RECLAMATION
Managing Water in the West

Aquatic Ecosystem Evaluation for the Yakima River Basin

A Component of
Yakima River Basin Water Storage Feasibility Study, Washington

Technical Series No. TS–YSS–22

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Upper Columbia Area Office
Yakima, Washington

January 2008

The mission of the U.S. Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Preface

The Congress directed the Secretary of the Interior, acting through the Bureau of Reclamation, to conduct a feasibility study of options for additional water storage in the Yakima River basin. Section 214 of the Act of February 20, 2003 (Public Law 108-7), contains this authorization and includes the provision "… with emphasis on the feasibility of storage of Columbia River water in the potential Black Rock Reservoir and the benefit of additional storage to endangered and threatened fish, irrigated agriculture, and municipal water supply."

Reclamation initiated the Yakima River Basin Water Storage Feasibility Study (Storage Study) in May 2003. As guided by the authorization, the purpose of the Storage Study is to identify and examine the viability and acceptability of alternate projects by: (1) diversion of Columbia River water to a potential Black Rock reservoir for further water transfer to irrigation entities in the lower Yakima River basin as an exchange supply, thereby reducing irrigation demand on Yakima River water and improving Yakima Project stored water supplies; and (2) creation of additional water storage within the Yakima River basin. In considering the benefits to be achieved, study objectives are to modify Yakima Project flow management operations to improve the flow regime of the Yakima River system for fisheries, provide a more reliable supply for existing proratable water users, and provide water supply for future municipal demands.

State support for the Storage Study was provided in the 2003 Legislative session. The 2003 budget included appropriations for the Washington State Department of Ecology (Ecology) with the provision that the funds ". . . are provided solely for expenditure under a contract between the department of ecology and the United States bureau of reclamation for the development of plans, engineering, and financing reports and other preconstruction activities associated with the development of water storage projects in the Yakima river basin, consistent with the Yakima river basin water enhancement project, P.L. 103-434. The initial water storage feasibility study shall be for the Black Rock reservoir project." Since that initial legislation, the State of Washington has appropriated additional matching funds.

Storage Study alternatives were identified from previous studies by other entities and Reclamation, appraisal assessments by Reclamation in 2003 through 2006, and public input. Reclamation filed a Notice of Intent and Ecology filed a Determination of Significance to prepare a combined Planning Report and Environmental Impact Statement (PR/EIS) on December 29, 2006. A scoping process, including two public scoping meetings in January 2007 identified several concepts to be considered in the Draft PR/EIS. Those concepts have been developed into "Joint" and "State" Alternatives.

The Joint Alternatives fall under the congressional authorization and the analyses are being cost-shared by Reclamation and Ecology. The State Alternatives are outside the congressional authorization, but within the authority of the state legislation, and will be analyzed by Ecology only. Analysis of all alternatives will be included in the Draft PR/EIS.

This technical document and others explain the analyses performed to determine how well the alternatives meet the goals of the Storage Study and the impacts of the alternatives on the environment. These documents will address such issues as hydrologic modeling, sediment modeling, temperature modeling, fish habitat modeling, and designs and costs. All technical documents will be referenced in the Draft PR/EIS and available for review.

CONTENTS

Chapter 1. SUMMARY: KEY HABITAT FINDINGS FOR THE EASTON, ELLENSBURG, LOWER NACHES AND WAPATO FLOODPLAIN REACHES

1.1 Introduction

An objective of the Yakima River Basin Water Storage Feasibility Study (Storage Study) is to analyze the fishery benefits for each alternative, which are No Action, Black Rock, Wymer Dam and Reservoir, and Wymer Dam Plus Yakima River Pump Exchange. This analysis incorporates several computer models both physical and biological types that quantified changes in fishery habitat, water temperature, sediment transport and fishery abundance between alternatives. The purpose of this technical report is to provide a description of how the models were integrated and used in the fishery analysis; and to provide a discussion of fishery model results, which will focus on the anadromous and resident salmonid indicators used in the Yakima River Basin Water Storage Feasibility Study.

This section is a summary of the key fisheries habitat findings for the Easton, Ellensburg, lower Naches and Wapato floodplains that are discussed in the Results and Discussion section beginning on page 45. To make this section complete required repeating some of the information presented in the Results and Discussion section.

1.2 Easton Floodplain Reach

1.2.1 Flow-to-Habitat Relationship

1.2.1.1 Spring Chinook and Steelhead Fry

- A flow of approximately 750 cfs provides the minimum amount of spring Chinook and steelhead fry habitat, and is greatest around 150 cfs (see Figure S1 and Figure S2).

- The percent of fry habitat between the main channel and side channel from low to high flow was more or less equal for both species (Figure S3 and Figure S4). This is a reflection of the numerous side channels that exist in the upper portion (upstream of Big Creek) of the Easton reach.

1.2.1.2 Spring Chinook and Steelhead Summer Subyearling

- A flow of approximately 300 cfs provides the maximum amount of spring Chinook and steelhead summer subyearling habitat, and decreases for flows up to approximately 1,100-1,200 cfs, and then increases (Figure S5 and Figure S6).

- For both species there were approximately equal amounts of summer subyearling habitat in the main channel and side channels at flows greater than approximately 900 to 1,100 cfs; and below this flow main channel habitat was dominate (~60% to 75%), which is expected at lower flows (Figure S7 and Figure S8).

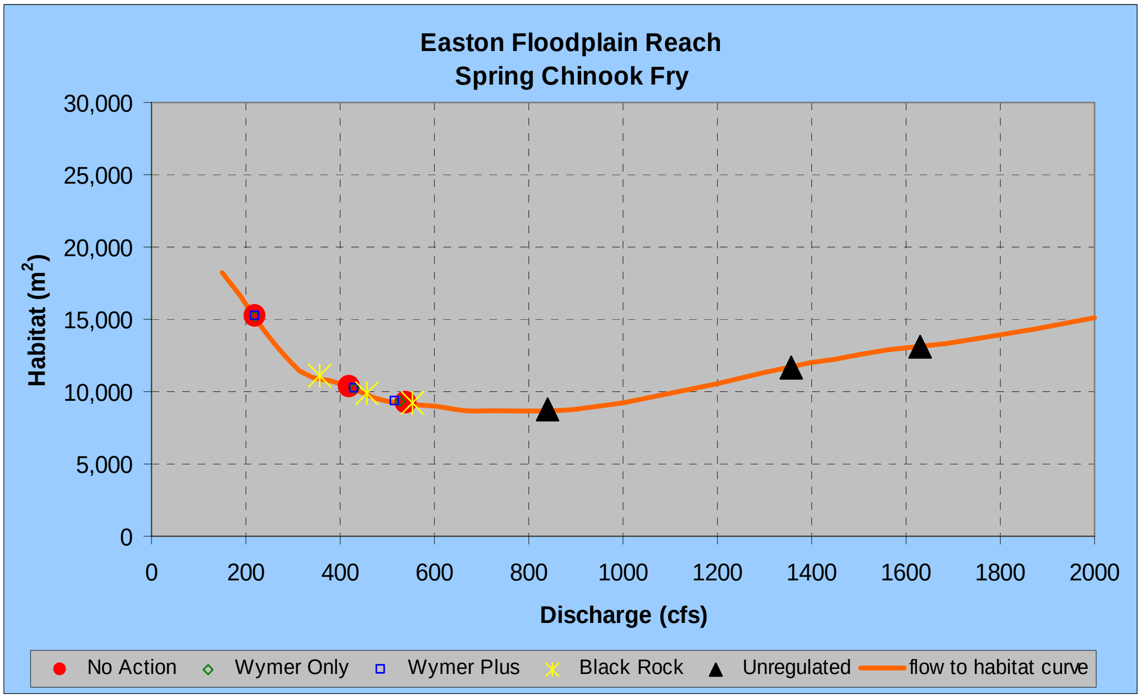


Figure S1. Flow-to-habitat curve for the spring Chinook fry lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Easton floodplain

