and benefits start accruing 4 years in the future.

E. Project costs

IP project costs are documented in a variety of IP-related documents, namely:

- Costs of the Integrated Water Resource Management Plan Technical Memorandum (HDR Engineering Inc. and Anchor QEA 2011)
- Cost Risk Assessment of Six Projects from the Proposed Integrated Water Resource Management Plan Technical Memorandum (HDR Engineering 2012)
- Preliminary Cost Allocation of the Proposed Integrated Water Resource Management Plan Technical Memorandum (HDR Engineering, Inc. 2012)

In many cases, multiple alternatives for a given project have been proposed, with differing costs. Our first-order criterion for defining the version of an IP project to include is its implementation in YAKRW. Because YAKRW is the basis for much of the benefits related to water distribution, we select cost estimates that pertain to projects as implemented in YAKRW. Secondly, in cases where the above documents present different cost estimates, we rely on the most recently completed estimates: those presented in the Preliminary Cost Allocation Technical Memorandum, published in October 2012. In some cases revised cost estimates have been updated for individual project components in response to the evolving nature of individual projects. Cost categories include construction; interest accrued during construction (IDC); and operation, maintenance, and replacement costs (OMR). Total costs reflect net present value over the period 2012 – 2111 unless noted otherwise. Following the Preliminary Cost Allocation Technical Memorandum (HDR Engineering, Inc. 2012, 7–8), all amounts are in millions of 2012 dollars and were calculated with a 4% discount rate. Mid-range cost estimates are used where planning documents provide a range of cost estimates, (HDR Engineering 2012), and construction costs include land acquisition costs (HDR Engineering, Inc. 2012). While cost estimates reflect the most recent estimates available, they may differ slightly for two reasons: (1) future, parcel-specific negotiations concerning land acquisition costs and (2) slight adjustments to project scope and timelines. Unless noted otherwise, estimated completion dates correspond to those from the Integrated Plan (HDR Engineering Inc. et al. 2011, 61). Cost estimates do not reflect joint costs previously identified under the AJE accounting method (HDR Engineering, Inc. 2012).

Cost estimates for some of the project components warrant elaboration. Since late 2012 revised construction cost estimates have been developed for the Keechelus to Kachess conveyance (HDR Engineering, Inc. and Anchor QEA 2013), the drought relief pumping plant (U.S. Bureau of Reclamation and prepared by HDR Engineering Inc 2013), and Wymer (HDR Engineering Inc. 2014). This analysis does not use the revised Wymer cost estimates for two reasons. First, revisions result in only minor changes in undiscounted construction costs ($2.9 M). Second, the analysis refers to previous analyses for detailed cost estimates (HDR Engineering Inc. 2014). We do not use updated cost estimates for K2K and KDRPP revisions in order to be consistent across projects. Revised estimates present net present values for construction costs, only, and do not reflect changes to interest payments during construction (IDC) or operation, maintenance and replacement costs (OM&R).

Table 7: Project cost[1] estimates and sources

Category	Project	Construction	IDC	OMR	Total	Construction duration (years)[2]
Habitat	Tributary / mainstem fish habitat enhancement	337.9	0.0	0.0	337.9	18
Reservoir Storage	Wymer 1 (adjacent intake)	1,151.2	71.5	108.5	1,331.2	4
	Kachess Drought Relief Pumping Plant (KDRPP)[3]	177.9	11.1	6.8	195.8	3
	Bumping	409.5	25.4	17.4	452.3	4
	Cle Elum Pool raise (CEPR)	15.5	0.7	0.1	16.3	3
Ground-water Storage	Shallow Recharge (Thorp/ WIP) ASR	84.0	4.3	43.0	131.3	3
	Yakima Municipal ASR[4]	3.0	0.0	3.6	6.6	-
Fish Passage	Keechelus	71.1	3.3	5.5	79.9	3
	Tieton	71.1	3.3	5.5	79.9	3
	Clear Lake	2.6	0.0	1.5	4.1	3
	Kachess	71.1	3.3	5.5	79.9	3
	Bumping	20.0	0.9	5.4	26.3	3
	Box Canyon Creek	0.8	0.0	0.5	1.3	-
	Cle Elum	71.5	3.3	6.7	81.5	3
Operations	Kacheelus to Kachess Conveyance (KKC)	125.6	7.8	4.8	138.2	4
	Power subordination[5]	13.1	0.0	0.0	13.1	0
Conservation	Agricultural Conservation	300.3	0.0	0.0	300.3	18
	Municipal Conservation	0.0	0.0	15.9	15.9	18
Marketing	Marketing	1.9	0.0	0.5	2.4	8

[1] Source: Tables 2-4 of the Preliminary Cost Allocation Technical Memorandum (HDR Engineering, Inc. 2012)
[2](HDR Engineering et al. 2012, p. 14)
[3]KDRPP. Revised cost estimates (more recent than that provided here reflect two alternatives under consideration and may vary from $154 million to $185 million ($2012) in net present value (U.S. Bureau of Reclamation and prepared by HDR Engineering Inc 2013) . We retain the earlier estimate.
[4]The Yakima Municipal, or Ahtanum Valley ASR (Golder Associates 2014) is implemented in YAKRW but as part of the Municipal demand component of YAKRW in a way that cannot be easily separated out, so our analysis is conditional on its implementation but does not consider its economic efficacy.
[5]Power subordination costs listed in the construction column represent the foregone cost of electricity sales from annual decreases hydropower production over the months of April – June (U.S. Bureau of Reclamation 2011d). Please refer to the Power Subordination appendix for further details.

Construction costs of power subordination reflect the opportunity cost of foregone power consumption in the form of decreased electricity sales. The cost estimates are based on subordination levels of 25,000 MWH annually (U.S. Bureau of Reclamation 2011d) and 2009 power rates (Bonneville Power Administration 2010) that are assumed to be fixed in real terms over the 100 year valuation period. As further described in the Power Subordination Appendix VII.G, the present value of total costs from power subordination are estimated as $13.1 million as noted in the column for "construction costs" in the above table. We estimate this value by multiplying the total amount of power subordinated by month (in MWh) by mid-range, monthly electricity rates ($/MWh). We then discount the annual cost of foregone electricity sales and sum across years. For consistency with the YAKRW model, the enhanced agricultural conservation component does not include KRD and Wapatox canal improvements (HDR Engineering, Inc. and Anchor QEA 2011; HDR Engineering, Inc. 2014) that are identified as separate line items in previous planning documents (HDR Engineering, Inc. 2012). Costs of fish passage projects at Kachess, Keechelus and Tieton were evenly distributed where planning documents presented aggregate estimates (HDR Engineering, Inc. 2012). Detailed cost estimates of fish passage at these sites has not been conducted (HDR Engineering Inc. and Anchor QEA 2011).

1. *Discounting for consistency with benefit estimates*

All present value benefit estimates presented in Sections IV.D and IV.G are based on accruals beginning immediately. The costs presented in Table 7 are based on the beginning of construction as the initial time point (HDR Engineering 2012). For consistency in comparing the costs and benefits, the completion date of projects and the advent of benefits from that project must coincide mathematically in present value calculations.

The estimated completion times for water storage projects are all either three or four years (HDR Engineering et al. 2012, p. 14). Consider two projects. One takes three years to complete, with present value of costs at beginning of construction of PVC_3 and present value of benefits of PVB_3 beginning at completion time (three years after start). The other takes four years to complete with PVC_4 at beginning of construction and PVB_4, beginning at the end of construction. To make these benefits and costs comparable from the perspective of the beginning of construction, we can either discount benefits with reference to the beginning of construction compare PVC_3 with $PVB_3(1.04^{-3})$ and PVC_4 with $PVB_4(1.04^{-4})$ (assuming an interest rate of 4%). Or, we can inflate costs so as to reference the beginning of benefits, comparing $PVB_3$and PVB_4 with $PVC_3(1.04^3)$ and $B_4(1.04^4)$, respectively.

Comparing the costs against benefits for a suite of projects with different construction times is slightly more cumbersome. Because costs are in all cases separable across projects but benefits from all projects in a scenario simulated in YAKRW begin simultaneously, it is most direct to inflate costs for projects independently and compare the following two aggregate amounts:

$$PVC = PVC_3(1.04)^3 + PVC_4(1.04)^4, \text{ and } PVB = PVB_{3+4},$$

where PVB_{3+4} are the sum of the present value of benefits from projects 3 and 4. To change the reference to the beginning of construction of the most lengthy construction process (four years), the present value of both benefits and costs can be discounted by T periods, which may be four years from beginning of construction (T=4), or some other time-point of interest in the future:

$$PVC = 1.04^{-T}(PVC_3(1.04)^3 + PVC_4(1.04)^4), \text{ and } PVB = 1.04^{-T}(PVB_3 + PVB_4).$$

This sets the reference point for the benefits and costs at the beginning of the longest construction project and all projects are completed at the same time. These conventions allow a temporally consistent method for comparing benefits and costs for one or more projects, and allow direct comparison across projects, regardless of the actual start times, which may vary. Specifically beginning in Section IV.D, discounting is applied such that benefits begin contemporaneous with the end of construction of all projects, four years in the future, which is the presumed duration of the longest construction projects.

Agricultural conservation and Tributary / mainstem fish habitat enhancement are slated to take place over 18 years instead of three or four. The consequence of this is that the benefits do not accrue until projects are implemented, so benefits ramp up over this time period also. YAKRW implements these benefits, as with the others, as if they begin to accrue immediately upon project completion. However, because conservation activities as described make up a series of projects, their benefits accrue over the course of this time frame as well, not just at the final conclusion of construction. If we assume that these accrue evenly over the 18 years, it can be shown that their respective present values will be discounted to 72.6% of the value if accrual began immediately.

For the YAKRW runs that correspond to the IP as a whole, other than the agricultural conservation component, the projects all have duration of three or four years. We therefore, again, solely for comparison purposes, we assume that the IP would take four years to complete, and therefore discount IP benefits by four years relative to costs.

2. Cost uncertainty

This report largely takes previously estimated costs as given. Further, due to the complex interactions between the benefits that we examine in this report, we have opted to not systematically consider uncertainty and variance in projects costs for any specific projects. For further background on cost uncertainties, the Four Accounts analysis (end of Appendix D) provides a very general breakdown of estimated cost variance (in terms of percentiles) for the IP as a whole. It reports, for example that given their probability distribution over costs, their 10^{th} percentile estimate for the costs of the full IP is \$2.7 billion, the median cost (50^{th} percentile) is \$3.3 billion, and the 90^{th} percentile estimate is \$4.4 billion. Thus, the 10^{th} percentile estimate is 81% of the median, and the 90^{th} percentile is 133% of the median. This general rule could be applied to generate a rough estimate of the cost distribution for individual projects. However, the Cost Risk Analysis (HDR Engineering Inc. and Anchor QEA 2011) provides cost risk assessment for six potential IP project alternatives, and the Costs of the Integrated Water Resource Management Plan Technical Memorandum (HDR Engineering Inc. and Anchor QEA 2011) provides additional details as well.

IV. Results

The results of our analysis are presented in several stages in approximately the same order that methods are discussed in Section III. We begin with selected results from the hydrologic modeling. The economic benefits of water storage projects for agriculture (Section IV.D.B) and for municipalities (Section IV.D.C) are then examined, followed by an analysis of the net benefits of water storage projects of out-of-stream uses and the implications in terms of the opportunity cost of instream flows (Section IV.D). Results pertaining to the benefits of fish passage and restoration follow in Section IV.E. A discussion of some unquantified economic impacts is discussed in Section IV.F, and individual IP project summaries are presented in Section IV.G.

A. Hydrologic modeling summary

As described in Section III.B, we use the hydrologic model YAKRW to simulate basin-wide curtailment rates for each IP scenario and climate regime. Table 8 provides summary statistics for the mean curtailment, the probability of curtailment, and the mean non-zero curtailment given the baseline IP scenario and the different climate regimes.

Table 8: Mean curtailment, probability of curtailment, and mean nonzero curtailment for the different climate regimes considered.

	Mean c (%)	Probability c>0	Average c given c>0	Probability c ≥ 70
Historical, Baseline	11.1	0.39	28.6	0.02
CGCM, Baseline	16.0 (p=0.063)	0.66	24.2	0.01
HADCM, Baseline	31.3 (p=0.000)	0.85	36.8	0.13
HADGEM, Baseline	56.4 (p=0.000)	1.00	56.4	0.39
Historical, Full IP	10.0	0.44	23.0	0.00
CGCM, Full IP	13.1 (p=0.098)	0.67	19.6	0.00
HADCM, Full IP	28.3 (p=0.000)	0.87	32.7	0.04
HADGEM, Full IP	48.8 (p=0.000)	1.00	48.8	0.28

p-values are the probability of the mean being equal to the historical mean against the alternative that the future climate mean curtailment is larger.

The mean annual curtailment under the baseline historical climate regime is 11.1%; the probability of curtailment (proration <1) is 39%, and the mean curtailment rate given curtailment greater than zero is 28.58.[23] The intermediate climate change regime (HADCM) induces a mean curtailment rate of 31.38%, a probability of curtailment of 85%, and mean curtailment rates when positive of 36.76%. Under the most adverse climate scenario, the mean curtailment under the baseline (no IP) scenario is 56.4% and the probability of curtailment is 100%. Thus, these simulations suggest that adverse climate change has the capacity to increase the rate and magnitude of curtailments in the Yakima Basin. Figure 14 shows the curtailment sequence for the historical climate regime (black dots) and the most adverse climate regime that we simulate (HADGEM1), with means for the other two climate regimes shown as dotted lines.

Our data span 1925-2009 for historical data, and 1925 to 2006 for the future climate regimes. There have been no curtailments since 2005, so were these data included, the mean curtailment rates for the historical data would be lower if more recent data were available. Further, because the future

[23] YAKRW provides close estimates of mean annual curtailments, it tends to simulate small positive curtailments that are not actually implemented. Which is to say that when YAKRW curtailments are positive by small (i.e. less than about 10%, actual basin-wide curtailments tended not to be implemented. The implication is that the simulated probability of curtailment is higher than the actual probability of curtailment.

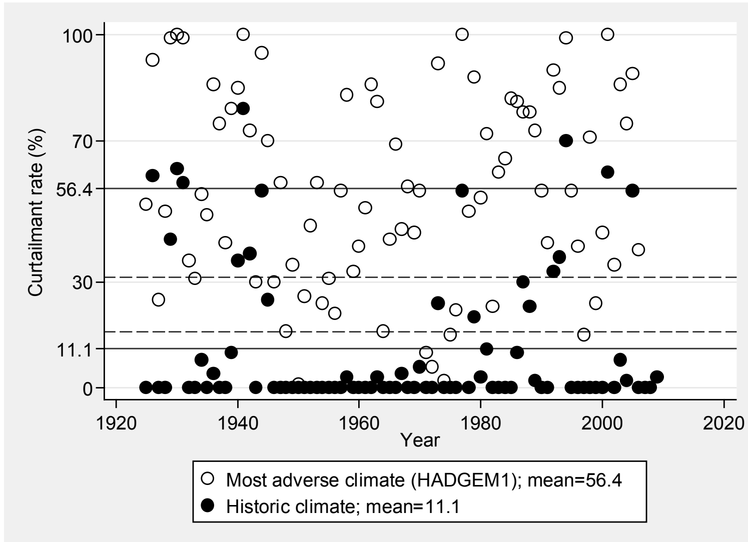

Figure 14: A comparison of historical and most adverse climate scenarios (HADGEM1), Baseline (no IP).

climate scenarios are basically "shifted" historical data based on CMIP 3 climate models, mean curtailments would be lower for these regimes as well if more recent data were available.

A comparison with the Four Accounts assumptions regarding the probability of severe curtailments will be useful for interpreting results later, especially because there is some ambiguity over the probability of a severe drought as described in the Four Accounts analysis. Table 12 in the Four Accounts Analysis describes their basis for calculating a probability of curtailment as "severe, 1-year droughts would occur every 5 years. A severe, 3-year drought would occur every 20 years" (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012). This statement is ambiguous in the sense that it can imply at least three different curtailment probabilities: 0.30, 0.32, and 0.35.

But there is also another way of calculating the implied probability of drought using their numbers. In the Four Accounts analysis, they find a benefit of $150 million in net farm earnings per year of severe drought. They conclude also that the expected net present value of this $150 million annuity over 100 years with a 4% discount rate is $0.8 billion ($800 million), which implies a definitive probability of drought since they assume only one type of drought (a severe one). Based on the standard annuity formula described below, this implies a probability of severe drought of 0.2176.[24]

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[24] The value of any (constant) annuity X received over 100 years with a 4% interest rate is $X \times d$, where

$$d = \frac{1 - 1.04^{(-100)}}{0.04} = 24.505.$$

The expected value of the integrated plan in any year is the probability of a drought times the benefits given a drought, so Table 13 and the associated description in the Four accounts analysis implies $d \times (\pi \times 150) = 800$, which implies that π, the probability of a curtailment, is calculated as $\pi = \frac{800}{d \times 150}$=0.2176.

Table 8 shows that curtailment of 70% or more happens about 2% of the time (0.02), and is higher than 0.2176 only under the most adverse climate regime. The implicit probability of curtailment that we calculate as 0.2176 is most likely driven by a combination of discounting and delayed implementation. It follows also that given their definition of a severe drought as 30% proration (70% curtailment) with no IP and that there is no curtailment with no drought, the average curtailment rate with no IP is $0.2176 \times 70\% = 15.232\%$.

Table 9 provides a comparison of mean curtailment rates between the baseline (no IP) and the full IP under the four climate scenarios. The difference in curtailment between the two IP scenarios increases in magnitude and (with one exception) statistical significance with increasingly adverse climate.

Table 9: Mean curtailment rates under baseline and Full IP, four climate scenarios

	Mean curtailment, Baseline	Mean curtailment, Full IP	Difference	Probability that mean c is lower with the IP than without (p-value)
Historical	11.09	10.00	1.09	0.3495
CGCM	15.96	13.15	2.82	0.1586
HADCM	31.38	28.27	3.11	0.2194
HADGEM	56.40	48.83	7.57	0.0384

Using the full available history of curtailments from 1925 to 2009, the mean annual curtailment under the baseline scenario is 11.09%, but under full IP implementation, the mean curtailment is 10.00%, for a difference of 1.09%.

Recall from above that the mean annual curtailment in the Four Accounts analysis for the No IP case is 15.232%. The analogous mean curtailment rate with the full IP is $0.2176 \times 30\% = 6.528\%$. The difference in the mean curtailment rate with the IP versus without is therefore $15.232 - 6.528 = 8.7\%$ based on the Four Accounts method. This difference is eight times the difference indicated by the HDR implementation of YAKRW over the full historical sample of 1925-2009, and more in line with the 7.57% difference under the most adverse climate regime. This will prove to be important factor in the estimated impacts of IP project.

B. Benefits to agriculture

To provide context for the reported individual project benefits, we begin by examining the relationship between curtailment and the net value of agricultural production. Because the benefits of individual components of the IP are dependent on implementation of other components of the plan, we provide an array of simulation results, including overall benefit estimates, individual-project benefit estimates, water market development impacts, and estimates of the opportunity cost of proposed changes in instream flows under the IP, all for various climate regimes.

1. *Relationship between curtailment, trade, and production value*

In the results that follow, we provide a battery of estimated benefits to agriculture for various IP scenarios, conditional on different climate regimes and different market regimes. As discussed in Section III.C.2, our working definitions of *no trading*, *intra-district trading*, and *inter-district trading* are designed to represent hypothetical bounds of complex processes, and are defined as follows:

1) *No trade* is implemented as proportional curtailment of crops in each district as a function of the districts curtailment rate, regardless of crop type.
2) *Intra-district trade* allows frictionless trading within districts.
3) *Full trade* allows frictionless trade across districts with some restrictions.

For most IP/climate scenarios, results for all three market outcomes are presented. In general, the results for "No trade" and "Full trade" represent hypothetical outer bounds for the continuum of results. Intra-district trade represents an intermediate outcome between No Trade and Full Trade assuming frictionless intra-district trading. While even the intermediate case of intra-district trade corresponds to a hypothetical frictionless trading scenario within districts, our results show that not only is it a useful intermediate benchmark for assessing IP scenario outcomes, but it helps illustrate the potential of intra- and inter-district trading for mitigating curtailment impacts. Given the reality of institutional constraints and market frictions, however, these frictionless outcomes are not in general achievable, but instead should be interpreted as they are --- benchmarks for the range of possibilities.

Figure 15 provides two perspectives on the value of water as a function of water available for irrigation. The left panel of Figure 15 shows the net value of agricultural production as a function of curtailment under the three market scenarios. The value of production corresponding to zero curtailment is on the left of the graph, and is equal across trading regimes. The flat region of the curves on the left results from irrigation districts not currently using their full water entitlement in an typical non-curtailment year. As the curtailment rate increases beyond this region, the value of

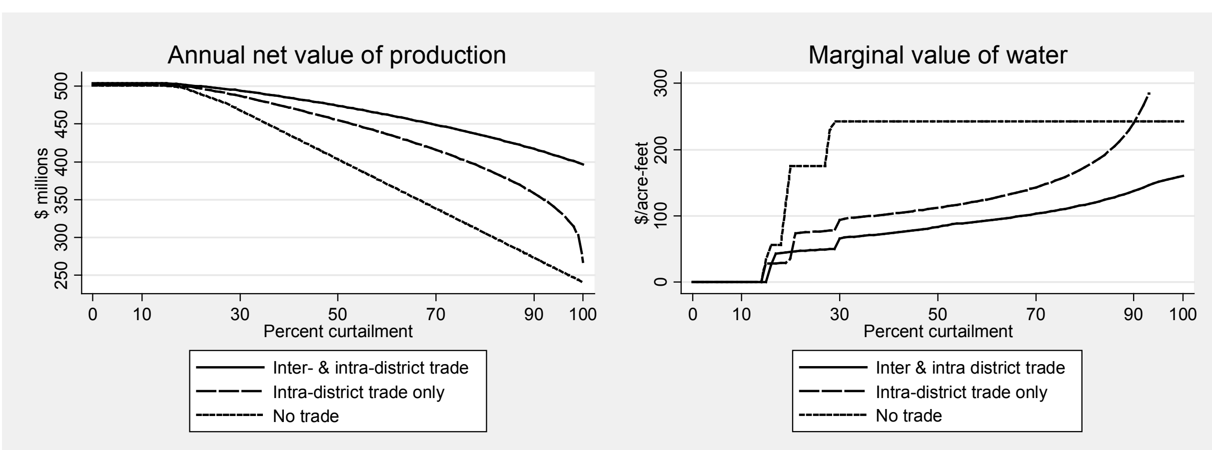

Figure 15: The net present value of agricultural production and the marginal value of water, aggregate over all districts.

production declines. However, it declines fastest for the "no trade" (proportional curtailment) scenario. Allowing for selective fallowing across crops within districts is equivalent to allowing intra-district trade, and this mitigates the losses in production that result from curtailment, represented by the middle line in the left hand graph. Allowing for both intra- and inter-district trading alleviates the impact of curtailment even further. None of these curves drop to zero because of districts' non-proratable water rights.

The right panel of Figure 15 shows the marginal value of water --- the value of one af/year given the curtailment rate, which is equivalent to the marginal cost of curtailment in terms of lost production value. In general, the marginal value of water increases as curtailment increases. The distinct steps in these functions between curtailment of 10% and 30% correspond to the curtailment rates at which districts begin to be water constrained (recall that they do not use their full entitlement in an typical non-drought year). The "no trade" case assumes that all crops are fallowed proportionally regardless of the marginal productivity of water, so the marginal value of water to a district is equal to the acreage-weighted mean value of productivity lost per af of curtailment across all crops in the district. Because high-value crops and low-value crops are curtailed by the same proportion, the cost of curtailment, and therefore the marginal value of water, is high but constant in a district once curtailment becomes binding. Intra-district trade allows selective fallowing such that crops with low marginal water value are fallowed first, which reduces losses due at low levels of curtailment. As the curtailment rate increases, increasingly high-value crops are fallowed, leading to an upward sloping marginal water value function. The highest valued crops are fallowed at very high level of curtailments, at at this point the marginal value of water is at its maximum. When intra- and inter-district trading is allowed flexibility for selective fallowing is maximized, so the cost of curtailment (and the marginal value of water) is lowest.

Table 10 provides some specific values corresponding to Figure 15 around which the proposed IP is designed, and the Four Accounts analysis is based. A stated goal for the IP is to guarantee a proration rate of not less than 70% (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012), which corresponds to a curtailment rate of 30%. With no trade (proportional fallowing), a curtailment rate of 30% result in a loss of $32.8 million. With frictionless intra-district trade, these losses are reduced to $14.4 million, and with robust intra- and inter-district trading, the simulated loss would be $9.5 million.

Table 10: Impact of 30% and 70% curtailments on aggregate annual production value ($millions).

Curtailment %	No trade	Intra-district only	Full trade
30	32.8	14.4	9.5
70	162.9	85.5	54.8

To assess the value of the IP, the Four Accounts Analysis relies on assumed distributions of a "severe drought", which they define as a drought for which the proration rate is 30% (curtailment of 70%). They estimate that given no intra-district trading and 30,000 af of inter-district trading (which we will refer to as "limited-trading"), the cost to agriculture of a proration rate of 30% is $163 million (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012, 39). Table 10 indicates an almost identical loss of $162.9 million for the four districts assuming no intra- or inter-district trading. (This excludes YTID which is not included in the Four Accounts losses; there are also no losses from senior KSR rights).

Based on relatively restrictive assumptions, the Four Accounts analysis suggests that IP market improvements could reduce drought-year losses by $40 million (U.S. Bureau of Reclamation, ECONorthwest, and State of Washington Department of Ecology 2011, Table 1). Our results show that the loss in annual net value under a 70% curtailment with efficient intra-district trading is $85.5 million, a reduction of about $77 million and less than half of the No Trade impact. With full intra- and inter-district trading the loss is $54.8 million, which is 34% of the losses under no trade. While the full-trade results should be interpreted as an outer bound on impacts, they do suggest that there is a large potential for gains from trade during drought years. Further, a review of the IP by Normandeau Associates et al. (2014) estimates a difference between the baseline evaluated at 70% curtailment and 30% curtailment at $77.2 million. Our estimate of this difference is $85.5-$14.4=$71.1 million. Thus, these estimates are very close to each other.

The left panel of Figure 15 shows that the value of production declines fastest with proportional curtailment, and slowest with full intra-and inter-district trading. With intra-district trading alone, the costs of curtailment are reduced within a district fallowing crops with the lowest marginal water value first, and move alone the district's inverse demand curves from right to left as water is curtailed. Inter-district trading scenarios allow water to move from one district to another. Figure 16 shows how water moves from one district to another in simulation as curtailment increases from zero to 100. No trading occurs up to the point where curtailment is a binding constraint to one or more districts (at a curtailment rate of approximately 20%). At this point, the simulation shows that Roza begins to buy water and continues to do so, while Kittitas Senior (KSR) sells water throughout.

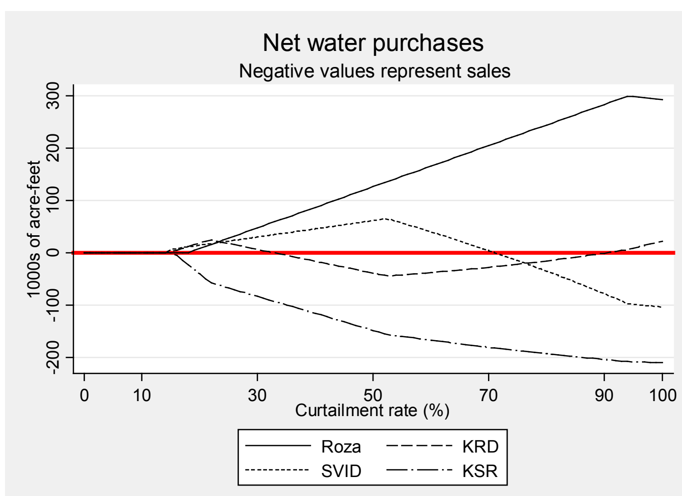

Figure 16: inter-district trade outcomes among trading districts.

SVID buys water at first, but at higher curtailment rates switches to become a net buyer, and KRD tends to sell at low curtailment rates, but buys at the highest curtailment rates.[25]

2. *Agricultural benefits of the IP*

Table 11 compares outcomes under no inter-district trading with outcomes with frictionless intra- and inter-district trading. The table has two data columns, one that corresponds to the baseline for evaluating the IP (HDR scenario 7.1) and one corresponding to the full implementation of the IP (HDR scenario 7.8).

Table 11: Agricultural benefits from IP with intra- and inter-district trade, $ millions. Historical climate regime.

Row	Value	Baseline (HDR 7.1)	Full IP (HDR 7.8)
1	Expected annual ag value, no trade	482.2	488.5
2	Expected annual ag value, intra-district trade only	492.1	495.6
3	Expected annual ag value, Full trade	497.8	500.0
4	Difference from baseline (HDR 7.1), no trade	--	6.3
5	Difference from baseline (HDR 7.1), intra-district trade only	--	3.4
6	Difference from baseline (HDR 7.1), Full trade	--	2.2
7	Present value of ag production, no trade	11,818	11,972
8	Present value of ag production, intra-district trade only	12,060	12,144
9	Present value of ag value, Full trade	12,198	12,252
10	Difference from baseline (HDR 7.1) no trade	--	154.0
11	Difference from baseline (HDR 7.1), intra-district trade	--	84.3
12	Difference from baseline, Full trade	--	53.4
13	Present value of intra-district gains from trade	242.3	172.6
14	Present value of inter-district gains from trade	138.6	107.7
15	Present value of gains from Full trade	380.9	280.3

The first three rows of data provide the annual expected value of agricultural production given the three trading regimes, respectively, based on the historical distribution of curtailment from 1935-2009 along with current crop acreage allocations. Rows 4-6 provide the difference in these annual expected values from the baseline case (HDR 7.1) for the trading regimes and IP cases. Depending on the trading regime, the IP as a whole provides average annual benefits to agriculture of $6.3 to $2.2 million/year. This illustrates that markets attenuate the value of additional water storage because they reduce the impacts of curtailment.

Rows 7-9 provide the expected net present value of agricultural production for each trade regime calculated as the sum of the present value of the annual expected value for each of 100 years given a

[25] KRD and KSR are relatively high in the basin. Third-party effects might preclude KRD from buying from SVID (at the high curtailment rates, above 90% for example), however, these trading results are consistent with KRD buying from KSR, which would be less likely to impose third-party effects and therefore less likely to be restricted from trade.

4% discount rate for a given trading regime. Rows 10-12 provide the expected present value of benefits from the IP, ranging from $154 million in agricultural benefits over the baseline assuming no trade, $84.3 million with intra-district trade, and $53.4 million with full trade.

Our largest estimate for the present value of benefits to agriculture of the integrated plan of $154 million is only 19.3% (about one fifth) of the estimated benefits presented in the Four Accounts Analysis of $800 million (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012, 39), despite the fact that both analyses use the same crop production model. The primary reason for this is the difference between the assumed frequency and magnitude of curtailments used in the Four Accounts analysis, the mean of which is eight times larger than the mean curtailment for the historical climate regime as illustrated in Table 9, Section IV.A. Assumptions about climate and curtailment are clearly crucial in estimating the value of the IP and its water storage projects.

Data rows 13 through 15 in Table 11 provide the present value of gains from trade. Relative to proportional curtailment, the present value of agricultural production is higher with intra-district trade, with inter-district trade, and with full trade, providing $242.3 million, $138.6 million, and $380.9 million, respectively under the baseline of no IP. Were the IP implemented, the gains from intra-district trade, inter-district trade, and full trade are $172.6, $107.7, and $280.3 million, respectively. These present values are based on a 4% interest rate. If the current Federally-set interest rate of 3.5% is used, these values are $194.7, $121.6, and $316.3 million respectively (about 13% higher). The Full IP provides the lower risk of curtailment to irrigation, both in terms of the frequency and the depth of curtailment, and the value of water markets is lower. In contrast, the gains from trade are highest when curtailments are highest, as under the baseline case (no IP projects) in the table.

The Market-Based Reallocation of Water Resources Technical Memorandum (U.S. Bureau of Reclamation, ECONorthwest, and State of Washington Department of Ecology 2011) provides estimates of the value of market development against which to compare these values. That analysis reports potential gains from trade of $40 million in a given year facing 40% proration (60% curtailment). Assuming a 24.5% probability of such a curtailment implied by Four Accounts assumptions, the expected value of trade would be about $10 million/year. Assuming the historical climate regime under the no IP scenario with only intra-district trade, the implied annual expected value of trade is $8.9 million (this is the annual value corresponding to the net present value over 100 years of $218.6 million in the table). Thus, while the assumptions underlying the Water Resources Technical Memorandum are different than our assumption of efficient intra-district trade only, the results are comparable. For our full-trade scenario, the net present value of $281.3 million presented in Table 11 correspond to expected annual gains from trade of about $11.48 million, which is about 1.8 times higher still, suggesting the potential for additional gains.

3. *Individual project benefits*

Table 12 provides the benefits of one project at a time relative to baseline ("HDR 7.1+1"), and the benefits of adding a project as the final component of the full IP ("HDR 7.8-1"), for each trading scenario under the historic climate regime. Because of diminishing returns to storage, the "7.1+1" provides the upper bound on a project's value, and the "7.8-1" scenario provides the lower bound on project-specific value. For example, were Wymer Reservoir created on its own with intra-district trading but no inter-district trading, it would provide an estimated $86.7 Million in agricultural net benefits over 100 years, but if it were part of a full IP implementation, it would provide about 45% of that, or $39.4 million. This difference again illustrates the diminishing returns to additional water storage. These numbers for Wymer can be compared to the agricultural benefits estimated in a previous report (U.S. Bureau of Reclamation 2008b), in which agricultural benefits are estimated to be $26.5 million, which is less than half of all estimates for Wymer alone presented here.

Table 12: Expected net present value of agricultural benefits of individual projects under historical climate; baseline (HDR 7.1) plus one project at a time, and IP (HDR 7.8) minus one ($ millions)

	No trade		Intra-district only		Full trade	
	One only (Base+1)	all but one (IP-1)	One only (Base+1)	all but one (IP-1)	One only (Base+1)	all but one (IP-1)
KKC	1.9	8.8	1.0	3.9	0.6	2.8
KDRPP	139.3	73.3	78.0	45.2	49.8	28.0
KKC+KDRPP	138.2	79.8	77.9	49.1	49.7	30.2
CEPR	6.6	5.7	3.6	3.0	2.3	1.9
ASR	28.2	24.3	15.4	12.4	9.6	8.2
Conservation	67.0	54.2	35.7	27.4	22.9	19.0
Bumping	111.7	53.5	59.9	29.0	38.5	18.3
Wymer	158.1	71.1	86.7	39.4	55.5	25.3

It is important to note that the baseline case against which the "only one" cases are compared assumes that the proposed IP instream flows are not implemented, while the full IP against which the "all but" comparisons are made assumes that the proposed IP instream flows are implemented, which reduces the amount of water diverted to out-of-stream uses for any given storage scenario.

There is a general pattern evident in Table 12 that each project provides higher benefits when implemented alone than when implemented as part of the IP, with the exception of KKC. KKC does not provide additional reservoir storage capacity, but instead provides benefits through allowing more flexibility to fill Kachess reservoir, and is designed to work in coordination with KDRPP. The higher simulated value of KKC benefits under the full IP may have to do with the fact that KDRPP is implemented (along with KKC) in the full IP.

4. HDR Sequenced scenarios

"HDR Sequenced scenarios" in Table 13 are scenarios corresponding to the proposed sequenced development of the Integrated Plan developed by HDR. These are sequences of the IP with additional project(s) implemented sequentially as the scenario increases (see Table 1 for scenario descriptions).

These results are provided primarily for reference to ongoing proposed IP planning. However, the impact of diminishing returns to storage can be discerned from this table. For example, HDR 7.5

implements KKC, KDRPP, and the Cle Elum pool raise. HDR 7.6 is the same as 7.5 except with the addition of Wymer. As such, the difference in present value represents the value of adding Wymer conditional on implementation of these other three storage projects. For example, assuming intra-district trading only, the value of Wymer is 140.4-87.7 = $52.7 million, which is (as expected) below its value if implemented alone ($86.7 million as shown in Table 12). It is also above its value if implemented as part of the full IP and $39.4 million (Table 12), though this difference is confounded by the fact that IP instream flows are also implemented in this case.

Table 13: HDR sequenced scenarios. HDR 7.1, baseline (historical) sample ($ millions)

	Net expected present value of production/year			Present value of difference from baseline (HDR 7.1)		
HDR run	No trade	Intra-district only	Full trade	No trade	Intra-district only	Full trade
7.1 (Baseline)	11,818	12,060	12,198	--	--	--
7.2	11,902	12,105	12,227	84.7	45.2	28.8
7.3	11,902	12,105	12,227	84.7	45.1	28.6
7.4	11,967	12,143	12,252	149.6	83.2	53.1
7.5	11,977	12,147	12,254	159.1	87.7	55.9
7.6	12,082	12,200	12,288	264.1	140.4	89.2
7.7	12,117	12,216	12,298	299.5	156.6	99.5
7.8 (Full IP)	11,972	12,144	12,252	154.0	84.3	53.4

5. Climate change scenarios

Under the most adverse climate regime examined (HADGEM), the average curtailment rate is 56.4% (hollow circles). The two intermediate regimes, CGCM and HADCM, lead to mean curtailment rates of 15.96 and 31.38, respectively (see Section IV.A). The increase in curtailment rates under CGCM occur despite the fact that precipitation is predicted to increase by 13.4% over baseline, though this change would be accompanied by an increase in the proportion of precipitation in the form of rain instead of snow.

Table 14 provides results for a series of climate forecasts, as well as additional comparisons to illustrate the potential benefits from trade. The first corresponds to the full IP assuming the historical climate regime. With no trade, the present value of benefits is $154 million. The net benefits to agriculture under the full IP drop by 45% to $84.3 million with efficient intra-district trading, and to about $41 million with both intra- and inter-district trading. This is because effective trade alleviates the impacts of curtailment for any given water storage scenario, and therefore attenuates the benefits of adding storage.

As might be expected, the agricultural benefits of the IP as a whole increase with increasingly adverse climate scenarios. Given no trade (proportional fallowing), the benefits of full IP climb as the climate scenario becomes more adverse, by about 39% (from $84.3 to $116.9 million), by 192% (to $246.6 million) and about 355% (to $383.9 million) for the increasingly adverse climate regimes, respectively.

Table 14: Expected net present value of agricultural benefits of the IP under different regimes. Baseline=HDR 7.1 ($ millions)

Climate Scenario	No trade	Intra-district trade	Full trade
IP (HDR 7.8), historical climate	154.0	84.3	53.4
IP, least adverse climate regime (CGCM)	214.0	116.9	74.0
IP, moderately adverse climate (HADCM)	390.9	246.6	142.0
IP, most adverse climate (HADGEM)	649.2	383.9	235.8

In Section IV.A, we estimate that under our interpretation of the Four Accounts assumptions, the implied mean curtailment rate with no IP (baseline case) is 15.23%. The climate regime that provides the closest approximation to this mean curtailment rate is the CGCM regime, which induces an mean curtailment rate of 15.96% under the baseline scenario (HDR 7.1). We therefore provide in Table 15 the results of "one only" and "all but one" project implementations for comparison.

Table 15: Expected net present value of agricultural benefits of individual projects; CGCM climate scenario baseline (HDR 7.1) plus one project at a time, and IP (HDR 7.8) minus one ($ millions).

CGCM	No trade		Intra-district only		Full trade	
	One only (Base+1)	all but one (IP-1)	One only (Base+1)	all but one (IP-1)	One only (Base+1)	all but one (IP-1)
KKC	12.1	1.6	6.1	1.2	4.1	0.9
KDRPP	134.2	64.3	77.3	35.3	48.3	21.8
KKC+KDRPP	157.0	60.3	88.0	33.2	56.5	20.8
CEPR	6.6	9.1	3.3	4.1	2.5	2.9
ASR	48.4	30.2	25.2	14.3	15.9	10.4
Conservation	21.8	1.1	12.5	0.8	8.1	0.4
Bumping	124.0	68.0	67.9	33.1	43.3	21.3
Wymer	194.4	87.5	107.1	46.4	68.6	29.2

A comparison of Table 15 and Table 12 shows that the value of water storage projects is in general higher under CGCM, as would be expected under a more adverse climate regime. However, there are some anomalies in this pattern for KKC and agricultural conservation, which are the two projects that do not provide additional storage. Conservation in particular shows substantially lower value under CGCM (Table 15) than under the historical climate regime (Table 12). It is not clear why this might be the case. However, we will consider these issues again later when we summarize the results for these individual projects in Section IV.G.