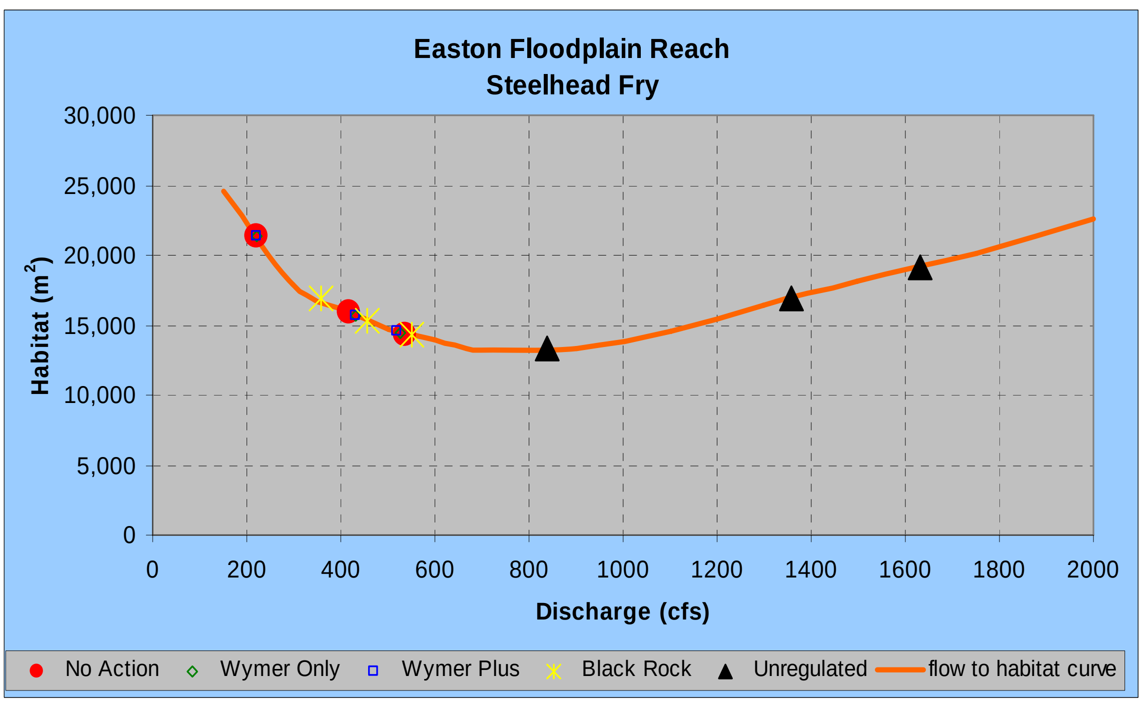


Figure S2. Flow-to-habitat curve for the steelhead fry lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Easton floodplain

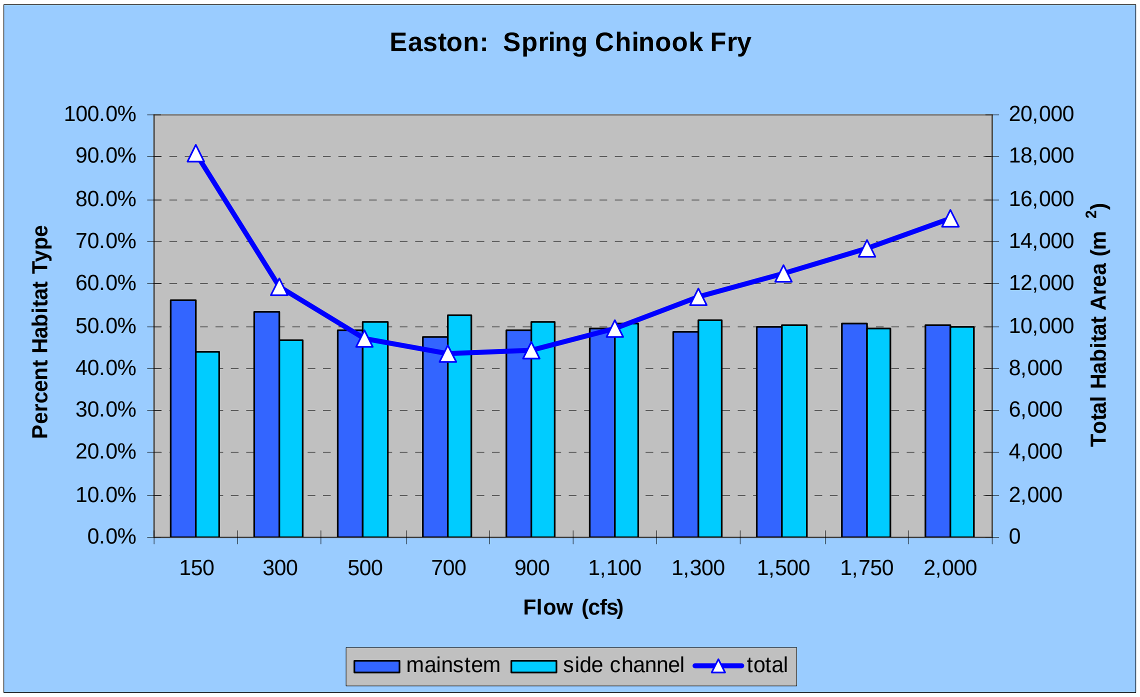


Figure S3. Flow-to-habitat curve for spring Chinook fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Easton floodplain

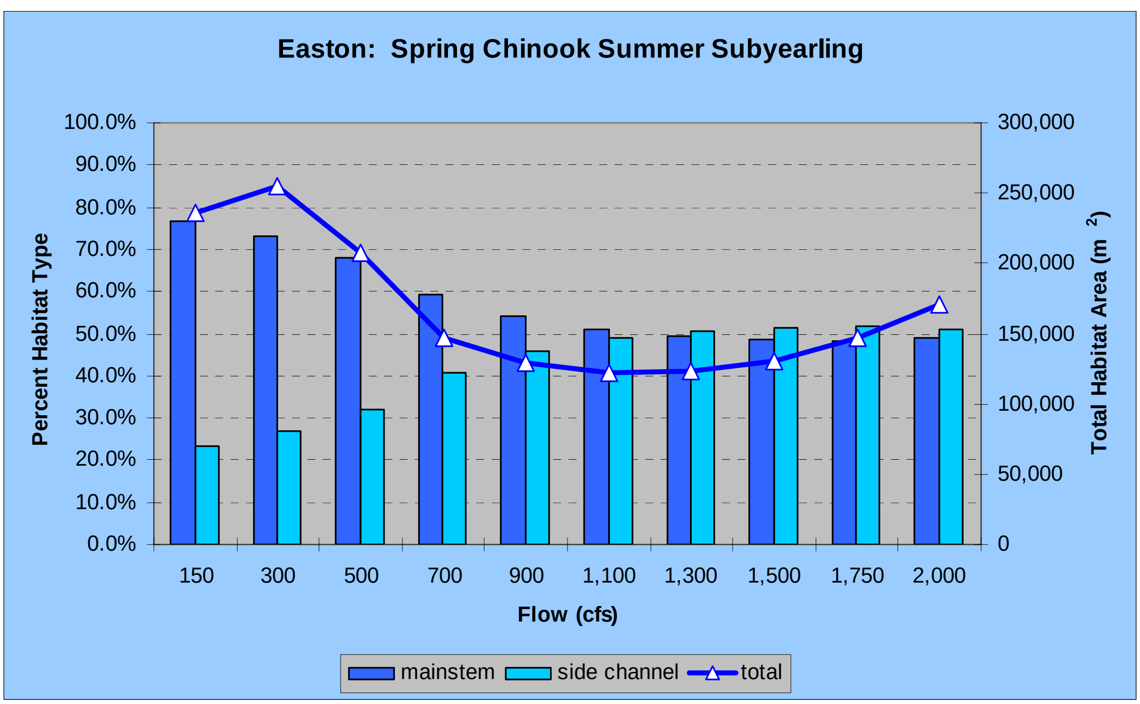


Figure S4. Flow-to-habitat curve for steelhead fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Easton floodplain

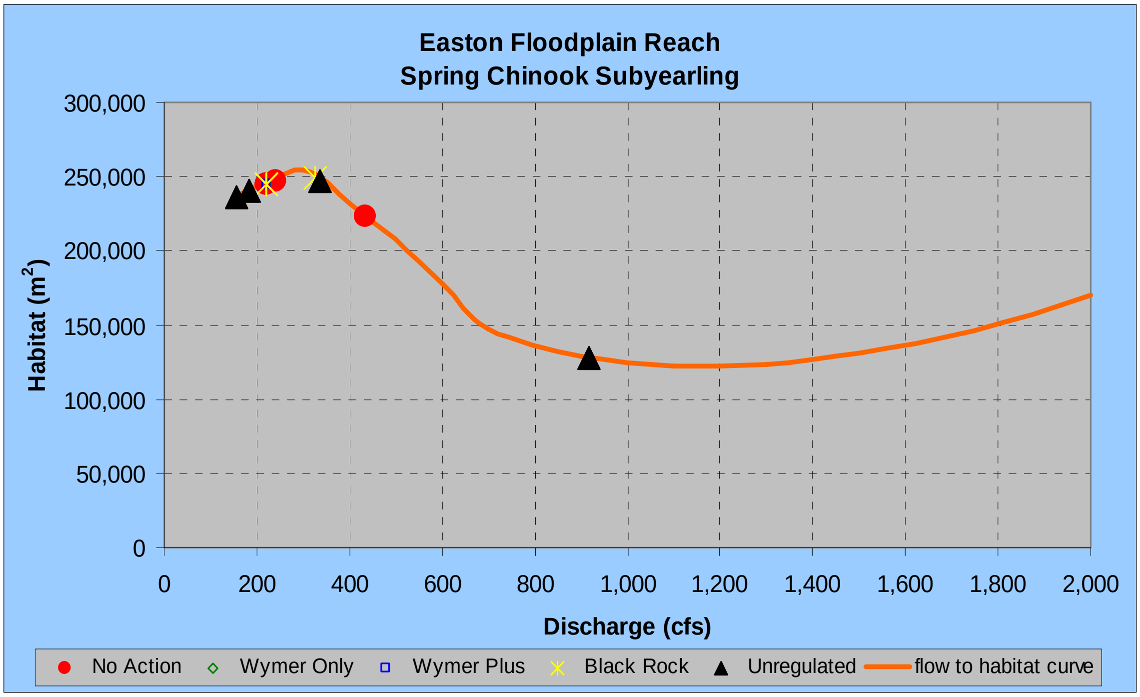


Figure S5. Flow-to-habitat curve for the spring Chinook summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Easton floodplain