Table 16 provides agricultural benefit estimates of individual projects for Base+1 and IP-1, assuming the most adverse climate scenario (HADGEM). The HADGEM Base+1 results provide the highest estimated benefits for all storage projects under more adverse climate regimes (all else constant), and therefore these estimates represent the largest benefit estimates that we report. As illustrated in Table 12 the contribution of individual projects will tend to decline if more than one project is implemented.

Table 16: Net present value of agricultural benefits under the most adverse climate scenario (HADGEM). $ millions.

HADGEM	No trade		Intra-district only		Full trade	
	One only (Base+1)	all but one (IP-1)	One only (Base+1)	all but one (IP-1)	One only (Base+1)	all but one (IP-1)
KKC	58.0	106.8	29.2	75.4	17.8	41.1
KDRPP	265.0	198.5	182.5	149.6	110.4	85.0
KKC+KDRPP	570.5	213.0	370.2	162.8	219.7	90.9
CEPR	35.6	0.4	16.7	-1.0	10.6	-0.5
ASR	178.4	129.7	104.5	121.7	65.4	53.0
Conservation	-0.1	10.1	-12.8	16.2	-1.8	4.6
Bumping	518.1	183.2	316.2	115.2	188.8	66.7
Wymer	867.0	328.4	585.6	256.8	337.0	133.6

Consistent with previous patterns, each storage project provides highest benefits with No Trade, and lower benefits with Full Trade. However, again, Conservation provides negative benefits under the full IP, and now CEPR provides negative benefits under the intermediate and full trade scenarios. Further, KKC and Conservation alone again provide higher benefits under the full IP than when implemented alone. The latter we have already discussed in the context of the CGCM results in Table 15 and so we will not revisit this issue.

The negative results for Conservation and CEPR occur only when the change in expected curtailment is exceptionally small. The base case for the expected curtailment under the Full IP minus CEPR is E(c)= 48.890, and the base case for comparison is the Full IP (7.8, HADGEM) is E(c)= 48.829, for a difference of only 0.061%. For agricultural Conservation, the baseline (HDR 7.1) expected curtailment is 56.402 and the expected curtailment is 56.378, a difference of only 0.02%. These small differences in curtailment lead to what amounts to rounding and simulation error. The benefits should be interpreted as zero in these cases. the Agricultural Water Conservation Technical Memorandum (U.S. Bureau of Reclamation, Washington State Department of Ecology, and Prepared by Anchor QEA 2011) states "In addition, these water savings are estimated for years when water users have a full water supply. Therefore, in drought years the water savings would be reduced because less water would be conveyed through irrigation systems and applied to farms, which, in turn, reduces seepage and other losses and results in less return flow. (p. 3)" Curtailment happens in every year under this scenario, which is likely to be the reason for these YAKRW results. See HDR Engineering, Inc. and Anchor QEA (2011) for more detail on YAKRW hydrologic modeling and results.

6. *Supporting evidence of the value of low curtailment risk: evidence from land sales*

While the above analysis relies on YAKRW simulation and estimates of water value conditional on current, static irrigated crop acreage allocations in the irrigation districts, there is additional empirical evidence that can corroborate, to a limited extent, the magnitudes of the simulated effects presented above. We provide some supporting evidence for the order of magnitude difference in the results we are reporting.

The market value of a property and an associated water right reflects the sum of benefits received from that land and water right. As such, an examination of irrigated land transactions provides an alternative method to estimate the effect of water supply volatility and incorporates the potential for a landowner to adapt to changing economic and environmental conditions. Brent (2014) estimates a hedonic price model to quantify the premium associated with a senior water right on agricultural land in the Yakima River Basin. Senior water rights are defined either as the percentage of senior rights held by an irrigation district or an indicator variable if the district holds more than 50% senior rights, which has been found to sufficiently insulate districts from droughts. The results indicate that on average additional water security associated with senior water rights is not capitalized into farm values.

This result relies on variation in water rights at the irrigation district level, which constitute the majority of water rights in the Yakima Basin. It is difficult to assess the role of water rights in driving variation in farm values across districts relative to other unobserved factors specific to the irrigation district. In particular the Wapato Irrigation Project constitutes 19% of all junior sales and lies within the Yakima Nation Reservation making it challenging to disentangle whether lower property values are due to less secure water rights or the factors associated with the reservation. Omitting an indicator variable for the Yakima Nation reservation results in a statistically significant senior premium of approximately 11%. One method to test the effect specific to irrigation districts is to examine all sales on either side of a border between a junior and senior district. A boundary discontinuity analysis (Black 1999) indicates that even without controlling for the reservation there is no premium for senior rights when restricting the sample to land near the border of senior and junior districts.

Despite the lack of a premium at the basin level, Brent (2014) shows that there is heterogeneity across counties, as Kittitas County exhibits a positive and significant premium of 24% (Brent 2014), for further information see Brent (2014). One explanation for the lack of a premium is that there are relatively low-cost mechanisms to cope with water supply volatility. There is evidence that supplemental water rights mitigate the effects of water volatility since private rights strongly capitalize into farm values in junior districts, but not in senior districts. Using the relative premium for farmland with senior rights provides an alternative to the production function approach applied by the USBR.

Table 17 presents the estimates from Brent (2014) for the benefits to the agricultural sector from storage enhancement in the Integrated Plan for three econometric modeling scenarios. Estimates for the gains to agricultural production are calculated by multiplying the per-acre premium for land with senior water rights by the irrigable acres of land with junior rights. The analysis is restricted to land served by the Yakima Project since data are readily available, making the results an effective lower bound on the benefits for the whole basin. Using the hedonic approach, the point estimates of benefits for increasing water supply security range from \$28 million to \$92 million depending on whether the parameters stem from the BMA, the base results, or the county level regressions.

Table 17: Estimates for Benefits from Increased Water Security in Yakima Basin

	Mean	Lower 95%	Upper 95%
Aggregate (BMA)	$27,789,981	-$125,859,536	$181,439,499
Aggregate (Base)	$54,395,045	-$63,328,439	$179,228,339
By county	$91,819,156	-$76,533,776	$133,431,079

Notes: The estimates are derived from parameters of the posterior distribution for the senior water right dummy variable. Estimates are scaled by using acreage of agricultural land with junior water rights in the Yakima Basin and the mean real price of agricultural land in 2008 dollars.

Examining the 95% confidence intervals reveals that the all the estimates include zero. This shows that the statistical results are relatively imprecise, and it means that we cannot (based on conventional confidence levels) reject the hypothesis the water security premium is zero. Nonetheless, none of the upper bounds are close to the $400 million estimate in the Four Accounts analysis. Indeed, the highest upper bound is $181 million.

Recall from Table 11 that our estimates of the benefits of the Full IP relying on the historical climate regime is $154 million, $84.3 million, and $53.4 million with no trade, intra-district-only trade, and full trade, respectively. The estimates made by Brent (2014) of $92, $54, and $27 million are similar to this range. While an exact comparison of these two estimates is not the goal of this analysis, these findings are important because they corroborate our findings in order of magnitude.

7. Summary of agricultural benefits from IP projects

The results presented in this section consistently illustrate (a) diminishing marginal economic returns to water storage, (b) more robust trade reduces the impacts of curtailments for a given amount of storage, and (c) more robust trade reduces the economic returns to new water storage in the basin, and (d) more adverse climate regimes increase the economic value of water storage.

C. Benefits to municipalities and domestic users

Following the approach in the Four Accounts analysis and our methodological approach developed in Section III.C.3, we report benefit estimates for the IP relating to two sources of demand: benefits that follow from avoided costs to municipalities of having to purchase water for new growth, and benefits to existing users of the IP plans to improve water market mechanisms.

1. Water security

In the water security component of the Four Accounts municipal/domestic analysis, the price of $2,500 is used to represent municipal/domestic willingness-to-pay for senior water rights, but it is applied as if it were an annual lease, not a permanent purchase. This has substantial consequences for the estimated impacts. As mentioned in Section III.3, the Four Accounts analysis assumes a marginal value of $1,000 for a senior(in this case non-proratable) right for agricultural irrigation such that the net value (gains from trade) are $1,500. However, by their own description, this value represents the net value of the transfer of a permanent right, which is equivalent in present value terms to a perpetual annuity of $1,500×0.04=$60/af/year where 0.04 represents a 4% discount rate. We show in Appendix Section VII.D.2 that the value of a senior water right for agricultural irrigation in an irrigation district with a mix of proratable and non-proratable rights ranges between

$286 and $864 with no IP and historical climate, while we would expect sale prices to be higher than this due in part to transaction costs, it suggests that $1,000/af is in the ballpark. Under a more adverse climate regime, the value of a non-proratable irrigation water right ranges from $1,206 to $3,665. Thus, under more adverse climate regimes, we would expect higher sales prices.

The use of $1,500 as an annually applied water price as a lease price is not supported empirically nor is it consistent with the justification given for using it.[26] Two appropriate uses of these numbers are (a) the sale price of $1,500/af for a permanent transfer is charged only once as a once-and-for-all purchase of a perpetual water right, or (b) the implied annuity value of $60/af/year is charged every year as if it were a recurring lease. Case (a) provides a simple illustration. Suppose the IP market infrastructure immediately provided the basis for trades. Municipalities could purchase 10,500 af of permanent rights at $2,500/af at a total cost of $26.25 million. The opportunity cost (foregone agricultural production value) of that water is $1,000*10,500= $10.5 million for net gains from trade of $1,500/af, or $15.75 million.[27] Discounting as they did in the Four Accounts analysis, which assumed delays in market development, provide a present value of gains from trade of just over $11 million, which is less than one twentieth of the analogous Four Accounts estimate of $280 million.[28] Applying Case (b) and discounting as in the Four Accounts analysis also provides an estimate of $11 million.[29] Appendix VII.D provides the calculations for this number and an approximation of the Four Accounts calculations.

There is another issue for the water security calculations that relates to existing junior water rights. The analysis estimates a willingness-to-pay for secure (senior) water rights for current municipal and domestic water users, but it implicitly assumes that their existing junior groundwater rights are of no value. To the contrary, existing junior groundwater rights are curtailed in low-water years, but provide value when not curtailed. Indeed, rather than assuming the purchase of permanent rights, a reasonable approach to incorporate this value would be to simulate long-term contingent contracts or options contracts (R. E. Howitt 1998; Michelsen and Young 1993; Whittlesey and Huffaker 1995) for water leases such that junior water rights holders can purchase senior water rights for low water years when they face curtailment. Under the historical hydrologic sample, YAKRW simulations suggest that under the full IP curtailment of proratable water rights to any level (that is, a

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[26] We believe this error in calculation may simply have been a mistake. It is noteworthy that Normandeau Associates et al. (2014) independently arrived at the same conclusion.

[27] This number ignores transaction costs associated with these transactions. Transaction costs can in some cases be substantial depending on the specifics of transactions, but tend to be larger per af for smaller water amounts (Colby 1990b). These costs would rightly be subtracted from gains from trade.

[28] The same value for municipal benefits ($280 million) was used for Wymer reservoir in a previous economic analysis of this project (U.S. Bureau of Reclamation 2008b). This estimate was based on an analysis with similar, but not identical, methods and assumptions.

[29] Although not supportable on the basis of being wholesale prices, if instead the larger value of $258/af/year (found in the new demand component of the municipal/domestic analysis) is used instead of $60, the present value of the savings is $48 million.

proration rate less than 1) would occur 44% of the time.[30] Because groundwater rights tend to be junior to proratable water rights, we that junior groundwater rights are curtailed to zero about 44% of years, and municipalities would purchase senior water rights on a spot lease market or contingent contract. The statistical expected value of the costs of these purchases can be calculated as 0.44 × \$11 million = 4.84, or about **\$5** million. Thus, if markets are assumed to be effective at allowing municipalities to cover their groundwater curtailments as described in the Four Accounts analysis, the expected net benefits to municipalities of doing so while making use of their existing groundwater rights is about one fiftieth of the Four Accounts analysis estimate of \$280 million.[31]

With that in mind, there are countervailing reasons as to why the \$5 million calculated above might over- or underestimate potential gains from trade. As noted in Section III.C.3 the \$2,500/af market price for ag-to-muni trades is a representative of a negotiated price that in each transaction falls between a seller's willingness-to-accept and a buyer's willingness-to-pay. The implication is that even if a municipality were to negotiate a \$2,500/af price, their marginal willingness to pay might be higher. For example, if the agricultural producer's opportunity cost is \$1,000/af, and the municipality's willingness-to-pay is \$10,000/af, they may negotiate a price of \$2,500, which would provide \$9,000 in total gains of which \$1,500 would go to the seller and \$7,500 to the buyers. There is a great deal of leeway in the negotiated price in this example (anywhere between \$1,000 and \$10,000), and the price actually negotiated will depend on the relative bargaining position of the two parties. The take-home message of this discussion is that even if the market price of \$2,500/af were a reasonable representation of a market equilibrium, to use \$1,500 --- the difference between the representative equilibrium price of \$2,500 and the opportunity cost of water to agriculture, assumed to be \$1,000 here --- would likely underestimate the gains from trade.[32] On the other hand, the discussion of water markets (Section IV.B.2) suggests that transaction costs, especially in the case of inter-sectoral transfers such as these, might amount to as much as one-third of the gains from trade.

Importantly, none of these water security benefits come from any IP water storage project, but only from the assumption that water markets will become more available as a result of IP activities to facilitate markets. However, to the extent that IP water storage reduces water scarcity in a drought of any given severity (or even in a non-drought year), it will also reduce water market prices, which in turn will benefit municipalities (though with countervailing reductions in agricultural benefits due to the price reductions). This price change is not accounted for in this analysis.

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[30] Note that many of these are small curtailments of less than 5% as YAKRW output, and are often not implemented in actuality. Nonetheless, the point here, in the spirit of the Four Accounts analysis, is that they represent relative drought years and may be the basis for curtailing even more junior groundwater use by municipalities. Therefore, we use this inflated curtailment probability to be relatively conservative.

[31] It might be argued that spot-lease prices will tend to be higher during more severe curtailments, when leasing is most likely. While this is true, a market-based \$1,500/af sale price (corresponding to a \$60/af/year annual lease) in principle accounts for expectations on both the supply and demand side of future curtailments, and so would account for such effects to the extent that they are incorporated into expectations.

[32] In reference to the section that follows: this distinction between market price and buyer willingness to pay is not germane to the discussion of water purchases for new demand that follows.

2. *Benefits for new growth*

There are two accounting issues to address in the Four Accounts analysis in regards to the value of acquiring new water for growth through IP implementation. The first is whether to use $60/af/year or $258/af/year as the marginal water value/cost. The Four Accounts analysis relies on a wholesale water price of $258. Wholesale water rates are generally defined as the rate that one utility charges another utility for water service. Wholesale water is generally priced to cover pre-transfer water treatment, and any transport and administrative costs borne by the seller. Given that these costs would be incurred for municipal water (either directly or through the price of purchase) regardless of whether acquired through the IP or not, it is inappropriate to include these costs when estimating the value of the IP. As such, a wholesale price would be biased upward for the purposes of this analysis. Further, utility-to-utility water prices even net of these costs tend to be higher than irrigation-to-utility transfer prices (Libecap 2010; Brewer et al. 2007), in part because the opportunity cost to utilities is often higher. Thus, given that water sales are likely to come from the agricultural sector, we argue that it is more reasonable to use the value of $60/af/year (instead of $258), which represents the gains from trade of a lease and supports a net present value of gains from trade used in the Four Accounts analysis of $1,500/af (an assumed purchase price of $2,500 minus the opportunity cost to irrigation of $1,000).

Either $60 for annual gains from trade or its corresponding net value of $1,500 the net value of permanent sale could be used to calculate the net present value of market transactions to municipalities. It is useful to begin by supposing that all 10,900 af of water were purchased outright immediately to cover the forecasted growth to 2060. This would lead to gains from trade of 41 [years]X $1,500 X 1193 [af] = $73,369,500. Assume as in the Four Accounts analysis that municipal purchases occur at 1193 acre feet per year as demand increases (all else constant) provides an estimate of $**27 million**, which is less than a quarter of the estimate provided in the Four Accounts analysis.[33] Calculations are provided in Appendix VII.D Table 44, including an approximate recreation of Four Accounts Analysis calculations.

While we have gone to some effort to justify the use of $1,000 as an opportunity cost of irrigation water and $2,500/af to represent an equilibrium agriculture-to-urban trade, there many macroeconomic, environmental, and local factors that can affect equilibrium market prices for water that are subject to uncertainty. In Appendix VII.D we provide a brief and simple explanation of the theory behind the market conditions and prices being used. We also perform some robustness analysis in Section IV.D.2 by examining the impact of differences in the value of a senior water right for agriculture, and by doubling the ag-to-urban sale price.

Another convenient benchmark is to assume that growth continues at the same rate for 100 years, which is the planning horizon for the IP projects rather than increasing demand horizon ending at

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[33] Whether treated (appropriately) as a permanent sale or a recurring lease, using a lease price of $258 or its corresponding permanent sale price of $6,450 provides a net present value of $115 million as reported in the Four Accounts Analysis.

2060. If municipal demand growth continues at an additional 1193 af/year until 2112, the net present value of this the incurred costs would be about $33 million rather than $27 million.

Additionally, the Four Accounts analysis ignores existing inchoate water rights held by municipalities. Based on data from the Washington State Department of Ecology Water Resources Explorer database, the municipalities included in the Four Accounts analysis hold more than enough inchoate rights to cover the forecasted water demand growth to 2060 (State of Washington Department of Ecology 2014b). It is possible that some of these inchoate rights will not be fully available to municipalities to cover future demand growth for a variety of reasons (e.g. court-imposed mitigation requirements for future groundwater use as has occurred in the upper Kittitas for domestic groundwater use), but to the extent these inchoate rights will be available, municipalities will be delayed beyond 2060, or more precisely beyond the point where their current inchoate rights will support them (which is generally beyond 2060 by our understanding of the municipal water rights in the basin).[34]

Finally, because the Four Accounts analysis was published in 2012, plans continue to be developed for the Ahtanum Valley Aquifer Storage and Recovery project (Golder Associates 2014). This ASR project is not addressed in the Four Accounts analysis, but it is integrated in the YAKRW simulations developed by HDR as a source of water for municipalities outside of IP development. In other words, the demand growth assumed in the Four Accounts analysis is partially mitigated by the estimated 6,000 af provided by this ASR. The ASR would capture and store additional later summer water, which in turn would reduce the benefits of the IP to municipalities, regardless of whether this water is used directly for municipal and domestic purposes or diverted for other uses. While we do not incorporate this development explicitly in any analyses, accounting for it would further reduce, perhaps substantially, the estimated benefits to municipalities of the IP.

3. *Benefits due to individual projects*

As described in the Four Accounts analysis, the water security benefits are claimed to result from the improvements in markets that are attributed to the IP. As such, these benefits do not follow from any infrastructure development.

Our approach for allocating these benefits of the estimated $27 million in benefits from support of new municipal and domestic water demand across projects is to allocate them in proportion to each

[34] Another point relates to the exact status of new municipal rights provided by the IP. While the new municipal rights would in principle be junior water rights (relative to all previously acquired water rights), the Four Accounts analysis implicitly assumes that these would be uninterruptible rights. This makes some sense in that municipalities generally must rely on uninterruptible rights for planning purposes, but we have not found any explicit statement in any descriptions of the IP, including the FPEIS, that states that these municipal rights would hold uninterruptible status. If they are interruptible rights, their value would have to be discounted by the expected frequency of interruption. As discussed in the water security section above, if junior water rights are curtailed in 44% of years (assuming the historical climate regime), the expected value net present value of the IP-provided junior water rights would be 66% of the $27 million (senior water rights would need to be leased in the 44% of years in which they would be curtailed). Thus, an estimate of the expected net present value of benefit to municipalities of junior water rights from the IP are 0.66*$27 million = $17.8 million.

project's contribution to water storage. Table 18 provides these contributions.[35] Each of the storage projects, except the Cle Elum pool raise, has the capacity to provide the entire estimated increases in municipal/domestic demand up until 2060.[36] If only one water storage project is implemented in a scenario, it accrues (provides) 100% of the estimated benefits to municipalities/domestic users, with the exception of the Cle Elum pool raise. This proposed project would provide 14,600 af of new water storage, which is only 30% of the estimated 48,900 af of new water demand. Therefore, if the Cle Elum pool raise were implemented alone, the municipal benefits would be 0.30*17.8 =$5.34 million. If two projects are implemented, one providing 100,000 af and the other providing 200,000 af, the smaller of these will be credited with 1/3, and the second with 2/3 of the municipal benefits (totaling an estimated $27 million). Thus, the average benefits to municipalities will tend to decline as the number of implemented projects increases.

Table 18: Municipal net benefits distributed among contributing storage projects.

Project	New storage (acre-feet)	Fraction of new IP storage	Benefits ($millions)
ASR	100,000	0.16	4.26
Bumping	156,300	0.25	6.66
CEPR	14,600	0.02	0.62
Conservation*	0	0.00	0.00
KKC+KDRPP**	200,000	0.32	8.53
Wymer	162,500	0.26	6.93
Total	633,400	1.00	27.0

Conservation investments do not increase storage, but primarily affect water distribution over time and space.
**KKC does not add to total storage capacity, but instead augments inflows into Kachess. Strictly speaking, then the contribution of KKC to new storage is zero.

To assess the value of individual projects we focus in Sections IV.D and IV.G on two bookend cases: the benefits of a project when it is the sole storage project implemented, and the benefits of the project when all other storage projects are also implemented. As noted above, for single-project implementation, the $27 million is credited to the benefits of the sole project. When all projects are implemented, the municipal benefit attributed to a project is in proportion to its share of storage provided by it.

The Four Accounts analysis estimates the benefits of the IP at about $400 million ($0.4 billion). Our revision, based on their methodological approach suggests benefits of the IP to municipalities and domestic users of around $32 million or lower in expected net present value terms; $27 million

[35] Note that this allocation of water across projects applies only to new water, not the market security benefits.
[36] In fact, the RiverWare YAKRW model is parameterized to allow an approximation of this demand growth, though this affects agricultural curtailment frequency and magnitude through its effect on water supply available for irrigation. It allows a setting such that municipal water demand for 2040 is fully provided as a component of any IP scenario including the base (no IP projects) case, et of water provided by the proposed Ahtanum ASR. 2040 is the midpoint of the time period (2020-2060) within which municipal/domestic benefits are accrued.

from avoided costs to accommodate new growth, and about $5 million to provide security for existing groundwater users.

We conclude this section with a few important points. First, water curtailments are always economically harmful, and can be especially harmful if they are imposed on municipalities, if for no other reason than that under current water entitlements, municipal and domestic water users often have a higher willingness-to-pay for water at the margin than is economical for irrigation users (Brewer et al. 2007). These estimates represent the cost to acquire uninterruptible water rights, and should not be confused with the economic impact of municipal water curtailments, which can have much larger impacts relative to the costs of water acquisition. Nonetheless, an avoidance cost approach as relied on here is appropriate given the legal requirements of municipalities to provide secure water for their populace, and an ability to do so.

D. Water storage projects and operations

Water storage projects provide benefits for both out-of-stream uses to agriculture and municipalities, and instream flows for the support of fish populations. We begin by reporting the net benefits of the water storage projects in terms of out-of-stream benefits. These net benefits provide information about the minimum value that instream flows would have to provide for the projects to break even. We then report results that show the opportunity cost of proposed IP instream flows in terms of foregone agricultural production value.

1. Net benefits for out-of-stream uses

Table 19 provides the estimated total benefits and net benefits of water storage to out-of-stream uses assuming implementation of all IP water storage projects. Costs account for all water storage projects: KKC, KDRPP, Cle Elum pool raise (CEPR), Ag Conservation, passive ASR, Bumping, and Wymer. All costs and benefits are discounted as described in Section III.E. Specifically discounting is applied such that benefits begin contemporaneous with the end of construction of all projects, four years in the future (the presumed duration of the longest construction projects).

Table 19: Net benefits of water storage for out-of-stream uses (present value at start of construction). $Millions.

		Total out-of-stream benefits			Net benefits		
run	Cost[1]	No trade	Intra-district	Full trade	No trade	Intra-district	Full trade
IP, historical climate	2,850	155	95	69	-2,695	-2,755	-2,781
IP, CGCM climate	2,850	206	123	86	-2,644	-2,727	-2,764
IP, HADCM climate	2,850	357	234	144	-2,493	-2,616	-2,706
IP, HADGEM climate	2,850	578	351	225	-2,272	-2,499	-2,626

[1]Projects included in these costs include KKC, KDRPP, Cle Elum pool raise, Ag Conservation, passive ASR, Bumping, and Wymer. Present values represent the start of construction, assuming simultaneous completion and the beginning of construction of four-year projects as described in Section III.E.

Specifically, the total cost of $2,850 million ($2.85 billion) represents the discounted sum of the costs of: KKC, KDRPP, Cle Elum pool raise, Ag Conservation, passive ASR, Bumping, and Wymer. Total benefits are equal to those provided in Table 19 of the agricultural irrigation benefits in Section IV.B plus the municipal and domestic benefits estimated in Section IV.C.

After discounting to the beginning of IP infrastructure construction, the total out-of-stream benefits (agriculture and municipal/domestic) range from $69 to $578 million depending on climate and market regime. All estimates are all substantially lower than the estimated $1.2 billion combined benefits from these two sectors estimated in the Four Accounts analysis. A large part of this difference results from the difference in municipal benefits, and some of the difference is due to differing base years.

Notice that the cost of IP storage net of out-of-stream benefits is negative, and ranges between -$2,272 and -$2,781 million depending on climate and trading regime.[37] Proposed IP instream flows are implemented in the full IP scenario, so these measures underestimate the total net benefit by the value of instream flows provided by the IP. B/C ratios can also be easily calculated as the total benefit divided by the total cost. For example, the B/C ratio for the case of intra-district trade (HADCM climate) is 234/2,850= 0.082. For CGCM climate, the B/C ratio is 0.043. Again, this B/C ratio does not account for any benefits accrued from instream flows, meaning these B/C ratios would be biased downward depending on the magnitude of instream flow benefits via provided by the IP.

If the federally-set interest rate for 2014 of 3.5% is used instead of 4% (which we used to be consistent with the Four Accounts analysis), net benefit estimates in Table 20 range from -$2,191 to -$2,777, a maximum of about 4% difference in net present value of benefits after accounting for costs, municipal, and agricultural value. While we do not report these comparisons in the remaining results below, the differences do not change the sign of B-C outcomes (or change B/C ratios from below to above 1) in any scenario considered for either individual projects or the IP as a whole, regardless of market or climate regime.

In the municipal benefits section we noted the potential for the long-run "settled" price of $2,500/af might be lower or higher, depending on multiple factors. If this ag-to municipal price were lower, then the municipal benefits would drop, suggesting that the net benefits of the IP in Table 20 would be even less than otherwise. However, net benefits would be higher (less negative) as municipal benefits increase. This would be the case for a municipality that would have to pay $5,000 instead of $2,500. Then the net benefits of not having to purchase IP water to cover growth would be about $72 million instead of $27 million. The range of net benefits from IP water storage would slightly less negative, ranging between -$ 2,234 million to -$ 2,743. These numbers are comparable to those

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[37] Only one point estimate of costs is provided for each scenario to for parsimony. Section V.E suggests as a rough guide to generate a range of cost estimates to use the percentiles provided in Appendix D of the Four Accounts analysis. For example, an estimate of the 10th percentile would be 81% of the point estimate of $2,850 million, or $2,309 million, and an estimate of the 90th percentile cost would be $3,791 million. These can then be used to estimate a range of net benefits and B/C ratios for each scenario.

listed under "Net benefits" in Table 19. Municipal benefits are relatively small, and different assumptions on municipal value have relatively small impacts on outcomes when spread across all IP water storage projects.

Table 20 provides the total and net benefits of the individual components of the storage-related IP projects without the IP instream flows implemented, under the least and most adverse climate scenarios.[38] Under the individual scenarios (Base+1), IP instream flows are not implemented, so no additional fish benefits would accrue; these are therefore final net benefit estimates. Furthermore, given that these are "one at a time" implementations, municipal water benefits are fully credited to each "total benefit" estimate. This is in contrast to when the IP is implemented as a whole.

Table 20: Out-of-stream net benefits of individual water storage projects implemented alone (Base+1). $millions. Present value at start of construction.

	Project	Total benefits			Net benefits		
Run Base+[project]	Cost	No trade	Intra-district	Full trade	No trade	Intra-district	Full trade
CGCM climate scenario (least adverse future climate scenario)							
KKC	138.2	33.4	28.3	26.6	-104.8	-109.9	-111.6
KDRPP	195.8	137.8	89.1	64.3	-58.0	-106.7	-131.5
KKC+KDRPP	334.0	157.3	98.3	71.4	-176.7	-235.7	-262.6
CEPR	15.7	12.6	9.7	9.0	-3.1	-5.9	-6.7
ASR	126.3	64.5	44.7	36.6	-61.8	-81.6	-89.6
Conservation	256.7	18.6	10.7	6.9	-238.1	-246.0	-249.8
Bumping	452.3	129.1	81.1	60.1	-323.2	-371.2	-392.2
Wymer	1,331.2	189.3	114.7	81.7	-1,141.9	-1,216.5	-1,249.5
HADGEM climate scenario (most adverse)							
KKC	138.2	72.7	48.0	38.3	-65.5	-90.2	-99.9
KDRPP	195.8	249.6	179.1	117.5	53.8	-16.7	-78.3
KKC+KDRPP	334.0	510.8	339.5	210.8	176.8	5.5	-123.2
CEPR	15.7	37.4	21.1	16.0	21.7	5.5	0.3
ASR	126.3	175.6	112.4	79.0	49.3	-13.9	-47.3
Conservation	256.7	-0.1	-10.9	-1.5	-256.7	-267.6	-258.2
Bumping	452.3	466.0	293.4	184.4	13.7	-158.9	-267.9
Wymer	1,331.2	764.2	523.6	311.1	-567.0	-807.6	-1,020.1

As is apparent from the net benefits, individual storage projects provide positive net benefits only under the most adverse climate scenario (HADGEM). Under this climate scenario, KKC+KDRPP and CEPR provide positive net benefits of 5.5 million each (by coincidence) under the intermediate

[38] Recall that the CGCM climate regime approximates the average curtailment rates implied by the assumptions of the Four Accounts analysis, and shows higher benefits than the historical regime. The net benefits under the historical climate regime would be lower (more negative).

trade scenario Conservation benefits are again an anomaly for the HADGEM results in Table 20 as they were in Table 16. These values remain negative here because Conservation does not provide additional storage and so is not credited for municipal benefits.

If municipalities were given uninterruptible rights with implementation of individual projects, and this saved them from having to purchase at $5,000/af rather than $2,500/af, municipalities would save about $72 million rather than $27 million. If this amount is credited to one individual project (as assumed in Table 20), CEPR would provide positive net benefits ranging from $8.4 to $4.8 million depending on the trading regime under the moderate (CGCM) climate regime (not shown in Table 20). Under the most adverse climate regime (HADGEM), KKC+KDRPP, ASR, and Cle Elum would all provide positive net benefits for low and intermediate trading regimes. It is important to note again that the net benefits are affected more when municipal benefits are credited to one project only rather than across the full set of projects, and not even CEPR provides positive net benefits with the higher municipal benefit estimates when the full IP is implemented. In fact, the sum of net benefits for KKC+ KDRPP, ASR and CEPR are $85.6 million under the adverse climate scenario and intermediate trading. This value is larger than the assumed $72 million saved by municipalities, and so this limited group of IP projects would not jointly satisfy a B-C criterion for out-of-stream uses as a group under these assumptions.

Table 21: Benefit-Cost ratios assuming IP Instream flows are not implemented.

	CGCM climate			HADGEM climate		
Project (Base + 1)	No trade	Intra-district trade	Full trade	No trade	Intra-district trade	Full trade
KKC	0.24	0.20	0.19	0.53	0.35	0.28
KDRPP	0.70	0.46	0.33	1.28	0.92	0.60
KKC+KDRPP	0.47	0.29	0.21	1.53	1.02	0.63
CEPR	0.80	0.62	0.58	2.38	1.35	1.02
ASR	0.51	0.35	0.29	1.39	0.89	0.63
Conservation	0.07	0.04	0.03	0.00	0.00	0.00
Bumping	0.29	0.18	0.13	1.03	0.65	0.41
Wymer	0.14	0.09	0.06	0.57	0.39	0.23

Table 21 provides B/C ratios for the IP projects, assuming no IP instream flows based on the results presented in Table 20, for the least and most adverse future climate scenarios. For example, assuming intra-district trade and CGCM climate, Bumping Lake expansion has a B-C ratio of 81.1/452.3=0.18 (numbers taken from Table 20). None of the projects satisfy the B-C criterion of 1 or greater under the less adverse climate scenario. Under the intermediate trading regime and less adverse climate, Cle Elum Pool raise provides the highest B-C ratio of 0.62, implying that it provides out-of-stream benefits that are about 2/3 of its costs. Both CEPR and KKC+KDRPP provide B/C ratios above 1 under the most adverse climate scenario and moderate trade. CEPR provides the highest return of $1.35 per dollar of cost. In addition, CEPR also provides a B/C ratio above 1 for full trade.

Table 22: Out-of-stream net benefits ($millions) and B/C ratios for individual projects implemented as part of the full IP under the most adverse climate scenario (HADGEM).

	Net Benefits (B-C)			B/C ratios		
Project (Base + 1)	No trade	Intra-district	Full trade	No trade	Intra-district	Full trade
KKC	-46.9	-73.8	-103.1	0.66	0.47	0.25
KDRPP	-18.8	-60.6	-115.9	0.90	0.69	0.41
KKC+KDRPP	-144.6	-187.6	-249.1	0.57	0.44	0.25
CEPR	-14.8	-16.0	-15.6	0.06	0.00	0.01
ASR	-11.8	-18.5	-77.3	0.91	0.85	0.39
Conservation	-248.1	-242.8	-252.7	0.03	0.05	0.02
Bumping	-290.0	-348.1	-389.6	0.36	0.23	0.14
Wymer	-1,044.5	-1,105.8	-1,211.1	0.22	0.17	0.09

Table 21 provides estimates for individual projects implemented alone. Table 22 provides estimates of out-of-stream net benefits and B/C ratios for individual project when implemented as part of the full IP assuming the most adverse climate scenario (HADGEM). The table shows that no project provides positive net benefits under these conditions for any water market scenario.

2. *IP instream flows: Break-even values and opportunity costs*

Before examining the benefits of instream flows, we examine the costs of providing them. There are two relevant measures of costs of instream flows in the context of this analysis:

1) The cost of IP storage projects net of the out-of-stream benefits, when proposed IP instream flows are implemented ("net remaining costs").
2) The out-of-stream water use value lost when proposed IP instream flows are provided, with or without additional IP water storage ("opportunity costs").

The first measure is based on the cost of new infrastructure net of out-of-stream uses, which Interpreted another way represents the benefits that must accrue from instream flows for the IP storage projects to satisfy a benefit-cost criterion. The second is the opportunity cost of the instream flows in terms of foregone out-of-stream benefits, regardless of IP infrastructure investment (Grantham et al. 2014; Ward 1987). This measure can also be interpreted as the minimum payment required to purchase water rights to provide instream flows. In each case, the analysis relies at least in part on the results of the out-of-stream (agricultural and municipal) benefits.

Recall from Table 19 at the beginning of this section that the cost of IP storage net of out-of-stream benefits is negative, and ranges between -$2,272 and -$2,792 million depending on climate and trading regime. Proposed IP instream flows are implemented in the IP scenarios, so the (negative) net benefits represent the economic benefits that the IP instream flows would have to provide, primarily through fish-production benefits, for the IP water storage projects as a group to provide a non-negative net benefit, and a B/C ratio of one or greater. Thus, the cost of providing IP instream flows with IP infrastructure ranges between $2,272 and $2,792 million.

The negative net benefit values for individual projects presented in Table 20 analogously represent the instream flow benefits each project must provide for their net benefits to be non-negative, and B-C ratios to be 1 or greater.

Another way to "implement" IP instream flows is to simulate the purchase of out-of-stream water rights to provide IP instream flows without investing in IP infrastructure. Proposed IP instream flows are implemented in YAKRW are described in HDR Engineering, Inc. (2014), and can be implemented in YAKRW independently of other IP storage projects. Parameterizing YAKRW to implement IP instream flows but no storage project (that is, baseline + IP instream flows only) generally reduces water allocated to out-of-stream uses, and thus imposes an opportunity cost on them through reduced diversions and higher curtailment in drought years. This opportunity cost represents the minimum payment that irrigators might accept to relinquish water rights for instream flows. It should be noted immediately that the costs of acquiring rights from irrigation to augment instream flows are likely to be higher than these opportunity costs suggest due to transaction costs, relative bargaining position, and other factors.

Table 23 provides estimates of the opportunity cost of instream flows in terms of agricultural production. We focus primarily on the costs relative to the baseline case (HDR 7.1) for the different climate regimes. To make these comparable to the values in Table 19 and Table 20, these opportunity costs have been discounted by four years to represent a baseline of four years in the future to correspond to completion of water storage projects as described in Section III.E.[39]

Table 23: The cost of proposed IP instream flows in terms of agricultural production value. Present value, $ millions.

run	No trade	Intra-district trade only	Full trade	Reduction in diversions (af) due to IP instream flows
Base+Instream, historical climate	267.2	158.5	97.7	76,823
Base+Instream, CGCM climate	230.9	128.2	81.7	71,604
Base+Instream, HADCM climate	482.4	327.2	186.0	113,715
Base+Instream, HADGEM climate	546.3	489.5	236.5	114,043
IP-Instream, historical climate	155.9	76.1	48.3	51,847

As the table shows, given the historical climate regime the IP instream flow operations would lead to opportunity costs ranging from a high of $267.2 million given no trade, and a low of $97.7 million under full trade. Under the historical climate regime, implementing IP instream flows reduces mean irrigation water available to the districts by 76,823 af/year. To purchase instream flows in perpetuity

39 To calculate present value with current year (beginning of construction) as the base year, multiply by $(1.04)^4$.

under the historic climate regime with intermediate trade would cost $2,063.2/af (corresponding to $84.2/af/year if it were an equivalent lease. Adding transaction costs of a third of this would imply a cost of $2,744/af for a purchase of instream flows. With full trade, the analogous numbers (opportunity cost plus transaction costs) would imply a purchase cost of $1,692/af.

This amount of water represents about 4% of the 2 million af of water rights held in the five major federal districts, and about 9% of non-proratable rights. This is not an inconsequential volume of water, and while we show it is likely the least costly method of providing the proposed instream flows among the options considered, transferring this amount of senior water rights out of irrigated agricultural production may have substantive local economic activity and public finance consequences.

Interestingly, the estimated cost of providing instream flows under the CGCM scenario is lower. This is ultimately related to the way in which the predicted increase in precipitation under CGCM interacts with the instream flow constraint specification. The moderate and adverse climate scenarios lead to higher costs of implementing the IP instream flows via purchase. With intra-district trading, for example, the opportunity cost of providing instream flows (with a purchase) under the most adverse climate scenario (HADGEM) is $2,877. With transaction costs, this amounts to $3,826.The scenario "IP-Instream, historical climate" represents the opportunity cost of instream flows given full IP implementation. It is included as a reference to illustrate the fact that the opportunity cost of IP instream flows is lower when the additional IP storage is available.

A comparison of Table 19 and Table 23 (adding transaction costs of 1/3 of each value) offer an important cost comparison for providing IP instream flows either with, or without, IP storage projects. Table 24 provides the ratio of the cost of providing IP instream flows with and without providing IP storage infrastructure for each climate and trade regime. For example, assuming intra-district trade and the CGCM climate regime, providing IP instream flows by building the IP storage projects costs about 25 times more (2,744/110.5=25) than relying on reducing existing out of stream agricultural uses to meet instream flow targets.

After netting out the out-of-stream benefits from the IP, the cost of providing instream flows via full IP implementation is between 3 and 25 times the opportunity cost of water without the IP, suggesting that the lower-cost approach for providing proposed instream flows would be to transfer water rights from out-of-stream uses to instream uses.

Table 24: Ratio of IP instream costs with and without IP storage

climate regime	no trade	Intra-district trade only	Full trade
Historical	8	13	21
CGCM	9	16	25
HADCM	4	6	11
HADGEM	3	4	8

The use of water banks and public purchase of water for instream flows has been developing in Washington State through various programs such as the Trust Water Rights Program and the

Washington Water Acquisition Program.[40] While these programs are relatively small in terms of water and transaction volume and have had mixed success across the state (Lovrich et al. 2004), they show promise for future development and may, with further development, to provide a basis for such transactions. As noted above, transferring this amount of senior water rights out of irrigated agricultural production may have substantive local economic activity and public finance consequences.