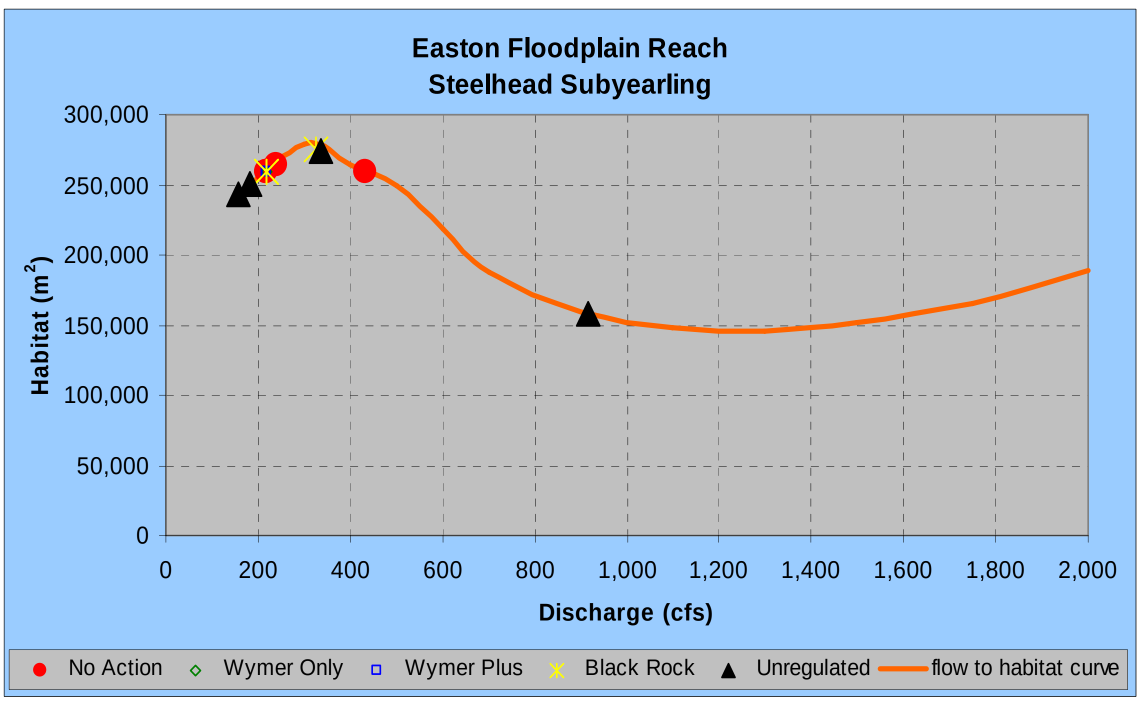


Figure S6. Flow-to-habitat curve for the steelhead summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Easton floodplain

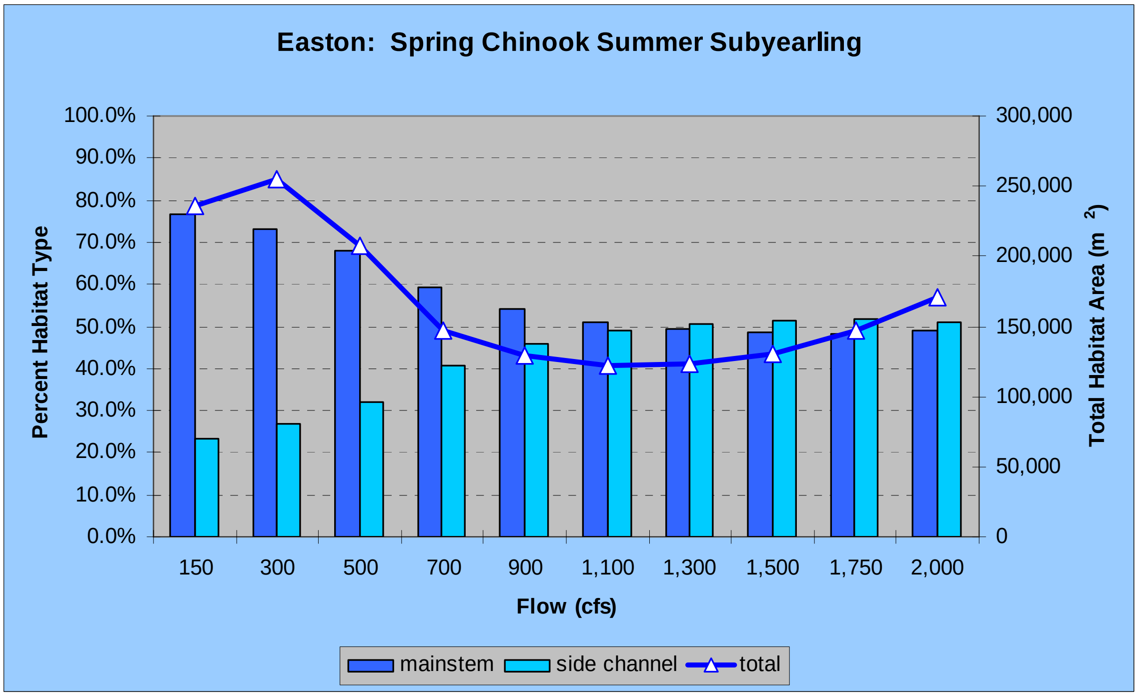


Figure S7. Flow-to-habitat curve for spring Chinook fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Easton floodplain

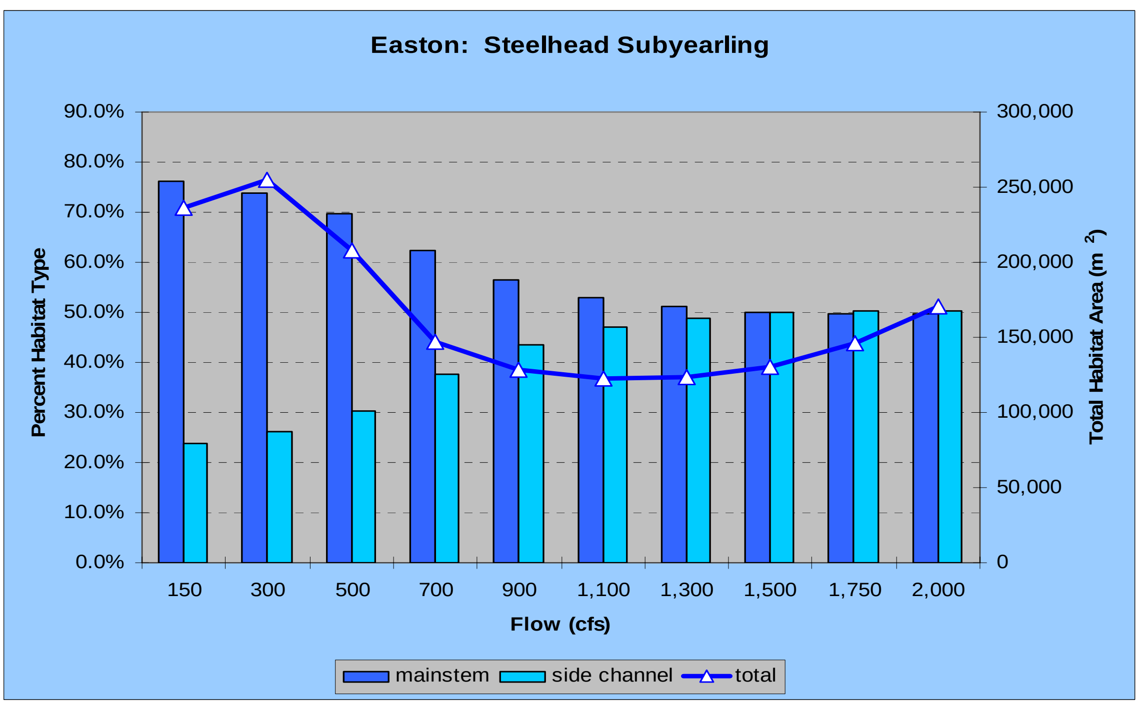


Figure S8. Flow-to-habitat curve for steelhead fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Easton floodplain

1.2.1.3 Alternative Accomplishments

- There was not much difference between alternatives in the amount of spring Chinook and steelhead fry habitat provided on a monthly basis (Figure S9 and Figure S10); and the amount of fry habitat provided by each alternative was moderate to approaching maximum depending on the monthly flow (~250 cfs to 500 cfs).