E. Fish passage and habitat restoration

As noted in Section III.D.1, actions to improve fish populations in the basin can be categorized as follows:

1) Fish passage for one or more existing dams in the basin
2) Operation changes to improve instream flow conditions for fish
3) Other fish habitat restoration

This section examines fish-related impacts from these three categories of IP management activities. The estimated benefits from fish are basically the product of two types of values: the estimated expected increase in fish abundance due to IP investments, and the marginal (individual) value of fish. The estimation methods used in the Four Accounts and supporting analysis as well as the FPEIS are described in Section III.D.

The Four Accounts analysis is again the foundation for our analysis. We use it as a starting point for assessing the relative contribution of fish passage, instream flows, and other restoration to the extent possible. We then reassess the estimated aggregate value of fish impacts, both in terms of fish abundance impacts and the valuation of abundance, and find that the Four Accounts analysis is overly optimistic both in terms of fish abundance impacts, the marginal value per fish in the current environment, and the aggregate value of the fish benefits provided by the IP. We then disaggregate this value to provide B-C metrics for each fish passage project, instream flows, and other restoration to the extent possible.

1. Implications of the Four Accounts and other existing IP analyses

We begin by distinguishing between sockeye and non-sockeye, and fish passage versus non-fish passage investments (instream-flows and other restoration activities).

Wild sockeye salmon principally use lake habitat for reproduction. Sockeye currently have no access to reservoirs in the Yakima Basin, and there exists no viable wild sockeye population. The five fish passage projects of the IP are designed to open up spawning habitat for sockeye. As described in Section III.D.1, the sockeye recruitment model that provides estimates for the Four Accounts analysis relies on spawning capacity of lakes, and does not condition sockeye recruitment on non-passage restoration activities, which is to say that non-passage restoration activities do not factor into estimates of sockeye success in the modeling framework used (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012; U.S. Bureau of

[40] See the department of Ecology Water Program website http://www.ecy.wa.gov/programs/wr/market/market.html.

Reclamation, HDR Engineering Inc., and Anchor QEA 2011). Assuming IP fish passage projects were implemented, sockeye salmon recruitment back to the Columbia River estuary attributable to IP fish passage is estimated at 170,000 to 380,000, which is 80 to 95 percent of the total low and high fish recruitment impacts of 181,650 to 472,450 for all species. These estimates are conditional on restoration activities being implemented. This means that sockeye accounts for between $4.6 and $6 billion of the total Four Accounts estimates of IP fish benefits, which ranges from $5 to $7.4 billion.[41]

Inferring from the Fish Benefits Analysis Technical Memorandum (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011), 25% of the recruitment of chinook, steelhead and coho come from fish passage, and 75% come from restoration for both high and low estimates. Further, because sockeye modeling implicitly assume that non-passage restoration activities do not affect sockeye success, non-sockeye species convey 100% of the restoration benefits. From the above information, we can infer the implied breakdown of fish and economic benefits from sockeye versus non-sockeye, and from fish passage and non-passage investments, which is presented in Table 25.

Table 25: Implied breakdown of fish and economic benefits from sockeye versus non-sockeye, and from fish passage and non-passage investments based on Four Accounts estimates and modeling assumptions.

	Fish estimates		Percent (%)		Four Accounts $millions	
	low	high	low	high	low	high
Sockeye	170,000	380,000	93.6	80.4	4,679	5,952
Non-sockeye	11,650	92,450	6.4	19.6	321	1,448
Fish passage	172,913	403,113	95.2	85.3	4,759	6,314
Non-passage	8,738	69,338	4.8	14.7	241	1,086
total	181,650	472,450	100	100	5,000	7,400

In particular, Table 25 provides the share of benefits attributable to fish passage and non-fish passage. This is useful information for reassessing aggregate estimates of fish population impacts and fish value, as described in the next section.

2. *Reassessment of fish abundance impacts and economic benefits*

In Section III.D (Methods) we qualitatively characterize several reasons to conclude that abundance estimates and marginal fish values reported in the Four Accounts analysis are overly optimistic. While we cannot quantitatively address most of these concerns, we are able to examine two important assumptions that underlie their results by bringing to bear additional data: a) fish population growth rates, and b) baseline fish abundance. In this section we summarize our contention that the fish population growth rates implicit in the Four Accounts analysis are too

[41] Note also that these numbers imply an average value per sockeye of $27,529 at the low abundance end) to $16,711 at the high abundance end.

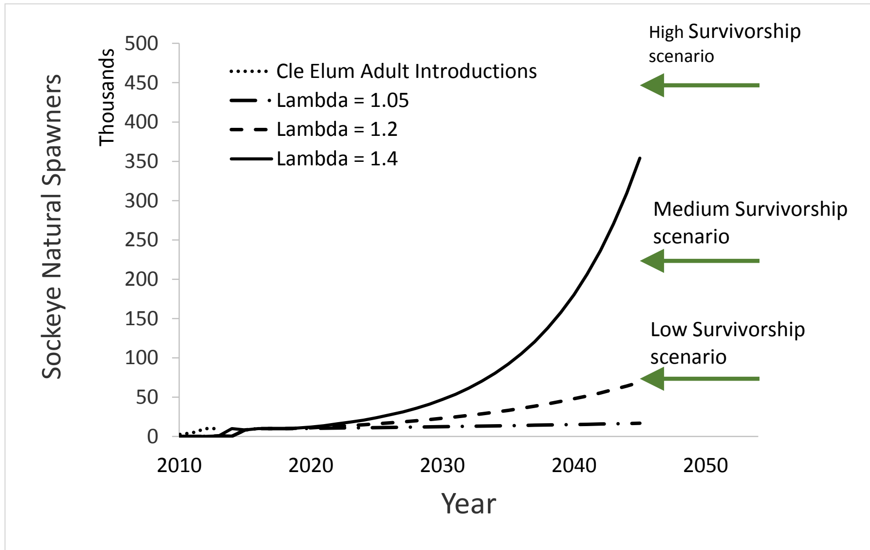

Figure 17: Projections of sockeye salmon abundance based on a range of population growth rates over the BIP planning horizon. These projections incorporate current reintroductions.

optimistic, and that baseline fish abundance in the Columbia River basin appear to have been increasing since 1998, which may have substantial impacts on the value of the additional fish from IP projects. More extensive methodological explanation is provided in Appendix section VII.E and VII.F.

Figure 18 illustrates various rates of population growth for sockeye as an example. At a population growth rate of λ[Lambda]=1.05 the current stock would grow to over 12,000 fish in the 10 year planning horizon, and 17,000 fish after 30 years.[42] If the long-term population growth rate is as high as λ=1.2, then abundances may exceed 16,000 after 10 years, and will enter the lowest YBIP forecasts after 30 years. Abundances reach the higher end of YBIP forecasts only if the population growth rate is set to an extraordinary high values (e.g. 1.4) and the planning horizon is 30 years.

Based on available monitoring data for sockeye abundance in the Yakima basin, population growth rates (λ) would have to exceed any known biologically realistic value to hit IP forecasts within near-term time horizons. Indeed, even if the time horizon were extended out to 2045, the necessary values of λ would have to exceed 10 to hit forecast targets. A biologically relevant range of λ for a growing population would be between 1.0 and 1.3, with very few Columbia River salmon populations exceeding 1.05 (McClure et al. 2003).[43] We can examine the impact of a more conservative and arguably more likely growth rate of λ=1.05 and 1.10 on the net present value of

[42] The rate of population growth λ is defined in terms of the ratio of the population size at time t to the population size at time t+1. Thus, population growth in percentage terms is λ-1, so that λ =1.05 corresponds to a population growth rate of 5%/year.

[43] Of the 131 populations examined in 05 (McClure et al. 2003), only 18 (14%) have growth rates over 1.04.

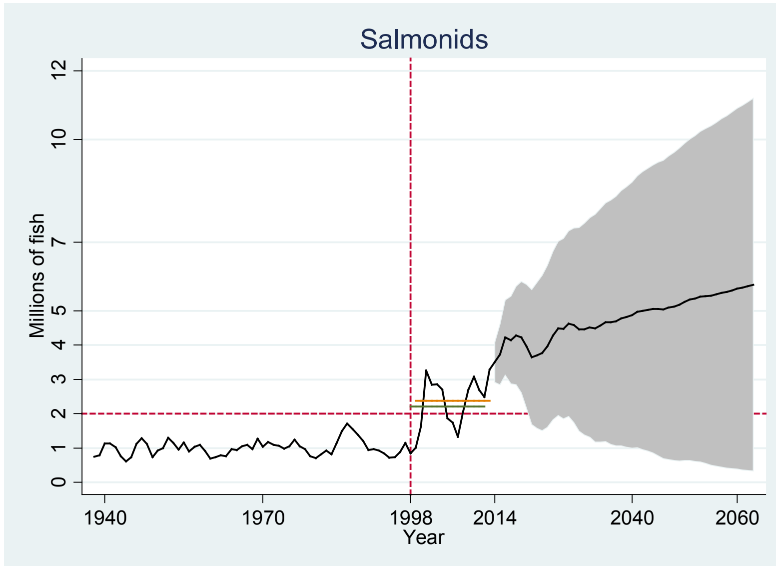

Figure 18. Salmonid counts at Bonneville Dam and Willamette fall. Forecasts and 95% confidence intervals (grey area) beyond 2014 generated using an AutoRegressive Integrated Moving Average (ARIMA) model of order (1,1,1), with a 3-year seasonal lag. The two short lines between 1998-2012 and 1999-2013 are means for that period.

implied fish numbers, using these growth rates until they reach the low and high estimates reported in the Four Accounts analysis.

The second issue we examine is that the Four Accounts analysis assumes a non-increasing fish population baseline of two million fish between 1998 and 2012. An examination of Figure 18 shows that fish counts until 1998 actually are lower than the two million assumed in the Four Accounts analysis, but then begin to increase in 1999, reaching a high of around 3.20-3.30 million fish in 2013. The mean fish count for 1998 to 2012 (which coincides with the range of time between the LBP analysis and the Four Accounts analysis) is about 2.21 million salmonids. Over this time period, the lowest value in this range was 845,939 in 1998, and the highest value of 3,291,654 in 2013 was omitted from this range. If 1998 were omitted and 2013 were included, the mean fish count for the period would be 2,369,867 (2 million plus almost 370,000 above baseline), so using the 1998-2012 range is conservative in this regard. The forecasted values from 2014 to 2060 have 95% credibility intervals that illustrate one component of uncertainty in these numbers, and is large due to their high variance, especially since 1998. Nonetheless, it seems reasonable based solely on the average fish counts that the baseline population is increasing.

Table 26 shows the sensitivity of results to both higher baseline fish populations and slower fish growth than is assumed in the Four Accounts analysis. These calculations rely on the high-end IP increase of 472,450 fish, which the Four Accounts estimated would produce $7,477 million in economic benefits. Incorporating 1998-2012 fish increases and delaying achievement of the IP fish targets required some modification of the Four Accounts/LBP approach. We describe these modifications in detail in the fish valuation appendix.

The table shows that fish values decline with lower fish population growth rates, and with higher baseline fish populations. It further shows that the results are much more sensitive to changes in baseline fish populations than delays in fish growth. For example, if the baseline is 2.2 million, which is 200,000 fish above the Four Accounts baseline and just below the mean Salmonid counts for 1998-2012, and growth rates are sufficiently large such that the low and high fish populations are reached by 2042 (30 years) the low and high fish benefits estimates drop to $1.4 billion and $2.7 billion (down from $5 and $7.4 billion with a two million fish baseline).

Table 26. Economic benefits (millions of 2012$) to Washington and Oregon households conditional on growth rates and baseline increases. Hi and Lo correspond to the High and Low Four Accounts estimates are 472,450 fish and 181,650 fish, respectively. Washington only benefits equal 63% of the estimates in the table.

	Non-IP related fish population increases 1998-2012							
Year that IP fish impacts stabilize	0		100,000		200,000		300,000	
	Low	High	Low	High	Low	High	Low	High
2042	5,003**	7,387	2,288**	3,957	1,402**	2,699	1,018**	2,081
2052	4,593	7,056**	2,120	3,717**	1,290	2,510**	934	1,926**
2062	4,147	6,670	1,927	3,440	1,159	2,292	834	1,745
2072	3,822*	6,348	1,780*	3,216	1,062*	2,120	762*	1,610
2082	3,523	6,025	1,635	3,005	967	1,960	691	1,476
2092	3,239	5,744*	1,518	2,825*	891	1,825*	634	1,367*

**Correspond to growth parameter λ=1.05.   **Correspond to growth parameter λ=1.10*

There is an underlying fish growth rate implicit in the result for any given baseline, year to stabilization, and stabilized fish numbers (whether high or low), as discussed in the context of sockeye recovery in Appendix section VII.E.a. In that section it is noted, based on (McClure et al. 2003), that growth rates corresponding to growth parameter λ greater than 1.05 are very unusual, and would be considered very high growth rates relative to what is commonly observed. The Four Accounts analysis implicitly assumes growth rates associated with λ much higher than this --- as much as λ=1.40 to reach the high fish abundance estimates, which is larger than any recorded in McClure et al. (2003) and would probably require active hatchery or importation investments not included in the IP.

In Table 26, values with a single asterisk are associated with outcomes that most closely correspond to λ=1.05. At this growth rate, the low end increases in fish numbers are reached around 2072, and the high end fish increases are reached by 2092. If the Columbia River Baseline of 2.2 million fish is used as the mean baseline fish count for 1998 to 2012, the fish benefits amount to $1,062 million (about $1.1 billion) for the low-end fish estimate (of 181,650), and $1,825 million **(**$1.8 billion) for the high fish estimate (472,450 fish). The values with double asterisks correspond to a higher still growth rate with λ=1.10, though we contend that growth rates this high would be exceptionally unlikely.

In Section III.D.3.c on page 59 we note that the Four Accounts analysis assumes that fish benefits start to accrue immediately (in 2012), whereas it would be reasonable to "start" accrual of fish benefits after completion of the enabling infrastructure. However, given the survey language in the LBP study about how and when fish benefits are accrued in the future, either interpretation is consistent with the LBP approach. As a robustness check, we also consider the implications of pushing back the accrual of benefits 4 years (as if to 2016). If this delay were assumed in the Four Accounts analysis, the estimated benefits drop from about $5.0 billion to $3.8 billion on the low end and from about $7.4 billion to $5.5 billion. With our baseline (higher by 200,000 fish), the low end estimate is $870 million and the high end is $1,478 million; accounting for delay lowers the estimates in the previous paragraph by an additional 20%.[44]

In summary, if we account for the empirically observed increases in baseline fish numbers in the Columbia that are not accounted for in the Four Accounts analysis, and if we assume a positive growth rate that is relatively high but within observed and more credible ranges, we arrive at point estimates for **fish benefits around $1 and $2 billion** instead of the Four Accounts range of $5 to $7.4 billion in fish benefits. The differences in our revised benefit estimates compared to the Four Accounts estimates also do not account for other factors that we argued suggest lead to upward bias in the valuation estimates.

Relatively recent research by Montgomery and Helvoigt (2006) provides some interesting corroboration of a potential trend in attitudes and WTP for salmon recovery investments. Based on data collected in 2002 and 2006 in Oregon, they find a decline in WTP for salmon recovery efforts. While they find various socioeconomic factors account for some of this trend, they speculate that increases in fish counts during this period (as we illustrate in Figure 18) may lead to lower marginal WTP for fish restoration, which is exactly what is driving our lower benefit estimates in response to higher fish baselines.

The degree of uncertainty in these point estimates is very high. This uncertainty comes from various sources, including uncertainty about fish carrying capacity, growth rates, natural annual and spatial variation in fish abundance arising from both inside and outside the Yakima basin, as well as variance related to the marginal valuation of fish. It is worth noting however that all else equal, the variance of aggregate value will tend to be lower than the sum of the variance of fish abundance and their marginal value because they are negatively correlated (marginal value declines as fish abundance increases). Nonetheless, neither the Four Accounts estimates nor our revised estimates are *statistical*

[44] These calculations maintain the assumption that fish increases are achieved by 2042, as well as all other aspects of the Four Accounts valuation approach except that no household benefits accrue in 2012-2016. The differences observed are due to two effects: first, the elimination of four years of household payments in 2012-2016 that are not heavily discounted, and second, the assumption of linear fish population growth pushes more of the fish increase into the 2032 period, making the percentage increase in the first period smaller and therefore household WTP in all years in the period 2012-2031 smaller.

point estimates. The point estimates are based on simulation methods and summary data from various sources. We cannot therefore claim that there is any statistically-significant difference between the $1-$2 billion range and the range reported in the Four Accounts analysis. We do conclude, however, that this lower range is far more likely.

Given this revised range of total fish benefit numbers, the total contribution of sockeye, non-sockeye, fish passage, and non-fish passage are estimated and provided in Table 27 absent any assumptions that species-specific population growth rates are intrinsically different, and rounding revised aggregate low and high benefit estimates to $1 and $2 billion.[45] This table is the direct analogue of Table 25, except with the new aggregate fish numbers. Together, the estimate of aggregate fish passage benefits in these two tables can be used to the contribution of each fish passage project to the total.

Table 27: Estimated contribution of sockeye, non-sockeye, fish passage, and non-fish-passage to fish benefits given revised aggregate estimates. Percentages are taken from Table 25.

	Percentage of fish		$ millions	
	low	high	low	high
Sockeye	93.6	80.4	936	1,609
Non-sockeye	6.4	19.6	64	391
Fish passage	95.2	85.3	952	1,706
Non-passage	4.8	14.7	48	294
total	100	100	1,000	2,000

3. Fish passage

Table 28 uses the estimated total fish benefit along with relative contributions of each reservoir to adult survival and cost estimates of passage projects to develop benefit-cost estimates. Tables 2-4 and 2-5 in the Fish Benefits Technical Memorandum (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011) provide high and low abundance impacts by reservoir for which fish passage is being proposed, used here to provide estimates of the relative contribution of each reservoir to sockeye recovery were passage implemented. The cost estimates are reported and described in Table 7 in Section III.E. The revised benefit estimate totals of $952 and $1,706 are taken from the fish-passage row of Table 27, and the individual reservoir contributions are then calculated as a fraction of these numbers according to their percent contribution to total abundance.

Table 28 shows that based on the revised fish value estimates, all fish passage projects satisfy the B-C criterion, with B/C ratios ranging from 1.43 to 11.68. The average B/C ratio for the low-end

[45] This is probably not a realistic assumption. Given that sockeye populations are very low relative to the predicted growth in them, it might be reasonable to think that growth rates would be higher for sockeye, especially during initial and intermediate establishment. Given that this is the case, the economic implications of the results will not change.

aggregate fish value estimate is 2.74, and 4.91 for the high estimate. As a group of projects, these are the strongest results presented in this report.[46]

The numbers for Bumping lake assume the Bumping lake expansion. Without it, the lake is 17% the size listed (33,700 af rather than 198,000 af (HDR Engineering, Inc 2011). It would therefore provide about 17% benefits, or $29 to $52 million. Assuming the same cost structure, it would provide B/C estimates ranging from 1.11 to 1.98, which at the low end just barely satisfies to B-C criterion.

Table 28: Contribution of reservoirs to fish passage benefits.

Reservoir	Contribution to total Abundance %		Cost[2] $mill.	Four Accounts Benefits $millions		revised benefit estimates $millions		B/C ratios for revised estimates	
	low	high		low	high	low	high	low	high
Keechelus	12	16	79.9	571	1,010	114	205	1.43	2.56
Kachess	29	31	79.9	1,380	1,957	276	495	3.46	6.19
Cle Elum	27	23	81.5	1,285	1,452	257	461	3.15	5.65
Tieton[3]	13	17	79.9	619	1,073	124	222	1.55	2.78
Bumping[4]	18	14	26.3	857	884	171	307	6.52	11.68
Total	100	100	347.5	4,759	6,314	952	1,706	2.74	4.91

[1]Adapted from Tables 2-4 and 2-5 in U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011).
[2] Costs taken from Table 8 in Section III.E.
[3]If Clear Lake fish passage provides the same benefits per acre as Tieton, the B/C ratio would range from 26 to 52 given estimated costs of $4.1 million.
[4]These numbers assume the Bumping lake expansion and Cle Elum pool raise. Without it, Bumping Lake would provide B/C estimates ranging from 1.11 to 1.98 assuming the same costs. The effect of the Cle Elum pool raise would be very small because it adds only 3% of the volume and negligible additional habitat.

Another perspective on this result is to consider the minimum number of fish the passage projects must contribute to break even. This minimum contribution of fish passage to the IP is conditional on IP habitat restoration and instream flows being implemented. Table 25 shows that based on the Four Accounts distribution of fish benefits across fish passage and non-passage projects, non-passage projects contribute a low estimate of 8,738 fish and a high estimate of 69,338 fish. If non-passage projects were not implemented or provided no fish, the marginal value of each fish contributed by fish passage would be higher than if non-passage were productive. In particular, if the non-passage projects were not implemented and therefore provided no additional fish, then fish passage projects as a whole would need to contribute a minimum of 62,000 fish in the steady-state to cover their aggregate costs of about $350 million. If non-passage projects were implemented and provided the low estimate of 8,738 fish, the fish passage projects together would have to contribute

[46] Though not shown in the table, the B/C ratios for the Four Accounts estimates range from 7 to 33.

72,500 fish in steady state to cover their costs.[47] If the non-passage projects provided the high-end fish increases, the fish passage projects together would have to contribute 144,500 fish to cover their own costs. Even this largest number is lower than the estimated low and high estimated contributions shown in Table 25 of 172,913 and 403,113 fish, respectively, and so fish passage projects would on average pass the B-C test based on these estimates.

4. *Habitat restoration and instream flows*

The recruitment benefits to non-sockeye species focused on in the previous studies (chinook, steelhead, coho) comes primarily from habitat restoration and instream flow augmentation. The impact and net economic contribution of habitat restoration and instream flows for fish abundance in the Yakima Basin is less clear than that from fish passage. Not only are the EDT estimates questionable as per the discussion in the Appendix (VII.E), restoration and instream flow impacts are assessed together in the existing reports using EDT, and it is difficult to identify the relative contribution of flows versus other restoration. We therefore consider restoration and instream flows together first. Given the dearth of information to separate out the impact of instream flows from those of habitat restoration, we can provide very little useful information about these two categories separately.

Further, the analysis in the Fish Benefits Technical Memorandum (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011) assumes that IP restoration is always implemented if fish passage projects are implemented (that is to say, fish passage is implemented conditional on restoration in every case). This assumption masks the potential contribution of restoration to fish passage productivity. We will examine the implications of this for interpreting restoration benefits as well.

a. *Net benefits of instream flows and restoration combined*

Table 25 shows that the Four Accounts implies that habitat restoration provides $241 to $1,086 million in benefits from non-passage restoration and instream flow benefit estimates in the Four Accounts analysis.[48] Our revised estimates shown in Table 27 suggest that non-passage projects would provide benefits ranging from $48 to $294 million.

Mainstem restoration costs are estimated to be $338 million, spread over about 18 years. Even if instream flows provide no fish benefits whatsoever, these restoration expenditures exceed the maximum non-passage benefits of $294 million inferred from the Four Accounts analysis and supporting documentation, and so would not appear to satisfy a B-C criterion based on our revised aggregate fish benefits estimates.

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[47] New estimates for the Keechelus Reach would add about 750 and 1,500 steelhead and spring chinook, respectively (J. Hubble 2014). If these numbers are added to the low and high end non-passage estimates, fish passage would have to contribute 73,500 and 146,400 fish to break even. These are slightly higher than without these higher non-passage contributions, but it does not change any qualitative implications.

[48] Again, new estimates for the Keechelus Reach would add about 750 and 1,500 steelhead and spring chinook, respectively (J. Hubble 2014). This will not substantively change our conclusions, so we retain the original numbers.

As discussed in Section IV.D.2, the estimated costs of providing proposed IP instream flows based on IP water storage projects range between about $2,200 and $2,800 million (Table 19 on page85), which is much higher than the estimated benefits of all non-passage restoration combined, even those implied by the Four Accounts analysis. However, if feasible, purchasing IP instream flows at their agricultural opportunity cost would cost around $100 to $150 million under moderate climate and market conditions. As reported in Table 7 in Section III.E, the tributary/mainstem fish habitat enhancement costs are estimated at $338 million. Adding instream flow purchase costs to the restoration costs provides total IP instream flow and restoration costs around $450 million. This is higher than the estimated benefits of IP instream flows and restoration ranging from $48 to $294 million.

b. *Conditional benefits of restoration and flows*

There are two ways in which fish passage and non-passage benefits interact. First, like water from storage, diminishing returns to fish according to the LBP valuation function means that greater fish abundance lowers the value of each additional fish. Second, there may be multiple technical complementarities in the production of fish passage and non-passage projects, which is to say that the technical effectiveness of fish passage may be dependent on whether or not restoration and/or proposed instream flows implemented, and vice-versa.

Unfortunately, these inter-relationships are difficult to assess given the existing information. The analysis in the Fish Benefits Technical Memorandum (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011) assumes that IP restoration is always implemented if fish passage projects are implemented. This assumption masks the potential contribution of restoration to fish passage productivity.

Consider the implications of diminishing marginal returns first, and assume temporarily that there are no technical complementarities between fish passage and non-passage projects. Using the LBP valuation function and the conditions assumed for our revised estimates of aggregate benefits, we can show that if only non-passage projects were implemented, simulated fish increases range between 8,738 and 69,338. As shown in Table 25, the value of these benefits would range from $65 to $387 million, which is higher than the comparable values of $48 and $249 million with fish passage implemented. Again, this higher value of non-passage projects without fish is due to diminishing marginal value of fish for the same basic reason that water storage projects provide more benefits when implemented alone than as part of the IP as a whole. Nonetheless, the upper bound of $387 million still does not cover the estimated non-passage costs of about $450 million.

Now consider the possibility of technical complementarities between fish passage and non-passage. In the Four Accounts analysis, the sockeye population modeling comprised two basic components: lake area for spawning, and assumed survival rates. In the model, these survival rates are not explicitly dependent on whether or not habitat restoration was implemented, in part because it is assumed to occur if fish passage is implemented. Nonetheless, the effectiveness of fish passage may be dependent on whether restoration and IP instream flows are implemented. To the extent this is true, the difference between the productivity (and associated value) of fish passage with versus without restoration and instream flows can be credited as restoration benefits assuming fish passage is implemented. This may be the case for the Cle Elum fish passage project, which may function better and provide greater mobility for fish if Cle Elum reservoir and associated instream flows are managed with this in mind. Unfortunately, the existing analyses underlying the Four Accounts analysis and the FPEIS do not allow us to estimate the marginal contribution of restoration and instream flows to fish passage benefits.[49] As such, we can provide no additional quantitative analysis. However, we have found that if there are complementarities between restoration/instream flows and fish passage and fish passage is implemented, then the estimated benefits of $48 and $249 from restoration and instream flows are biased downward and instream flows and restoration may be cost effective.

c. *Contribution of instream flows versus other restoration activities*

As mentioned at the beginning of this section, the models used to estimate the impact of habitat restoration (EDT) and fish passage (Spawner per Hectare method) on fish abundance does not allow us to distinguish between the contributions of instream flows and other habitat restoration. As such, we cannot say much about the individual benefits of instream flows and other restoration activities. We can only discuss the net benefits of them together.

5. Summary of fish impacts and value

The analysis in this section suggests that the aggregate fish benefits from the IP are likely to be around $1 to $2 billion, which is lower than the four Accounts estimate range of $5 to $7.4 billion. The difference between these estimates stems solely from a difference in the assumed growth rate of salmonid populations and the assumed baseline salmonid fish populations in the Columbia River system, the choice of which we motivate with existing evidence and previous studies. There are other concerns that suggest that both the abundance measures and valuation metrics my still be biased upward, but data do not exist to test the sensitivity of results to these concerns.

Our results show that fish passage projects all satisfy a B-C criterion, with B/C ratio point estimates ranging from 1.3 to 11.68. Habitat restoration and instream flows combined are estimated to provide an high-end estimate of $249 million (with fish passage implemented) do not provide benefits that cover their costs of about $450 million (assuming instream flow purchases), but the benefits may be an underestimate if, in the aggregate, IP instream flow augmentation and habitat restoration are technical complements.

Finally, we cannot dissect the relative contribution of proposed IP instream flows and habitat restoration to their overall benefits. What is clearer is that instream flow benefits cannot (based on

[49] The technical, (physical) contribution of restoration to fish passage would be the difference in fish abundance with versus without restoration/flows, *conditional on fish passage being implemented.* This is the metric that we cannot estimate, and without this metric we cannot estimate the economic value of it. However, if there are net technical complementarities between these, its value would be positive in the sense that fish passage would be more effective with habitat/flow augmentation than without.

our estimates) be large enough to justify the shortfall in IP water storage benefits net of out-of-stream benefits.

F. Other considerations for IP project net benefit estimation

Other potentially important aspects of the valuation approach include impacts associated with reservoir expansion, reservoir drawdown, additional storage, and changes in instream flows.

1. Reservoir creation and expansion, pool raises and drawdowns

Completion of the IP's water storage and operational components would affect water levels at all reservoirs in the Yakima Basin. Natural resource economists have found that water level changes influence lakeshore property and other recreational values (Cordell and Bergstrom 1993; Lansford and Jones 1995). Some have also associated changes in reservoir levels with minor changes in the regional economy(Allen et al. 2010). Dickes et al. (2011) summarize the main findings from this literature:

"A common finding among these studies is that proximity to the water source and the size of lake (water) frontage increase property values. Lansford and Jones (1995) confirm that scenic view, waterfront location and water level are all statistically significant contributors to enhanced property values. While proximity to the lake makes the most substantial impact on housing prices, consumers do appear to exhibit a positive preference for higher water levels as capitalized in the value of homes" (Dickes et al. 2011, 2).

Lansford and Jones (1995) estimate recreational and aesthetic benefits to lakeshore property of $652 for a one-foot increase in long-term water level changes in North Texas. Eiswerth et al. (2000) estimate that a one-foot increase in water levels produce an additional $12-$18 in annual, per-person use values for fishermen on Lake Walker, Nevada. Studying near shore property sales at California's Lake Almanor from 1987 – 2001, Loomis and Feldman (2003) find that an additional foot of exposed shoreline decreases home sales price by $108 - $119. These effects are critically important in the baseline conditions however, so should be interpreted carefully. In many cases insufficient information limits the ability of researchers to accurately estimate the relationship between water-based recreation and lake level changes (Ward, Roach, and Henderson 1996). For this reason it is difficult to determine the aggregate effect of water level changes at individual reservoirs with the costs and benefits of the Integrated Plan.

2. Recreation and amenity values

This report focuses on the fish benefits of instream flows, but the uncertainty surrounding the productivity of instream flows for anadromous fish in the basin contribute to the uncertainty about the economic value of instream flows. Numerous studies have estimated the value of water for instream flows, but their results vary substantially depending on the uses of instream flows (e.g. whitewater boating, fishing, fish productivity more generally) (Johnson and Adams 1988; Duffield, Neher, and Brown 1992; Ward 1987; J. B. Loomis 1998; Grantham et al. 2014). Johnson and Adams (1988) examine the value of instream flows explicitly for steelhead benefits on the John-Day river, and find that the value of additional instream flows averages about $5/af in 2014 dollars ($2.40 in

1987) for recreational steelhead fishing value alone, though the value of consumptive use of instream flows can be ten times this amount, suggesting that the marginal value of instream flow consumptive use value can exceed $50/af when accounting for benefits to other valuable fish species as well. Ward (1987) finds recreation values from fishing and boating to range up to $2,300/af (in 2014 dollars). Again, context matters significantly for these estimates. The Four Accounts analysis of fish value in principle includes fish values associated with all uses, it does not directly account for additional recreation benefits that might accrue from other recreational activities. We do not consider these further.

3. Flood control

Flood control is one of the primary goals of the Yakima River Project (U.S. Bureau of Reclamation 2002). Additional storage is likely to provide additional flexibility for reservoir management when balancing irrigation, summer instream flow, and spring flood risk (HDR Engineering Inc. et al. 2011). However, we are not aware of any existing research that provides an assessment of the potential flood risk mitigation that the additional storage might provide, or any estimates of the benefits thereof. While engineering flood risk assessment would be a necessary component of an economic assessment of flood control benefits, performing an engineering assessment of the impacts of flood control capacity is beyond the scope of this project. We therefore do not consider it further.

Where applicable, we discuss additional potential impacts that we do not quantify for specific projects in their individual summaries in Section IV.G. Other existing studies, including the Four Accounts analysis (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012) as well as the FPEIS (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012) discuss additional non-quantified impacts to some degree for additional background.

G. Project and scenario results summary and discussion

This section summarizes the results for the individual IP projects. The summaries draw from the sections above, and add additional context and assessment where applicable. Water storage and conservation projects are summarized first, followed by operations and fish passage.

1. Water storage and conservation projects

Water storage and conservation projects primarily provide out-of-stream benefits, as well as instream flow benefits to fish. Because there are diminishing marginal returns to additional storage, the benefits from a project differ depending on whether they are implemented alone, or along with other water storage projects. Further, when more than one water storage project is implemented, we allocate municipal benefits according to relative contribution to storage. Although there is a great deal of uncertainty about the benefits of instream flows, what we have shown is that (a) the value of instream flows for the IP as a whole cannot be high enough for the IP storage projects to satisfy an B-C criterion, and (b) the cost of purchasing instream flows outright, if feasible, would likely be substantially lower than providing them by infrastructure development. Because of these two issues we do not include instream flow benefits in the numbers below. Benefits and costs, as described in Section III.E, have been discounted to represent a base year of the beginning of construction, assuming that benefits begin accruing at the end of construction.

a. *Proposed IP Instream flows and their implications for water storage projects*

As discussed in Section IV.E.4, our revised estimates of total non-passage restoration benefits conditional on implementation of fish passage projects range from $48 to $294 million. Only a portion of these benefits are presumably due to instream flows; the rest attributable to proposed tributary/mainstem fish habitat enhancement investments of about $340 million in present value. Given the methods used to estimate these values as discussed in Section IV.E, it is difficult to assess the relative contribution of instream flows versus habitat enhancement. Nonetheless, instream flows cannot provide the $2 to $2.5 billion in benefits to justify the full suite of water projects as shown in Table 19 on page 85. This also implies that individual projects cannot each provide instream flow benefits to cover their costs.

To make this point, the IP FPEIS states that half of Wymer's 162,500 ac-foot of new storage is to be allocated to IP instream flows: "On average 82,500 af of the storage capacity would be used annually to improve instream flows upstream and downstream of the reservoir." (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012)[50] Even if Wymer were credited with 100% of IP instream flow benefits it would not cover the net shortfall of Wymer implemented with the Full IP, because even under the most adverse climate and restrictive market conditions Wymer provides net out of stream benefits of -$567 (net benefits are more negative under more moderate climate and market assumptions (See Table 20). Nonetheless, if Wymer were credited with all IP instream flow benefits, then none could be credited to the other storage projects. The conclusion for Bumping lake is qualitatively the same as that for Wymer.

In contrast, the Cle Elum pool raise results in net out-of-stream benefits far more favorable than Wymer, ranging from $-3 million to -$7 million in net out-of-stream benefits (Table 20). It is conceivable, and perhaps likely, that under intermediate climate and markets conditions if Cle Elum were credited with as little as 25% of the low estimate and 4% of the high range of IP instream flow benefits (again, ranging $48 to $294 million *assuming no restoration benefits*), instream flows could justify the Cle Elum pool raise. KDRPP+KKC is intermediate case (net out-of-stream benefits ranging around -$136 to -$305 million), which would require it to be credited with higher proportions of IP instream flow benefits. Passive ASR is similar in this regard.

There are three important caveats to these quantitative conclusions about instream flow benefits attribution. First instream flow benefits would be lower than $48 to $294 million to the extent that habitat restoration (at a cost of $340 million) provides part of these benefits. Offsetting this, however, is the recognition that available data do not support estimates of the contribution of instream flows to the estimated fish passage benefits. As such, these combined flow/habitat

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[50] In addition, the YAKRW operating rules state that the scenarios considered by HDR Engineering Inc, implement IP instream flows only if Wymer is implemented (HDR Engineering, Inc. 2014).

estimates would be downward biased. But finally, our results (Section IV.D) suggest that the opportunity cost of providing IP instream flows are likely to be substantially lower than the cost of satisfying IP instream flows by building infrastructure, and suggests that it is more economically to provide IP instream flows by purchasing senior water rights than by building storage under the conditions considered if water market infrastructure is in place to do so.

b. *Habitat Restoration*

As noted above, we cannot separate the economic contributions of IP instream flow augmentation and other habitat restoration activities. However, the estimated cost of these restoration programs is $340 million, and the estimated benefits as just described range from $48 to $294 million. Based on these numbers, if (contrary to the discussion in the last section habitat restoration provided all of these benefits, it would provide B/C ratios ranging from 0.14 to 0.86, and so would not be justifiable based on these B/C ratios alone. To the extent that proposed IP instream flows provide some of these benefits, the B/C ratios would be lower. That said, habitat restoration may be a technical complement to fish passage (as instream flows might), because habitat restoration may improve the effectiveness of fish passage. As such, some fish passage benefits may be attributable to habitat restoration at the margin. However, we have no basis for assessing whether or to what extent this is the case.

The following subsection provides a summary of outcomes for each storage and conservation project. Note that the "With IP" numbers in these columns correspond to the marginal contribution of the project conditional on the rest being implemented, including IP instream flows. As such, the net benefits, when negative, can be interpreted to represent the shortfall that instream flows must cover for the project to satisfy a B-C criterion. The "Alone" results are the benefits assuming no other IP storage projects, and no IP instream flows. In these cases, the net benefit and B/C ratios are final in the sense that instream flow benefits are irrelevant because IP instream flows are not implemented.

c. *KKC and KDRPP*

KKC and KDRPP are considered together because of their close connection geographically and because in principle, KKC facilitates the use of KDRPP by allowing Lake Kachess to refill faster whether or not KDRPP is actually implemented. Results are shown in Table 29. An interesting pattern of effects is shown by KKC. Under moderate climate (CGCM), KKC provides very little benefits as part of the full IP. Implemented alone, it provides higher benefits, but still, its benefit-cost ratio ranges under 0.25. With adverse climate (HADGEM), KKC provides higher benefits as expected, but in this case, it is more effective with the full IP than without, perhaps because the high and more regular curtailment rates limit the degree to which it allows improved water allocation from Keechelus to Kachess (which is its sole function). KKC provides no additional reservoir capacity, so we credit municipal benefits to KDRPP. Benefit/Cost ratios range from zero to 0.66 under the most adverse climate and restrictive water market scenarios.

Table 29: KKC and KDRPP out of stream net benefits.

run	cost	No trade			Intra-district trade			Full trade		
		PB[1]	NB[2]	BC[3]	PB	NB	BC	PB	NB	BC
						KKC				
With IP, CGCM	138	1	-137	0.01	0	-138	0.00	1	-137	0.01
Alone, CGCM	138	33	-105	0.24	28	-110	0.20	27	-112	0.19
With IP, HADGEM	138	91	-47	0.66	64	-74	0.47	35	-103	0.25
Alone, HADGEM	138	73	-66	0.53	48	-90	0.35	38	-100	0.28
						KDRPP				
With IP, CGCM	196	62	-134	0.32	38	-158	0.19	26	-170	0.13
Alone, CGCM	196	138	-58	0.70	89	-107	0.46	64	-132	0.33
With IP, HADGEM	196	177	-19	0.90	135	-61	0.69	80	-116	0.41
Alone, HADGEM	196	250	54	1.27	179	-17	0.91	118	-78	0.60
						KDRPP+KCC				
With IP, CGCM	334	59	-275	0.18	36	-298	0.11	25	-309	0.08
Alone, CGCM	334	157	-177	0.47	98	-236	0.29	71	-263	0.21
With IP, HADGEM	334	189	-145	0.57	146	-188	0.44	85	-249	0.25
Alone, HADGEM	334	511	177	1.53	340	6	1.02	211	-123	0.63

[1]PB=present value of benefits; [2]NB=Net benefit for out-of-stream uses, [3]BC=Benefit cost ratio for out-of-stream uses.

Results for KDRPP alone and as part of the Full IP follow typical patterns. It provides highest benefits and a B/C ratio of 1.27 when implemented alone, assuming no trade and the most adverse climate. B/C ratios for all other scenarios are less than 1, and as low as 0.10.

KKC+KDRPP provide the highest benefit cost ratio of the three scenarios at 1.53 under the most adverse climate and market restrictions. For intermediate climate and market conditions, it's B/C ratio is 0.29 if implemented alone (that is nothing else implemented but KKC+KDRPP, and 0.19 if implemented as part of the full IP.

There is at least one additional consideration for these projects. The KDRPP may lead to significant drawdowns in severe drought years. Recreation may be negatively impacted during these drawdowns, and if drawdowns occur with sufficient frequency and magnitude, decreases in near shore property values may result, the magnitude of which will depend on the frequency of use and extent of drawdowns. Even if a drought year drawdown is offset through refill in the following year, drought-year drawdowns impose recreational costs. In a 2006 – 2007 survey of Kachess Reservoir recreationists, 20% of respondents expressed satisfaction with May-June water levels but dissatisfaction with those in August-September. Thirty-five percent of respondents agree that higher water levels make boat launching easier, boating safer, scenery more enjoyable, and activities like kayaking, fishing, swimming and water-skiing better. Finally, 30% of respondents said low water levels had the opposite effect (Aukerman, Haas & Associates LLC 2008).

These additional potential property value and recreational costs would be highest if the KDRPP were to be implemented alone, because KKC would not provide additional water to Kachess, and because in the absence of other storage projects, KDRPP would be utilized the most. Thus, recreational and property value impacts would be the highest when the value KDRPP as a drought relief mechanism is at its highest, suggesting that the highest B/C ratios for KDRPP should lower than those in Table 29 especially if implemented alone and the curtailment distribution becomes more severe due to climate change.

d. *Bumping Lake Expansion*

Bumping Lake Expansion net benefits for out-of-stream uses are all negative except under the most adverse climate and trade conditions. B/C ratios range from 0.4 with the full IP implemented, full trade and a less adverse climate; to a high of 1.03 in the most adverse climate with no trade and implemented alone, though with only two values of 0.5 or above.

Table 30: Bumping Lake enlargement, out of stream net benefits.

		No trade			Intra-district trade			Full trade		
	cost	PB[1]	NB[2]	BC[3]	PB	NB	BC	PB	NB	BC
With IP, CGCM	452	64	-389	0.14	34	-418	0.08	24	-428	0.05
Alone, CGCM	452	129	-323	0.29	81	-371	0.18	60	-392	0.13
With IP, HADGEM	452	466	14	1.03	293	-159	0.65	184	-268	0.41
Alone, HADGEM	452	162	-290	0.36	104	-348	0.23	63	-390	0.14

[1]PB=present value of benefits; [2]NB=Net benefit for out-of stream uses, [3]BC=Benefit cost ratio for out of stream uses.

Like KDRPP, there are additional considerations for Bumping Lake Expansion, though different in their characteristics. The Bumping Reservoir expansion would flood a public campground and boat launch. It would also flood roads, hiking trails and a summer cabin and resort on land managed by the U.S. Forest Service (HDR Engineering, Inc 2011). One economic estimate of the value of these impacts is the costs required to relocate or replace these structures, neglecting changes in the quality of recreational amenities. Replacement costs are included as a subset of the cost estimates for the Bumping Reservoir Enlargement. (HDR Engineering Inc. and Anchor QEA 2011). Of the $3.5 million in Bumping project relocation costs, the IP identifies $1.2 million to relocate recreational facilities and $0.3 million for cabin siting and access road surveys (HDR Engineering, Inc. 2012, Appendix J). While not unimportant, these costs are small in proportion to total costs of the Bumping expansion.

There is also the potential for additional impacts with regard to the local environmental amenities given its location. A previous study of a plan for Bumping Lake enlargement provides detail on the potential impacts (United States Bureau of Reclamation 1979). There are several stated preference studies and "travel cost" studies that have estimated willingness-to-pay to protect old-growth forest, most commonly in the context of spotted owl habitat. The most relevant study surveyed households in California and New England on willingness-to-pay to protect old-growth spotted owl habitat from fire (J. Loomis and Gonzalez - Caban 1998). The authors estimated that median annual willingness-to-pay to protect 1000 acres (roughly the same amount flooded by Bumping Reservoir) is $20.12 (p. 321); converted to 2012 dollars, multiplied by the same number of WA households as used in the Four Accounts in 2012 and using the same 4% real discount rate and 100-yr timeframe produces an estimate of damages from lost old-growth forest of $1.85 billion. If this value were included as a cost of Bumping Lake expansion, which it arguably could be, it would provide B/C ratios ranging from 0.05 to 0.02.

e. *Wymer Dam and Reservoir*

An economic analysis of Wymer was conducted in 2008 (U.S. Bureau of Reclamation 2008b). The analysis estimated total benefits of $411.5 million ($439 inflated to 2012), which included $280 million in municipal benefits ($299 million in 2012 dollars), $26.5 million in agricultural benefits ($28.3 in 2012 dollars, and recreation benefits of $103.9 million ($110.8 in 2012 dollars). With estimated costs of $1,148 million ($1,225 in 2012 dollars), they report a "most probable" benefit/cost ratio of 0.36. The biggest difference between our results and these relate to the estimated municipal benefits, which we argue are overestimated by a factor of approximately 10 based on similar arguments provided in Section IV.C, though there were some differences that we would also argue unjustifiably inflate the estimate. In particular, in contrast to the Four Accounts analysis, this study did not adjust predicted costs of water for growth to account for the lower consumptive use of municipalities relative to agriculture. It is also noteworthy that our estimates of agricultural benefits are higher than in this previous study even in the most conservative scenarios the lowest of which is $68.6 million when implemented alone (Table 15, for agriculture only), instead of their $28.3 million (2012 dollars)).

Estimated out-of-stream uses for Wymer Dam are provided in Table 31. Our analysis suggests that for the intermediate market and climate scenario, the out-of-stream benefits fall short by about $1.3 billion if Wymer were to be implemented as part of the full IP.

Table 31: Wymer Dam and Reservoir out of stream net benefits.

		No trade			Intra-district trade			Full trade		
	cost	PB[1]	NB[2]	BC[3]	PB	NB	BC	PB	NB	BC
With IP, CGCM	1,331	81	-1,251	0.06	46	-1,286	0.03	31	-1,300	0.02
Alone, CGCM	1,331	189	-1,142	0.14	115	-1,217	0.09	82	-1,250	0.06
With IP, HADGEM	1,331	287	-1,045	0.22	225	-1,106	0.17	120	-1,211	0.09
Alone, HADGEM	1,331	764	-567	0.57	524	-808	0.39	311	-1,020	0.23

[1]PB=present value of benefits; [2]NB=Net benefit for out-of-stream uses, [3]BC=Benefit cost ratio for out-of-stream uses.

The scope of our mandate does not include estimation of recreation benefits. However, if the recreation benefits of $110.8 million for Wymer reported in U.S. Bureau of Reclamation (2008b) were taken as given and added to the benefits in Table 31, it would increase the net benefits and B/C ratios (see Table 32 for these results). For example, the B/C ratio for moderate trade and climate with Wymer implemented alone is 0.23 instead of 0.09 without accounting for recreation. Even with recreation benefits added, all B/C ratios are less than 1 and therefore do not satisfy the B-C criterion.

Table 32: Wymer net benefits and B/C ratios including estimated recreation benefits.

	No trade		Intra-district trade		Full trade	
	NB1	BC2	NB	BC	NB	BC
With IP, CGCM	-1,140	0.14	-1,175	0.12	-1,190	0.11
Alone, CGCM	-1,031	0.23	-1,106	0.17	-1,139	0.14
Alone, HADGEM	-456	0.66	-995	0.25	-1,100	0.17

[1]NB=Net benefit for out-of-stream uses, [2]BC=Benefit cost ratio for out-of-stream uses.

One further point should be made in regard to instream flow benefits. As noted above, the IP FPEIS states that half of Wymer's 162,500 af of new storage is to be allocated to IP instream flows (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). Table 33 shows that Wymer provides positive total benefits under each trading regime when implemented alone, though net benefits are negative. When IP instream flows are implemented, it imposes costs to out-of-stream uses ranging from $244 to $75 million. When both Wymer and IP instream flows are implemented, the costs of the instream flows to out-of-stream uses outweighs the benefits of Wymer, leading to negative net out-of-stream benefits ranging from $111 to $25 million. As discussed in Section IV.E. even if all of the upper bound $1.05 billion in instream flow and restoration benefits implied by the Four Accounts analysis were credited as instream flows provided by Wymer (an untenable proposition), Wymer would still not break even, and we estimate the upper bound of restoration and instream flows together to be much lower, at $48 to $294 (see Section IV.E.4.a).

Table 33: Wymer and Instream flows. Historical climate regime.

		Total out-of-stream benefits			Net out-of-stream benefits		
run	cost	No Trade	Intra-district trade	Full Trade	No Trade	Intra-district trade	Full Trade
Wymer Only	1,331	158	97	71	-1,173	-1,234	-1,261
IP Instream flows only	--	-244	-135	-75	--	--	--
Wymer and IP Instream flows	1,331	-111	-55	-25	-1,442	-1,386	-1,356

f. *Cle Elum Pool Raise*

Cle Elum Pool raise is the least expensive project other than the Ahtanum (City of Yakima) ASR, and while its storage contribution is also relatively small (adding 14,600 af for a total storage capacity of 451,500 af, or roughly 3.3% of current storage capacity), it provides the highest set of B/C ratios of the water storage project. Under moderate climate outcomes, intermediate trade, and implemented alone, it provides a B/C ratio of 0.62. Implemented with the IP under these conditions it provides a B/C of 0.26. This is due to its limited contribution to total storage applicable to both agricultural diversions and municipal benefits.

However, under the most adverse climate scenario we consider it provides positive B/C ratios for out-of-stream use of any project when implemented alone. For the market conditions considered, ranging from 2.38 to 1.02. In contrast, when implemented as part of the full IP, it has very low B/C ratios, ranging from 0.06 to zero. This is likely because the its contribution is not large enough to cover the reduced diversions that follow from the IP instream flows that are implemented under the IP and are large under the HADGEM climate scenario (see Table 23).

Table 34: Cle Elum Pool raise out of stream net benefits.

		No trade			Intra-district trade			Full trade		
	cost	PB[1]	NB[2]	BC[3]	PB	NB	BC	PB	NB	BC
With IP, CGCM	16	8	-7	0.53	4	-12	0.26	3	-13	0.19
Alone, CGCM	16	13	-3	0.80	10	-6	0.62	9	-7	0.58
With IP, HADGEM	16	1	-15	0.06	0	-16	0.00	0	-16	0.00
Alone, HADGEM	16	37	22	2.38	21	5	1.35	16	0	1.02

[1]PB=present value of benefits; [2]NB=Net benefit for out-of stream uses, [3]BC=Benefit cost ratio for out of stream uses.

The draft environmental impact statement for Cle Elum pool raise considers several alternatives. One of these alternatives allows water use to be optimized for instream flows and reservoir water levels thereby optimizing for fish production and passage, or contributing also to water available for irrigation, though this latter alternative would require additional congressional authorization (U.S. Bureau of Reclamation and State of Washington Department of Ecology 2014). Thus, under current rules, the water would all be made available for instream flows. In any case, while the B/C ratio is only 0.26 based on out-of-stream benefits alone, the shortfall in net benefits is relatively small, and its contributions to instream-flow benefits (which contribute to our estimated benefits of $48 to $294 million for instream flows and restoration combined).

There is some concern that without the IP instream flow augmentation particularly for the Cle Elum River, and/or the Cle Elum pool raise itself, fish passage at Cle Elum would be less effective than otherwise, and that the Cle Elum pool raise is therefore important for the effectiveness of fish passage. While IP instream flow augmentation for the Cle Elum River is part of the proposed IP Instream Flows (HDR Engineering, Inc. 2014), and reservoir level management may affect fish passage effectiveness, this does not imply that the Cle Elum pool raise is necessary to operationally implement IP instream flows or maintain reservoir levels to facilitate passage. Although we argue that purchasing instream flows would likely be less costly than providing them on the basis of IP infrastructure, the potential contributions of the Cle Elum Pool raise to provide these benefits along with its relatively low cost make it the most likely project for satisfying a B-C criterion of any IP storage project.

The Cle Elum Pool Raise will permanently raise maximum water levels by three feet, and marginal water level increases have been shown to produce economic impacts including benefits in other studies. Lansford and Jones (1995) and Eiswerth et al. (2000) find that increased pool height may have a positive effects on property and recreation values, but these effects are likely to be context specific. It is not clear that property or recreational benefits would accrue beyond the costs incurred to landowners that are compensated for in the cost estimates for this project.

g. *Passive Aquifer Storage and Recovery (ASR) at Thorpe and WIP*

Passive aquifer storage and recovery, also called groundwater infiltration, would be applied to spreading areas like ponds and canals, each of which would be roughly 2-10 acres in size (2011). This infiltrated water would reduce the volume of water required from reservoir releases, supplementing the total water supply available (TWSA) and base flows in the Yakima River during low-water seasons (U.S. Bureau of Reclamation, Washington State Department of Ecology, and Prepared by Golder Associates, Inc and HDR Engineering, Inc 2011). Between 160 and 500 acres of infiltration area would be required to store 100,000 af (Golder Associates and Washington State Department of Ecology 2009), the mean annual volume that could be made available for other uses (Reclamation and Ecology 2011n).

Table 35: Passive ASR; out of stream net benefits.

		No trade			Intra-district trade			Full trade		
	cost	PB[1]	NB[2]	BC[3]	PB	NB	BC	PB	NB	BC
With IP, CGCM	126	29	-97	0.23	16	-110	0.13	13	-114	0.1
Alone, CGCM	126	64	-62	0.51	45	-82	0.35	37	-90	0.29
With IP, HADGEM	126	114	-12	0.91	108	-19	0.85	49	-77	0.39
Alone, HADGEM	126	176	49	1.39	112	-14	0.89	79	-47	0.63

[1]PB=present value of benefits; [2]NB=Net benefit for out-of stream uses, [3]BC=Benefit cost ratio for out of stream uses.

The results show negative net benefits under all but the most adverse climate and market conditions. Benefit cost ratios are below 0.5 in all but the HADGEM climate regime.

2. *Conservation*

The IP includes categories for both agricultural conservation and municipal conservation. We consider each in turn.

a. *Agricultural conservation*

Agricultural water conservation measures include lining or piping existing canals, automating canals, constructing re-regulating reservoirs on irrigation canals, improving water measurement and accounting systems, installing on-farm water conservation improvements, and other measures. These investments do not provide additional storage, but modify the spatial and temporal distribution of water in the Basin.

As discussed in Section IV.B.3 in relation to Table 12 through Table 15, the results for future climate scenarios are somewhat anomalous. Table 36 shows that, unlike any other IP project, the estimated benefits for agricultural conservation are highest under the historical climate regime. We therefore consider these scenarios here. In particular, B/C ratios for the historical climate regime range from 0.16 to 0.05, whereas the B/C ratios for the other climate regimes are at or below 0.05.

In the case of the most adverse climate scenario (HADGEM) the estimated present value of gross benefits is actually negative. As described earlier, this result should be interpreted as zero, and it follows from the fact that conservation measures, as parameterized in YAKRW, have essentially no effect on curtailment rates and therefore essentially no out-of-stream benefits under the most adverse climate regime. As noted previously, the Agricultural Water Conservation Technical Memorandum (U.S. Bureau of Reclamation, Washington State Department of Ecology, and Prepared by Anchor QEA 2011) states "In addition, these water savings are estimated for years when water users have a full water supply. Therefore, in drought years the water savings would be reduced because less water would be conveyed through irrigation systems and applied to farms, which, in turn, reduces seepage and other losses and results in less return flow. (p. 3)" Curtailment happens in every year under this scenario, which may be driving these YAKRW results. See HDR Engineering, Inc. and Anchor QEA (2011) for more detail on YAKRW hydrologic modeling and results.

These water conservation projects are scheduled to be implemented over about 18 years, rather than the three or four year time schedule of the rest of the projects (HDR Engineering et al. 2012). If benefits are assumed to ramp up evenly over this time period instead of accruing immediately as is implicitly assumed in the PB numbers in Table 36, it can be shown that the present value of benefits amount to 72.6% of reported present values, thus reducing net benefits and B/C ratios further.

Table 36: Agricultural water conservation for out-of-stream net benefits.

		No trade			Intra-district trade			Full trade		
	cost	PB[1]	NB[2]	BC[3]	PB	NB	BC	PB	NB	BC
With IP, historical	257	34	-223	0.13	17	-240	0.07	12	-245	0.05
Alone, historical	257	42	-215	0.16	22	-235	0.09	14	-243	0.06
With IP, CGCM	257	1	-256	0.00	0	-257	0.00	0	-256	0.00
Alone, CGCM	257	14	-243	0.05	8	-249	0.03	5	-252	0.02
With IP, HADGEM	257	6	-250	0.02	10	-247	0.04	3	-254	0.01
Alone, HADGEM	257	0	-257	0.00	-8	-265	-0.03	-1	-258	0.00

[1]PB=present value of benefits; [2]NB=Net benefit for out-of stream uses, [3]BC=Benefit cost ratio for out of stream uses.

As with the other water storage project results in this section, the "Alone" results in Table 36 are implemented without IP instream flows implemented. However, as mentioned in Section II, some of the estimated "conserved water" would be reserved for instream flows benefits. These specific instream flows are not implemented in YAKRW, and so in contrast to the other storage project, all rows in Table 36 should be interpreted with a recognition that they are underestimates of the benefits to the extent they contribute to instream flow benefits.

There is another reason to interpret the results for agricultural conservation carefully. Agricultural conservation does not provide more water storage capacity to hold water for the summer months, but instead by design reduce seepage from irrigation canals. These investments will allow some irrigation districts more control and effective use over their water entitlements, which will be beneficial to them. However, to the extent that the saved seepage is retained by the irrigation districts and used consumptively, return flows to the lower basin may decline, and may impact water users downstream. For example, Kennewick Irrigation District (KID) is not included in our market and impact analysis in part because they have historically not been subject to substantial curtailment because, despite the fact that they hold proratable rights, they are low in the basin and return flows contribute to their water availability. If upstream conservation practices reduce return flows available to KID, it may increase curtailment rates faced by KID. These potential losses are not accounted for in Table 36 but in principle should be. If these losses do accrue, net benefits of these conservation measures would be lower.[51]

The general point is that agricultural conservation will have *distributional* impacts on water availability and curtailments across irrigation districts, time, and space, but it is not clear what the benefits of the types of conservation practices would be in the aggregate. These aggregate results, therefore, have limited practical use for understanding these distributional impacts of conservation practices.

b. *Municipal conservation*

Under the IP municipal conservation program, educational measures and incentive-based actions to achieve municipal and domestic conservation estimates are set forth in the Integrated Plan (HDR Engineering Inc. et al. 2011, 58). Average municipal conservation savings under the Integrated Plan are estimated to be 7,600 af annually (HDR Engineering, Inc. 2011). Sixty percent of these annual savings are assumed to be accrued by 2030, and 100% by 2060. Costs for this basin-wide water conservation program are estimated to be between $0.5 and 1.5 million per year on an ongoing basis. Taking these details as given and assuming, as with municipal benefits in Section IV.C, that were it not for these water savings, municipalities would have to purchase additional water for growth at $1,500/af in terms of net value, the net present value of costs to 2060 ranges between $10.5 and $31.3 million, and the benefits are estimated at $6.36 million. This provides B/C ratios of 0.2 to 0.6, respectively. It should be noted that these costs and benefits were noted as preliminary in the supporting documentation, and we have not vetted the foundational assumptions.

3. Power subordination

Under the IP, instream flows would be augmented along the mainstem of the Yakima River by reducing diversions for electricity production the Roza and Chandler Power Plants. As a result of these reduced diversions, 14,000 fewer MWh would be produced over the months of April and May at Roza. At Chandler, 11,000 fewer MWh would be produced over the months of April, May and June (U.S. Bureau of Reclamation 2011d). Based in assumptions and calculations presented in Appendix VII.G, the annual value of foregone electricity production at Roza and Chandler combined is $534,500, for a present value of $13.1 million dollars.

Unfortunately, we do not have sufficient precision about the impacts of these instream flow augmentations on fish abundance in the basin to estimate the value of instream flows from Roza

[51] As noted in Section III.B.1, YAKRW focuses on surface water hydrology, and it deals with groundwater very simplistically. This is yet another reason to be skeptical of the aggregate numerical values presented for agricultural conservation.

and Chandler, except to say they must be lower than the combine total of $48 to $294 for IP instream flows and restoration combined. We therefore are unable to estimate the net benefits of the operations change.

4. Markets

One component part of the IP is to facilitate water market development. We consider the role of markets both within the agricultural sector and across sectors, between agriculture (as a potential seller of water) and both municipalities, for municipal water security, and the state (or other potential buyers) for instream flows.

c. *Water market gains from trade within Agriculture*

The gross potential gains from trade within and among irrigation districts can be interpreted as the increase in the value of production that is accrued relative to a more restrictive market setting. Table 37 provides the estimated gains from intra-district trade, the additional benefits from adding inter-district trade, and total gains from trade. These results are analogous to those presented in Table 11 (page 72) but are based on different climate regimes.

Table 37: Gains from trade for with and without the IP. $millions. Historical climate.

	annual gains from trade			present value of gains from trade			
run	intra-district trade	inter-district trade	Full trade	intra-district trade only	inter-district trade	Full trade	Net of Trans. Costs[1]
Baseline, CGCM climate	12	6	18	287	153	439	317
Full IP, CGCM climate	8	5	12	189	110	299	216
Baseline, HADGEM climate	49	32	82	1,212	787	1,999	1,436
Full IP, HADGEM climate	39	26	65	946	639	1,585	1,138

[1]Transaction costs are assumed to be 1/4 of gains from intra-district trade and 1/3 of gains from inter-district trade. No adjustment was made to account for reduced transactions due to transaction costs.

One factor leads to two persistent patterns in this table: water scarcity increases gains from trade. Water markets are more valuable without the IP, and with the more adverse climate scenario. Under the full IP and the less adverse climate, full trade would provide at most an estimated $12 million in gains from trade, for a present value of $299 not accounting for transaction costs, whereas without the IP under the most adverse climate scenario, the potential gains from trade reach a present value of up to $1.6 billion.

It bears reiterating that these are *potential* gains from trade in the sense that the results are based on a number of strong assumptions about market performance as outlined in Section III.C.d. In reality, market transactions for water can be costly in terms of both time/effort and financial resources beyond the per-af purchase price. As noted in Section III.C.2.d, several studies have estimated the transaction costs associated with water transaction. These costs vary depending on whether the transaction occurs within an irrigation district, across districts, or when one of the parties is a government entity. Transaction costs are also not based on the volume of water traded, but on a per-transaction basis, which makes estimation of transaction costs somewhat difficult. However, McCann et al. (2005) citing others find that transaction costs can amount to up to a quarter of the purchase price of water for typical water transactions, and anecdotal evidence from Kittitas county transactions suggest transaction costs of nearly one-third of the total purchase cost in legal and regulatory processing fees alone.

It is noteworthy also that intra-district gains from trade make up about 60 – 65% of total gains from trade in Table 37, and inter-district trades account for only 35-40%. Intra-district trades are likely to be associated with lower transaction costs in part because regulatory oversight is not required for intra-district transactions. This is not to say they are costless, however. For example, YTID charges $150 per transaction plus up to an additional $50 depending on additional factors.

The impacts of these fees and other less tangible costs of transactions are explained here. First, to the extent that these costs represent real resource and time costs, they should be subtracted from the aggregate benefits. A rough estimate of the gains from trade net of transaction costs are presented in the last column of Table 37, assuming that transaction costs amount to 25% of intra-district trades and 33% of inter-district trades. After netting out transaction costs, the potential gains from trade range from $317 million to about 1.1 billion.

The second effect of significant transaction costs is that it will limit the number of transactions that are worth carrying out. The Four Accounts restriction that trades only occur for crops with net revenues above $150 can be viewed as a way to impose a minimum "gap" in crop types that would be eligible for trades. Because transaction costs are likely to be lower for intra-district trades, the volume of transaction in a well-functioning intra-district market are likely to more closely approach the hypothetical bounds than inter-district trading.

Previous IP studies have reported estimates for IP market development, including capital costs of $2.1 million and annual O&M costs of $212,000 (HDR Engineering et al. 2012) --- for a present value of about $2.4 million. There is no detail in the IP regarding which actions are envisioned in the water marketing component, nor how proposed changes would differ from current market infrastructure and conditions. Presumably these are administrative costs for market development and operations. Our numbers above include administrative costs in the sense that the transaction costs discussed assume these costs are passed on to buyers and sellers as transaction fees. It is worth noting that the transaction costs implied by transaction costs of 25% and 33% of intra- and inter-district trades leads to aggregate transaction costs ranging from nearly $100,000 to nearly $500,000 (compared to $2.4 million reported in the previous study). These costs are not inconsequential, but they accompany larger net gains from trade.

One final point about transaction costs is that to some extent they are a function of the regulatory environment and infrastructure available to potential buyers and sellers, as well as and as such can be lowered by well-designed market structure.

d. *Water markets across sectors*

The Four Accounts analysis credits the IP with potential gains from trade from municipal purchase of senior water rights to increase water security for current municipal water users. We estimate potential gains from trade of about $5 million (Section IV.C), not accounting for transaction costs and assuming that municipalities address their risk through leasing during curtailment years. Any increases in this value would depend on the extent that the marginal value of water to municipalities is greater than the assumed $100/af/year as relied on in the Four Accounts analysis. This is probably likely in many cases where municipalities face curtailment risks.

As described in Section IV.D, it is likely that the instream flow augmentation proposed under the IP can be purchased at lower cost than if they were to be provided by IP water storage infrastructure. We estimate this value to be approximately $100 million (not accounting for transaction costs, and depending substantially on climate) based on water transfers upward of 75,000 af/year from agriculture to instream flow use assuming that these transactions are possible. There are undoubtedly barriers and costs to carrying out market transactions such as these. Some of the general barriers to trade have already been discussed in Section III.C.d but in the case of instream flow augmentation, the capacity of the Department of Ecology or other entities for funding and carrying out such transactions is probably insufficient without additional capacity. Among the institutional barriers that may exist is that change of use for federal project water --- which describes the water held by the large irrigation districts in the Yakima Basin --- may call for legislative action to facilitate, as was the case for California (e.g. the Central Valley Improvement Act, 1992. Sec 3405; http://www.usbr.gov/mp/cvpia/title_34/public_law_ complete.html).

It is beyond the scope of this project to recommend alternatives to the proposed IP or for recommending strategies for water market development, and it should be noted that water market infrastructure has indeed been progressing, especially over the last 15 years or so. The Washington State Department of Ecology Water Resource Program website (http://www.ecy.wa.gov/programs/wr/wrhome.html) is but one illustration of these developments. However, it is likely that there are still substantial gains to be made to reduce transaction costs and willingness to participate in water markets through additional legal, regulatory, administrative, educational, and contractual avenues. Among the possibilities, there seems to be potential for stronger emphasis on developing long-term contractual solutions for water trading (such as contingent contracts) to prepare for drought, rather than having to pursue market options in emergency response to them.

5. *Fish passage*

A total of seven fish passage projects are proposed under the IP: one for Keechelus, Kachess, Cle Elum, Tieton, Clear Lake, and Bumping reservoirs. In addition, Fish Passage for Box Canyon Creek, which is a tributary into the Kachess reservoir, is proposed as part of the IP. We examine the first five, and then comment on the last two.

a. *Five major fish passage projects*

The summary results for the five major fish passage projects are listed in Table 38, the elements of which are taken from Table 28. In general, fish passage projects have the highest B/C ratios of any set of projects in the IP, providing B/C estimates ranging from 1.43 to 11.68.

Table 38: Benefits and costs of the five major fish passage projects. $millions. Taken from Table 28.

Reservoir	Contribution to total Abundance %		Cost[2] $mill.	revised benefit estimates $millions		B/C ratios for revised estimates	
	low	high		low	high	low	high
Keechelus	12	16	79.9	114	205	1.43	2.56
Kachess	29	31	79.9	276	495	3.46	6.19
Cle Elum	27	23	81.5	257	461	3.15	5.65
Tieton[3]	13	17	79.9	124	222	1.55	2.78
Bumping[4]	18	14	26.3	171	307	6.52	11.68
Total	100	100	347.5	952	1,706	2.74	4.91

The numbers for Bumping lake assume the Bumping lake expansion. Without it, the lake is 17% the size listed (33,700 af rather than 198,000 af (HDR Engineering, Inc 2011). It would therefore provide about 17% benefits, or $29 to $52 million. Assuming the same cost structure, it would provide B/C estimates ranging from 1.11 to 1.98, which at the low end just barely satisfies to B-C criterion.[52] The effect of the Cle Elum pool raise would be very small because it adds only 3% of the volume and negligible additional habitat.[53] Individual projects with the lowest estimated B/C ratios, such as Keechelus and Tieton would be the first to be called into question.

Section IVE.b4 discussed the potential impact of technical complementarities between and among projects, and as noted above in the discussion of the Cle Elum pool raise, concern related to such complementarities was voiced in a comment on a draft of this report. The concern is that without the IP instream flow augmentation particularly for the Cle Elum River, fish passage at Cle Elum would be less effective than otherwise, and that the Cle Elum pool raise is important for providing the proposed instream flow augmentation to support fish passage effectiveness. While IP instream flow augmentation for the Cle Elum River is part of the proposed IP Instream Flows and may increase the effectiveness of Cle Elum fish passage, this does not imply that the Cle Elum pool raise is necessary to operationally implement IP instream flows. The pool raise will increase storage capacity of the Cle Elum reservoir by about 3.3% by adding 14,600 af for a total storage capacity of

[52] The costs of Bumping Lake Fish passage are estimated to be approximately equal with the existing dam or with the new dam under the Bumping Lake Expansion (HDR Engineering Inc. and Anchor QEA 2011).

[53] The productivity of Clear Lake fish passage is dependent on fish passage at Tieton. Box Canyon fish passage impacts may also be dependent on fish passage at Kachess dam. More discussion of this is provided below.

451,500 af (U.S. Bureau of Reclamation and State of Washington Department of Ecology 2014).[54] This is not a large addition, especially in relation to current total water storage in the basin. The Cle Elum pool raise would not be necessary to meet proposed augmented instream flows in the Cle Elum River because releases from the all existing storage can be jointly managed to provide water for instream flows and irrigation. Water from Cle Elum reservoir can in principle be held in Cle Elum to augment instream flow needs in Cle Elum River with releases from additional reservoirs compensating for other uses as needed and perhaps requiring additional water rights to mitigate for these instream flows.

The point is that while instream flow augmentation may improve the effectiveness of fish passage at Cle Elum dam, the pool raise is not strictly necessary to provide these instream flows. If instream flow augmentation is not provided, then the net benefits, and the associated B/C ratio, may be lower. The same critique applies to other fish passage projects to the extent that the same type of complementarity exists between fish passage and instream flow at other dams. Granted, to the extent that additional storage is not developed, water rights may need to be acquired (purchased) to provide instream flow augmentation as discussed in Section IV.D.2.

b. *Additional passage: Box Canyon and Clear Lake*

Less information is available for two less expensive and more or less unrelated fish passage projects: Box Canyon and Clear Lake. While these two projects are not related infrastructurally, we group them together here to make only some indirect inferences about these two projects.

The Clear Lake dam is located upstream of Tieton Reservoir. The proposed fish passage improvements would overcome the limitations of the current fish ladders, promoting upstream fish migration and enhance the value of fish passage improvements at Tieton (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). Presuming that Tieton Fish passage is completed, and assuming that the fish habitat quality in Clear Lake is equivalent to that in Tieton and the fish passage is as effective as lake dispersion, then we can estimate the additional benefits of adding passage to Clear Lake given their lake sizes and the low and high estimates of fish benefits from Tieton. Using these assumptions and data, Table 39 estimates B/C ratios of 5.2 and 9.3.

Table 39: Estimating potential benefits from Clear Lake Fish Passage.

		Benefits			B/C ratio	
	acres	Low	High	Cost	Low	High
Tieton	745	124	222[1]	79.9[1]	1.55	2.78
Clear Lake	127	21	38	4.1	5.2	9.3

[1]Taken from Table 28.

[54] Cle Elum Reservoir levels have fluctuated by as much as 120 feet (U.S. Bureau of Reclamation and State of Washington Department of Ecology 2014). In percentage terms, 3 additional feet of elevation in the Cle Elum pool is only 2.5% of this range.

The assumptions underlying these numbers are certainly strong, but the projected costs are relatively low compared to fish passage at Tieton.

Box Canyon Creek would expand the amount of accessible habitat as well as enhance the quality of existing shoreline habitat for fish; primarily bull trout (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012), at an estimated cost of $1.4 million. Even less informative quantitative data are available for Box Canyon in terms of benefits. However, the implementation and use of the Kachess Drought Relief Pumping Plant during drought years may negatively impact fish passage effectiveness of the Box Canyon fish passage improvements (U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). To the extent that the benefits of Box Canyon fish passage provide its primary benefits during low-water conditions in Lake Kachess, the impact on the benefits of the Box Canyon Creek fish passage project may substantial.

V. Conclusion

The objective of this analysis is to perform benefit-cost analysss for the individual component projects of the integrated plan. This research is in response to Section 5057 of the State of Washington Capital Budget for 2013, which charges the State of Washington Water Research Center "to prepare separate benefit-cost analyses for each of the projects proposed in the 2012 Yakima river basin integrated water resources management plan (Yakima integrated plan)." Further, "[t]o the greatest extent possible, the center must use information from existing studies, supplemented by primary research, to measure and evaluate each project's benefits and costs." Finally, "The Center must measure and report the economic benefits of each project on a disaggregated basis, so that it is clear the extent to which an individual project is expected to result in increases in fish populations, increases in the reliability of irrigation water during severe drought years, and improvements in municipal and domestic water supply." This report is in response to this charge.

We present an expansive set of results that vary depending on different assumptions about climate and potential market water outcomes, and are conditional on various assumptions about IP implementation. Because each of the proposed IP projects would operate within the Yakima Basin hydrologic system, there are extensive interdependencies among projects such that the benefits of one project are often dependent on the implementation status of other projects. We show that the value of any given water storage projects is highest when no other water storage projects are implemented, and that because water markets act to reduce the economic impact of water curtailment, the extent of water market development also affects the value of water storage projects. The economic tradeoffs between instream flows for fish and out-of-stream water uses are also dependent on these factors. Selected specific results include the following:

- *A snapshot of IP benefit estimates for moderate climate, water market, and baseline fish scenarios.*
  - Agricultural irrigation benefits: $117 million.
  - Municipal and domestic benefits: $32 million.
  - Fish benefits: $1 to $2 billion.

- *When implemented together as part of the IP, the major water storage projects as a group do not pass a B-C test.* Net present value for out-of-stream benefits (NB) from the IP range from -$2.2 to -$2.7 billion (B/C ratios from 0.02 to 0.20) depending on market and climate assumptions. Estimated benefits of proposed instream flow increases cannot make up for this shortfall.
- *No individual water storage project provides positive net benefits for out-of-stream uses when implemented as part of the full IP, even under the most adverse climate and restrictive market conditions.*
- *Net benefits for out-of-stream use of individual water storage projects implemented with no other projects implemented are negative, with some exceptions under the most adverse climate and water market conditions.* Based on moderate climate and market outcomes, storage infrastructure projects implemented alone and without proposed IP instream flow augmentation result in the following estimated out-of-stream net present value and B/C ratios, none of which passes a B-C test:
    - Bumping Lake Expansion: NB=-$371 million; B/C ratio of 0.18.
    - Cle Elum Pool raise: NB= -$6 million; B/C ratio of 0.62. Under the most adverse climate scenario and moderate market conditions, NB=$5 million with a B/C ratio is 1.35. It is also the most likely of the storage projects to satisfy a B-C test under moderate climate based on the sum of out-of-stream and instream use value.
    - Keechelus to Kachess Conveyance: NB= -$110 million; B/C ratio of 0.20.
    - Kachess Drought Relief Pumping Plant: NB= -$107 million; B/C ratio of 0.46. Under the most adverse climate considered, Keechelus to Kachess Conveyance and Kachess Drought Relief Pumping Plant together provide net benefits of $6 million and a B/C ratio of 1.02.
    - Passive Aquifer Storage and Recovery: NB=-$82 million; B/C ratio of 0.35.
    - Wymer Dam and Reservoir: NB= -$1,217 million; B/C ratio of 0.09.
    - Due to diminishing economic returns to water in the basin, increasing the number of IP storage projects reduces the value of each water storage project implemented.
- *Instream flow benefits are insufficient to support the full suite of IP water storage projects given the net benefit shortfall in out-of-stream benefits, but proposed instream flows may be supportable through market purchases.*
    - Purchases of senior water rights to implement proposed IP instream flows would be less expensive than providing instream flows via IP storage infrastructure, with estimated costs ranging from $85 million to $500 million depending on water market and climate conditions.
    - Because of its low cost, Cle Elum pool raise is most likely to satisfy a B-C test under moderate climate based on the sum of estimated out-of-stream and instream benefits.
- *Reservoir fish passage projects are likely to provide positive net benefits through their pivotal role in supporting wild sockeye reintroduction into the basin.* Fish passage is estimated to provide benefits ranging from about $0.95 to $1.7 billion and cost a total of $0.35 billion for all fish passage projects, which provide B/C ratios ranging from 2.7 to 4.9 for the individual fish Passage projects.
- *Fish habitat restoration is unlikely to satisfy a B-C test.* Results for the net benefits of instream flow purchases and restoration investment together range from about $48 million to $294 million, which fall below their estimated combined costs of $450 million. IP restoration costs are estimated at $338 million, so our results suggest that restoration does not satisfy a B-C test. However, insufficient evidence exists to estimate the contribution of habitat restoration to fish passage productivity, which may affect the value of restoration.

- *Water markets show potential for reducing the impacts of basin-wide curtailment.* We estimate that potential net gains from trade net of estimated transaction costs range between $216 million and $1.4 billion depending on climate, the extent of market development, and the extent of IP development. We show that markets act as a substitute for IP water storage infrastructure in that more active markets reduce the value of IP water storage infrastructure.

This report is not intended to be a review of prior benefit-cost estimates of the IP, but does utilize and extend existing IP analyses, and sheds some light on the sources and accuracy of the estimated benefits in the Four Accounts analysis. The Four Accounts analysis estimates agricultural benefits of $0.8 billion, municipal benefits of $0.4 billion, fish benefits ranging from $4 to $7.4 billion, and costs ranging from $2.7 billion to $4.4 billion. These numbers for the IP as a whole indicate positive net benefits and B/C ratios of 1.4 and higher. Our estimated benefits as presented above are lower for each category for a host of reasons. Notably, the assumed climate regime has substantial consequences for agricultural benefit estimates and the assumed baseline salmonid abundance in the Columbia River Basin has important consequences for the valuation of fish benefits from the IP. The contribution of these and a host of other factors to the difference in overall estimates are described in detail in the report. Based on the engineering cost estimates used in the Four Accounts analysis and supporting reports, our benefit estimates suggest that the expected net present value of the IP is likely to be negative.

Despite the differences in results, there are important similarities in findings. Fish passage projects alone comprise a small percentage of median IP costs but provide about 75% to 80% of the estimated benefits of the IP. In contrast, IP investments for instream and out-of-stream uses account for about 66% of median costs but provide a small fraction of benefits. This distribution of costs and benefits drives the strong results for fish passage although it is not explicitly shown in the Four Accounts analysis.

In accordance to the legislative charge, this report focuses sharply on benefit-cost analysis to assess the economic efficacy of individual projects. It does not include an economic *impact analysis* to assess the indirect economic impact of IP investments on the local economy or the statewide impacts of the potential use of state funds to support the IP. Nor does this report cover costs and benefits from ongoing, non-IP programs within the basin whose outcomes may impact IP benefit metrics, such as fish translocation or hatchery operations.

Due to data limitations, the majority of the results are based on simulation methods rather than statistical analysis, though statistical analysis is provided when feasible and useful. The consequence is that although some robustness exercises are performed, the majority of our results do not lend themselves to statistical confidence assessment. Many necessary tradeoffs were made with respect to modeling approaches due to the scope of this research mandate.

Refinements are certainly possible and may be warranted for any given modeling approach relied upon in this analysis. First, despite the fact that we were not charged to examine climate impacts, potential climate change in the basin is an important determinant of outcomes in this report. To better address the effects of climate, the updated CMIP 5 climate scenarios should be used. Further, because the results of this study suggest that delaying, if not foregoing, investment in water storage infrastructure, more sophisticated modeling of the development of climate distributions over time would be useful in understanding the optimal timing of infrastructure construction.