- There was not a substantial difference between alternatives in the amount of spring Chinook and steelhead summer subyearling habitat (Figure S11 and Figure S12).

- Monthly median flows between the alternatives (220 cfs to 430 cfs) coincided close to the maximum amount of spring Chinook and steelhead summer subyearling habitat (Figure S5 and Figure S6).

1.2.1.4 Management Considerations

Since there is temporal overlap between the fry and smolt lifestages for spring Chinook and steelhead, managing for increased smolt outmigration flows will result in some loss of fry habitat until flows exceed approximately 750 cfs. For example, for spring Chinook, at 400 cfs (which represents the approximate middle value in the observed flow range for all the alternatives) there is roughly 10,600 m^2, and at 750 cfs, 8,700 m^2. Notice that a flow of approximately 1,200 cfs is required to approximate the amount of fry habitat at 400 cfs.

- Nonflow related actions should focus on preservation of high quality habitat conditions that exist in the upper (Easton Dam to Big Creek) and lower (Peterson Creek to the Cle Elum River confluence) portions of the Easton reach (Easton Dam to Cle Elum River confluence).

- The remaining sections of the Easton reach are highly developed (i.e., residential) and afford minimal opportunity to enhance the existing habitat for fisheries. And any additional development to existing properties should be conducted in manner that at a minimum does not further degrade fishery habitat and ideally would enhance the existing habitat.

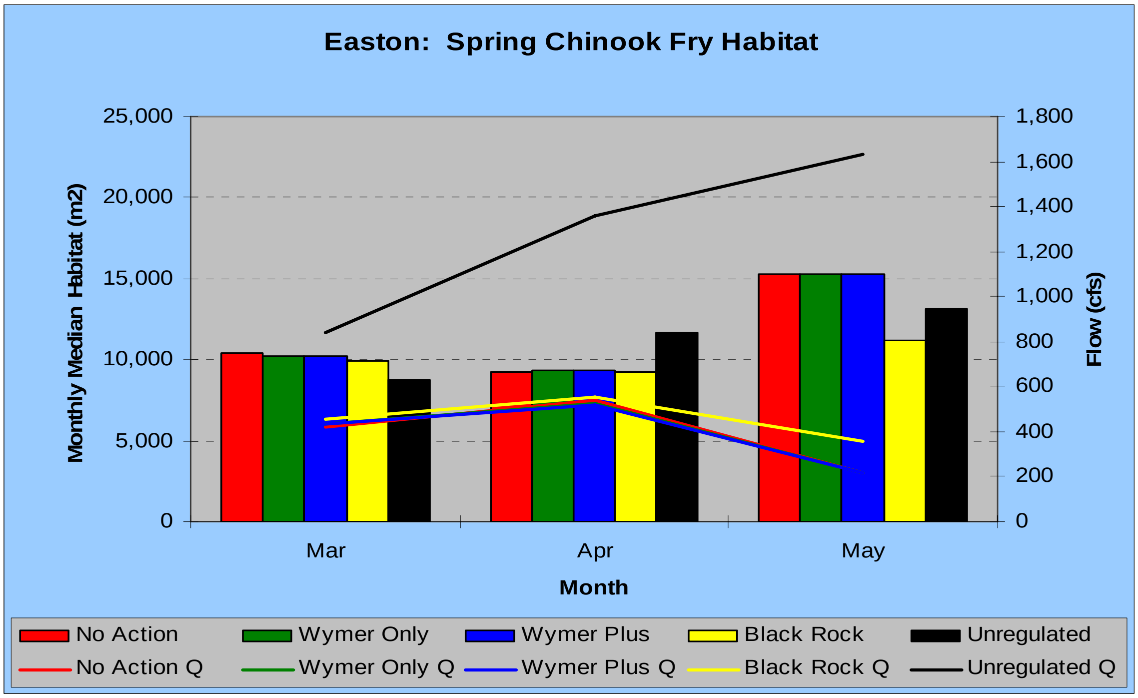


Figure S9. Summary of the amount of median monthly spring Chinook fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by the lines.)

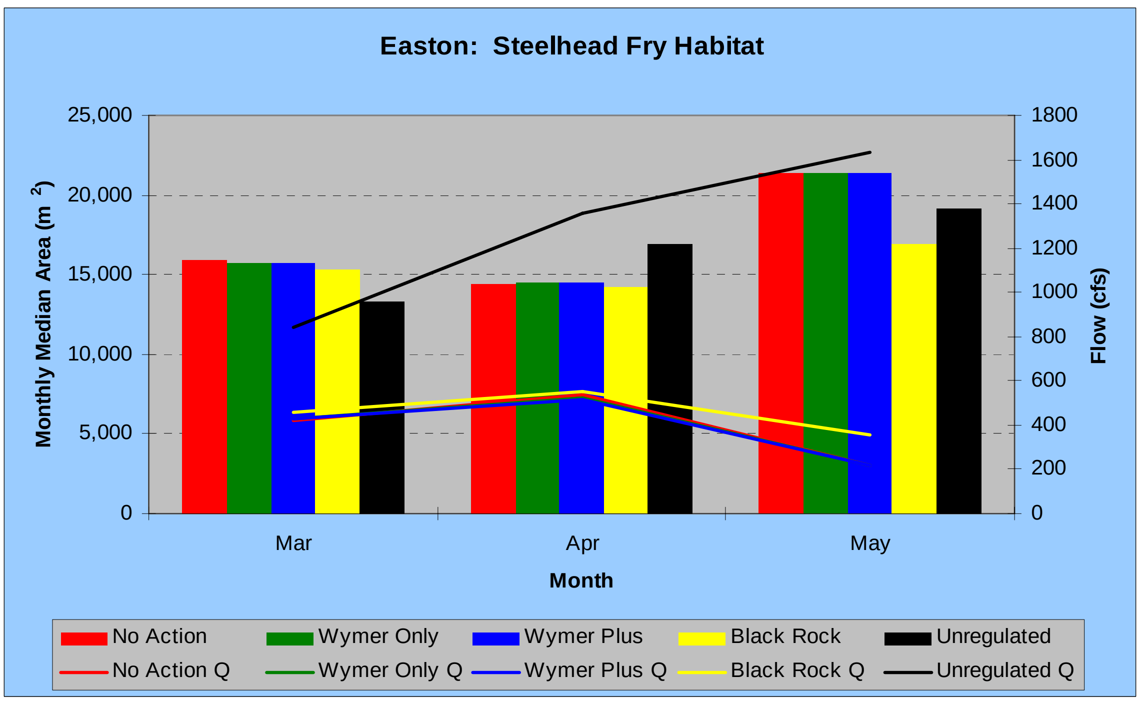


Figure S10. Summary of the amount of median monthly steelhead fry subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by the lines.)

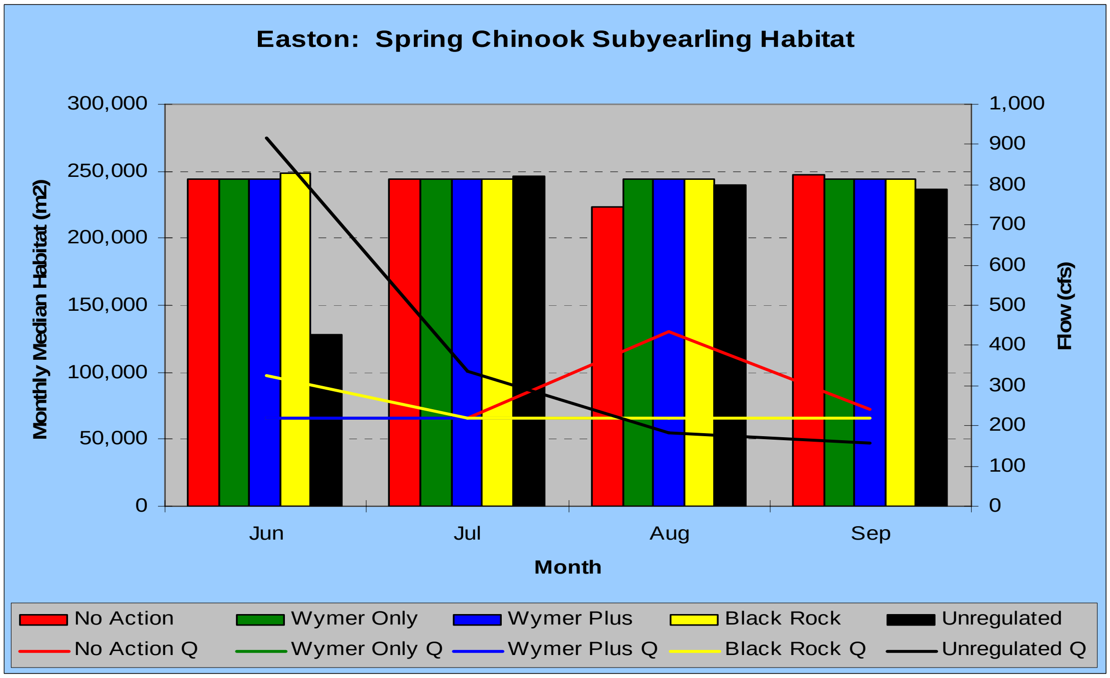


Figure S11. Summary of the amount of median monthly spring Chinook summer subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by the lines)