The crop model used in this report was adapted from prior studies, and relies on several restrictive assumptions. First, it assumes that the impacts of irrigation curtailment last only one season, and have no multi-year impacts even on perennial crops such as hay and fruit trees. This simplification is likely to underestimate curtailment impacts. We also assume that fallowing is the only response to dealing with curtailment, which would lead to overestimation of impacts, whereas allowing deficit would mitigate this bias. The model also assumes static crop mix, whereas in the long run, irrigators are able to modify their crop mix in response to curtailment risk over time. In addition, we have not accounted for emergency groundwater pumping during droughts. This could mitigate drought impacts substantially for some irrigators depending on the distribution of emergency well rights.

Fish abundance impacts are very difficult to assess based on existing information. Among the most fundamental needs to assess the benefits of instream flow, restoration, and/or fish passage is better and more data that allow more precise estimation of impacts. This would be a substantial undertaking, but given the amount of resources being invested annual in fish restoration, data such as this would provide substantial benefits in understanding impacts.

Our fish valuation relies on the methods used in the Four Accounts analysis. While we hypothesize that the LBP study provides upwardly biased estimates of fish value in the context of the IP, we did not have the capacity to generate the data necessary to test this hypothesis. To do so, new survey work would be required with a focus on the Yakima Basin and the IP specifically. Further, it has become clear in our review of the literature that the development of new non-market valuation methods that better integrate the effect of outcome uncertainty on valuation would be well suited for the kinds of questions being asked about IP impacts. We do, however, demonstrate that incorporating any increases in fish populations between 1998 and 2012 resulting from any of the non-IP efforts in the Columbia Basin dramatically decreases the benefits attributable to the IP.

Several weaknesses of the municipal benefits analysis would also be useful to address. First, fully integrating municipal demand growth in an integrated model of water trading would allow for better estimates of equilibrium market outcomes (e.g. prices, quantities) and gains from trade. Second, a careful examination of the effect of large divergences between agricultural water value and municipal water value on water price volatility would be useful in understanding and predicting future market outcomes. Third, we relied entirely on the existing forecasts of population increases in relation to water rights, whereas updated analysis of these fundamentals is warranted.

Project-specific costs for most projects have been reported in existing reports. Where this is the case, we have taken these costs as given, in most cases without substantive assessment.

Finally, our market simulations rely fundamentally on frictionless intra- and inter-district trading to assess outer bounds on both infrastructure impacts and gains from trade. While we take considerable pains to recognize the impact of institutional constraints and market transaction costs on water trading, we integrate these factors into the market simulations only loosely. Much is still unknown about the reasons for persistently thin and inactive water markets and how to reduce transaction costs and facilitate transactions. However, the Yakima Basin is the beneficiary of the *Acquavella* general water rights adjudication, which is a crucial foundation for water market development in the basin. It seems clear that despite some substantial water market developments in the last couple of decades, opportunities still exist to further facilitate water market activity through additional legal, regulatory, administrative, educational, and contractual avenues.

VI. References

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VII. Appendix

A. Irrigation water value

As described in the body of this report the methodological approach used to estimate the benefits to agriculture from the individual YBIP projects builds on the approach used in the Four Accounts study, which was based on the spreadsheet model developed by Scott et al. (2004). A number of modeling capabilities were developed. In particular, we develop marginal value functions for water that allow us to compare the outcomes of three types of water market scenarios: a no trading scenario, an intra-district trading only scenario, and a full trading scenario with both intra- and inter-district trading. This appendix explains the relationship between crop production and water value by developing water value functions, also known as inverse demand functions for water. The next Appendix illustrates how these inverse demand functions are used to assess market outcomes.

Table 5 on page 32 of the report provides a breakdown of crop acreage allocation, water use, and value per acre, by irrigation district. The relationship between water availability and the marginal value of water implied in that table can be visualized for each district by ordering the crops from highest to lowest value ($/af) and placing them on an x and y-axis where the x-axis is af of water and the y-axis is $/af. This provides a step function representing the marginal value of water for crop production. Figure 19 illustrates the step function for the Roza district, conditional on that districts crop acreage allocation. The height of each step represents the value of water for a given crop and the length of each step is the amount of water used for that crop in a given district. Assuming that

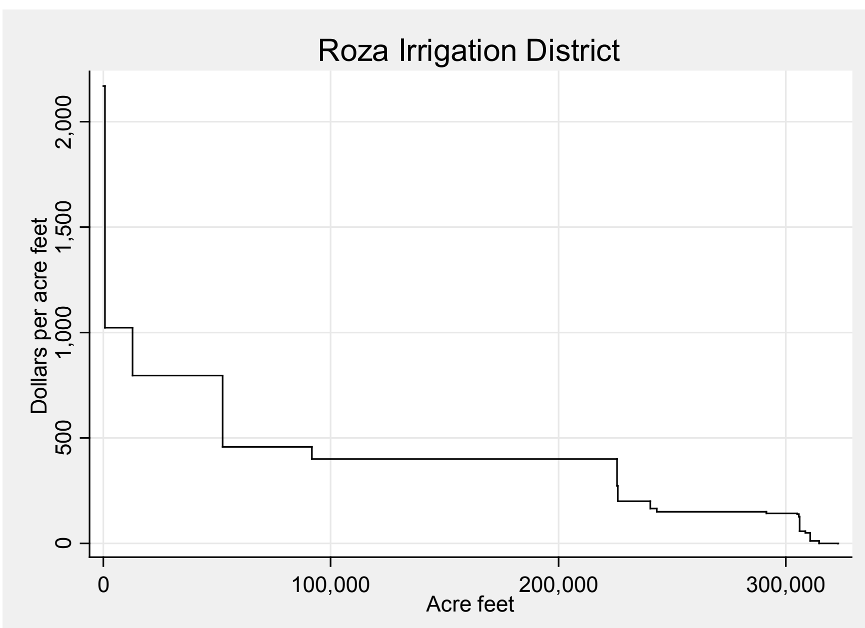

Figure 19: Illustration of marginal crop value as a function of water availability, arranged from highest to lowest value.

water is allocated to higher valued uses first, the total value of production for any given amount of water equals the area under the step function to the left of the amount of water available. For example, in Figure 19, the total value of production provided by 200,000 af of water as applied optimally across Roza crop acreage is the area under the step function to the left of 200,000 af.

The Scott model uses these step functions directly to implement the economic optimization model described above. To facilitate our market analysis, we approximate these step functions by fitting continuous and monotonically decreasing functions of the form

$$p = Bq^{\theta}e^{\varepsilon},$$

where p is the marginal value of water evaluated at quantity q, B and θ are parameters, e is the exponential function, and ε is a random disturbance with mean zero. Transforming both sides of the inverse demand equation provides $\ln p = \ln B + \theta \ln q + \varepsilon$, which permits the linear regression equation that can be estimated using ordinary least squares. This general procedure for estimating water demand curves from underlying step functions is described by Burt (1964). Regressions are run for each irrigation district, and each estimated regression is retransformed using the method described by (Duan 1983) to account for the fact that the expected value of the error term in the log-log model is not zero after retransformation (that is, $E[e^{\varepsilon}] \neq 0$) even though $E[\varepsilon] = 0$). Our estimated inverse demand curves can be defined in general as $\hat{p} = \hat{B}q^{\hat{\theta}}\hat{D}$,where $\hat{D}$ is Duan's smearing estimate of $E[e^{\varepsilon}]$.

The estimated inverse demand curves provide a close approximation to the step functions implied by Table 5 on 32, but the area under these functions, which represents the total value of production, are not guaranteed to match the area under the original step functions. Therefore, we calibrate our estimated inverse demand functions so that the area under the curves is equal to the total profit in a non-drought year for each district i. The calibration is based on the following equation that defines the area under an inverse demand curve for a given district:

$$\pi(\bar{Q}) \approx \int_{m}^{\bar{Q}} \hat{p}\, dq = \frac{DB}{1+\theta}\left(\bar{Q}^{1+\theta} - m^{1+\theta}\right)$$

Where $\hat{p}$ is the inverse demand function defined above, $\bar{Q}$ is the amount of water used during a non-drought year (which is typically less than a district's full entitlement), and m is the calibration instrument. The calibration involves changing the lower limit of integration to a value above zero when the area under the inverse demand function with a lower and upper limit of integration of 0 and the maximum water use in a non-drought year, respectively, is greater than the assumed value for total profit in a non-drought year. It is feasible for this area to be less than the assumed total profit in a non-drought year. Had this occurred the function could have been shifted upward but this was not the case for any of the irrigation districts. It is also possible to shift the entire function downward for cases where the total profit estimate was too high by multiplying by a constant less than 1. However, calibration through increasing the lower limit of integration provides a higher estimate of agricultural benefits for water storage projects and it was deemed preferable to err on the high rather than low side of agricultural benefits.

The total profit for SVID, Roza, KRD, and Wapato required calibration while Kittitas Sr. did not. The lower limits of integration along with the other relevant parameters are provided in Table 40.

Table 40 Estimated parameter and calibration instrument values for water inverse demand functions

			District		
Parameter	Roza	KRD	Wapato	SVID	Kittitas Sr.
B	13.03	10.35	16.42	13.79	9.37
θ	-0.63	-0.541	-0.943	-0.728	-0.484
m	4,000	3,500	5,000	5,000	0
D	1.21	1.282	1.655	1.192	1.16

Figure 20 shows the estimated functions and their corresponding step functions. These estimated inverse demand curves for water are used in two ways: first, they are used to estimate the aggregate

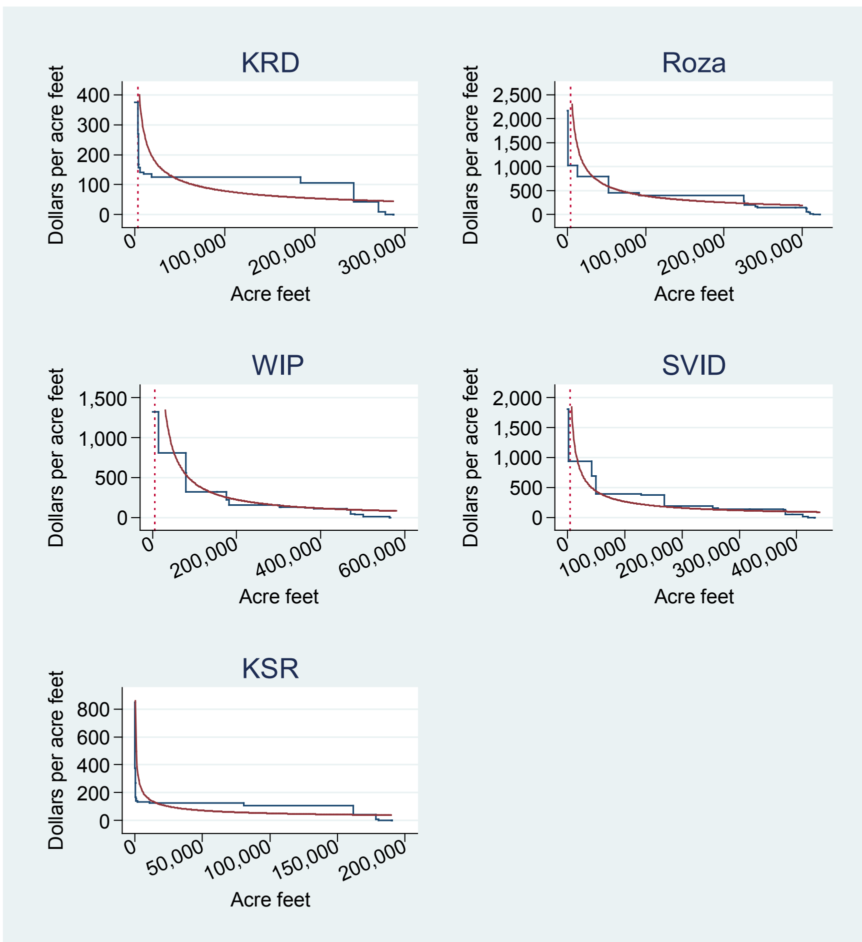

Figure 20: Calibrated Inverse demand functions for all districts. The vertical dotted lines represent the parameter *m*. The area under the fitted curve to the left of *m* is subtracted to ensure that the total value of production is the same under the step functions and fitted functions.

value of production given intra-district trade, and second, they are used to simulate inter-district trading. These processes are described in general in Section III.C.1 of the main body of the report, and in more detail in Appendix VII.B directly below.

B. Water markets

This appendix describes how the different market scenarios are implemented in this report. We begin by providing a comparison of our approach in relation to the Four Accounts analysis in general. We then provide a technical description of our assumptions and procedure for the three types of market outcomes shown in the body of the report.

1. *Summary of Four Accounts analysis of market benefits*

The Four Accounts analysis of water marketing activity relies on two important assumptions: (1) that irrigators growing higher-valued crops will lease water rights from irrigators growing lower-valued crops, but only where the buyers' crop earns $150 per af or more; and (2) that only 10% of an irrigation district's allocation can be leased outside the district (ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012, 36). The supporting Technical Memorandum (U.S. Bureau of Reclamation, ECONorthwest, and State of Washington Department of Ecology 2011) uses a slightly different definition of "severe" drought (40% vs 30% in the Four Accounts) and relaxes several of these constraints. In general, we rely on the results from the Four Accounts analysis.

The water marketing component provides benefits by reducing drought year losses incurred by farmers. Water marketing benefits are measured relative to a baseline scenario where proratable irrigators receive 100% of their annual entitlements (U.S. Bureau of Reclamation, ECONorthwest, and State of Washington Department of Ecology 2011) and there is no water market activity within or between irrigation districts. A core "severe drought" scenario (without the IP) assumes that growers of crops with net revenue greater than $150 per af would lease water from farmers with crops with lower net revenues, such that 30,000 af of water would be traded between districts for crops. Without the IP, no trading would occur within districts., which implies proportional fallowing, discussed more below. In the Four Accounts analysis, with all elements of the IP implemented, the amount of inter-district trading remains 30,000 af, but intra-district trading increases from zero to 110,000 af. Similary, in the Technical Appendix where a severe drought represents 40% of water supply in a non-drought year, intra-district trading increases from zero to 130,000 af with only the market-based component of the IP. Under these same conditions, inter-district trading increases from 30,000 to 50,000 af. Allowing more than 10% of a district's water supply to leave the district, and allowing growers of crops with earnings less than $150/af allows the amount of water traded to increase. There is no discussion in the Four Accounts analysis or the Technical Appendix on exactly how the IP is expected to increase intra-district trading.

To estimate the benefits and costs of increased use of market-based re-allocation, we build on the marginal value functions described above for agricultural users, rather than use the Four Accounts' spreadsheet-based, step-wise value function approach. We do, however, compare our results with those in the Four Accounts and find relatively close agreement. We follow the Four Accounts in implicitly modeling <u>leases only</u>, rather than permanent sales. We use the terms "buyer" and "seller" below in place of the terms "lessor" and "lessee". These leases could be in the form of one-year leases that are negotiated in the midst of a drought year. Although not discussed in the Four Accounts, the leases could also be in the form of a pre-negotiated option contract (or "dry year option") that specifies in advance a) the amount of water to be transferred, b) the price that would be paid (the "strike" price), and c) the conditions that would trigger the option contract to take effect (i.e. the TWSA, or percent prorationing, on a certain date).

2. *Modifications to the Four Accounts methods and assumptions*

There are several important points of departure from the Four Accounts analysis. First, unlike the Four Accounts analysis, we examine IP outcomes for three different market scenarios. The three market regimes that we consider are:

- No water trading
- Intra-district water trading
- Full trading: both intra- and inter-district trading

The no trading regime imposes the restriction that when water is curtailed during a drought, all crops are curtailed in the same proportion. The intra-district trading regimes allows frictionless efficient water distribution within irrigation districts, but no trading across districts. Full trading allows both intra- and inter-district trading such that water is distributed efficiently to its highest valued uses across districts, with some cross-district trade limitations described below.

The assumption of (frictionless) intra-district trade is reasonable to the extent that a) landowners grow multiple crops on plots under their control and make profit-maximizing decisions about where to allocate scarce water and/or b) when irrigation districts have systems in place to allow customers to temporarily swap or lease water rights to other customers within the district. These trades have little or no impact on water users outside the district,they pose no legal problems and only need to be approved by the district's Board of Directors (RCW 90.03.383 sect 3). Intra-distict trades during the the 2001 and especially the 2005 severe drought years were apparently common in Sunnyside (SVID), Roza (RID), and Kittitas (KRD). Recall that the Four Accounts analysis implies *no* intra-district trading at all without the IP, and significant intra-district trading when the market-based component of the IP is implemented.

The Full trading market regime that allows both intra- and inter-district trade represent an outer bound on the impacts and benefits from increased markets. We rely on this approach and a frictionless market scenario because most, if not all, ad hoc limits on market transactions are relatively arbitrary especially in the long run and may eventually relax or disappear, including some legal barriers to trade. There is, however, at least one fundamental constraint on water markets that will almost certainly always remain, and that is that transactions may be limited in the case of potential for third-party harm. Nonetheless, water markets may be slow to develop, but there is a long history of market evolution and development in the face of scarcity.

A second point of departure is our inclusion of "senior" water rights holders (those dated before May 10 1905) in Kittitas County (Ecology subbasins 1-15), a group not modeled in the IP analysis.[55] These water rights holders have a potentially important role to play in water markets in the Yakima Basin because their position in the upper part of the Basin could in theory allow downstream transactions with few third-party effects or legal concerns. A number of these rights are already actively involved in water markets due to the requirement to mitigate formerly "exempt" groundwater wells. As of October 2014, there are 12 water rights being sub-divided as "water banks" and sold, mainly to domestic users. A total of 116 af have been sold in 269 transactions; a separate document detailing the amount available in these upper Kittitas banks via Ecology's website as well as the number and volume of individual transactions is available from the authors on request (see also (Robert Barwin 2013).

These Kittitas Senior rights represent a relatively large pool of water. Based on the Yakima Superior Court's Adjudication records, we calculate the total amount of water held in these rights to be 222,925 af. This estimate includes private irrigation companies and individual water rights holders, but excludes muncipalities, counties, the federal government, and timber companies. We subtract the 116 af that have been re-assigned to mitigate groundwater uses in the upper Kittitas as of October 2014. We assume that the fraction of these diversions that could be transferred is 72.6%, matching the consumptive use assumed for the Kittitas Reclamation District (HDR Engineering and Anchor QEA 2011). In total, this is 161,759 af of consumptive use. The adjudication record does not consistently report what beneficial uses (i.e. what crops) the water right is used for, so we rely on results from a mail survey in 2009 (Cook and Rabotyagov 2014) to estimate the crop mix. We pool these "senior" rights together and model them as if they were another irrigation district for computational simplicity only, fitting a marginal value function using the techniques described above.

C. Modeling details for market scenarios

An important assumption made in the Scott model that is typical in modeling drought impacts is to assume that a reduced water budget is met only through fallowing of acres (R. Howitt et al. 2014). This prohibits what is often referred to as deficit irrigation where an amount of water is applied that is less than the level associated with maximum yield. The result of this assumption is that water and land are used in a fixed proportion that is crop and location specific. This type of fixed proportions production relationship is often called a Leontief production function. This assumption is made in many economic impact studies based on input/output economic models (e.g. IMPLAN®) simplifies analysis because the production decision only depends on one variable rather than two. Choosing how many acres to fallow of each crop directly determines how much water is used for each crop.

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[55] The Technical Appendix on Market-Based Reallocation briefly mentions (footnote 4 on page 6) the potential for trading "outside the Yakima Project" and projects the amount of water traded for various purposes by 2040, though without a citation or documentation of how these amounts were arrived at. These water transfer amounts do not factor into their main analysis.

A graphical representation of the Leontief production function is shown in Figure 21. Isoquants map out all the combinations of land and water that produce the same amount of output. Isoquant 1 shows a lower level of production while Isoquant 2 shows a higher level of production. While each isoquant is a combination of a vertical and horizontal line the only relevant point for production is the vertex of these two lines. The shape of the isoquants follows from the fact that increasing one input without increasing the other does not increase production. This means that there is no benefit to moving away from the vertex of the isoquant. Following this logic, the possible production levels are combined in the dotted line that goes through the origin. The level of production that maximizes profit for the producer is determined by the land or the water constraint. The land constraint, represented by the vertical dashed line, is the limiting resource in a non-drought year because water law prohibits spreading. Diversion rights are not limiting in a non-drought year which is revealed by the fact that all irrigation districts use less than their entitlement in a non-drought year. In a drought year the water constraint, represented by the lower horizontal dashed line, becomes limiting so that production is limited to the blue isoquant.

This graphical examination only considered the production of one crop. When water becomes scarce the irrigators problem becomes one of how to allocate limited amount of water across crops. Assuming a Leontief production function restates the problem as *"how many acres of each crop should be fallowed?"* Our three trading scenarios differ inly in the degree of freedom that water owners have as a group to allocate water across corps within and across districts.

Four Accounts estimates the agricultural benefits in the baseline scenario to be $0.8 billion. Our attempt to replicate their results leads us to conclude that they arrived at this number by assuming proportional curtailment across crop acreage, rather than selective curtailment. This means that the marginal value of water is constant and does not depend on drought severity. Estimates of benefits using this approach are as follows. The cost of a drought is the curtailment measured in af multiplied by the value of water for each district (which is a constant). To summarize, the average value of water for each crop in a district is calculated by dividing profit per acre by water use per acre [($/acre)/(af/acre)]. Then, the value of water for each crop is multiplied by that crop's share of total

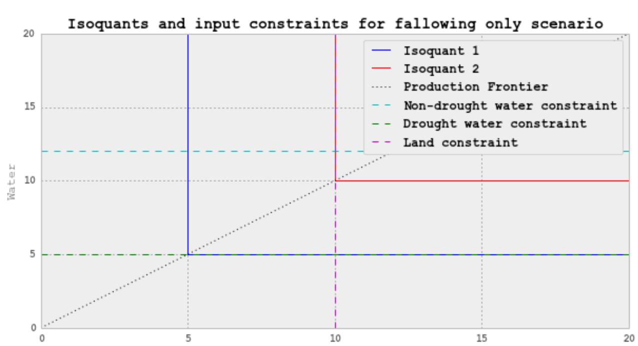

Figure 21. Fixed proportions isoquants and production frontiers with land and water constraints.

acreage in the district. For example, say a district has two crops where Crop A and Crop B have an implied value of water of \$100/af and \$200/af. If Crop A and Crop B constitute 3,000 and 1,000 acres, respectively, then the value of water for the district weighted by acreage is equal to \$100/af*0.75+\$200*0.25, which is equal to \$125/af. The specific values used for each district which come directly from the Four Accounts report (they were not altered in any way for this study) are presented in Table 6 of this report.

The trading scenarios require accounting for differences in the value of water across crops and districts. The economic problem is classified as a constrained optimization problem where some representative decision maker allocates water across potential uses to maximize profit given access to a limited amount of water and land. This problem can be written in equation form as shown below. The crop production function assumes fixed proportions. *L* stands for the Lagrangian function which is used to find the profit maximizing water allocation by taking first-order conditions.

w_i : water applied to crop i
π_i : profit per acre
p_w : per unit water price
p_i : crop i price
g_i : water applied per acre for crop i
W : water constraint
L : land constraint
F : crop production function
$F_i(w_i, l_i) = w_i g_i^{-1}$

$$\max_{W_i} \sum_{i=1}^{n} \pi_i w_i g_i^{-1} - p_w \sum_{i=1}^{n} w_i$$

subject to

$$\sum_{i=1}^{n} w_i \le W$$
$$\sum_{i=1}^{n} w_i g_i^{-1} \le L$$

$$L = \sum_{i=1}^{n} \pi_i w_i g_i^{-1} - p_w \sum_{i=1}^{n} w_i + \lambda \left(W - \sum_{i=1}^{n} w_i \right) + \gamma \left(L - \sum_{i=1}^{n} w_i g_i^{-1} \right)$$

$$\frac{\partial L}{\partial w_i} = \pi_i g_i^{-1} - p_w - \lambda - \gamma g_i^{-1} = 0 \text{ for } i = 1,\ldots,n \text{ crops}$$

$$when\ \gamma = 0,\ \pi_1 g_1^{-1} = \ldots = \pi_n g_n^{-1} = p_w + \lambda$$

In a non-drought year the land constraint is binding and $\gamma>0$ and $\lambda=0$. In a drought year the opposite is true. This is the standard result that profit is maximized by equating the marginal value product of water across uses. Although not explicit in the equations above, the price of water in equilibrium depends on the total water supply available as well as other parameters in the model: $p_w = P_w(W,.)$.

The intra-district trading scenarios use the fitted inverse demand curves estimate drought impacts by calculating the area under each curve from m up to the amount of water available for each district based on the severity of the drought, each districts mix of proratable and non-proratable water rights, and their entitlement.

The Full Trading scenarios must account for differences in the value of water across districts. The constrained optimization problem is implemented by finding the allocation of water across districts that are assumed to be trading that maximizes the total profit of all the districts. For example, if Roza and SVID are the only trading districts, then the optimization problem finds the allocation of water across crops and maximizes profit for Roza and SVID combined. This depends both on the mix of crops and the percent of proratable rights.[56] Specifically, the constrained optimization problem consists of an objective function and a set of constraints. The objective function is the sum of profit for all trading districts. The constraints bound the amount of water a district can receive. The lower bound is zero, which is often referred to the non-negativity constraint, which is always present in this type of economic model. The upper bound is the maximum water used by each district in a non-drought year. The model is solved numerically using the sequential least squares quadratic programming (SLSQP) algorithm implemented in the Python package PyOpt. While the model described above shows that the optimal allocation of water is achieved where the marginal value of products are exactly equal to each other across uses this is not necessarily the result if corner solutions are possible due to the bounds.

We impose several constraints to inter-district trading. In the case of inter-district trading, we assume that WIP and YTID do not trade between districts. We impose this constraint on WIP because it retains institutional limitations that are likely to limit its market participation in the intermediate, and potentially even the long run (Ross 2014; U.S. General Accounting Office 1997). We preclude YTID from trading because it is relatively hydrologically isolated in such a way to limit water sales, and its crop values and non-proratable status limits it incentives to buy.

Another constraint the potential for third-party effects of transactions, especially in the case of transactions between downstream sellers and upstream buyers, which can negatively impact instream flows (and therefore also the diversion capacity of other water rights holders) between the transactants. In particular, we would be concerned about KRD buying from SVID or other downstream districts for this reason, but the crop mix and associated water value functions (and our assumption that WIP does not trade) essentially precludes such transactions from happening and so no explicit constraint is needed. Although our market model is not spatially explicit, Figure 16 shows that the simulated trading outcomes are such that the KRD does not buy from SVID in the sense that it only buys if curtailment reaches above 90%, at which point Kittitas Senior sells more than enough water to cover KRD purchases.

[56] The model used in this study was implemented in the programming language Python (python.org).

D. Municipal and domestic water value

This appendix examines the pricing assumptions used in both the Four Accounts analysis and our own in regards to the municipal and domestic benefits of the IP. We first examine the marginal value of water to agriculture as the opportunity cost of a lease, then we examine the value of a senior water right for agricultural irrigation as the opportunity cost of the sale of a permanent senior water right. We also include in a final table the calculations for the benefits of municipal conservation, which we discuss in IV.G.b.

1. *Empirical support for lease prices*

Based on a dataset on western states water transfers (Libecap 2014), we find that water sale prices for agriculture to urban transactions averaged $612.25/af and lease prices average 79.38/af/year, the latter of which has a present value of $1,984.67 (these prices are inflated to 2012 dollars). Analogous averages for WA, OR, and ID tend to be lower, at $434.61/af for sales and 42.61/af/year (present value $1,061.72). There are many reasons why we would not expect the present value of market lease prices treated as a perpetual annuity to equal water sales prices, including the fact that transaction costs are different between the two, uncertainty about future water availability, and other factors will affect the outcomes. What is most pertinent here is that the range of these values are within the ballpark of the $1,000-$2,500 sale and purchase prices, as well as lease prices relied on in our analysis rather than prices in the range of the wholesale price used in one part of the Four Accounts analysis.

We can corroborate these values based on the agricultural water value simulations using YAKRW and the crop production value discussed in detail in Section IV.B. Table 41 includes simulated marginal water values under the baseline scenario (HDR 7.1) and the full IP, by climate regime, and by trading regime, *conditional on curtailment* (that is proration level less than full entitlement), under the assumption that municipalities will only lease water during curtailment years.

Table 41: Average marginal value of water conditional on curtailment, $.

run	No trade	Intra-district trade	Full trade
Baseline (HDR 71), historical climate	131	71	45
Baseline (HDR 71), CGCM climate	107	56	37
Baseline (HDR 71), HADCM climate	157	133	59
Baseline (HDR 71), HADGEM climate	215	290	90
IP (HDR 7.8), historical climate	125	61	39
IP (HDR 7.8), CGCM climate	112	52	33
IP (HDR 7.8), HADCM climate	180	101	59
IP (HDR 7.8), HADGEM climate	227	275	83

Under the historical climate regime and the baseline IP, the average marginal value of water *conditional on curtailment* is $131/af/year given no intra- or inter-district trading (that is, assuming proportional fallowing), $71 given intra-district trading only, and $45 given full trade. The analogous values under the full IP implementation are $125, $61, and $39. Both the "No trade" and "full trade" are extreme bounds on trading behavior, and so the "Intra-district trading" regime might be taken as a reasonable intermediate case. In any case, the marginal value of water for irrigation under the historical climate regime ($71 without the IP and $61 with the IP) are higher than assumed $40/af/year lease value (net present value of $1,000 at a 4% interest rate) used as the opportunity cost of water in the municipal demand analysis. It is noteworthy, that as the climate scenarios become more adverse, the marginal value of water under curtailment becomes higher. The only exception to this is that, somewhat surprisingly, the price drops between the historical climate regime and the CGCM regime. While not shown in the table, this is because the average curtailment rate conditional on curtailment (mean[c]|c>0) declines, even though both the probability of curtailment (Prob[c>0]) and the unconditional mean of curtailment (mean[c]) are both larger under CGCM than the historical regime.

The net benefits from the IP that accrue to municipalities as modeled in the Four Accounts analysis and here represent the avoided purchase costs net of the opportunity cost to the seller, presumed here to be irrigated agriculture. In the Four accounts analysis and ours, we assume this price to be $40/af/year (lease price) or $1,000/af as a sale price. If the opportunity cost is higher, as we find in for all cases except under the full IP and full trade (Table 41), then the net benefits of the IP for municipalities will be lower. For example the sale value equivalent to a $61/af/year and $71/af/year lease price are sales prices of $1,525/af and $1,775/af, ignoring transaction costs. If the purchase price municipalities face is $2,500/af as assumed in the Four Accounts analysis, the net gain to municipalities is $975/af and $725/af instead of the assumed gain of $1,500/af. If this is the case, municipal benefits reported in both the Four Accounts analysis and here assuming the $2,500 purchase price by municipalities is too high.

2. Sale prices for senior water rights

The opportunity cost of a permanent sale of a senior water right for irrigation requires a different estimation approach because it is based on the unconditional expectation of curtailments into the future. The value of water to senior agricultural irrigation water rights holders (irrigation districts in this case) depends on the reductions in agricultural production value that results from their sale, and this represents a lower bound in sale price. The Four Accounts analysis assumes that a senior water right is worth about $1,000 (p. 52), and we can examine the veracity of this value in terms of expected foregone agricultural production.

The minimum price a senior water right owner would likely to be willing to accept for the sale of a water right for an af of water is approximately equal to the expected marginal net present value of that water for irrigation. If $V(W)$ is the aggregate value of irrigated agricultural production and W is water applied to provide V, then $\partial V(W)/\partial W$ is the marginal value if water at any level of W.

However, irrigation districts in the Yakima Basin are prorated in a drought year based on the basin-wide proration rate and the share of proratable versus non-proratable water rights it holds in its portfolio, and the opportunity cost of selling water depends on the effective proration rate it faces. In a given curtailment year with basin-wide proration rate p, the effective proration rate for a district that has E_n af of non-proratable water rights and E_p af of proratable water rights, but sells S acre feet of nonproratable rights, the district's post-sale prorated water available is $W(S) = p_d E_s =$

$[(E_n - S) + pE_p]$, where $p_d = [(E_n - S) + pE_p]/[E_n + E_p - S\,]$ is the post-sale proration rate defined such that the amount of water received in a curtailment year given post-sale entitlements $E_s = E_n + E_p - S$ (which represents the total water entitlement after a sale that it would receive in a non-drought year). Note that if a district has no non-proratable rights E_n (and therefore none to sell), then $p_d = \frac{pE_p}{E_p} = p$. If a district has no proratable rights, then $p_d = \frac{E_n - S}{E_n - S} = 1$ regardless of the basinwide proration rate p and there is never any curtailment.

At proration rate p_d, the marginal opportunity cost of selling nonproratable water is $\left|\frac{\partial V(W(S))}{\partial(W(S))}\frac{\partial(W(S))}{\partial S}\right| = \frac{\partial V(W_s)}{\partial W_s} p_d \equiv M$, or the marginal value of water for agricultural production times the effective proration rate.

Given inverse demand functions for irrigation water for the districts and the effective proration rate for each district, M can be calculated for each district and year, or for the basin as a whole for each year; and the mean of this distribution of values over the history of curtailment, $\bar{M} = \sum_{t=1}^{N} M_t$, is an estimate of the statistical expectation of the marginal cost of selling a senior water right in any given year. Dividing this expectation through by the interest rate provides $PV_s = \bar{M}/r$, which is an estimate of the expected net present value of a senior water right in terms of agricultural production when a district faces curtailment of its proratable rights. It therefore represents the minimum price a senior water right holder would accept for its sale assuming that the rights holder expects to maintain this use if the water is not sold.

Based on the inverse demand functions described in Appendix VII.A , we generated an estimate for the marginal value of a senior water right using the shadow-price curves for the four districts and the effective curtailment rates for the four districts of WIP, Roza, SVID, and KRD, by aggregating production value and entitlements such that $p_d = W_a/E_a$ where E_a is the sum of all proratable and nonproratable entitlements in the four districts and W_a is the total water allocated to them in each year. Multiplying this by the marginal value of water for that year (given a basin-wide proration rate) provides M_t for year *t*. The average of these, $\bar{M}$, is the average estimated value of a senior water right over the sample years. We then used these to calculate the present value of a senior water right as a perpetual annuity at discount rate *r=0.04*. Table 42 provides results.

For the baseline and IP cases under the historical weather regime, the value of a senior water right ranges from \$35 to \$11 af/year, with present values ranging from \$864 to \$286. Note that the value of a senior water right tends to be higher under the IP, even though the marginal value of water for a lease would actually be lower at the (higher) average proration rate. This is because the higher expected proration rate under the IP more than offsets the lower marginal water price at these levels.

Table 42: Value of a non-proratable water right for irrigation under historical climate and adverse climate (HADGEM

			Average expected marginal value of water given trading regime			Expected net present value of non-proratable water ($/af).		
run	p	p_d	No trade	Intra-district only	Full trade	No trade	Intra-district only	Full trade
Baseline (HDR 7.1), historical	89	92	35	18	11	864	453	286
IP (HDR 7.8), historical climate	90	93	41	20	13	1,023	491	314
Baseline (HDR 7.1), HADGM	44	61	123	124	48	3,083	3,098	1,190
IP, (HDR 7.8), HADGM	51	66	147	124	48	3,665	3,096	1,206

It should be noted immediately that one would expect these marginal valuations in Table 42 to be lower than prices garnered in a market setting given that buyers tend to be those with relatively high-valued uses, and sellers tend to be able to negotiate to something other than their minimum willingness to accept. Indeed, given that municipalities often are willing to pay more than this given existing water entitlements, higher prices would tend to be negotiated for agriculture to municipal trades (Libecap 2010; Brewer et al. 2007; although see Brookshire et al. 2004 for a counterexample). Thus, this range of values can be compared to the $1,000/af noted in the Four Accounts Analysis (page 52) as the average value of ag-to-ag water sales, and thus supports our use of the $1,000 (sale) and $40 (lease) values to represent the opportunity cost of a senior water right to agriculture.

Table 42 also show, however, that the opportunity cost of a lease and sale are higher under the adverse climate regime, up to $3,098/af for the intra-district trade case with no IP. The consequence of higher opportunity costs in the event of this outcome is that the net benefits of trade for a given municipal valuation are lower, but that equilibrium market prices will likely be higher also.

3. *A descriptive model of Agriculture to urban trades*

Recent anecdotal data from the Yakima basin suggest substantial change and volatility of water prices, especially in inter-sectoral trades. A very simple model of a water market can help illustrate why high volatility can occur in inter-sectoral trade prices, and how we might expect prices to behave as water markets mature.

Figure 22 provides a standard supply and demand graph, where supply in this case is taken to be the opportunity cost to the agriculture sector of selling senior water rights, and demand is the marginal value of water (the inverse demand curve) for municipal water. A well-functioning, perfectly competitive market as illustrated in this graph will result in a an equilibrium quantity consumed by municipalities of W^*, and a price of $2,500/af. To coincide with the assumed long-run equilibrium market price assumed in the Four Accounts municipal analysis and adopted here. Given that existing senior water rights are generally held by agriculture and markets are not functioning well, we may instead be in a position like W^t, where municipalities value water at the margin much higher

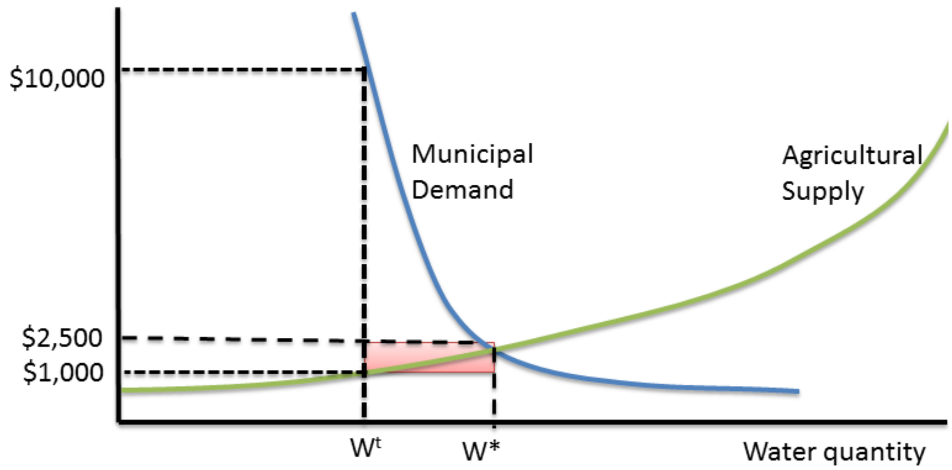

Figure 22: Water market price example.

than agriculture (and are willing to pay much more than agriculture is willing to accept, if they were to have to.

If a municipality starts with W^t and wants to buy an additional af of water starting at W^t, it the price of a mutually beneficial transaction could range anywhere from $1,000 (the opportunity cost to agriculture at W^{-t} and $10,000, the value that the municipality places on the water. Where in this range the price lands depends on the relative bargaining position of the two. If a municipality faces an emergency situation and an agricultural senior water right holder is in no particular hurry to sell (perhaps because of other potential buyers, the municipality may end up paying nearly $10,000, with the lion's share of the gains from trade going to the seller. In such a situation, even if water value and opportunity costs are not different across individual buyers and sellers we can see big variation in prices simply due to differences in bargaining positions. This type of variation will tend to diminish, though, as markets become closer to clearing.

In the Four Accounts analysis of the value to municipalities of being given uninterruptible rights via the IP, we use $2,500 as a long run, equilibrated price that the municipality would have to pay, and assume basically that the opportunity cost to agriculture remains unchanged, such that the net savings from the IP is equal to the red box. This is an overestimate of the savings to municipalities to the extent that the transactions that would occur without the IP would drive up the opportunity cost of water to agriculture.

4. *Review of municipal water use, conservation, and population growth forecasts*

Aspect Consulting, LLC (Aspect), under contract to WSU, reviewed the methodology and assumptions related to the non-economic portions of the Yakima River Basin Study related to municipal and domestic uses, as presented in the Water Needs for Out-of-Stream Technical Memorandum prepared by HDR Engineering, Inc and Anchor QEA (June 2011). The review involved a 4 step process including 1) verification of calculations, 2) verification of sources including variables and formulas, 3) researching potential alternative methodologies, studies or resources, and 4) assessment of impacts related to any significant findings of tests 1 through 3.

A key finding of the HDR / Anchor report is estimation of approximately 19,560 acre feet of increased net consumptive use (from 2010 to 2060) associated with out of stream municipal and domestic purposes such as residential, commercial, industrial, governmental, irrigation, and other demands. This value was derived generally using a 4-step process involving 1) estimating demand on a per system (large systems) or capita (smaller systems) basis, 2) estimating in-basin population including growth through the planning horizon (2060), 3) applying consumptive use factors, and 4) adjusting future demand based upon anticipated conservation and other factors.