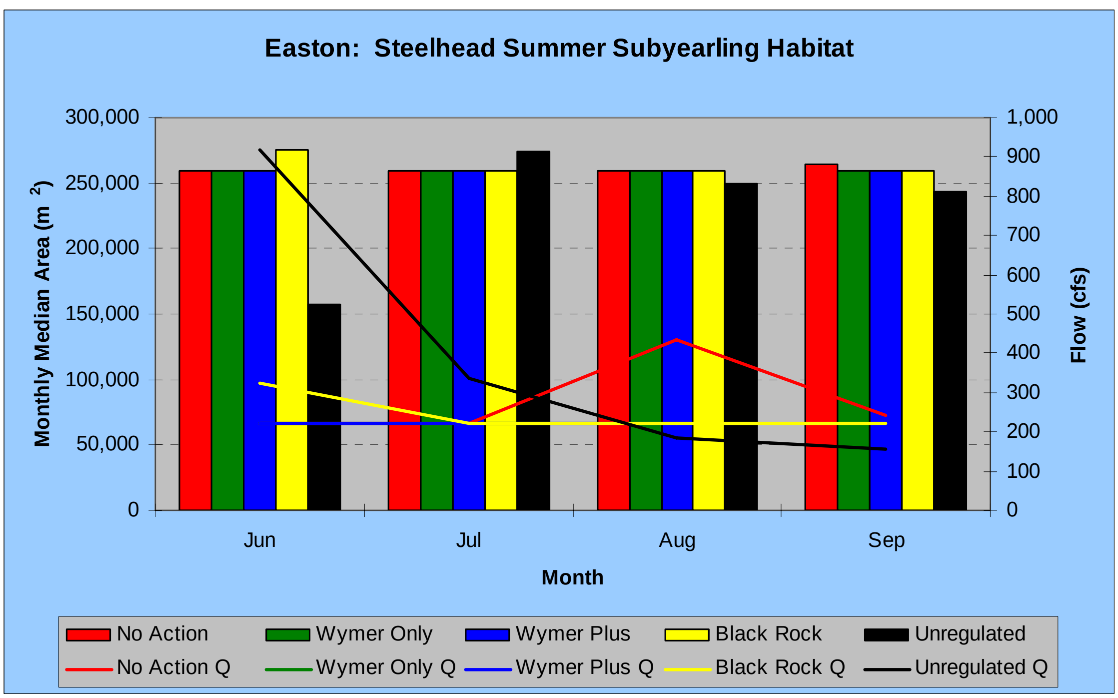


Figure S12. Summary of the amount of median monthly steelhead summer subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines)

1.3 Ellensburg Floodplain Reach

1.3.1 Flow-to-Habitat Relationship

1.3.1.1 Spring Chinook and Steelhead Fry

- Maximum fry habitat for both species occurs around 2,400 cfs and decreases somewhat up to 2,700 cfs, and then increases (figures S13 andS14). In general to realize an equal or greater amount of fry habitat than provided by the alternatives requires flows greater than approximately 3,500 cfs. The percent (~75% to ~85%) of side channel habitat for spring Chinook and steelhead fry began to level off at flows greater than approximately 2,300 cfs. At flows decreasing from 2,300 cfs to 400 cfs the percent of main channel habitat steadily increased from about 20% to 65% (figures S15 and S16).

1.3.1.2 Spring Chinook and Steelhead Summer Subyearling

- The least amount of spring Chinook and steelhead summer subyearling habitat occurs in a flow range of approximately 2,500 to 3,000 cfs. At flows greater than approximately 3,000 cfs the loss of additional habitat with increasing flows does not occur, and in fact begins to slightly increase. At flows less than 2,500 cfs the amount of habitat increases rapidly with decreasing flows (figures S17 and S18).

- At flows less than 2,500 cfs an ever increasing percent of the spring Chinook and steelhead summer subyearling habitat occurred in the main channel (50% to 90%), this is expected as side channel wetted area decreases with declining flows (figures S19 and S20).

1.3.1.3 Alternative Accomplishments

- Spring Chinook and steelhead fry habitat more or less increases or remains fairly constant from March to May for the alternatives, and No Action and unregulated for spring Chinook have the most change from month to month (figures S21 and S22).

- In general all of the alternatives provide relatively high amounts of fry habitat for both species (figures S21 and S22).

The amount of spring Chinook and steelhead summer subyearling habitat was similar between alternatives for June, July and August; for September the amount of habitat was nearly the same for No Action, Wymer Dam and Reservoir and Wymer Plus, but higher for Black Rock, which was the result of a slightly lower median monthly flow of approximately 1,380 cfs (figures S23 andS24).

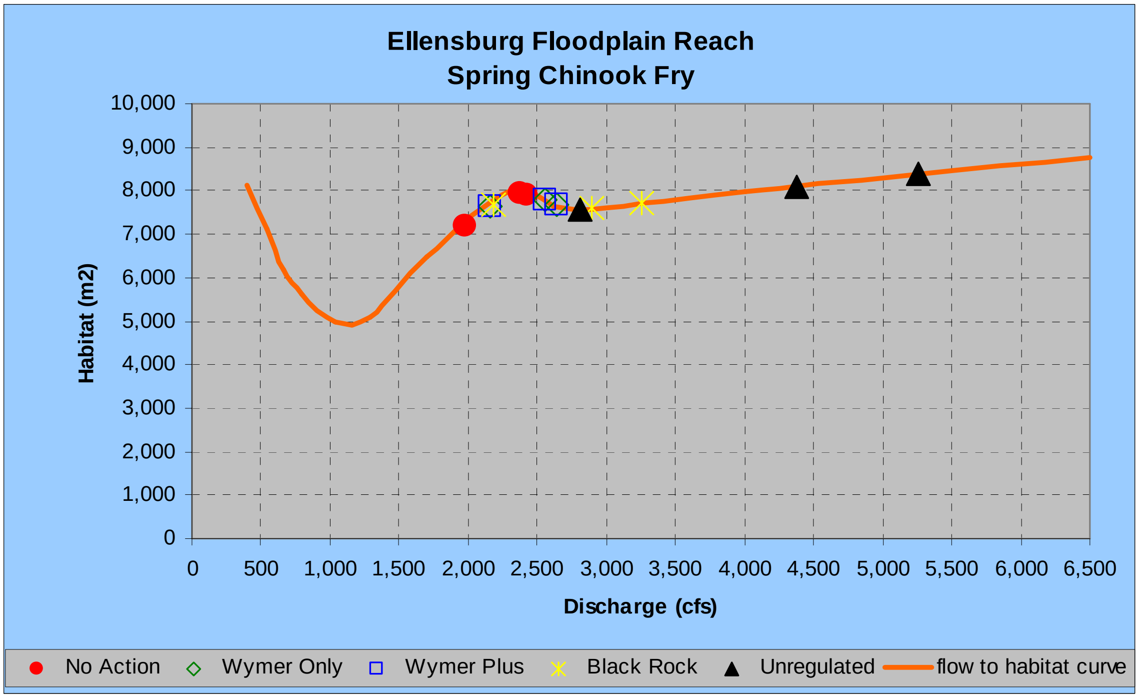


Figure S13. Flow-to-habitat curve for the spring Chinook fry lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Ellensburg floodplain

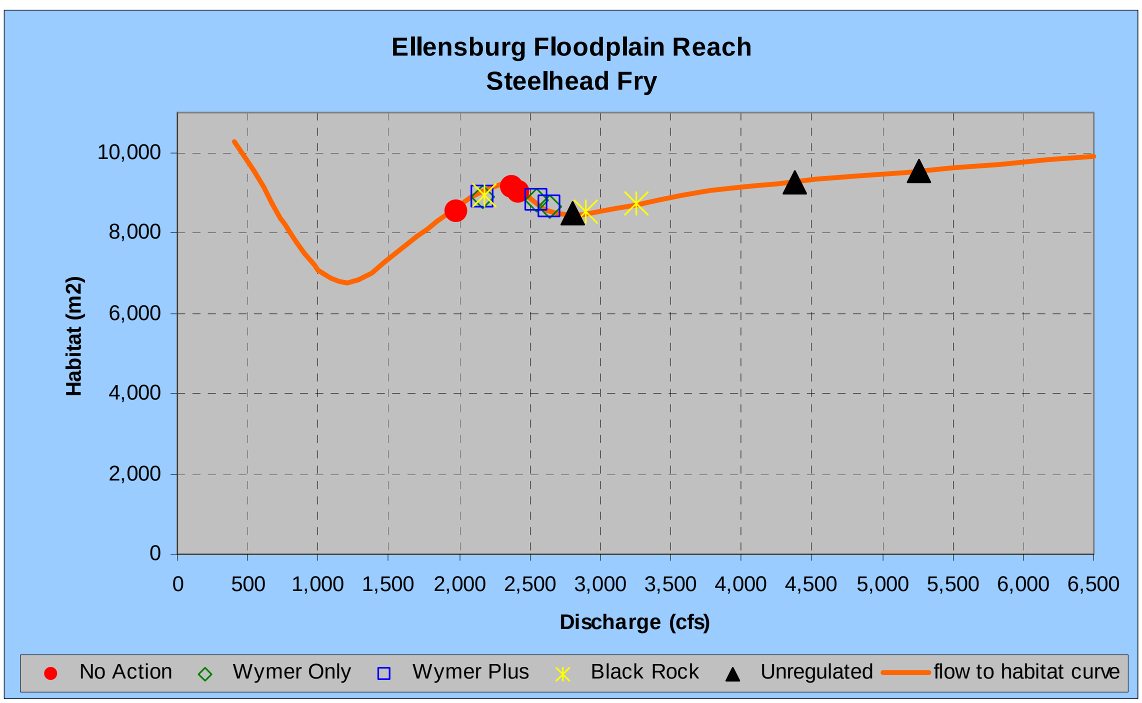


Figure S14. Flow-to-habitat curve for the steelhead fry lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Ellensburg floodplain.

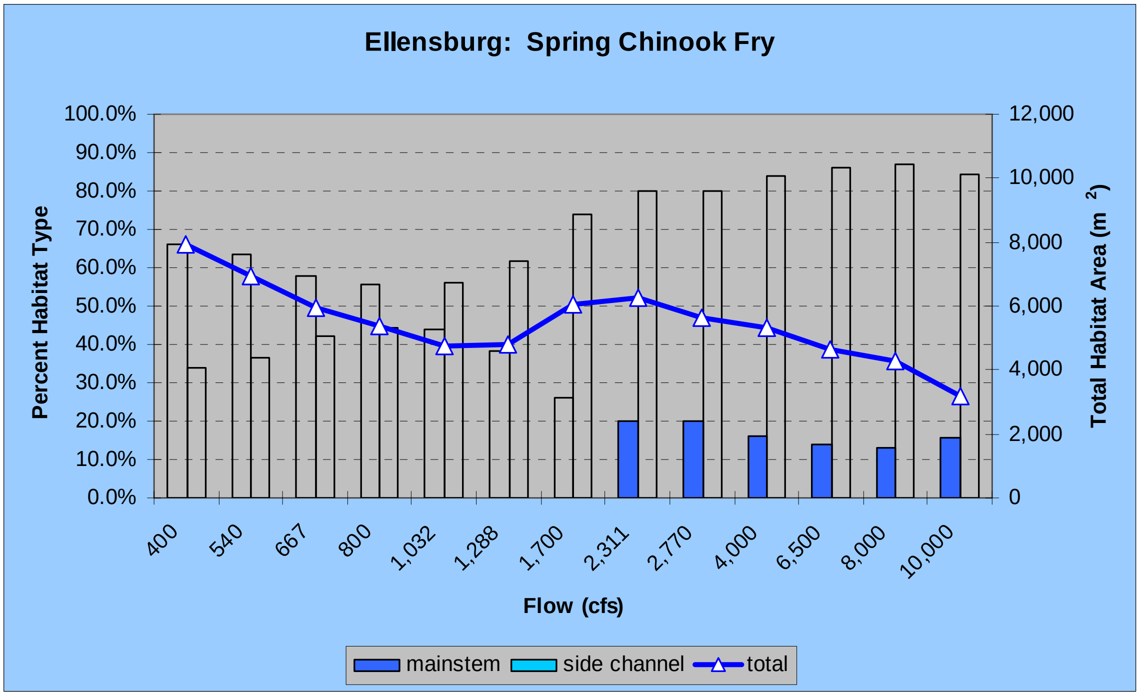


Figure S15. Flow-to-habitat curve for spring Chinook fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Ellensburg floodplain

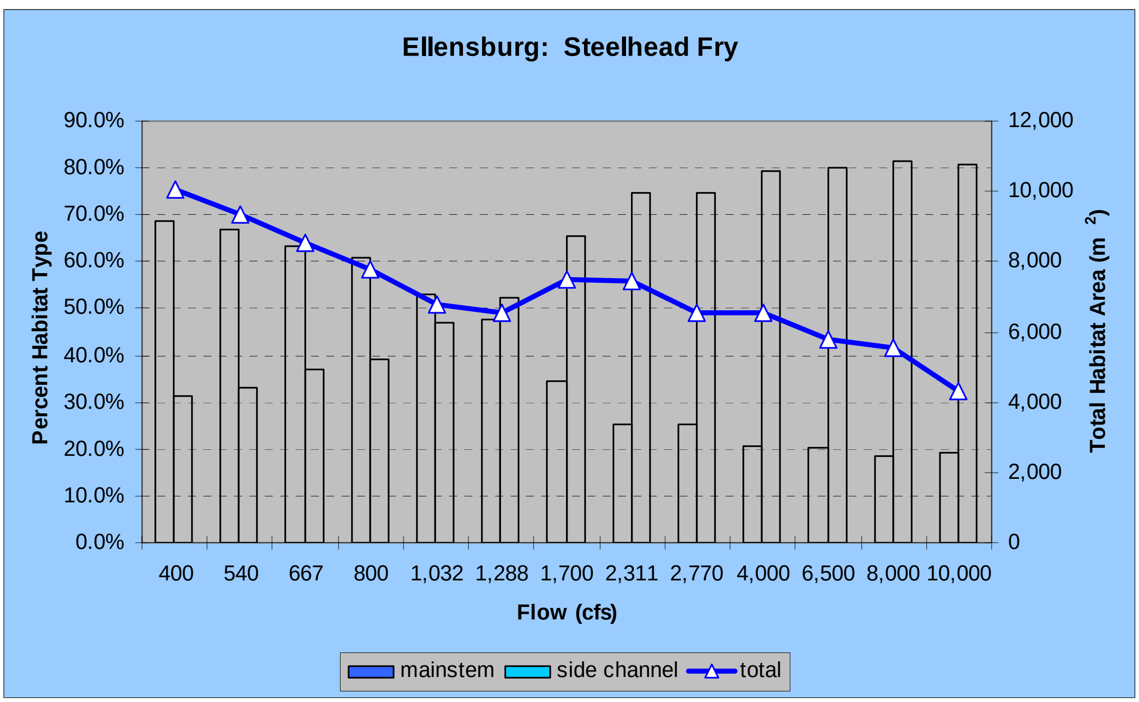


Figure S16. Flow-to-habitat curve for steelhead fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Ellensburg floodplain.