Approximately 1/3 of the basin population resides within the 8-largest systems. Water system planning data was obtained by HDR / Anchor for these systems from comprehensive water system plans to determine total source production. In some cases, quantities associated with irrigation within municipal water system boundaries was included in the total (Yakima, Ellensburg). Aspect determined that residents other than Yakima and Ellensburg within this set of 8-systems receives additional irrigation water from local irrigation districts that was not accounted for; therefore, total municipal use as characterized under this heading may be understated. Demand for all other systems smaller than the largest 8 systems was estimated based upon population data multiplied by an estimated per capita water use of 250 gpcd, a value selected in part by engineering judgment. By examining water systems plans for the next 8 additional smaller systems, Aspect found that this value roughly corresponded to 250 gpcd. However, the reporting in these plans typically excluded separate irrigation. Therefore, this is a further indicator that 250 gpcd may understate the true out of stream demand of this subset of the population. The HDR / Anchor report acknowledged this fact and indicated that some of the irrigation demand in municipal / domestic settings is accounted for in the agricultural discussion of the report; however, the municipal portion of irrigation supply is not totaled separately. The review of this data suggests that the process used for estimating demand for large municipal systems and per capita demand for smaller systems is either adequate or possibly low. Improved accounting of irrigation practices within municipal and rural-residential settings would likely increase the estimated out of stream use.

Much of the population data was derived from the Washington State Office of Financial Management (OFM) Population Unit's, 5-year projections (2002 version). This forecast estimates population growth by County to the year 2025. Population estimates to the year 2060 were extrapolated using slightly reduced growth rates from historical to account for observable trends. While Aspect could not reproduce population estimates to the year 2060 exactly as the HDR / Anchor team had, the results were calculated to within reasonable level of error. Aspect further estimated population growth with newer OFM projection data (2007 version) which resulted in an increased estimated population (approximately 9,000 more individuals by 2060). If this population is used, this variance translates to approximately 1,000 acre-feet of additional consumptive use required by 2060 (approximately 5% more than currently estimated).

The consumptive use portion of out of stream demand is difficult to estimate and highly variable based upon development density and geographic location. In the HDR / Anchor study, 60% return flow for municipal purposes was selected and applied to determine consumptive portion of total municipal/domestic use. Aspect looked at various methods of verifying the appropriateness of this proportion including estimating based on typical indoor and outdoor consumptive use for lots of various size and geographic location. Aspect concluded that lots that are either high in the basin or have relatively small yards result in return flows at or above 60%, while lots that are low in the basin or are relatively large result in return flows below 60%. The net growth in total consumptive use (19,560 acre-feet) is highly sensitive to return flow factor selected, with 5% variation in return flow across the basin resulting in over 12% variation in net growth of consumptive use over the study period (from 2010 to 2060). However, given the uncertainty of how and where development will occur over time, the selection of a return flow factor at the lower end of a standard range as was done in the HDR / Anchor report is reasonable.

In aggregate, the methods and assumptions used in the HDR / Anchor estimation of increases demand associated with municipal / domestic uses are likely adequate. To the extent any alternative assumptions or methods may be adopted, the resulting net growth in consumptive use attributable to municipal and domestic demands would more likely increase rather than decrease primarily due to higher population estimates and better accounting of irrigation practices within municipal / domestic setting.

5. *Data tables for present value calculations*

Table 43: Water security benefits: comparison of Four Accounts revision

			Four Accounts Analysis		Revision: Annual leasing		Revision: purchase of perpetual right	
Year	t	water purchased (af/yr)	Current value ($1,500 X $583 X t)	Present value [(Current value)/(1.04^t)]	Current value ($60/af/yr)	Present value [(current value)/(1.04^t)]	Current value ($1,500/ af/yr)	Present value [(current value)/(1.04^t)]
2013	1	583	$874,500	$840,865	$34,980	$33,635	$874,500	$840,865
2014	2	1,166	$1,749,000	$1,617,049	$69,960	$64,682	$874,500	$808,524
2015	3	1,749	$2,623,500	$2,332,282	$104,940	$93,291	$874,500	$777,427
2016	4	2,332	$3,498,000	$2,990,105	$139,920	$119,604	$874,500	$747,526
2017	5	2,915	$4,372,500	$3,593,876	$174,900	$143,755	$874,500	$718,775
2018	6	3,498	$5,247,000	$4,146,780	$209,880	$165,871	$874,500	$691,130
2019	7	4,081	$6,121,500	$4,651,837	$244,860	$186,073	$874,500	$664,548
2020	8	4,664	$6,996,000	$5,111,909	$279,840	$204,476	$874,500	$638,989
2021	9	5,247	$7,870,500	$5,529,709	$314,820	$221,188	$874,500	$614,412
2022	10	5,830	$8,745,000	$5,907,809	$349,800	$236,312	$874,500	$590,781
2023	11	6,413	$9,619,500	$6,248,644	$384,780	$249,946	$874,500	$568,059
2024	12	6,996	$10,494,000	$6,554,521	$419,760	$262,181	$874,500	$546,210
2025	13	7,579	$11,368,500	$6,827,626	$454,740	$273,105	$874,500	$525,202
2026	14	8,162	$12,243,000	$7,070,027	$489,720	$282,801	$874,500	$505,002
2027	15	8,745	$13,117,500	$7,283,682	$524,700	$291,347	$874,500	$485,579
2028	16	9,328	$13,992,000	$7,470,443	$559,680	$298,818	$874,500	$466,903
2029	17	9,911	$14,866,500	$7,632,063	$594,660	$305,283	$874,500	$448,945
2030	18	10,494	$15,741,000	$7,770,200	$629,640	$310,808	$874,500	$431,678
2031	-	10,494	$15,741,000	$7,471,346	$629,640	$298,854	$0	$0
2032	-	10,494	$15,741,000	$7,183,987	$629,640	$287,359	$0	$0
2033	-	10,494	$15,741,000	$6,907,680	$629,640	$276,307	$0	$0
2034	-	10,494	$15,741,000	$6,642,000	$629,640	$265,680	$0	$0
2035	-	10,494	$15,741,000	$6,386,538	$629,640	$255,462	$0	$0
2036	-	10,494	$15,741,000	$6,140,902	$629,640	$245,636	$0	$0
2037	-	10,494	$15,741,000	$5,904,714	$629,640	$236,189	$0	$0
2038	-	10,494	$15,741,000	$5,677,609	$629,640	$227,104	$0	$0
2039	-	10,494	$15,741,000	$5,459,240	$629,640	$218,370	$0	$0
2040	-	10,494	$15,741,000	$5,249,269	$629,640	$209,971	$0	$0
2041	-	10,494	$15,741,000	$5,047,374	$629,640	$201,895	$0	$0
2042	-	10,494	$15,741,000	$4,853,244	$629,640	$194,130	$0	$0
2043	-	10,494	$15,741,000	$4,666,581	$629,640	$186,663	$0	$0
2044	-	10,494	$15,741,000	$4,487,097	$629,640	$179,484	$0	$0
2045	-	10,494	$15,741,000	$4,314,516	$629,640	$172,581	$0	$0
2046	-	10,494	$15,741,000	$4,148,573	$629,640	$165,943	$0	$0
2047	-	10,494	$15,741,000	$3,989,013	$629,640	$159,561	$0	$0
2048	-	10,494	$15,741,000	$3,835,589	$629,640	$153,424	$0	$0
2049	-	10,494	$15,741,000	$3,688,067	$629,640	$147,523	$0	$0
2050	-	10,494	$15,741,000	$3,546,218	$629,640	$141,849	$0	$0
2051	-	10,494	$15,741,000	$3,409,825	$629,640	$136,393	$0	$0
2052	-	10,494	$15,741,000	$3,278,678	$629,640	$131,147	$0	$0
2053	-	10,494	$15,741,000	$3,152,575	$629,640	$126,103	$0	$0
2054	-	10,494	$15,741,000	$3,031,322	$629,640	$121,253	$0	$0
2055	-	10,494	$15,741,000	$2,914,733	$629,640	$116,589	$0	$0
2056	-	10,494	$15,741,000	$2,802,628	$629,640	$112,105	$0	$0
2057	-	10,494	$15,741,000	$2,694,834	$629,640	$107,793	$0	$0
2058	-	10,494	$15,741,000	$2,591,187	$629,640	$103,647	$0	$0
2059	-	10,494	$15,741,000	$2,491,526	$629,640	$99,661	$0	$0

2060	-	10,494	$15,741,000	$2,395,698	$629,640	$95,828	$0	$0
2061	-	10,494	$15,741,000	$2,303,556	$629,640	$92,142	$0	$0
2062	-	10,494	$15,741,000	$2,214,957	$629,640	$88,598	$0	$0
2063	-	10,494	$15,741,000	$2,129,767	$629,640	$85,191	$0	$0
2064	-	10,494	$15,741,000	$2,047,853	$629,640	$81,914	$0	$0
2065	-	10,494	$15,741,000	$1,969,089	$629,640	$78,764	$0	$0
2066	-	10,494	$15,741,000	$1,893,355	$629,640	$75,734	$0	$0
2067	-	10,494	$15,741,000	$1,820,533	$629,640	$72,821	$0	$0
2068	-	10,494	$15,741,000	$1,750,513	$629,640	$70,021	$0	$0
2069	-	10,494	$15,741,000	$1,683,185	$629,640	$67,327	$0	$0
2070	-	10,494	$15,741,000	$1,618,448	$629,640	$64,738	$0	$0
2071	-	10,494	$15,741,000	$1,556,200	$629,640	$62,248	$0	$0
2072	-	10,494	$15,741,000	$1,496,346	$629,640	$59,854	$0	$0
2073	-	10,494	$15,741,000	$1,438,794	$629,640	$57,552	$0	$0
2074	-	10,494	$15,741,000	$1,383,456	$629,640	$55,338	$0	$0
2075	-	10,494	$15,741,000	$1,330,246	$629,640	$53,210	$0	$0
2076	-	10,494	$15,741,000	$1,279,083	$629,640	$51,163	$0	$0
2077	-	10,494	$15,741,000	$1,229,887	$629,640	$49,195	$0	$0
2078	-	10,494	$15,741,000	$1,182,584	$629,640	$47,303	$0	$0
2079	-	10,494	$15,741,000	$1,137,100	$629,640	$45,484	$0	$0
2080	-	10,494	$15,741,000	$1,093,365	$629,640	$43,735	$0	$0
2081	-	10,494	$15,741,000	$1,051,313	$629,640	$42,053	$0	$0
2082	-	10,494	$15,741,000	$1,010,878	$629,640	$40,435	$0	$0
2083	-	10,494	$15,741,000	$971,998	$629,640	$38,880	$0	$0
2084	-	10,494	$15,741,000	$934,613	$629,640	$37,385	$0	$0
2085	-	10,494	$15,741,000	$898,666	$629,640	$35,947	$0	$0
2086	-	10,494	$15,741,000	$864,102	$629,640	$34,564	$0	$0
2087	-	10,494	$15,741,000	$830,868	$629,640	$33,235	$0	$0
2088	-	10,494	$15,741,000	$798,911	$629,640	$31,956	$0	$0
2089	-	10,494	$15,741,000	$768,184	$629,640	$30,727	$0	$0
2090	-	10,494	$15,741,000	$738,638	$629,640	$29,546	$0	$0
2091	-	10,494	$15,741,000	$710,229	$629,640	$28,409	$0	$0
2092	-	10,494	$15,741,000	$682,913	$629,640	$27,317	$0	$0
2093	-	10,494	$15,741,000	$656,647	$629,640	$26,266	$0	$0
2094	-	10,494	$15,741,000	$631,391	$629,640	$25,256	$0	$0
2095	-	10,494	$15,741,000	$607,107	$629,640	$24,284	$0	$0
2096	-	10,494	$15,741,000	$583,757	$629,640	$23,350	$0	$0
2097	-	10,494	$15,741,000	$561,304	$629,640	$22,452	$0	$0
2098	-	10,494	$15,741,000	$539,716	$629,640	$21,589	$0	$0
2099	-	10,494	$15,741,000	$518,958	$629,640	$20,758	$0	$0
2100	-	10,494	$15,741,000	$498,998	$629,640	$19,960	$0	$0
2101	-	10,494	$15,741,000	$479,805	$629,640	$19,192	$0	$0
2102	-	10,494	$15,741,000	$461,351	$629,640	$18,454	$0	$0
2103	-	10,494	$15,741,000	$443,607	$629,640	$17,744	$0	$0
2104	-	10,494	$15,741,000	$426,545	$629,640	$17,062	$0	$0
2105	-	10,494	$15,741,000	$410,140	$629,640	$16,406	$0	$0
2106	-	10,494	$15,741,000	$394,365	$629,640	$15,775	$0	$0
2107	-	10,494	$15,741,000	$379,197	$629,640	$15,168	$0	$0
2108	-	10,494	$15,741,000	$364,613	$629,640	$14,585	$0	$0
2109	-	10,494	$15,741,000	$350,589	$629,640	$14,024	$0	$0
2110	-	10,494	$15,741,000	$337,105	$629,640	$13,484	$0	$0
2111	-	10,494	$15,741,000	$324,139	$629,640	$12,966	$0	$0
				$279,730,952		$11,189,238		$11,070,555

Table 44: Benefits for new growth.

year	t	Demand growth (1193 af/yr)	Four Accounts: Assumes purchase each year (lease-like) Current lease value ($258 X af/yr)	Four Accounts: Present value	Revision: Assumes purchase of perpetual right Current sale value ($1,500 X 1193 af/yr)	Revision: Present value
2020	8	1,193	$307,794	$224,902	$1,789,500	$1,307,570
2021	9	2,386	$615,588	$432,504	$1,789,500	$1,257,279
2022	10	3,579	$923,382	$623,804	$1,789,500	$1,208,922
2023	11	4,772	$1,231,176	$799,748	$1,789,500	$1,162,425
2024	12	5,965	$1,538,970	$961,236	$1,789,500	$1,117,716
2025	13	7,158	$1,846,764	$1,109,119	$1,789,500	$1,074,727
2026	14	8,351	$2,154,558	$1,244,204	$1,789,500	$1,033,392
2027	15	9,544	$2,462,352	$1,367,257	$1,789,500	$993,646
2028	16	10,737	$2,770,146	$1,479,004	$1,789,500	$955,429
2029	17	11,930	$3,077,940	$1,580,132	$1,789,500	$918,681
2030	18	13,123	$3,385,734	$1,671,294	$1,789,500	$883,348
2031	19	14,316	$3,693,528	$1,753,105	$1,789,500	$849,373
2032	20	15,509	$4,001,322	$1,826,151	$1,789,500	$816,704
2033	21	16,702	$4,309,116	$1,890,985	$1,789,500	$785,293
2034	22	17,895	$4,616,910	$1,948,130	$1,789,500	$755,089
2035	23	19,088	$4,924,704	$1,998,082	$1,789,500	$726,047
2036	24	20,281	$5,232,498	$2,041,310	$1,789,500	$698,122
2037	25	21,474	$5,540,292	$2,078,257	$1,789,500	$671,272
2038	26	22,667	$5,848,086	$2,109,342	$1,789,500	$645,453
2039	27	23,860	$6,155,880	$2,134,961	$1,789,500	$620,628
2040	28	25,053	$6,463,674	$2,155,490	$1,789,500	$596,758
2041	29	26,246	$6,771,468	$2,171,281	$1,789,500	$573,806
2042	30	27,439	$7,079,262	$2,182,669	$1,789,500	$551,736
2043	31	28,632	$7,387,056	$2,189,969	$1,789,500	$530,516
2044	32	29,825	$7,694,850	$2,193,478	$1,789,500	$510,111
2045	33	31,018	$8,002,644	$2,193,478	$1,789,500	$490,492
2046	34	32,211	$8,310,438	$2,190,233	$1,789,500	$471,626
2047	35	33,404	$8,618,232	$2,183,993	$1,789,500	$453,487
2048	36	34,597	$8,926,026	$2,174,993	$1,789,500	$436,045
2049	37	35,790	$9,233,820	$2,163,455	$1,789,500	$419,274
2050	38	36,983	$9,541,614	$2,149,587	$1,789,500	$403,148
2051	39	38,176	$9,849,408	$2,133,585	$1,789,500	$387,643
2052	40	39,369	$10,157,202	$2,115,634	$1,789,500	$372,733
2053	41	40,562	$10,464,996	$2,095,908	$1,789,500	$358,397
2054	42	41,755	$10,772,790	$2,074,569	$1,789,500	$344,613
2055	43	42,948	$11,080,584	$2,051,772	$1,789,500	$331,358
2056	44	44,141	$11,388,378	$2,027,659	$1,789,500	$318,614
2057	45	45,334	$11,696,172	$2,002,366	$1,789,500	$306,360
2058	46	46,527	$12,003,966	$1,976,019	$1,789,500	$294,576
2059	47	47,720	$12,311,760	$1,948,737	$1,789,500	$283,247
2060	48	48,913	$12,311,760	$1,873,785	$1,789,500	$272,353
2061	49	0	$12,311,760	$1,801,717	$0	$0
2062	50	0	$12,311,760	$1,732,420	$0	$0
2063	51	0	$12,311,760	$1,665,788	$0	$0
2064	52	0	$12,311,760	$1,601,720	$0	$0
2065	53	0	$12,311,760	$1,540,115	$0	$0
2066	54	0	$12,311,760	$1,480,880	$0	$0
2067	55	0	$12,311,760	$1,423,923	$0	$0
2068	56	0	$12,311,760	$1,369,157	$0	$0
2069	57	0	$12,311,760	$1,316,497	$0	$0
2070	58	0	$12,311,760	$1,265,862	$0	$0

2071	59	0	$12,311,760	$1,217,175	$0	$0
2072	60	0	$12,311,760	$1,170,361	$0	$0
2073	61	0	$12,311,760	$1,125,347	$0	$0
2074	62	0	$12,311,760	$1,082,064	$0	$0
2075	63	0	$12,311,760	$1,040,447	$0	$0
2076	64	0	$12,311,760	$1,000,429	$0	$0
2077	65	0	$12,311,760	$961,951	$0	$0
2078	66	0	$12,311,760	$924,953	$0	$0
2079	67	0	$12,311,760	$889,378	$0	$0
2080	68	0	$12,311,760	$855,171	$0	$0
2081	69	0	$12,311,760	$822,280	$0	$0
2082	70	0	$12,311,760	$790,654	$0	$0
2083	71	0	$12,311,760	$760,244	$0	$0
2084	72	0	$12,311,760	$731,004	$0	$0
2085	73	0	$12,311,760	$702,888	$0	$0
2086	74	0	$12,311,760	$675,854	$0	$0
2087	75	0	$12,311,760	$649,860	$0	$0
2088	76	0	$12,311,760	$624,865	$0	$0
2089	77	0	$12,311,760	$600,832	$0	$0
2090	78	0	$12,311,760	$577,723	$0	$0
2091	79	0	$12,311,760	$555,503	$0	$0
2092	80	0	$12,311,760	$534,137	$0	$0
2093	81	0	$12,311,760	$513,594	$0	$0
2094	82	0	$12,311,760	$493,840	$0	$0
2095	83	0	$12,311,760	$474,846	$0	$0
2096	84	0	$12,311,760	$456,583	$0	$0
2097	85	0	$12,311,760	$439,022	$0	$0
2098	86	0	$12,311,760	$422,137	$0	$0
2099	87	0	$12,311,760	$405,901	$0	$0
2100	88	0	$12,311,760	$390,289	$0	$0
2101	89	0	$12,311,760	$375,278	$0	$0
2102	90	0	$12,311,760	$360,844	$0	$0
2103	91	0	$12,311,760	$346,965	$0	$0
2104	92	0	$12,311,760	$333,621	$0	$0
2105	93	0	$12,311,760	$320,789	$0	$0
2106	94	0	$12,311,760	$308,451	$0	$0
2107	95	0	$12,311,760	$296,588	$0	$0
2108	96	0	$12,311,760	$285,180	$0	$0
2109	97	0	$12,311,760	$274,212	$0	$0
2110	98	0	$12,311,760	$263,665	$0	$0
2111	99	0	$12,311,760	$253,524	$0	$0
		48,913		$114,028,713	$73,369,500	$27,188,010

Table 45: Municipal Conservation benefits and costs

Year	time period	annual cost ($millions)		Present value ($millions)		Cumulative water conservation	water saved per year	$/af	annual purchase ($millions)	Present value of purchase ($millions)
		low	high	low	high					
2015	1	0.5	1.5	0.48	1.44	285.0	285.0	$1,500	0.43	0.41
2016	2	0.5	1.5	0.46	1.39	570.0	285.0	$1,500	0.43	0.40
2017	3	0.5	1.5	0.44	1.33	855.0	285.0	$1,500	0.43	0.38
2018	4	0.5	1.5	0.43	1.28	1,140.0	285.0	$1,500	0.43	0.37
2019	5	0.5	1.5	0.41	1.23	1,425.0	285.0	$1,500	0.43	0.35
2020	6	0.5	1.5	0.40	1.19	1,710.0	285.0	$1,500	0.43	0.34
2021	7	0.5	1.5	0.38	1.14	1,995.0	285.0	$1,500	0.43	0.32
2022	8	0.5	1.5	0.37	1.10	2,280.0	285.0	$1,500	0.43	0.31
2023	9	0.5	1.5	0.35	1.05	2,565.0	285.0	$1,500	0.43	0.30
2024	10	0.5	1.5	0.34	1.01	2,850.0	285.0	$1,500	0.43	0.29
2025	11	0.5	1.5	0.32	0.97	3,135.0	285.0	$1,500	0.43	0.28
2026	12	0.5	1.5	0.31	0.94	3,420.0	285.0	$1,500	0.43	0.27
2027	13	0.5	1.5	0.30	0.90	3,705.0	285.0	$1,500	0.43	0.26
2028	14	0.5	1.5	0.29	0.87	3,990.0	285.0	$1,500	0.43	0.25
2029	15	0.5	1.5	0.28	0.83	4,275.0	285.0	$1,500	0.43	0.24
2030	16	0.5	1.5	0.27	0.80	4,560.0	285.0	$1,500	0.43	0.23
2031	17	0.5	1.5	0.26	0.77	4,661.3	101.3	$1,500	0.15	0.08
2032	18	0.5	1.5	0.25	0.74	4,762.7	101.3	$1,500	0.15	0.08
2033	19	0.5	1.5	0.24	0.71	4,864.0	101.3	$1,500	0.15	0.07
2034	20	0.5	1.5	0.23	0.68	4,965.3	101.3	$1,500	0.15	0.07
2035	21	0.5	1.5	0.22	0.66	5,066.7	101.3	$1,500	0.15	0.07
2036	22	0.5	1.5	0.21	0.63	5,168.0	101.3	$1,500	0.15	0.06
2037	23	0.5	1.5	0.20	0.61	5,269.3	101.3	$1,500	0.15	0.06
2038	24	0.5	1.5	0.20	0.59	5,370.7	101.3	$1,500	0.15	0.06
2039	25	0.5	1.5	0.19	0.56	5,472.0	101.3	$1,500	0.15	0.06
2040	26	0.5	1.5	0.18	0.54	5,573.3	101.3	$1,500	0.15	0.05
2041	27	0.5	1.5	0.17	0.52	5,674.7	101.3	$1,500	0.15	0.05
2042	28	0.5	1.5	0.17	0.50	5,776.0	101.3	$1,500	0.15	0.05
2043	29	0.5	1.5	0.16	0.48	5,877.3	101.3	$1,500	0.15	0.05
2044	30	0.5	1.5	0.15	0.46	5,978.7	101.3	$1,500	0.15	0.05
2045	31	0.5	1.5	0.15	0.44	6,080.0	101.3	$1,500	0.15	0.05
2046	32	0.5	1.5	0.14	0.43	6,181.3	101.3	$1,500	0.15	0.04
2047	33	0.5	1.5	0.14	0.41	6,282.7	101.3	$1,500	0.15	0.04
2048	34	0.5	1.5	0.13	0.40	6,384.0	101.3	$1,500	0.15	0.04
2049	35	0.5	1.5	0.13	0.38	6,485.3	101.3	$1,500	0.15	0.04
2050	36	0.5	1.5	0.12	0.37	6,586.7	101.3	$1,500	0.15	0.04
2051	37	0.5	1.5	0.12	0.35	6,688.0	101.3	$1,500	0.15	0.04
2052	38	0.5	1.5	0.11	0.34	6,789.3	101.3	$1,500	0.15	0.03
2053	39	0.5	1.5	0.11	0.32	6,890.7	101.3	$1,500	0.15	0.03
2054	40	0.5	1.5	0.10	0.31	6,992.0	101.3	$1,500	0.15	0.03
2055	41	0.5	1.5	0.10	0.30	7,093.3	101.3	$1,500	0.15	0.03
2056	42	0.5	1.5	0.10	0.29	7,194.7	101.3	$1,500	0.15	0.03
2057	43	0.5	1.5	0.09	0.28	7,296.0	101.3	$1,500	0.15	0.03
2058	44	0.5	1.5	0.09	0.27	7,397.3	101.3	$1,500	0.15	0.03
2059	45	0.5	1.5	0.09	0.26	7,498.7	101.3	$1,500	0.15	0.03
2060	46	0.5	1.5	0.08	0.25	7,600.0	101.3	$1,500	0.15	0.03
				$10.44	$31.33					$6.36

E. Fish productivity

In various places abundance is used to represent different characteristics of fish populations. Principally, there are important differences between recruitment and escapement as a measure of abundance of fish, and in different contexts these terms have been used. To prevent confusion we will try to provide a clear distinction.

In the Four Accounts Memorandum, recruitment is explicitly defined as fish mature enough to be exploitable from commercial, subsistence, or sport fisheries, or to spawn, minus the fish that die, prior to spawning, by non-human causes (ECONorthwest, Natural Resources Economics, and ESA 2012). Based on the usage in the Four Accounts Memorandum (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011), this amounts to the adult fish arriving in the Columbia River Estuary that are potential spawners, but from which some in-river harvest and loss can occur. In the Four Accounts Memorandum adult fish represent recruitment. For this reason, where possible we have referred to abundance estimates as estimates of recruits.

Escapement is the number of fish that having recruited to the potentially breeding population, survive adult harvest and other in-river sources of mortality to arrive at the spawning grounds as potential spawners. These are the fish that actually arrive in the Yakima basin's spawning grounds to contribute to reproduction and population growth. They are also the property of the population that is estimated from in-basin monitoring programs using redd counts, carcass counts, weirs or other adult enumerations. Escapement is then calculated by expanding these observations often based on the fraction of the habitat sampled (for methodological review of expansions from monitoring data, see: Courbois et al. 2008).

Importantly, the data available on adults from which accessory analysis is performed, is for escapement rather than recruitment. Recruitment in this sense is not easily obtained for Yakima basin wild fish. Indeed, given the methods used in estimating Sockeye salmon abundance relied on the physical capacity of the reservoirs to support spawning adults, there was a conceptual reason to relate population growth to the abundance of fish that actually make it to the spawning grounds. Therefore, when comparing YBIP forecasts with available data on fish abundance we will generally use escapement unless it is specifically noted otherwise.

1. *Assessment of existing fish impact estimates*

As noted in Section III.D and IV.E the fish benefits of the IP and its component parts relates to the product of the contribution of IP projects to fish abundance and the value of those fish. The accuracy and precisions of the aggregate estimates depends on the accuracy of those population forecasts and value estimates. This section of the appendix focuses in fish population impact forecasts, and the next focuses in valuation.

Population forecasts rely on assumptions and are subject to considerable uncertainty, and in this case the forecasts for each species cover a wide range of values. So it is appropriate to review those forecasts to identify where uncertainties may exist and what relative likelihoods and/or reasonable expectations we may attach to the range of forecasts in the IP. We will consider the sockeye forecasts first and then evaluate the other anadromous salmonids second.

a. *Sockeye: Habitat capacity and historical abundance*

As mentioned above, forecasting the responses of sockeye salmon to the IP is complicated for several reasons. These include that the fish were extirpated from the basin in the early 20th century and the only sockeye currently observed in the basin are either the small numbers of fish that are presumably straying into the Yakima from other, adjacent sub-basins, or are introduced adult sockeye as part of the joint Yakima/Klickitat Fisheries project of the Yakima Tribe and WDFW, and thus not representative of habitat-based production. In addition, the majority of habitat that the IP now proposes to leverage to support a reintroduced sockeye population (i.e. the reservoirs behind the dams) did not exist when the sockeye were in the basin a century ago. Finally, given that sockeye production is estimated based on the capacity of the reservoirs in the basin, the forecasts are entirely dependent on the removal of passage barriers to those reservoirs, and so no other scenarios, such as habitat restoration by itself, were deemed relevant or considered.

The original estimates of sockeye abundance in the Fish Benefits memo (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011) used a value of 30 spawners per hectare of lake surface area, and then applied some fixed values of egg-smolt and smolt to adult survival to estimate subsequent adult returns for each reservoir which were then summed. The low, medium and high production scenarios were differentiated by different estimates of reservoir level and different levels of smolt to adult survivorship. The range of forecasts for sockeye adult abundance in all reservoirs (escapement rather than recruitment) was 73,631 to 446,903. Since abundance in the reservoirs was the variable of interest in evaluating the life cycle of this species numbers refer to escapement rather than recruitment; values for recruitment to the Columbia River estuary ranged from 112,243 to 681,255 in the Fish Benefits memo (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011; see above for discussion of escapement vs. recruitment).

Subsequent to that report, US BOR (J. D. Hubble 2012) published an Environmental Impact Statement containing a revised estimate of sockeye abundance forecasts resulting from the YBIP. This later revision reflected a more sophisticated ecological approach in that it included a discounting for relative quality of reservoir area in terms of water clarity and production capacity, as well as relating reservoir area to smolt production rather than adult spawner density. This later revision resulted in a significant reduction in the high production scenario forecast. The range of these revised forecasts for sockeye adult abundance in all reservoirs ranged from 112, 428 to 251,310.

Figure 23 shows how these forecasts for sockeye abundance compare with the recent history of abundance. Recent fish counts in the Yakima River system have ranged from 0 to 691 adults, but the forecasts range to the four hundred thousands. Thus, the plotted scale gives the incorrect impression that the current abundance is zero with little or no variance. While the plot does not easily convey the recent abundances of sockeye from monitoring data, it does convey the wide gap between the recent history of abundance and where the YBIP anticipates things to go within the planning horizon. It seems prudent to ask if there is information to allow an assessment of relative likelihood of any of the outcomes within this wide range.

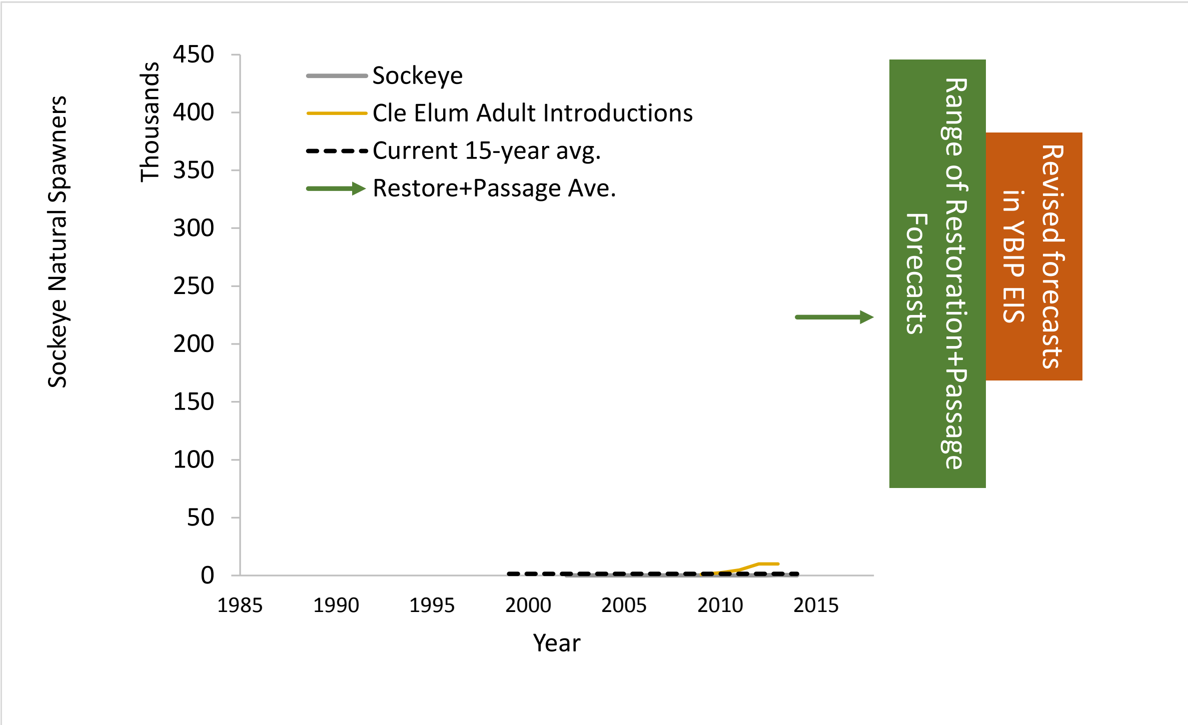

Figure 23: Time series plot of recent adult sockeye salmon abundance scaled to escapement forecasts in the Four Accounts analysis.

Some of this gap results from the modelled capacity of reservoir area to support spawners (30/hectare). The literature suggests that 30 may be at the high end of the range for this value in similar lakes, with other studies estimating the value between 0.1 and 50 sockeye spawners per hectare (Groot and Margolis 1991; Goodlad, Gjernes, and Brannon 1974). Studies have documented higher spawner densities, but the estimates were done in very different watersheds with the highest values in the Siberian far East, and with different anthropogenic impact, freshwater travel distance to the sea, and hatchery influence (Burgner 1991; Groot and Margolis 1991). Parsimony suggests that the reservoirs in the Yakima basin may be variable with spawner densities that will frequently be lower than the modelled estimates in the YBIP.

These forecasts may also be optimistic in light of comparisons to estimates of historical sockeye salmon population sizes in the Yakima. There have been multiple attempts to estimate the size of the populations of sockeye that were present in the system prior to when the dams were built in the early 20th century. Population size estimates have ranged from 100,000 (Davidson 1953) to approximately 200,000 (Gustafson et al. 1997; CBFWA 1990). These estimates are both on the lower end of the range of YBIP forecasts. Indeed, if the IP achieves sockeye population levels near those of the late 19th century (but less than half of the IP forecasts) regardless of management regime, it would be remarkable given the presence of so many other sources of mortality in play now such as mainstem dams and high seas fisheries. With this in mind, it would seem parsimonious to suggest that the forecasts of twice the largest estimate of historical population size (i.e. >400K) be viewed as a very low likelihood.

Importantly, sockeye population forecasts based on reservoir area may exceed historical levels given that the dams built in the early 20th century greatly increased the total lake area in the Yakima basin. On the one hand, the increased area may indeed support increased numbers of fish. On the other hand however, this new lake bottom area has never been shown to sustain sockeye, and it remains to be seen if the naïve lake bottom has suitable quality manifest in fish use. The combination of reintroducing fish to habitat that itself has also been "introduced" in this context makes the IP proposal a more complicated management experiment, and more difficult to predict quantitative responses of fish populations than if the fish were the only re-introduction, as was the case with coho salmon in the Yakima basin.

Independent of the capacity of the habitat to support a larger sockeye salmon population, one needs to ask where the additional fish would come from. Given the current monitoring data showing adult sockeye in the Yakima basin in the range of 40 to ca. 700 individuals over the last five years, it is important to ask what level of population growth would be required to generate a mean population of 100K to 400K fish on the current planning horizon. Based on estimates of current monitoring data of sockeye abundance in the Yakima basin the population growth rates (λ) would have to exceed any known biologically realistic value. Indeed, even extending the time horizon out to 30 years, to 2045, the necessary values of λ would have to exceed 10. A biologically relevant range for λ for a growing population would be between 1.0 and 1.3, with few Columbia River salmon populations exceeding 1.05 (McClure et al. 2003).

As previously mentioned, the Yakima/Klickitat Fisheries project of the Yakima Tribe and Washington Dept. of Fish and Wildlife has been introducing adult sockeye salmon into the Cle Elum reservoir starting in 2009 (Bureau of Reclamation and Washington State Department of Ecology 2012; U.S. Department of the Interior Bureau of Reclamation and State of Washington Department of Ecology 2012). The program started with 1000 fish in 2009 and has increased up to 2500 in 2010, 4800 in 2011 and 10,000 in each of the last two years, and are composed of Wenatchee and Lake Osoyoos stocks. There is some variability in the time spent holding in freshwater and in the number of years spent in the ocean, but on average sockeye produced in one brood year will return after four winters have passed (Groot and Margolis 1991). Thus, potential spawners from this program will only be returning in the last two years and may in fact be reflected in the increase in observed sockeye in the basin in 2013 and 2014.

If this program continues, and these introduced adults are incorporated into the breeding population of sockeye, we can re-evaluate the population growth rate necessary to reach the YBIP forecasts (Figure 24). If we include the introduced adult sockeye and estimate the 4-year geometric mean abundance as the standing stock, we then can estimate the abundance of fish at the end of the planning horizons for various population mean growth rates. We use the four-year, geometric mean to accommodate the multi-year population structure, resulting population cycles and high, year-to-year sampling variance as is customary (e.g. McClure et al. 2003). At a population growth rate of 1.05 the current stock would grow to over 12,000 fish in the 10 year planning horizon, and 17,000 fish after 30 years. If the long-term population growth rate is as high as 1.2, then abundances may exceed 16,000 after 10 years, and will enter the lowest YBIP forecasts after 30 years (Figure 24).

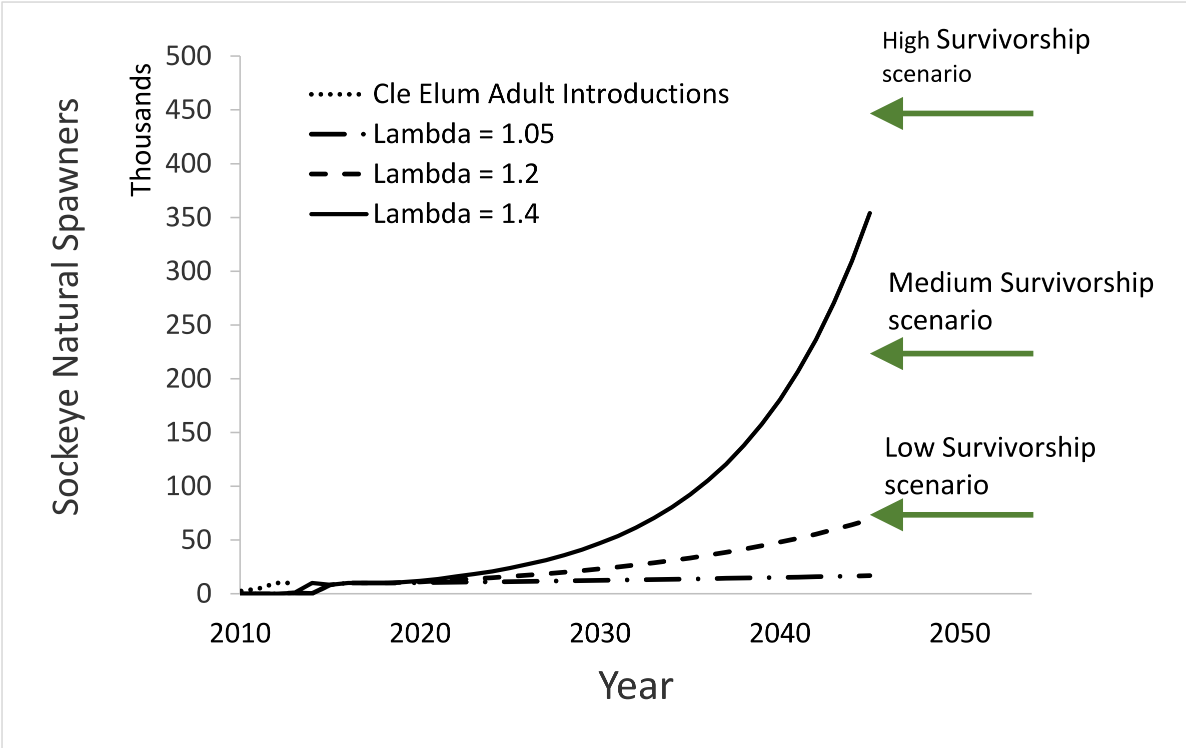

Figure 24: Projections of sockeye salmon abundance based on a range of population growth rates over the BIP planning horizon. These projections incorporate current reintroductions.