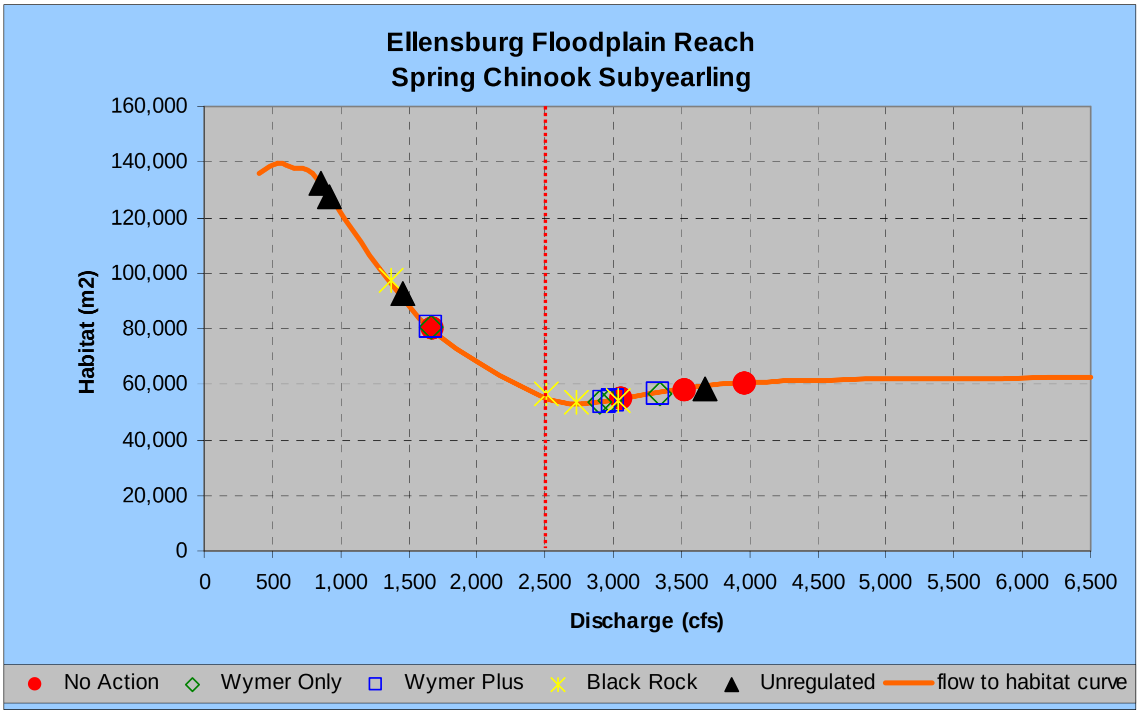


Figure S17. Flow-to-habitat curve for the spring Chinook summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Ellensburg floodplain.

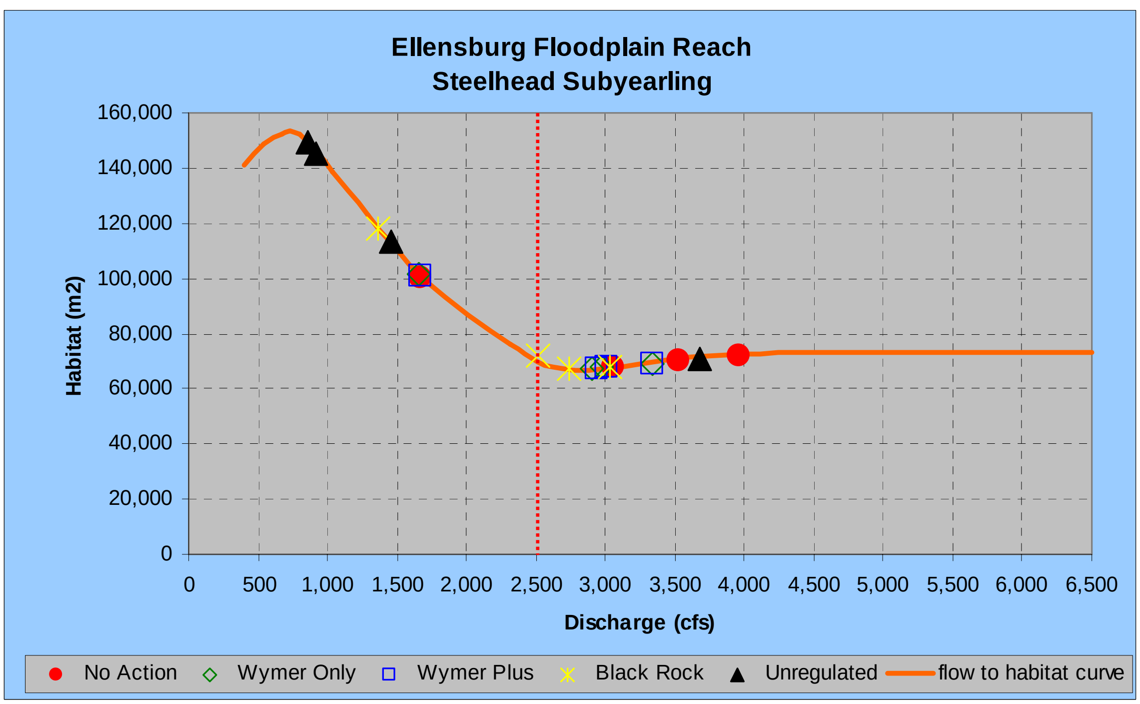


Figure S18. Flow-to-habitat curve for the steelhead subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Ellensburg floodplain.

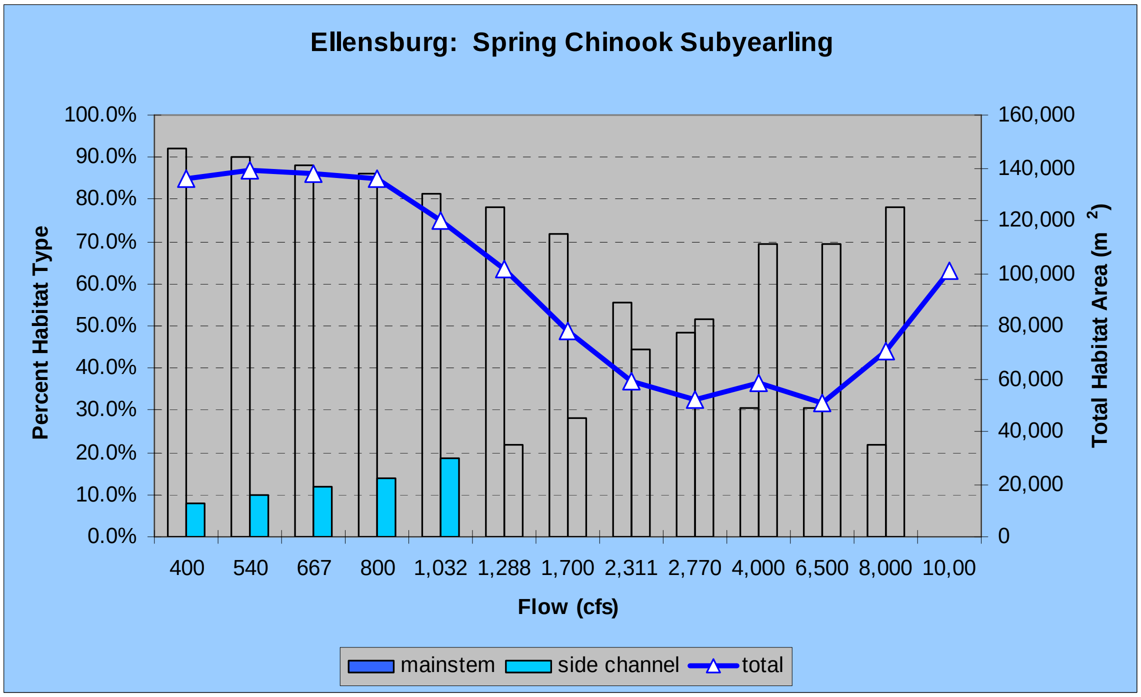


Figure S19. Flow-to-habitat curve for spring Chinook summer subyearling showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Ellensburg floodplain.

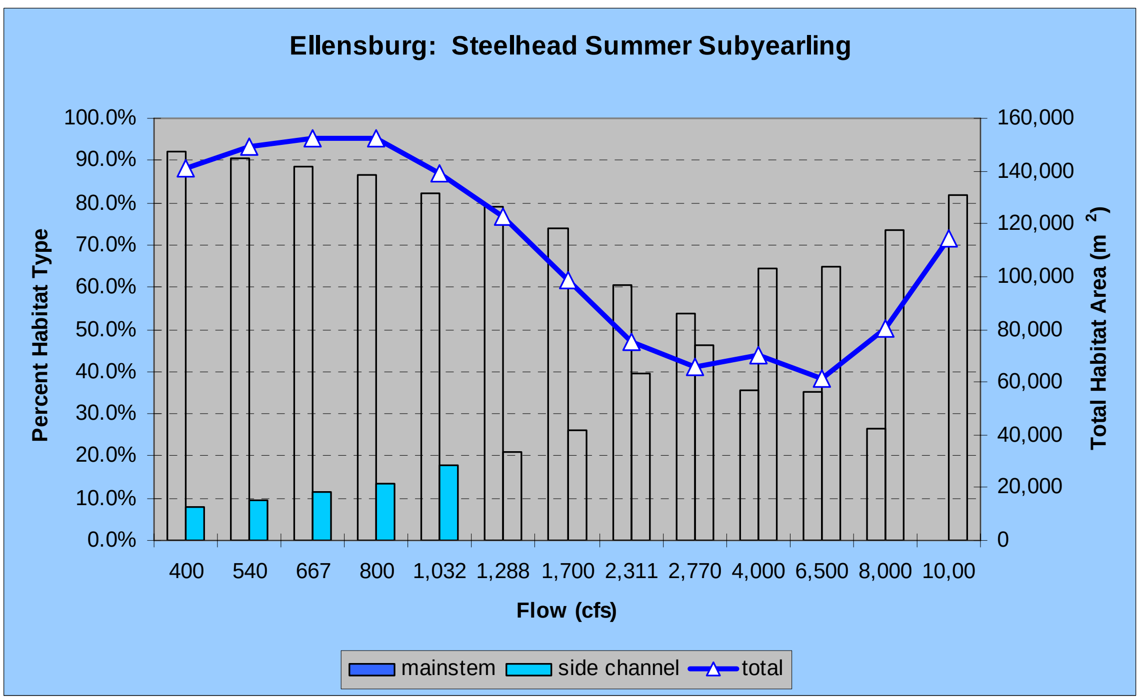


Figure S20. Flow-to-habitat curve for steelhead summer subyearling showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Ellensburg floodplain.