Abundances reach the higher end of YBIP forecasts only if the population growth rate is set to an extraordinary high values (e.g. 1.4) and the planning horizon is 30 years. In spite of the limitations this analysis suggests, this introduction program seems to be a requirement for any level of sockeye recovery in the Yakima basin. Given the profoundly low numbers of sockeye currently monitored in the basin, it seems unlikely that even if passage issues are resolved large numbers of adults will recolonize the reservoirs within the forecast time horizons without some intervention such as these introductions. Indeed, the ability of coho reintroductions to sustain in the absence of a parallel, hatchery-based supplementation has been viewed as unlikely (Bosch et al. 2007). Importantly, the costs of maintaining a re-introduction program are not included in the IP cost structure and would represent additional challenge to a favorable B/C ratio.

These estimates require a large set of assumptions for which there is little support from specific studies on these fish. In each case we have allowed what are aggressive assumptions about potential carrying capacity and population growth rates. And yet the results indicate that the higher value estimates in the YBIP are a relatively low likelihood. The lower value estimates for sockeye abundance attributed to the YBIP would on the one hand be a disappointing in terms of balancing the benefit-costs of the IP, but on the other hand would be a major conservation success in approximating historical abundances of an extirpated population. It is likely however, that sustaining this success would still require extended maintenance of the management plan out into the future given reasonable estimates of population growth rates.

The preceding analysis represents a coarse approach; there are undoubtedly more nuanced analyses that would need to be performed to resolve a more specific forecast for sockeye in the Yakima (e.g. explicitly age structured population models, discretized stage-specific survivorship, stochastic population growth, etc.). Embarking on those analyses at this point appears premature. Indeed, introducing hundreds of thousands of "non-native" salmonids into habitat occupied by listed steelhead and bull trout, with whom far more numerous sockeye smolts will surely compete for resources, will certainly require a consultation with the ESA regulatory authorities (NMFS and US FWS). Such consultations would trigger much more involved population status assessments and recovery planning, and make a more detailed analysis at this point moot.

This coarse approach does suggest that it is worth downscaling the anticipated benefits for sockeye that one can attribute to the IP. Given a revised estimate of *mean* population abundance, a priori reasons to change the *relative* contributions of each of the passage projects are not at hand. Thus, the relative benefits of each project can be estimated once a reasonably discounted estimate of population abundance is resolved. Unfortunately, while we have good support for asserting that the largest forecasts of the IP (681K fish recruiting to the Columbia River) are unlikely, the reasons reviewed above make it difficult to propose a single best alternative estimate.

As stated, asking what is a reasonable level of recovery given the historical capacity of the basin and the present-day sources of mortality is a challenge. There are no entirely comparable case studies of an endangered species that has been so completely extirpated from its range and subsequently reintroduced to sustainable levels. Of the 27 species that have been delisted in the United States several, including Gray whales, Bald Eagles and Brown Pelicans, have been driven to very low population status and have experienced large recoveries (Goble, Scott, and Davis 2005; National Research Council 1995), but these species were never so extensively extirpated from their ranges as have sockeye salmon in the Yakima basin. Example species that have been largely extirpated and reintroduced, such as Mexican Wolves (U.S. Fish and Wildlife Service 2013b), California Condors (U.S. Fish and Wildlife Service 2012) and Black Footed Ferrets (U.S. Fish and Wildlife Service 2013a) have not yet seen a similar, robust level of recovery. As such, the levels of recovery of Yakima sockeye forecast in the IP are unprecedented and thus difficult to which to attach likelihoods.

The closest parallel for sockeye is surely coho salmon in the Yakima. As mentioned above, wild coho were largely extirpated in the 1980's and ongoing hatchery fish releases were leveraged to reintroduce them to the Yakima basin (Dunnigan, Bosch, and Hubble 2002). As highlighted above however, reintroducing coho was not also accompanied by large increases in habitat capacity, and it is unclear if the reintroduction will achieve sustainability independent of supplementation (Bosch et al. 2007) Those limitations aside, estimates of historical coho abundance in the Yakima range from 44,000 to 100,000 (Kreeger and McNeil 1993; Bosch et al. 2007; Yakama Indian Nation, Washington Department of Fisheries, and Washington Department of Wildlife 1990). In the twenty years since the coho reintroduction program started, adult abundance has increased, with a mean of ca. 4,080 over the last 15 years (see below), or means more than an order of magnitude lower than historical abundance estimates. If a similar level of success is achieved with sockeye, one could see abundances of 6,000 to 20,000[57], which while lower than the high abundance forecasts, would still be a considerable achievement in terms of conservation. However, this abundance would only be achieved with significant expense attributed to the hatchery and reintroduction program, none of which are YBIP activities, are included in IP cost structures, nor considered here.

b. *Non-sockeye species: Empirical examination of forecast accuracy*

As mentioned, coho, chinook salmon and steelhead trout population responses to the YBIP were modelled with the EDT process coupled with the All-H simulator. The All-H simulator is an accessory to the population process model that allows the consideration of alternative management scenarios, but its outputs are dependent on the population estimates it receives from EDT. In principle, EDT works on the premise that each habitat unit has intrinsic qualities that affect the survivorship of the fish that encounter it. These qualities can vary across units, and their functional responses can vary across the life history stages and species of fish; a specific feature of a given pool might positively affect the parr of one species, but negatively affect smolts of a different species. If the unit-level estimates are accurate, one could sum them up over all units for all life stages of each species and forecast the abundance of fish and have quantitative associations between abundance and habitat quality – allowing the prioritization of specific habitat improvement actions. Conceptually, this is a rational approach.

In actuality, this approach has a number of limitations. Many of these limitations have been summarized elsewhere (Paine et al. 2000; McElhany et al. 2010) and so here will not be repeated in detail but only as a list of relevant highlights. From a statistical point of view, this approach is a multi-regression with many (many hundreds to thousands, McElhany et al. 2010) parameters used to estimate numbers of fish in the future. This is widely recognized as over-parameterization, and it results in the generation and propagation of errors and generating untestable predictions (Burnham and Anderson 2002; Freedman and Freedman 1983; Freedman, Navidi, and Peters 1988; Leinweber 2007). In addition, this approach makes demands on the habitat quality data far in excess of available monitoring data. For those many EDT parameters for which fish and habitat data are lacking, experts are polled for their opinions on what the actual values are likely to be. Thus, much of EDT products result from an "expert-panel" process rather than a data-based, scientific process. As such, many of the uncertainties that exist within the process that might otherwise influence our characterization of the uncertainty in the ultimate forecasts are subjective, based on opinion rather than data, and ultimately unknowable. Due to its high spatial resolution, EDT does provide very specific forecasts, although its uncertainties mean its accuracy cannot be evaluated. This is an important distinction, that EDT is an expert-panel process does not make its predictions wrong, but it does limit the ability for a scientific review to test its predictions. That said, the limited literature that attempts to characterize the reliability of EDT forecasts has indicated that it has relatively poor performance and is not useful for forecasting population sizes based on habitat assessment (McElhany et al. 2010).

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[57] The historical sockeye population size of 200,000 times the rate of current coho per historical coho (4,080/100,000) result in an equivalent success level of 8,160 sockeye as a benchmark.

With those cautions in hand, it should be acknowledged that there are few alternatives to EDT to deploy in this context. In order for an alternative modelling framework to perform better than EDT and also provide a basis for scientific testing of the habitat-basis for its fish population forecasts, such an alternative would require far more environmental and fish monitoring data than are currently available. In addition, a far more extensive information base on the functional relationships between each habitat character and specific life-stage survival of fish would be required than currently exists. Absent the necessary data and knowledge bases, the alternatives to EDT are only able to make very imprecise estimates, although their accuracies and uncertainties can be evaluated.

Absent independent measures of uncertainty from the expert panel process, it is difficult to attach likelihoods to the range of forecasts for fish benefits in the YBIP. One approach adopted here is to compare the range of forecasts in the YBIP with recent histories of fish abundances in the Yakima basin. We can evaluate this comparison through the habitat-capacity lens described above; we can create opportunities for fish to exploit new or improved habitat, but that is only an opportunity – we cannot create new fish.

If we plot the time series of estimates of spawners for the various species for the last 15-30 years for Fall and Summer chinook and coho salmon and steelhead trout, we can then compare these to the YBIP forecasts for these species (Figure 25). There are some common features across these comparisons. All of these fish were at very low abundance (<5000 per annum) in the period prior to 1998, and then experienced large increases (5000-10,000 per annum) in the period since, with in some cases large year-to-year variability. This is consistent with current population process models that attribute large, saltatory changes in survivorship to alternation of ocean conditions (Logerwell et al. 2003; Lawson et al. 2004; Mark D. Scheuerell and Williams 2005). This observation has the additional implication that caution is required in evaluating recent increases in abundance; recent step-change increases, in the presence of large inter-annual variation, could easily be mistaken for an increasing trend, but which could as easily be followed by a step decrease as ocean conditions revert to prior states.

Also evident in these figures, the potential forecast increase in fish numbers due to passage beyond that due to habitat improvement is quite small for these species (i.e. the difference between green and black vertical bars). This is consistent with our understanding of their ecology, and lack of exploitation of the reservoir habitats (for review see: Groot and Margolis 1991). This provides a foundation for attributing fish benefits to specific component actions in the YBIP; passage projects are anticipated to generate benefits for sockeye salmon, flow management and habitat restoration provide benefits for non-sockeye.

Another common feature of these forecasts is that the lower range of the forecasts for all scenarios are only marginally, although consistently, higher than the recent (15-year) average population size. While one could suggest that the lowest forecast expectations are optimistic given that they are somewhat larger than the recent past, this difference is modest. More importantly, that these lower bounds are similar to recent abundance estimates is consistent with our understanding of the recovery paradigm outlined above. Specifically, that forecasts need to include current values within the range for forecasts because our management can create opportunities for fish, but cannot force the numbers of fish to increase.

These comparisons do suggest a basis for evaluating the relative likelihoods for the range of forecasts provided by the EDT process. As pointed out above, we lack explicit estimates of the uncertainties in the EDT forecasts. However, when we compare them to the recent history of spawner estimates, we see that the lowest forecasts are similar to recent conditions that they go up from there. Given that there is a large amount of autocorrelation in the time series of spawner abundance (Fall chinook first order autocorrelation coefficient = 0.705, Spring chinook = 0.516, steelhead = 0.603, coho = not sig.), we can expect any given trajectory of future spawner

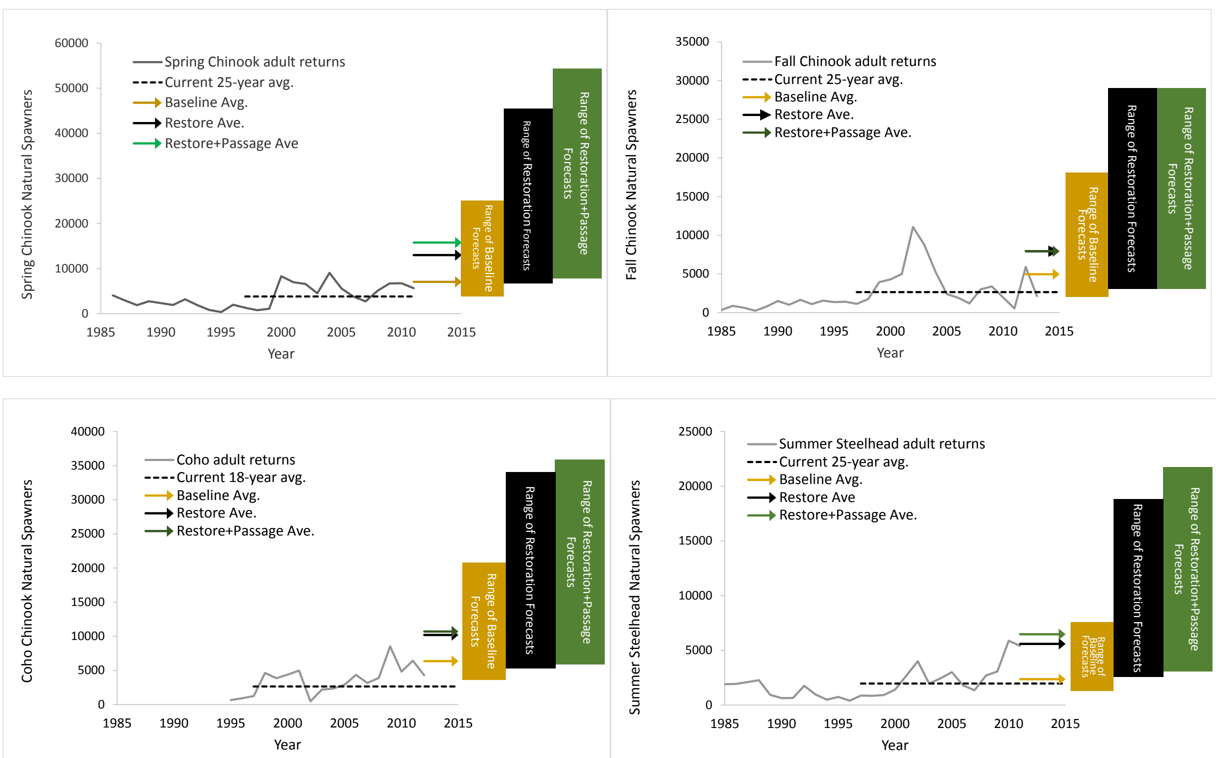

Figure 25 Time series of recent adult spawner estimates for A) spring chinook, B) fall chinook, C) coho and D) steelhead trout in the Yakima Basin. In each case the time series are compared with the estimates of escapement for each species from the Fish Benefits Memorandum for the Baseline, Restoration and Restoration plus Passage scenarios (U.S. Bureau of Reclamation, HDR Engineering Inc., and Anchor QEA 2011).

abundances to be more similar to, rather than more different from current conditions. While we cannot yet forecast how quickly the probability will decrease going from the low to high abundance forecasts, all things being equal we do expect the probability to decrease going from the low end to the high end of the forecasts range.[58] Importantly, this is a "weight of evidence" and parsimony approach, rather than a statistical test.

2. *The role of habitat and flow in salmonid survival*

As described above, the YBIP proposes a strategy for salmonid recovery and resulting economic benefits that is based on a set of tactics to change passage, in-stream flow and habitat quality. We have further dichotomized passage as a prerequisite for sockeye salmon recovery, but habitat restoration and flow as principally focused on the other anadromous species. These benefit estimates arise from the EDT process (described above), the predictions of which are based on expectations for changes in habitat unit-based survival impacts, rather than being based principally on historical relationships between survival and habitat variability. Data on in-stream flow in the basin, the history of habitat restoration in the Yakima basin and contemporary estimates of smolt production and adult spawner abundance do exist. Thus, we can evaluate the degree to which variability in potential predictor variables predict estimates of salmon survival in order to estimate the potential population effects of changes in flow or habitat restoration.

Using available time series data on adult and smolt abundance for each species, abundance of restoration actions, spill at McNary dam and flow residuals in the lower mainstem Yakima river (see Sections III.D and Appendix Section VII.E.a), we built statistical regression models where we predict the smolt to adult return (SAR) and smolt produced per adult spawner (SPA) for each species within the years we have data for with measures of restoration Projects, Flow and Spill. We use these models to test the hypothesis that there are measurable effects of Flow and Restoration with which we may evaluate the fish benefits in the YBIP that are attributable to specific management outcomes.

a. *Data and analysis details*

The data and methodological details of the above statistical analysis are presented below, along with full regression output.

(1) *Salmonid data*

(a) Steelhead

Data on the annual escapement for wild adult steelhead were obtained for the period of record (1980-2013) available from Washington Department of Fish and Wildlife (WDFW) (WDFW 2014). The same source provided annual escapement data at the resolution of major sub-basins in which steelhead are known to spawn, including the Upper Yakima River sub-basin (1992-2013), Satus Creek sub-basin (1988-2013), Toppenish Creek sub-basin (1989-2013), and the Naches River sub-basin (1994-2013). Annual escapement estimates for the entire Yakima River basin are based on

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[58] This is to say that the probability density function will tend to be higher on the left (low end of future abundance) and lower at the high end of abundance.

counts at Prosser Dam plus tribal harvest below Prosser and minus sport and tribal harvest above Prosser. Escapement estimates for the major geographic areas were calculated using a combination of fish counts at Prosser and Roza Dams, combined with estimates of mortality and movement (based on historical radio-tracking), using the expansion method developed by the ICTRT (2008). In addition to dam counts, redd counts are conducted over the course of the spawning season by foot and as weather allowed season in several tributaries in the Satus Creek and Toppenish Creek geographic areas, with that data also being incorporated into the expansion method (ICTRT 2008).

Data on juvenile steelhead was based on information provided by StreamNet (www.streamnet.org, 5 August, 2014), in which we obtained data for the Upper Yakima River (HUC 4 #17030001), Naches River (HUC 4 #17030002), and the Lower Yakima River sub-basin and tribs (HUC 4 #17030003). We used two types of data. First, we obtained estimates of steelhead smolt passage at Chandler Juvenile Monitoring Facility (CJMF), where daily counts are expanded by the canal entrainment, canal survival and sub-sampling rates to estimate daily passage at Prosser Dam and from smolt trapping efforts in Satus, Toppenish and Ahtanum Creeks (Neeley 2000). Second, we compiled estimates of steelhead smolt capacity for all sub-basins listed on StreamNet (www.streamnet.org, 5 August, 2014) and summed the estimates for each major geographic area to generate a total smolt capacity estimate. Methodology for model estimates is described in Fast et al. (1989).

(b) Chinook salmon

Data on the annual escapement for wild and hatchery chinook salmon were available at the scale of three major sub-basins were obtained for the period of record (1984-2013) available from WDFW (WDFW 2014). Data for the Upper Yakima River (1984-2013) were based on Roza Dam counts and a census of hatchery and wild fish from 1997 to present, while the escapement estimate for the Naches River sub-basin were based on counts at Prosser Dam minus harvest above Prosser and minus the Roza Dam count. Escapement estimates for the American River geographic area were based on Prosser Dam counts minus harvest below Prosser and minus Roza Dam, and that number is multiplied by the proportion of redds in the American River sub-basin (American/Naches+American). Data on Yakima River fall chinook salmon for the Lower Yakima sub-basin were based on fish counts at Prosser Dam from 1983-1999 and redd count surveys below Prosser Dam from 1999-2013, which were conducted by the Yakama Nation fisheries personnel in the main-stem Yakima River once per week for six weeks during the spawning season.

We relied on three types of data for juvenile chinook salmon. First, we used the number of hatchery chinook salmon smolts released at three acclimation ponds on the main-stem Yakima River from 2000-2011, including Clarks Flat, Easton, and Jack Creek (Sampson, Fast, and Bosch 2012). Second, we used estimates of wild and hatchery chinook salmon smolt production in the Yakima River basin for 2000-2010 from Sampson et al. (2012) and from StreamNet (www.streamnet.org, 6 July, 2014). Lastly, we compiled estimates of chinook salmon smolt capacity for all sub-basins listed on StreamNet (www.streamnet.org, 6 July, 2014) and summed the estimates for each major geographic area to generate a total smolt capacity estimate via Fast et al. (1989).

(c) Coho salmon

Data on the annual escapement for adult coho salmon, number of adults estimated to spawn in the Yakima River basin, were obtained for the period of record, 1995-2013 (Washington Department of Fish and Wildlife 2014). The period of record is shorter for coho salmon because they were extirpated and then reintroduced in the early 1990's (YRBS-FBATM 2011). Escapement estimates are based on fish counts at Prosser Dam, excluding jacks, although those estimates are likely high because several hundred fish a year may be removed for hatchery brood stock.

We accessed two types of data on juvenile coho salmon. First, we used the number of hatchery coho salmon smolts released from 2000-2011. We also used estimates of coho salmon smolt passage at CJMF for 2000-2005 at StreamNet (www.streamnet.org, 6 July, 2014), where daily counts are expanded via raw counts of smolts (Forrest 1998).

(d) Sockeye salmon

Data on the annual escapement for adult sockeye salmon, number of adults estimated to spawn in the Yakima River basin, were obtained for the period of record (2002-2013) available at Roza Dam (http://www.cbr.washington.edu/dart/query/adult_daily). Escapement estimates are unaltered counts from the dam, although in recent years (2009-current) a large number of adult sockeye salmon have been recaptured from other locations in the Columbia River and transported into the upper Yakima River to jumpstart recovery (http://yakamafish-nsn.gov/restore/projects/sockeye). Data on juvenile sockeye salmon was not available.

(2) *Habitat data*

(a) Habitat Restoration Actions

Measures of habitat restoration projects are total project number with a completion date in the year prior to the salmon outmigration year. Data were compiled from the Pacific Northwest Salmon Habitat Project Database (PNSHP, Katz et al. 2007b). Restoration project data are reported as total projects regardless of type as the metadata for extent and complexity of each project are not available.

(b) Time series of Spill and Flow

In June 2005, the U.S. district court (=”the Redden Court”) granted a preliminary injunction requiring NMFS, via the US ACE & Bonneville Power Administration, to increase flow and spill at certain FCRPS dams starting the summer of 2005 and continuing (U.S. Court of Appeals for the Ninth Circuit - 481 F.3d 1224). The premise was that increasing water flux through the mainstem hydro-system would improve survival of outmigrating fish. Under this injunction a set of operating rules were put in place where some dams (e.g. Bonneville) had fixed values of spill, but others (e.g. McNary) had spill that was a specified fraction of discharge and was therefore variable.

Data on daily discharge and spill from McNary Dam was downloaded from the Fish Passage Center at www.fpc.org/river/flowspill/flowspill_query.html . Daily data was summed to estimate average daily spill for each month from January, 1990 to August, 2014. A plot of the monthly spill values for these years is presented in Fig. 25.

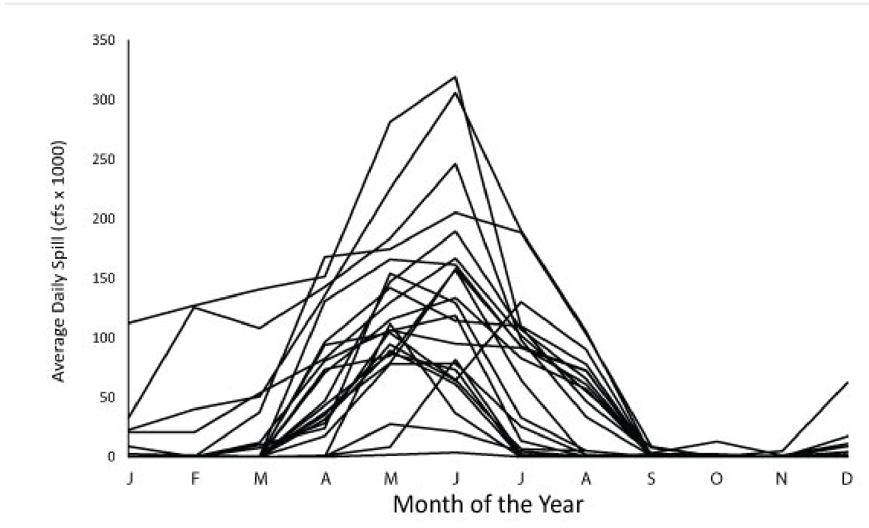

Figure 26. Daily average Spill at McNary dam for each month of the year from 1990 to 2014.

The seasonal pattern of spill is characterized by a highly variable spring and summer season, with a more regulated fall and winter. From a statistical point of view, the high variability seen in the summer months conveys the greatest signal of year to year difference. In addition, it is the time of year when much of the smolt outmigration reaches the mainstem river. For these reasons, the four months of May, June, July and August were averaged to produce an average value for each calendar year considered in the modelling that follows.

Measures of Flow represent flow within the Yakima basin, measured at the USGS stream gauge at Kiona, WA (USGA Stream Gauge 12510500; http://waterdata.usgs.gov/usa/nwis/uv?site_no=12510500). Average daily flow for each month of the year is plotted in Figure 27 for this period. Analysis of monthly average flow over the prior 25 years indicates that the greatest variance, and therefore statistical signal, of year-to-year variability occurs in the Spring months which also coincides with a large fraction of smolt outmigration (Groot and Margolis 1991). On that basis, flow for each year is reported as the average of April-May-June (AMJ). This index of flow and Spill share significant correlation ($r = 0.9$) and this lack of independence is a problem in linear model estimation. Therefore, this index of flow was regressed on Spill, and the residuals used in the linear models under the label Flow.

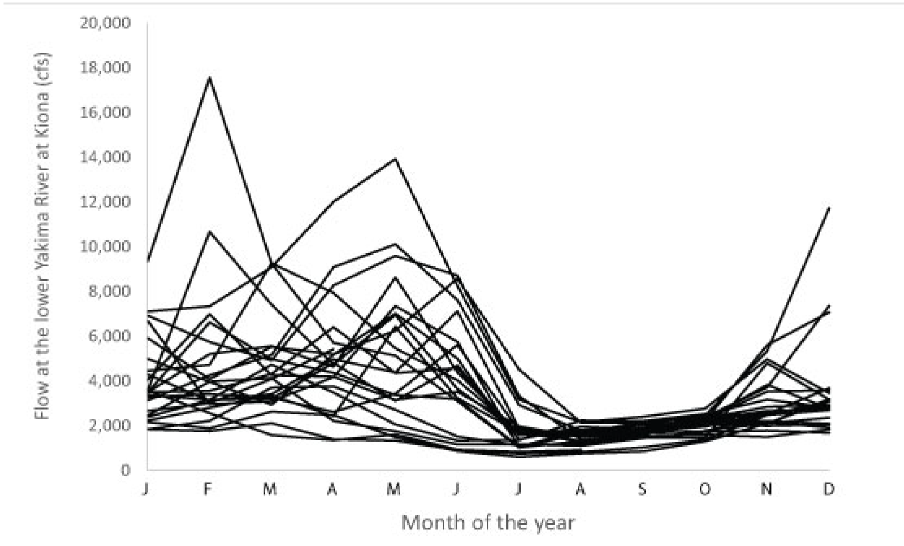

Figure 27: Daily average flow in the lower Yakima River measured at Kiona, WA, for each month of the year from 1990 to 2014

b. *Statistical modelling of fish survivorship and habitat management actions and flow*

Available data for fish spawner abundance and smolt production were combined to estimate the average number of adults returning to the basin per smolt outmigrant at an earlier time (SAR), and the number of smolt outmigrant fish per adult spawner abundance at an earlier time (SPA). SAR is a more common measure of salmonid survival, and in this case provides an index of fish survival for the part of the life history outside the Yakima basin. Relative survival over this period is anticipated to reflect in part fish condition developed in the prior portion of the life history, but is dominated by mortalities that accrue to the population from mainstem and ocean events (e.g. M.D. Scheuerell and Williams 2005).

Outmigrating smolts per adults in prior years is a less common metric of fish survival. This is because SAR's can be calculated from counts of individual fish passing mainstem dams, where the fish have a unique identifier from an acoustic or passive integrated transponder (PIT) tag. The rate of adult and smolt passage can be estimated without having detailed information about where the adults were going after leaving the mainstem Columbia. In this study, we have adults and smolts counts for fish originating and ending in the Yakima basin and so we can also estimate the freshwater portion of the life history with SPA.

Salmon within a single population do not either outmigrate nor return as adults at the same age (Groot and Margolis 1991), with spawners often ranging from 2 to 7 years of age with a broad distribution of spawner ages that varies with population within species. Exact estimation of both SAR and SPA require detailed knowledge of the age structure of the fish, which we lack in this study. Therefore, we adopted an average value for each life stage of each species and referenced time to the year of smolt outmigration. For steelhead trout the SAR's are estimated using the estimated number of adults returning two years after the smolts outmigrate, while the SPA is estimated as the number of smolts normalized by the estimate of adult abundance two years prior.

Both chinook salmon types have SAR's estimated using the estimated number of adults returning three years after the smolts outmigrate, but Spring chinook SPA's are estimated as the number of smolts normalized by the estimate of adult abundance two years prior, while Fall chinook SPA's are estimated using the estimated adult abundance one year prior to smolt outmigration. Coho salmon SAR's are estimated using estimated adult abundance three years after smolt outmigration, while the SPA is estimated with estimated adult abundance the year prior to smolt outmigration. While this approximation is not unusual, it is a simplification that introduces some error to the estimates of SAR and SPA. As long as the age structure of the returning adults does not vary profoundly, and as long as the year-to-year variation in age structure is stochastic rather than systematic, this simplification may lower precision of the estimates, but not the accuracy.

What follows are the detailed results from the statistical analysis of relationships between flow, spill and habitat restoration actions and our estimates of salmonid survival metrics (SAR & SPA). The data are presented for Steelhead trout, fall chinook, spring chinook and coho salmon in turn, in each case models are constructed to predict first SAR's and then SPA's. In each case, results are presented for the linear model estimates first, and the analysis of variance second. The estimates for the coefficients of the linear model are statistical estimates of the effect size, which in this case can be interpreted as expected change in the output variable (SAR or SPA) per unit change in the input variable (e.g. Flow). The analysis of variance on the other hand, expresses the degree to which the variance in the predictor set of variables predicts the variability in the output variables. It is possible, and observed below, for linear models to be able to predict the temporal pattern of variability in output variables well (= with high statistical significance) without any one predictor variable having a significant effect – i.e. no single predictor variable has an effect size that would allow one to say with confidence "we expect an XX% change in survivorship per unit change in flow."

Each model starts as a complete model with all possible main effects and interactions. Alternative models are selected using backward selection, where individual variables are removed and the fit of the model is evaluated with Akaike Information Criteria (AIC), which is a statistical method that takes the goodness of fit of the model and discounts it by the number of parameters used to estimate the model (Burnham and Anderson 2002). Up to a point, the more parameters that exist in a given model, the better that model will predict the data. Therefore, AIC "penalizes" more complex models to balance the goodness of fit with a reasonable complexity of statistical model (for detailed review, see: Burnham and Anderson 2002). The models reported below are those with the smallest AIC score, which along with the r^2 is reported in each case. All statistical models were performed in the R programming environment (R Core Team 2012).

c. *Modelling Results*

The results are mixed. In each case, different combinations of Flow, Spill and Projects and their statistical interactions produced the best fit of the statistical model to the observed time series of survival. The complete descriptions and tests for significance for the best models based on AIC are presented below in Tables 46-61. In two cases, SPA for coho and SAR for fall chinook, the time series was short and lack sufficient degrees of freedom to establish statistical significance. In the remainder, restoration Projects and some combination of Flow and/or Spill were common terms in the best fitting model of the survival data. Steelhead SAR's and spring chinook SPA's are examples of particularly good correspondence between the data and the models.

(1) *Steelhead*

Table 46: Steelhead SAR regression

Model: Projects + Spill + Flow + Projects:Flow (AIC=-52.093)				
Coefficients	Estimate	Std. Error	t value	p
Intercept	0.019970	0.025720	0.776	0.45
Projects	0.002147	0.000741	2.898	0.011
Spill	0.000441	0.000291	1.517	0.15
Flow.res	-0.000028	0.000018	-1.533	0.146
Projects:Flow.res	0.000001	0.000001	1.885	0.079

Table 47: Steelhead SAR ANOVA

ANOVA	Df	Sum Sq	Mean Sq	F-value	p-value
Projects	1	0.0298	0.0298	9.395	0.00786 **
Spill	1	0.00272	0.002717	0.858	0.36903
Flow.res	1	0.00002	0.000016	0.005	0.94425
Projects:Flow.res	1	0.01125	0.011254	3.553	0.07895
Residuals	15	0.04751	0.003167		

Table 48: Steelhead SPA regression

Model: Projects + Spill + Projects:Flow (AIC: 207.26)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	18.882	15.72144	1.201	0.2462
Projects	-0.0715	0.644335	-0.111	0.91294
Spill	0.622137	0.170745	3.644	0.00201 **
Projects: Spill	-0.01362	0.006015	-2.264	0.03694 *

Table 49: Steelhead SPA ANOVA

ANOVA	Df	Sum Sq	Mean Sq	F-value	p
Projects	1	9618	9618	11.074	0.00398 **
Spill	1	7291	7291	8.394	0.01002 *
Projects:Spill	1	4452	4452	5.126	0.03694 *
Residuals	17	14765	869		

(2) *Spring Chinook*

Table 50: Spring Chinook SAR regression

Model: Projects + Spill + Flow + Projects:Flow (AIC: -72.192)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	0.0129000	0.0155600	0.829	0.4201
Projects	-0.0001751	0.0004483	-0.391	0.7015
Spill	0.0002882	0.0001759	1.639	0.1221
Flow	0.0000257	0.0000110	2.334	0.0339 *
Projects:Flow	-0.0000006	0.0000004	-1.553	0.1413

Table 51: Spring Chinook SAR ANOVA

ANOVA	Df	Sum Sq	Mean Sq	F-value	p
Projects	1	0.000267	0.000267	0.23	0.6384
Spill	1	0.008287	0.008287	7.147	0.0174 *
Flow	1	0.004108	0.004108	3.543	0.0794
Projects:Flow	1	0.002796	0.002796	2.411	0.1413
Residuals	15	0.017392	0.001159		

Table 52: Spring Chinook SPA regression

Model: Projects + Spill + Flow + Projects:Spill + Projects:Flow (AIC: 226.14)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	31.44871	18.26929	1.721	0.104453
Projects	0.776971	0.82863	0.938	0.36236
Spill	0.931162	0.225234	4.134	0.000779 ***
Flow	-0.02232	0.011607	-1.923	0.07243
Projects:Spill	-0.02372	0.007854	-3.02	0.008134 **
Projects:Flow	0.000661	0.000342	1.932	0.071323

Table 53: Spring Chinook SPA ANOVA

ANOVA	Df	Sum Sq	Mean Sq	F value	p
Projects	1	9402	9402	7.58	0.0141 *
Spill	1	9384	9384	7.566	0.0142 *
Flow	1	106	106	0.086	0.7734
Projects:Spill	1	7418	7418	5.98	0.0264 *
Projects:Flow	1	4628	4628	3.731	0.0713
Residuals	16	19846	1240		

(3) *Fall Chinook*

Table 54: Fall Chinook SAR regression

Model: Projects (AIC: -19.704)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	0.100681	0.036759	2.739	0.0169 *
Projects	-0.00106	0.001651	-0.643	0.5314

Table 55: Fall Chinook SAR ANOVA

ANOVA	Df	Sum Sq	Mean Sq	F value	p
Projects	1	0.00503	0.005034	0.413	0.531
Residuals	13	0.15828	0.012175		

Table 56: Fall Chinook SPA regression

Model: Projects + Spill + Flow + Spill:Flow (AIC: 172.6)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	67.97457	30.60973	2.221	0.0506
Projects	-1.32845	1.045703	-1.27	0.2327
Spill	0.106127	0.355963	0.298	0.7717
Flow	-0.0556	0.027551	-2.018	0.0712
Spill:Flow	0.000621	0.000241	2.584	0.0272 *

Table 57: Fall Chinook SPA regression

ANOVA	Df	Sum Sq	Mean Sq	F value	p
Projects	1	12289	12289	3.134	0.1071
Spill	1	9628	9628	2.456	0.1482
Flow	1	1521	1521	0.388	0.5473
Spill:Flow	1	26177	26177	6.677	0.0272 *
Residuals	10	39207	3921		

(4) *Coho*

Table 58: Coho SAR regression

Model: Projects + Spill + Flow + Spill:Flow (AIC: -12.872)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	-0.079130	0.090090	-0.878	0.4135
Projects	0.005340	0.002306	2.315	0.0598
Spill	0.001896	0.001173	1.617	0.157
Flow	-0.000072	0.000090	-0.802	0.4533

Spill:Flow	0.000001	0.000001	1.422	0.2048

Table 59: Coho SAR ANOVA

ANOVA	Df	Sum Sq	Mean Sq	F value	p
Projects	1	0.08565	0.08565	7.655	0.0326 *
Spill	1	0.00228	0.00228	0.204	0.6676
Flow	1	0.04841	0.04841	4.327	0.0827
Spill:Flow	1	0.02263	0.02263	2.023	0.2048
Residuals	6	0.06714	0.01119		

Table 60: Coho SPA regression

Model: Spill:Projects (AIC: 76.392)				
Coefficients:	Estimate	Std. Error	t value	p
(Intercept)	10.69803	2.420208	4.42	0.00129 **
Spill: Projects	-0.00069	0.000583	-1.186	0.263

Table 61: Coho SPA

ANOVA	Df	Sum Sq	Mean Sq	F value	p
Spill: Projects	1	34.88	34.88	1.407	0.263
Residuals	10	247.9	24.79		

These results suggest that intensity of restoration, flow and spill variability play some role in determining the pattern of temporal variability in fish survivorship in the Yakima basin. However, the pattern of temporal variability in survivorship is different from a net change in survivorship or the amount of fish. To evaluate the effect of a unit change in Projects, Spill or Flow on changes in survivorship we look to the estimates of the coefficients in the fitted models. These coefficients are presented in Table 62 below, normalized by the estimate of the mean survivorship (= the "intercept" in the models), and reported as a percentage. Some of them are statistically significant, some are not, but our ability to estimate the values to a statistical significance does not provide a measure of their relative impact on survivorship metrics, which are also intrinsically highly variable. Therefore, also listed in Table 62 are measures of coefficient of variation (CV's) of the survivorship metrics, which is a measure of variability in the signal and estimated as the mean value normalized by its standard error and expressed as percent.

Table 62: Fish survival regression results.

Species Survival metric	CV (%)	Ratio of effect size for *Projects* and *Flow* to estimate of intercept (=mean) in best linear model	
Steelhead			
SAR	79.847	10.751%	*Projects*
		-0.140%	*Flow*
SPA	112.94	-0.379%	*Projects*
		r.f.m.[1]	*Flow*
Spring Chinook			
SAR	132.03	1.357%	*Projects*
		0.199%	*Flow*
SPA	123.48	2.471%	*Projects*
		0.071%	*Flow*
Fall Chinook			
SAR	111.91	1.055%	*Project*
		r.f.m.	*Flow*
SPA	74.570	1.954%	*Projects*
		0.082%	*Flow*
Coho			
SAR	74.926	6.748%	*Projects*
		0.091%	*Flow*
SPA	60.442	r.f.m.	*Projects*
		r.f.m.	*Flow*

(r.f.m. = removed from model due to lack of predictive power)

The important result of this analysis is the small effect size for Project and Spill. Looking at SPA's, which are the survivorship metric affected principally by YBIP implementation, Flow and Project have normalized effect sizes that range from 0.33% to 2.6% of the intrinsic variability in the survivorship metric. In addition, these effects are not consistently in the same direction; sometimes the effect is positive (Projects on Steelhead SAR's), and sometimes the effect is negative (Projects on fall chinook SAR's). This small relative magnitude and inconsistency in the direction of the impact, in the face of a highly variable signal does not support a credible forecast of numbers of adult fish in the basin that can be attributed to individual components of the YBIP plan.

This is an important distinction; the predictor variables do contain information that allows us to use them to predict the variability in fish survivorship, or indeed to detect a prior expression of restoration or flow effectiveness, but they contain poorer information with which to estimate absolute values of survivorship into the future. The absolute values of survivorship are determined more so by other drivers, some of which like ocean conditions and harvest rates, we are aware of, some of which we may not yet know. In either event, they are predictors we don't have access to in our modelling framework and do not appear to be under the control of the YBIP management program. In addition, resolving the limitations on the predictive power of restoration Projects and

Flow on fish survival also illuminates the reasons we are not able to make credible forecasts for fish abundance changes based on individual components of the IP; the effect sizes are too small to support individual forecasts with any certainty.

F. Fish valuation

This appendix supplements the discussion in the main text on valuing fish improvements. This appendix begins with a discussion of methods and the broader economic valuation literature that provide general support for the Four Accounts methods and results. We next provide more detail on the criticisms of the LBP valuation study and its application to the IP. The section concludes with a focus on two criticisms that are amenable to sensitivity testing: the time needed to achieve fish population increases and the "baseline" population of fish in 2012. We provide more detail on how we adapt the LBP valuation function for these calculations, and report results.

1. The LBP study and similar valuation studies

The LBP study is just one of many fish valuation research efforts that has been conducted since the 1980's. Many use the same valuation methodology (contingent valuation, CVM), estimating the value of various salmon species in Washington, Oregon, California, Rhode Island, Maine (Atlantic salmon) and Canada. Other studies do not collect their own primary data, but use existing studies to "transfer" the benefit estimate or function to their specific study site and species improvement. Because the IP's fish improvement and management plan do not match exactly those given respondents in the LBP study, the Four Accounts study is also a benefit transfer approach. A third type of study (meta-analyses) statistically compare willingness to pay for different threatened and endangered species across different sites.

We extensively assessed existing studies and conducted a sensitivity analysis on the effect of using other valuation studies or methods to calculate the benefits of the "low-end" fish estimates in the Four Accounts. Table 63 lists the other studies we found valuing salmon in the United States since the 1990's. We exclude studies before 1990 because a) household preferences are likely to have changed significantly over such a long time period and b) older studies are more likely to have used methods that are now considered less reliable. Table 64 compares estimates from the LBP (applied to the IP's low-end fish estimates) with those that might result from use of other valuation studies. As the table demonstrates, using a functional form from existing meta-analyses of willingness to pay for threatened or endangered species would lead to even higher estimates. The table also shows how sensitive the benefit estimates are to a) discount rates, b) standing (Washington residents only), c) changes in real income and differences in assumed income elasticity (the percentage increase in WTP with a 1% increase in income.

Table 63. Comparison of Willingness-to-Pay Estimates for Anadromous Salmon in the United States, Post- 1990

Year	Type*	Authors	Study location	Sample size	Pmt Per.	Pmt Freq	Baseline (1000s fish)	Change (1000s fish)	WTP	Pmt mech
1990	CVM - DC	Hanemann, Loomis, Kanninen	CA, OR, WA	1003	NS	Ann.	0.1	15	$324	taxes
1991	CVM - OE	Olson, Richards, Scott	WA, OR, ID, MT	1400	one-time	Mo.	2500	2500	$49 - $137	electric bill
1991	CVM - DC	Stevens et al	MA	1000	5 yr	Ann.	NA	complete loss	$13 (Atlantic salmon only)	trust fund
1992	CVM - OE	Duffield and Patterson	MT	796	one-time	lump sum	NS Status Quo	NS	$31	trust fund
1996	MA	Loomis & White	NA	NA	NA	NA	NA	NA	$100	NA
1996	CVM - DC	Loomis	WA & USA	1174	10 yr	Ann.	50	350	$91 - $113	taxes
2001	CVM – R	Layton, Brown, Plummer	WA & OR	1611	20 yr	Mo.	2000	3000	$167	utility bill
2003	CVM - DC	Bell, Huppert, Johnson	WA & OR	2209	5 yr	Ann.	64 - 69	64 - 146	$101 - $162 (WA)	taxes
2006	WTP - MC	Montgomery and Helvoigt	OR	5300	NS	Mo.	SQ	NS	$15 - $46 (mode)	utility bill
2007	BT (LBP 1999)	Goodstein and Matson	OR & WA	NA	NA	NA	NA	33 - 66% decrease	$33-$144	NA
2008	MA	Martin-Lopez et al	NA	NA	NA	NA	NA	NA	$76 - $149	NA
2009	MA	Richardson, L. and Loomis, J.	NA	NA	NA	NA	NA	NA	$92	NA
2009	BT (Loomis 1999)	Helvoigt and Charlton	OR	NA	NA	NA	NA	NA	$33	NA
2009	CVM - CE	Rudd, M.	Canada	2761	20 yr	Ann.	SQ	50 - 200% increase	$86	taxes
2012	CVM - CE	Johnston et al	RI	522	NS	Ann.	SQ	NS	NA	taxes
2012	CVM - CE	Wallmo, K. and Lew, D. K.	US	8476	10 yr	Ann.	SQ	De-list as threatened	$40	taxes
2012	CVM - CE	Mansfield et al	OR & CA	3,372	20 yr	Ann.	SQ	30 – 150% increase	$121 - $213	Taxes

Notes: *Primary valuation approaches include the contingent valuation method (CVM), benefit transfer (BT), and meta analysis (MA). CVM studies can be further classified by the survey response format: dichotomous choice (DC), open-ended (OE), choice experiment (CE), or censored ranking (R). Some survey characteristics are not applicable to individual studies (NA) or are not specified in individual studies (NS). Full references for the studies are available from the authors on request.

Table 64. Sensitivity of YBIP Low – End Fish Benefits* to Alternative Modelling Assumptions.

Scenario and Description	Fish Pop Increases (%)		Average Annual Household WTP ($)		Total Bens($B NPV)
[P1 & P2 represent period 1 & period 2]→	P1	P2	P1	P2	P1 + P2
1. FAA Low Base: 9.1% 2012 – 2051 fish population increases with linear growth through 2042 and stable thereafter, stable baseline fish populations without the IP, same WTP function for P1 and P2 as described in Figure on p.7; WA and OR residents have standing; 0.38 income elasticity of WTP for fish increases but zero change in real income since 1998; 4% discount rate	5.8	3.3	73	19	5.0
2. Loomis and White functional form (1996 meta-analysis of WTP for threatened and endangered species)	5.8	3.3	133	71	10.3
3. Richardson and Loomis functional form (2009 meta-analysis of WTP for threatened and endangered species)	5.8	3.3	126	77	10.1
4. FAA Low Base with 6% discount rate	5.8	3.3	73	19	4.1
5. FAA Low Base with 2% discount rate	5.8	3.3	73	19	6.3
6. FAA Low Base with standing for WA residents only	5.8	3.3	73	19	3.1
7. FAA Low Base with real annual income changes of -5% in WA since 1998 and -15% in OR relative to Washington in 1998 when LBP was conducted (refer to FAA, p.25). Income elasticity of WTP=0.38 from Jacobsen and Hanley (2009). Zero real income changes after 2012	5.8	3.3	WA–71 OR-67	WA-19 OR-17	4.8
8. Same as **7** with + 1 s.d. change in income elasticity of WTP (=0.62)	5.8	3.3	WA–70 OR-63	WA-18 OR-16	4.6
9. Same as **7** with -1 s.d. change in income elasticity of WTP (=0.14)	5.8	3.3	WA–72 OR-71	WA-19 OR-18	4.9

Notes: **The FAA estimate for low end estimate from the FAA assumes IP-related population increases 181,650 fish. CBD = cannot be determined from LBP (1999)

2. *Critiques of the LBP study and its application to the IP*

Below we describe several concerns about the LBP study and the way if was applied to the IP. We are able to address only a couple of these in any quantitative way for this study, but all have implications for fish benefit estimation.

a. *The uncertainty in IP fish outcomes is large*

The LBP survey does not directly confront respondents with the uncertainty inherent in predicting the impact of the IP's components on fish populations. They follow what is standard practice in stated preference surveys, in part because of respondents' difficulty in understanding probabilities and uncertainty, although a number of early stated preference studies engaged uncertainty by estimating option values (Desvousges, Smith, and Fisher 1987; Shogren and Crocker 1990).

LBP follows the accepted professional norms by including statements such as "issues dealing with fisheries are very complex and have been generalized for the purpose of this survey", and "scientists cannot say with certainty how the population of each and every species will change over the next 20 years". Their best estimates of the past and future population trends under the current set of fishery programs are shown below..." It is argued that the scientific uncertainty in forecasts can be dealt with separately from valuation of the endpoints by assuming that respondents are risk-neutral (or that the government as a public risk-aggregator should act as a risk-neutral agent) and one can simply examine expected values (probability of outcome x value of outcome). One could also incorporate an aversion to risky outcomes using relatively standard measures of risk aversion observed from experiments and behavior. The degree of uncertainty inherent in modeling survival of anadromous fish is, however, quite large relevant to many other types of stated preference topics. In essence, the survey is asking respondents to commit money to a risky investment where there is little professional consensus on how effective the program will be, as described elsewhere in this report. As Bell et al (2003, 28) note, "public confidence in the salmon enhancement program is inextricably linked to the willingness-to-pay for such a program." Many members of the public may misunderstand the degree of uncertainty inherent in fish recovery, and it is possible that a stated preference scenario that explicitly provided the risk of the program failing, or provided a wide range of outcomes, might deliver lower valuation estimates than those implied by simply weighting outcomes by scientists' best estimate of the probability of success. Some recent studies have experimented with providing respondents uncertain outcomes (Roberts, Boyer, and Lusk 2008; Rolfe and Windle 2014); Mansfield et al. (2012) elicit willingness-to-pay to reduce the numerical probability of two species in the Klamath River Basin from going extinct by 2060 as well as to increase their abundance.

b. *Hatchery vs. wild fish*

There is no distinction made in LBP or the IP between improvements in hatchery fish versus wild fish. Like most of the existing surveys eliciting values for recovering salmon runs, the LBP survey does not mention hatchery fish. It is possible, however, that respondents value improvements to wild fish populations differently than more-genetically-homogenous hatchery fish (which comprise the vast majority of returning adult fish in the Yakima, and will continue to under the IP improvements). On the other hand, members of the general public who are not active in the fishing community may have little knowledge or understanding of the difference between the two, as found in focus groups for a planned stated preference study of fish improvements in the Willamette River Basin in Oregon (Weber, Matthew and Papenfus, Michael 2014). On the other hand, the LBP study did not identify any fish populations as "endangered" or "threatened" under the Endangered Species Act. Since the Yakima Basin does contain endangered populations, willingness-to-pay would likely have been higher had this information been presented to respondents.

c. *Some households might object to the IP management plan*

Because the description in LBP of how fish improvements would be achieved is deliberately vague, it does not correspond directly to the proposals that comprise the IP. This gap in descriptions may impact valuation estimates. In particular, it is likely that a sizeable fraction of surveyed Washington households might object to the construction of a new storage project (Wymer) and resulting loss of shrub-steppe habitat, or the expansion of Bumping Reservoir and the loss of approximately 980 acres of old-growth forest that the expansion would entail (Johnston et al. 2012).

It is accepted practice in stated preference studies to have respondents focus on ecological endpoints (i.e. increases in returning adult fish) rather than the intermediate ecological conditions (i.e. increased stream flow, restored habitat) because of the potential for double-counting and because respondents may be confused by ecological terminology (Johnston et al. 2012). The focus is then typically on developing a management plan that can deliver the endpoints of interest in a way that is credible to respondents. However, details about the specific approaches to satisfy hypothetical fish abundance improvements can affect WTP. Dams have historically been controversial, in no small part due to their impacts on fish. Because the IP as proposed includes several water storage projects such as Wymer and the Bumping Lake expansion, achieving the hypothetical fish population increases via the proposed IP package might elicit substantially different WTP estimates, which we hypothesize might be lower because of the inclusion of dams and storage expansion.

d. *Standing: The use of Oregon households*

The question of standing and the distribution of benefits across states is likely relevant to investments by the State of Washington. The Four Accounts analysis was premised on both federal, state and local cost-sharing. From the perspective of the federal government, all U.S. citizens have "standing" in the project and any benefits or costs that accrue to them "count" in the benefit-cost analysis. In this sense, the benefits in the Four Accounts analysis (restricted to Washington and Oregon residents only) are conservative since it assumes no citizens in any of the other 48 states value salmon recovery in the Yakima Basin, or come to the Basin to fish recreationally. From the perspective of the Legislature, however, benefits that accrue to residents of Oregon or any other state may not have standing. The Four Accounts reports fish-related benefits to Washington residents only of \$3.1 billion to \$4.6 billion (pg. 32), instead of \$5.0–\$7.4 billion for fish-related benefits to households in both Washington and Oregon. In addition, these estimates obscure uncertainty in the underlying preferences of respondents, such that the actual benefits might be lower or higher (D. Layton, Brown, and Mark Plummer 1999, 20).

e. *The LBP payment period is long*

The length of the hypothetical payment period (20 years) assumed in the LBP study is relatively long. Although the LBP survey highlighted for respondents that the additional payments on their monthly water bill would be for the next twenty years, and did an exemplary job asking respondents to think about how these increased bills would displace other consumption, the period still may not have been particularly salient to respondents. This timeframe is fairly long by the standards of most stated preference studies, and is even long among those valuing salmon restoration, an activity with a naturally-long time frame (Table 65 summarizes relevant studies). Most respondents would have little experience with committing to monthly expenditures to a public good on such a long time scale.

The typical assumption is that respondents are forecasting into the future the impact of the increased taxes on their household budget, and discount those values into present-day terms. Using the 4% real discount rate used throughout the Four Accounts analysis, this assumes that a respondent would vote the same way when a scenario is presented with a payment of $25 per month for 20 years or a one-time payment of $4,377. Many, though not all, studies that have done split-sample tests vary annual vs. monthly payment or vary the length of time periods. A common finding from these studies is that respondents do distinguish between lump-sum and periodic payments, but that responses imply discount rates far higher than 4% (see Table 65). This in turn would imply that the present value of benefits to households is much less than $4,377.

Table 65. Summary of studies examining payment periods in contingent valuation studies

Author	Topic	Split Sample Pmt Sched	Payment Period	Sample size (RR)*	Implied discount rate**	Summary of Findings
Andersson et al (2013)	Car safety risk reduction (Losing $)	Annual vs. monthly	Not specified	N = 920 (49%)	NR	No significant difference in WTP at the lowest levels of risk reduction; for intermediate and high levels, annual payments are more than 2x as large as monthly payments per unit risk reduction
Beattie et al (1998)	Car safety risk reduction (Losing $)	Lump sum	1 year vs. 5 year	N = 52 (NA)	NR	5 year annual equivalent mean (median) WTP is 1.7 (2.6) times greater than the WTP for the 1 year program for low levels of risk reduction; and 2.0 (3.0) times greater for high levels of risk reduction.
Hammitt & Haninger (2007)	Reduced risk of foodborne illness (Losing $)	Per meal vs per month	Perpetuity	N = 3500 (NA)	NR	No significant difference in WTP
Bond et al (2009)	Protection of critical habitat (Losing $)	Annual	1, 5 and 15 years	N =3,000 (42 – 45%)	23% - 243%	Joint estimation of WTP and discount rate ("r"). If r is fixed across 1,5,10 year periods, it varies from 23% - 80%. If r is fixed across periods but varies by education and gender, it ranges from 64% - 243%. With covariates at mean values, r is 35% - 73%.

Warner and Pleeter (2001)	Armed services payments (Receiving $)	Lump sum vs. annual	Perpetuity, nominal $	N = 65,000 (NA)	0% - 30%	Military veterans demonstrate a strong preference for lump sum over annuity benefit payments. Allowing veterans to select their preferred method of payment saved the U.S. government $2.5 B compared with a scenario in which only annuity payments were available.
Harrison et al (2002)	Receive generic cash payout (Receiving $)	Lump sum	0.5, 1, 2, and 3 years	N = 268 (NR)	20% - 36%	There is no significant differences in discount rates between the 1 year and 3 year treatment horizons. Discount rates vary systematically by household characteristics, namely according to education and wealth
Kahneman & Knetsch (1992)	Toxic waste treatment (Losing $)	Lump sum vs Annual	5 years	N = 206 (NR)	NR	No significant difference between lump sum and 5 annual year payment periods for median WTP. Mean WTP is distorted by small sample effects and outliers.
Rowe et al (1992)	Oil spill prevention program (Losing $)	Lump sum vs Annual	5 years	NR (70 %)	20%	Mean lump sum WTP is 2.8 times mean annual WTP
Stevens et al (1997)	Movie pass (a) and salmon restoration (b) (Losing $)	Movie pass: lump sum vs weekly Salmon: lump sum vs. annual	Movie pass: 8 weeks; salmon: 5 years	N = 88 (NR)	50 – 270% salmon; >1000% movie passes	Students prefer to pay lump sum amounts rather than annual amounts for both scenarios (a) and (b). Median WTP was 1.3 – 2.9 times greater with lump sum than for annual payments for different levels of restoration.
Stumborg et al(2001)	Water pollution reduction (Losing $)	Annual	3 and 10 year	N = 500 (44%)	40%	With a 4% discount rate and covariates at mean values, NPV of average WTP with a 10 year schedule is $89 more than with a 3 year schedule
Kovacs and Larson (2008)	Open space (Losing $)	Monthly	1,4,7 and 10 years	N = 420 (37%)	Approximately 30%	The magnitude and range of the implicit discount rate increases as the payment schedule decreases. Implicit discount rates range from -5% to +71% for different functional forms and between different periods.
Curtis (2002)	Fishing profits (Losing $)	Annual. foregone profits in years 1 – 2 for increased profits in years 2 - 8	8 years	N = 40 (NR)	30 -40%	Individual discount rates range from 1 – 345% with most individuals reporting implied discount rates between 30 and 40%
Kim and Haab (2009)	Oyster reef restoration (Losing $)	Annual vs. lump sum	5 and 10 year and perpetual payments	NR (NR)	22% - 129%	WTP for the 5 year project is greater than for the 10 year project. There is support for hyperbolic discounting. There is no significant differences in WTP due to payment schedule when the project length is fixed. WTP otherwise varies widely across payment schemes and project lengths.

*Survey response rate (RR).
** Some study characteristics were not applicable to individual studies (NA) or not reported by study authors (NR)

f. *The baseline fish population and the impact of non-IP programs*

The Four Accounts analysis assumes that the total number of returning migratory fish in the Columbia is the same number of 2 million returning fish used in the LBP study in 1998 as the baseline fish population. Figure 28 show returning fish counts at Bonneville Dam and Willamette Falls for both salmonids (on the left) and all migratory/anadromous fish (including lamprey) on the right. There are several features of this graph relevant to the application of the LBP study to the IP.

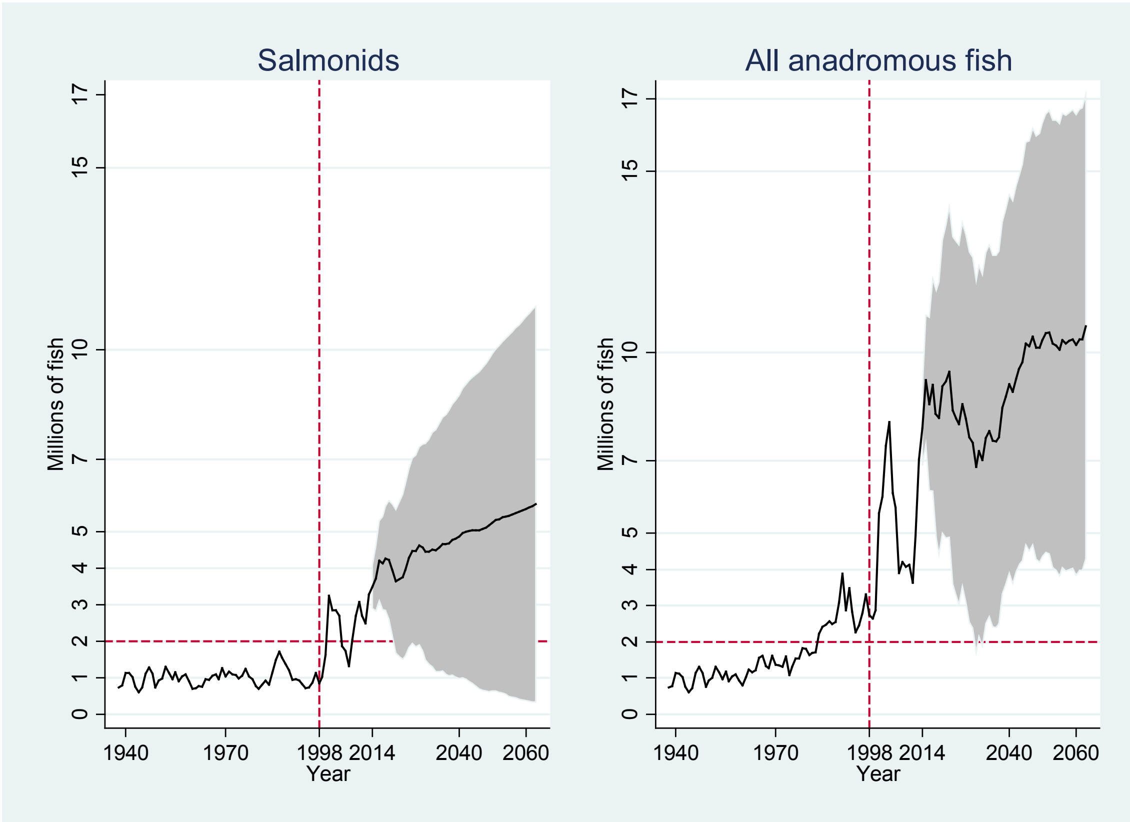

Figure 28. Fish counts at Bonneville Dam and Willamette falls. Total Salmonids (left) and all anadromous fish (right). Forecasts and 95% confidence intervals (grey area) beyond 2014 generated using an AutoRegressive Integrated Moving Average (ARIMA) model of order (1,1,1), with a 3-year seasonal lag.

First, the LBP survey does not specify whether migratory species should include non-salmon or steelhead species, merely defining migratory fish "such as salmon or steelhead." One could argue that the trend in populations of all migratory fish (including lamprey) has trended up since 1998, although a change in data collection methods in 2000 confounds the time trend. A second point is that although populations of salmon and steelhead are probably now varying around a mean of 2 million, in 1998 an assumption of 1 million or less might have been more appropriate. We suspect most respondents were not aware that lamprey are migratory fish and were not including them in their valuations. LBP also told respondents that populations of Eastern Washington/Columbia River migratory species "twenty years ago" was 8 million fish, which seems unsupported by the data in the Figure. This would have the effect of dramatically overstating the 20-year decline (1978-1998) and possibly upward-biasing willingness-to-pay under the declining baseline treatment. It may also have led to an overstatement of valuations in the constant baseline case if respondents believed that the fall in population had occurred in the recent, post-dam past, rather than in the pre-dam era of the late-19th and early-20 century (which is what we believe this number was meant to represent), and thus could be reversed with the type of programs described in LBP rather than large-scale dam decommissioning.

The second important point is whether there has been an increase in fish populations in the period since the late 1990's. As described in the main text, if any other non-IP programs designed to improve fish populations anywhere in "eastern Washington and the Columbia River" have had any impacts, or *could be expected* to have any impacts in the same timeframe as the IP, the willingness-to-pay of households for those changes should be accounted for in evaluating the IP. Year-to-year fish returns clearly fluctuate dramatically in Figure 28. As discussed in the preceding section on fish biology, it is difficult to attribute changes in smolt to adult returns to an inventory of existing habitat programs or changes in spill resulting from the Redden decision. We cannot definitively refute the assumption that the baseline population of migratory species in the Columbia Basin has remained constant at 2 million in the period between 1998 and 2012. The figure certainly suggests the possibility of an upward trend in fish populations without the Integrated Plan because of the many other local, tribal, state and federal actions underway. In the next section we present results showing that the IP's fishery benefits are highly sensitive to assumptions about the effectiveness of other programs that have preceded it in time. It is worth noting that this result is entirely dependent on the use of the LBP valuation function because of its nonlinear nature (which implies diminishing marginal value of fish as fish numbers increase).

g. *The timing of IP-related fish increases and adapting the LBP function*

As discussed above, the LBP study asked households to value fish population increases that would occur over the 20 years following the survey (i.e. 1998 – 2018). In contrast, the increases attributable to the IP are expected to take longer to reach their full effect. According to the Four Accounts analysis, some fish increases will occur in the first 20 years (i.e. 2012-2032), but the full effects will not be reached until 2042. This discrepancy in time periods between LBP and the application of LBP's valuation function to the IP is important given the predominance of non-use benefits in justifying the IP. Furthermore, as discussed above, we feel that 1) these fish population growth rates are optimistic and 2) fish populations are likely to have increased between 1998 and 2012, lowering the marginal value to households of further increases in fish populations. In this section we explain how the Four Accounts manages the discrepancy between time periods. We then model the benefits of slower-growing populations, and calculate IP-related benefits to households if fish populations have actually increased between 1998 and 2012, prior to the IP.

To reconcile the 20-year timeline of the LBP study with the expected time needed for the IP to reach its full effect (30 years), an analyst has two options. The first is to simply assume that household's annual willingness-to-pay (WTP) would extend to 30 years; implicitly assuming that households are patient and willing to pay an additional ten years of higher utility bills to see fish populations increases. This would be similar to assuming that WTP is – roughly speaking – 33% higher, and is very likely to lead to an overestimate of WTP. A second option, and the one followed by the Four Accounts, is to break the IP period into 20-year blocks. For the first 20 years (2012-2032), the LBP valuation function is used to calculate annual economic benefits for the percentage increase that accrues *in that time period only*. Annual household WTP for that period is multiplied by the number of households in Washington and Oregon in 2012, and the total annual WTP in future years (2013-2032) is discounted in the normal fashion. One then imagines that a new survey is administered in 2032, and the results of this survey produce the exact same relationship between percentage increases in fish populations and household's willingness to pay, i.e the same valuation function. Annual household WTP is then calculated based on the percentage increase in fish that occurs *only in the second period* (2032-2052), multiplied by the number of households in WA and OR projected in 2032, and discounted to current dollars.[59]

For example, the Four Accounts analysis' "high-end" fish population increase is 472,450, or a 23.6% increase over an assumed base of 2 million fish in 2012. This increase would occur over 30 years, with fish populations stabilizing after 2042. They assume populations increase linearly over those 30 years such that roughly two-thirds of the 23.6% increase, or 15%, happens in the first 20 year period, and the remainder (8.66%) occurs in the second 20-year period. To value the benefits to households in 2012, one can use the LBP valuation function for a 15% increase. The LBP function for monthly WTP for an x percent increase in eastern Columbia migratory fish populations is a piece-wise function that is linear for the first 5% increase and logarithmic for larger increases. The logarithmic portion is:

$$Monthly\ WTP = \frac{\beta_{columb.migr}(0-\ln(x))}{\beta_{cost}}\ for\ x > 5\%$$

The zero in the numerator of the equation above derives from the fact that LBP normalize results to a baseline change of zero. Substituting the coefficients from LBP's Table 3C[60]:

$$Monthly\ WTP = \frac{0.0673(0-\ln(x))}{-0.0266} = -2.53(0-\ln(x)))\ for\ x > 5\%$$

For changes less than 5%, one simply linearly interpolates between 0 and the WTP for a 5% improvement. Monthly WTP in 1999 dollars for a 5% improvement is equal to -2.53(-ln(5)) = $4.0719, so a linear interpolation implies that monthly WTP = 0.8144*x for x<=5%[61].

To convert to 2012 dollars, the Four Accounts uses a standard inflation index implying one 1999 dollar is equal in purchasing power to 1.377 dollars in 2012. Monthly payments are multiplied by 12 to get annual payments, ignoring any discounting within the year. The equations linking percentage improvements to economic benefits become:

$$Annual\ WTP(2012\$) = \begin{cases} 12*1.377*2.53*\ln(x) = 41.81*\ln(x)\ for\ x > 5\% \\ 12*1.377*0.813*x = 13.457x\ for\ x \leq 5\% \end{cases}$$

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[59] Because both theory and empirical evidence suggests that willingness-to-pay for environmental goods increases with income, any changes in real, inflation-adjusted income between 2012 and 2032 are relevant. To deal with this, the Four Accounts analysis assumes no change in real incomes over these twenty years. Given the difficulty in predicting economic growth for the median household, we think this assumption is reasonable and also rely on it for our calculations.

[60] These coefficients correspond to the "stable" baseline case in LBP.

[61] The Four Accounts (pg. 12) uses a linear interpolation factor of 1.06 rather than 0.8144. We believe this was an erroneous calculation, though it had no impact on the results because the IP improvements are modeled as larger than 5% and the linear portion of the valuation function was never actually used.

Returning to the 15% "high-end" improvement in the first period (2012-2032), the annual household WTP is 41.81 * ln(15) = $113. The total "high-end" improvement is 23.6%, however, with 8.6% occurring in the period 2032-2052.

The question now becomes how to value this 8.6% increase for households surveyed in 2032. One option is to simply assume the same valuation function as above for households in 2032, or 41.81*ln(8.6%) = $90 per household per year. Under the IP, however, a household surveyed in 2032 would have experienced a historical *increase* of 15% in the previous 20 years, a baseline not modeled in LBP. Given that WTP was lower in the constant baseline treatment of LBP than the declining treatment, it is reasonable to assume that WTP would be lower still for an "increasing baseline" treatment. We have no basis, however, for estimating how much lower.

A second option is to continue to use the 2012 fish population as the "baseline" for the 2032 hypothetical survey. This is the approach used in the Four Accounts and the one we use below. The first step is to calculate WTP for the total IP-related fish improvements: i.e. 41.81*ln(23.6%) = $132. The WTP associated with the first period is then subtracted from this total; i.e. $132 - $113 = $19, which is credited to the second period. This approach is consistent with the LBP approach of calculating WTP for state 2 and subtracting WTP for state 1. The time period, however, is not the 20 years used in LBP but much longer, which is again questionable. Nevertheless, we follow this approach to investigate the effect of increases in fish populations from 1998 – 2012.

Consider now an example. The average salmonid population between 1998 and 2012 (inclusive) is 2.21 million (2 million + 207,000, s.d.=0.77 million).[62] Assuming that the population of eastern Columbia migratory fish was 2 million in 1998, and if the population increased from 1998 to 2012 by 207,000, the baseline fish population in 2012 would be 2.207 million. This represents a 10.35% increase from the 1998 baseline of 2 million, and annual household WTP in 2012$ for this state of the world would be 41.81*ln(10.35) = $97.71. Suppose again the IP increases fish populations by 472,450 over 30 years. The total fish increase by 2042, adding the non-IP and the IP fish increases, is 679,450, or a 33.97% increase over the 1998 baseline of 2 million. The total WTP for this increase (in 2012$) would be 41.81*ln(33.97) = $147.40. The fish population at the end of the first period (2031) would be 2 million + 207,000 (non-IP) + 299,218 (IP-related increases in period 1) = 2,506,218 or a 25.31% increase from a base of 2 million. WTP for this state of the world is 41.81*ln(25.31) = $135.09. Following the same logic as above, annual WTP in the second period beginning in 2032 is $147.40 - $135.09 = $12.31. Annual WTP attributable to the IP in the first period is $135.09 - $97.71 (non-IP-related increases) = $37.38.

Table 66 summarizes this information for this sample calculation. This exercise of adding 207,000 additional fish before the IP is implemented has a dramatic impact on IP-related benefits: *total net present value of benefits to households in Washington and Oregon falls from $7.4 billion to $2.6 billion, or 36% of*

[62] 1998 was the lowest value in this range at 845,939, and the 2013 value of 3,291,654 is omitted from this range, which would be the highest value. If 1998 were omitted and 2013 were included, the average for the period would be 2,369,867 (2 million plus almost 370,000 above baseline. Thus using the 1998-2012 range is conservative in this regard.

the larger estimate. This is because of the form of the LBP valuation function which places a much higher marginal value on the earliest fish improvements, which in this case are non-IP increases.

Table 66. Example calculation for non-IP increase between 1998 and 2012 of 207,000 fish and the high-end IP increase of 472,450 fish by 2042

Year	Fish population	Percentage increase from 2m	Annual household WTP for this state	Annual WTP attributable to the IP
1998	2 m	--	--	---
2012	2.207m	10.35% (non-IP)	$ 97.71	$135.09 - $97.71 = **$37.38**
2032	2.506m	25.31%	$135.09	$147.39 - $135.09=**$12.30**
2042	2.679m	33.97%	$147.39	

To investigate the timing of fish increases, we use the same assumption that fish populations increase linearly. For example, a high-end increase of 472,450 over 30 years implies an increase of 472,450/30 = 15,748 fish per year. Assuming the IP takes 50 years to take full effect implies 9,449 fish per year. Rather than two periods (2012 and 2032), we assume growth could be slow enough to require a third, fourth, and fifth period of benefits equivalent to new surveys in 2052, 2072, and 2092. Again, though, because of discounting, benefits accrued after 2052 or so are heavily discounted, so the main effect of slower fish population growth is drawing fish improvements away from the first period. We make the same assumption as the Four Accounts about the number of households in Washington and Oregon in 2032. We assume the increase in the number of households in each future period is the same as between 2012-2032.

Figure 29 shows the impact of any non-IP related fish improvements that have occurred between

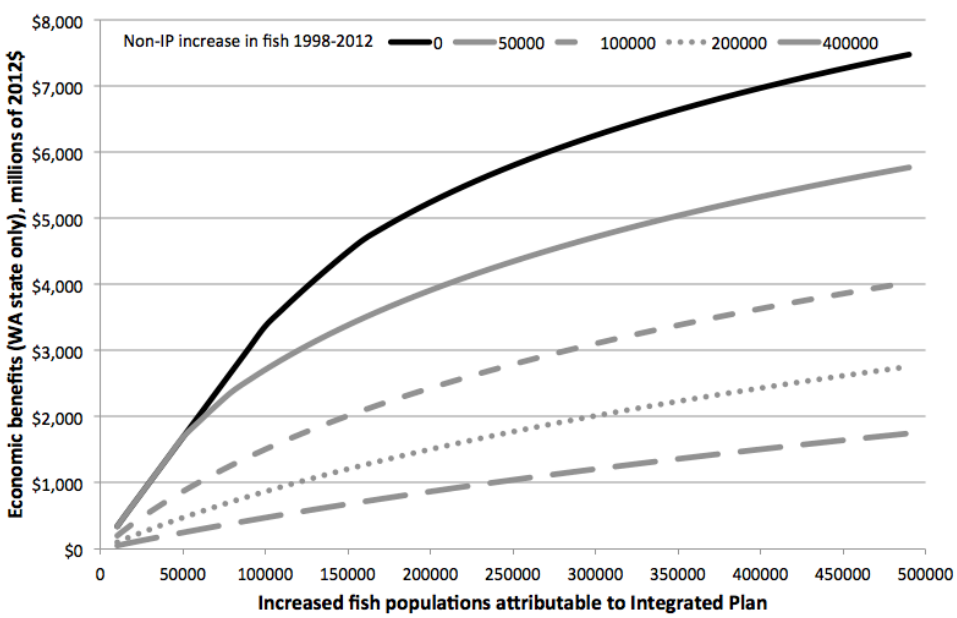

Figure 29. Benefits to Washington and Oregon households of IP fish improvements if the 2012 baseline population is higher than 1998.

1998 and 2012, but assuming that all IP-related fish improvements occur in 30 years. The black line represents the Four Accounts assumption that the 2012 population was the same as in 1998, or 2 million. For an increase of 472,450 fish (the high-end estimate), the total economic benefits to households in Washington and Oregon would be $7,387 million, replicating the result in the Four Accounts. If, however, there has been an increase in fish populations of 50,000 in the period 1998 to 2012 (solid gray line), and the new 2012 fish population is 2,050,000, the total fish-related economic benefits of the IP drop to $5,690 million. If the baseline fish population in 2012 is 2.4 million, the total benefits are $1,073 million.

Figure 30 shows the effects of increasing the time needed for the IP to affect fish populations. The black line shows the economic benefits of the IP when fish populations stabilize in 30 years, again replicating the Four Accounts results for the low- and high-end fish population estimates. The gray solid line calculates benefits when the IP takes 40 years to take effect, with populations stabilizing in 2052. If populations do not stabilize until 2072, total economic benefits for a high-end increase fall from the Four Accounts $7,477 million to $6,432 million.

3. *Reassessment of fish benefits based on baseline and population growth*

We have argued above that there is evidence to suggest that the baseline fish abundance appears higher than was assumed in the Four Accounts analysis, and that there is also evidence to suggest that the fish population growth rates implicit in the Four Accounts analysis are unreasonably high, especially for the high-end estimates. Section IV.E provides a description of our selection of baselines and their implications.

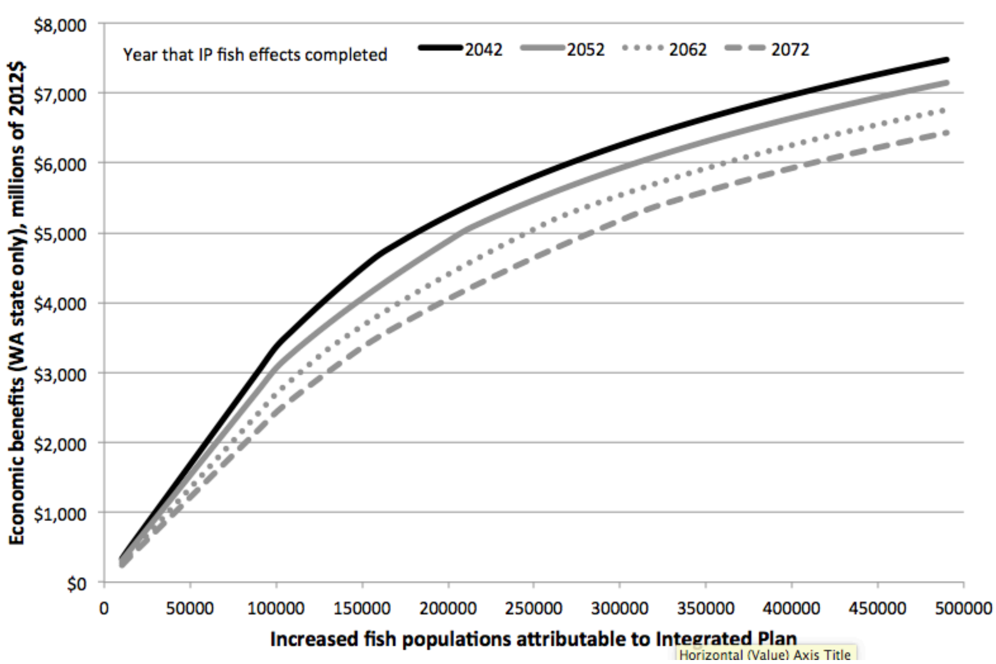

Figure 30. Benefits to Washington and Oregon households of IP fish improvements if the IP-related increase in population takes longer than 30 years.

G. Power Subordination

A portion of the Yakima Basin Integrated Water Resource Management Plan instream flow benefits would be produced by subordinating hydropower production at the Roza and Chandler power plants. The water currently used to produce electricity, but that would be relegated to instream flow under the IP, represents a cost from foregone electricity sales. At Roza, 14,000 fewer MWh would be produced over the months of April and May. At Chandler, 11,000 fewer MWh would be produced over the months of April, May and June(U.S. Bureau of Reclamation 2011d). To estimate the cost of foregone electricity production, we multiply monthly electricity prices by the amount of reduced power production in each month. Because it is not possible to predict the exact timing of electricity sales in a given year, we assume electricity sales would be spread equally across the subordination months (14,000 MWh/ 2 months = 7,000 MWh per month from Roza; 11,000 MWh/ 3 months= 3,667 MWh per month from Chandler), so that a total of 10,667 MWh less electricity would be sold in the months of April and May and 3,667 MWh less electricity would be sold in June.

Table 67 shows electricity rates reported by BPA as well as the average rates calculated to estimate the costs of subordinated power production. We report 2009 prices in to be consistent with the Power Subordination Technical Memorandum (U.S. Bureau of Reclamation 2011d, 2), but we then inflate the aggregate numbers to represent 2012 prices to be consistent with the Four Accounts analysis around which we most prices.

Table 67: Power rates by month (2009 prices)

Month	HLH Rate Amt* (mills/kWh)	LLH Rate Amt* (mills/kWh)	Average Load Rate ($/MWh)
January	30.42	22.00	26.21
February	31.07	22.22	26.65
March	28.82	21.12	24.97
April	27.04	19.44	23.24
May	22.59	15.61	19.10
June	20.45	10.86	15.66
July	25.18	18.44	21.81
August	29.49	21.88	25.69
September	30.45	24.43	27.44
October	32.19	23.58	27.89
November	34.33	25.04	29.69
December	35.83	26.29	31.06

* $1/MWh = 1 mill/kWh = $0.1¢/kWh

Monthly amounts of foregone electricity production are multiplied by average load rates, by month. Average load rates are calculated from the high load rates (HLH) and low load rates (LLH) reported by Bonneville Power Authority (Bonneville Power Administration 2010, 7).

Table 68 The total cost of foregone electricity production in a given year is estimated as $509,048. According to the Bureau of Labor Statistics (http://www.bls.gov/cpi/#tables, derived from table 25), 2012 energy prices were about 5% higher than 2009, so this value inflated to 2012 prices is $534,500.

Table 68: Estimated annual value of foregone electricity production.

	Combined Power Subordination at Roza and Chandler (MWh)	Average Electricity Rate ($/MWh)	Cost ($)
April	10,667	23.24	247,901
May	10,667	19.10	203,740
June	3,667	15.66	57,407
Annual Total	25,001	NA	509,048

To estimate the total value of foregone power production over the 100-year life of the Integrated Plan, we discount the annual cost of fewer electricity sales and sum over 100 years:

$$\text{Total Present Value Cost} = PVC_1 + PVC_2 + \ldots + PVC_{100} = \frac{\$509{,}048}{1.04^1} + \frac{\$509{,}048}{1.04^2} + \cdots + \frac{\$509{,}048}{1.04^{100}} = \$12.47\text{ M}$$

Using the same discount rate of 4 percent from the Four Accounts Analysis(ECONorthwest, Natural Resources Economics, and ESA Adolfson 2012), the present value of foregone power production is estimated to be $13.1 million.