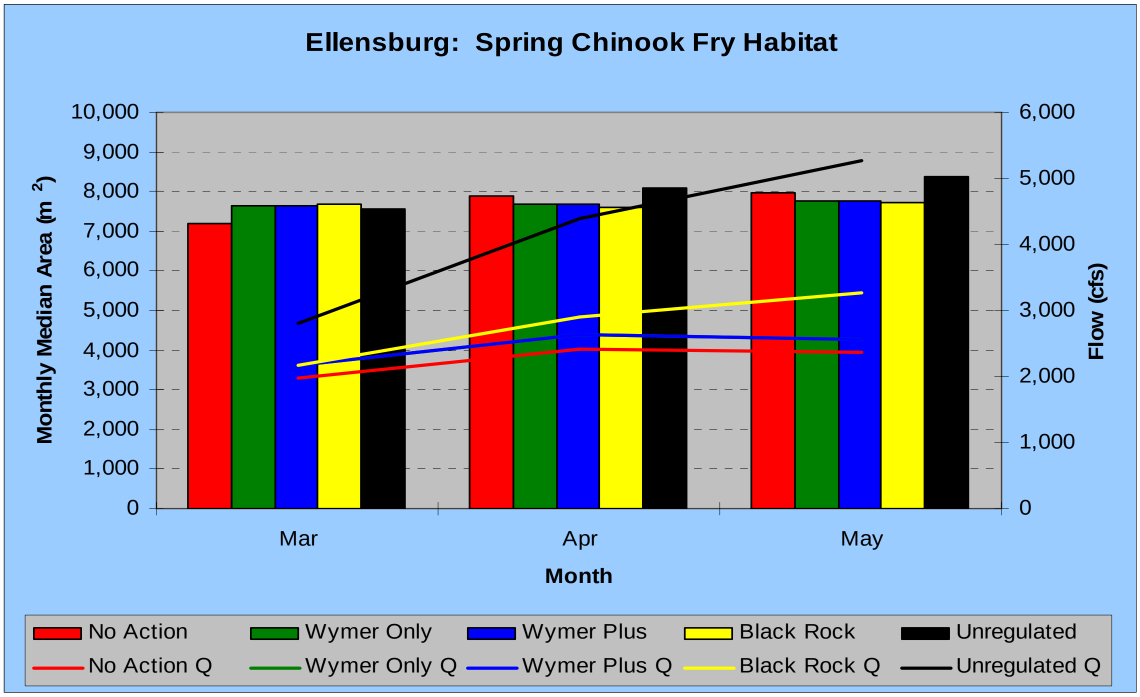


Figure S21. Summary of the amount of monthly median spring Chinook fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

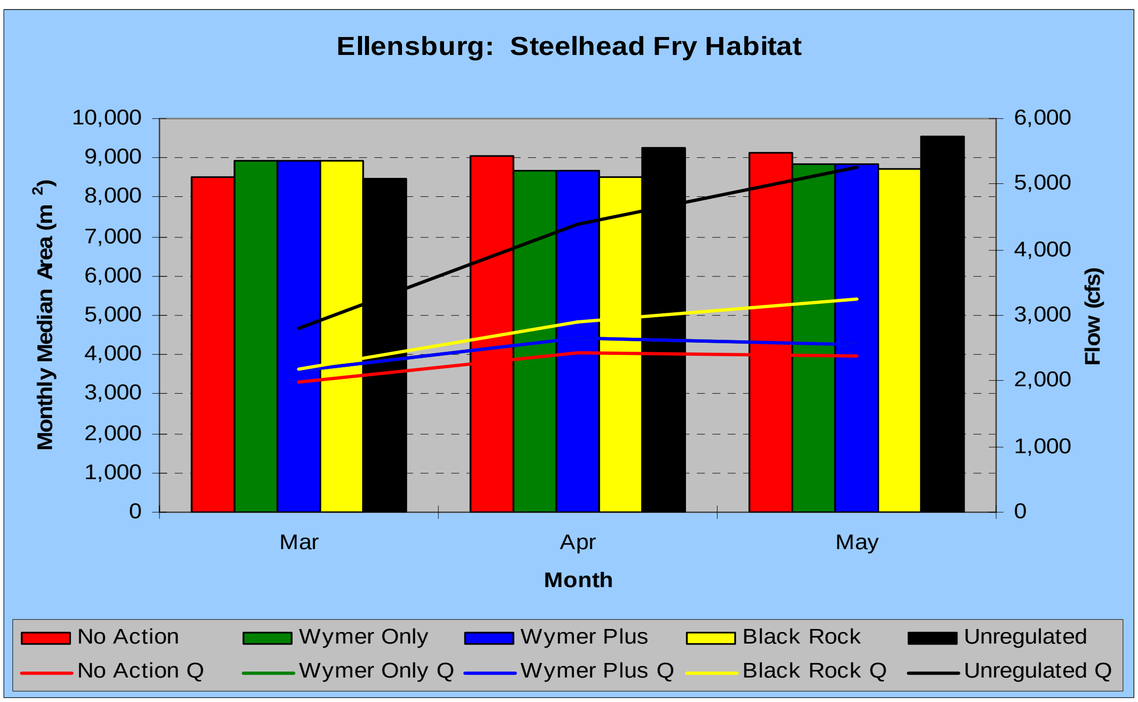


Figure S22. Summary of the amount of monthly median steelhead fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

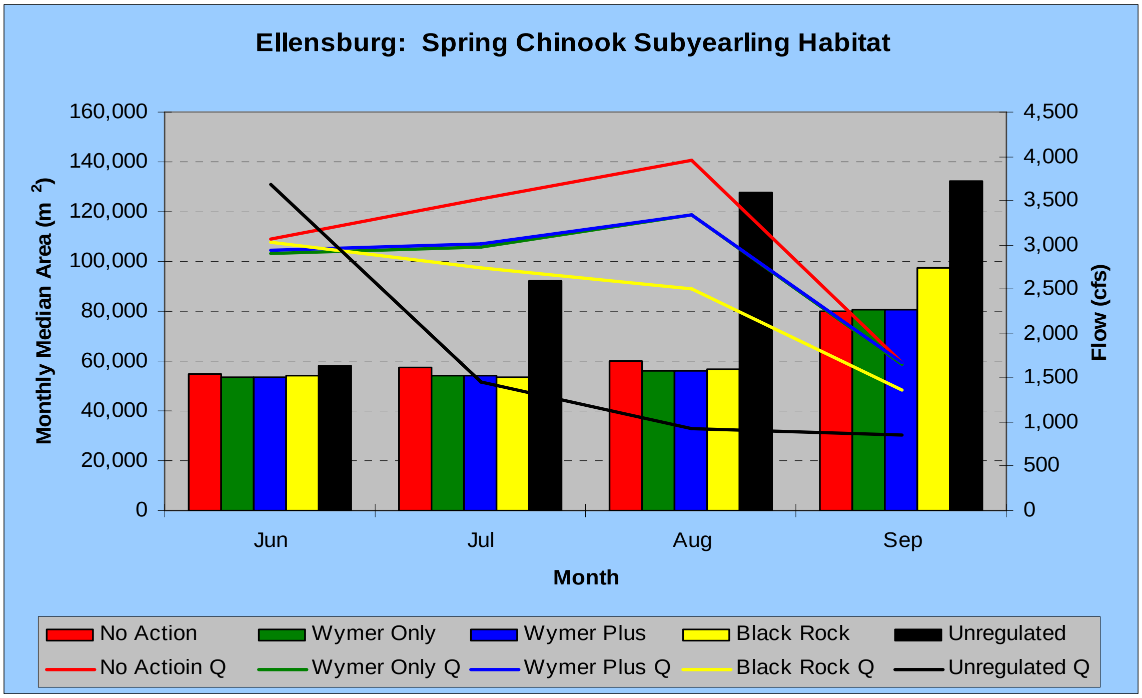


Figure S23. Summary of the amount of monthly median spring Chinook subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

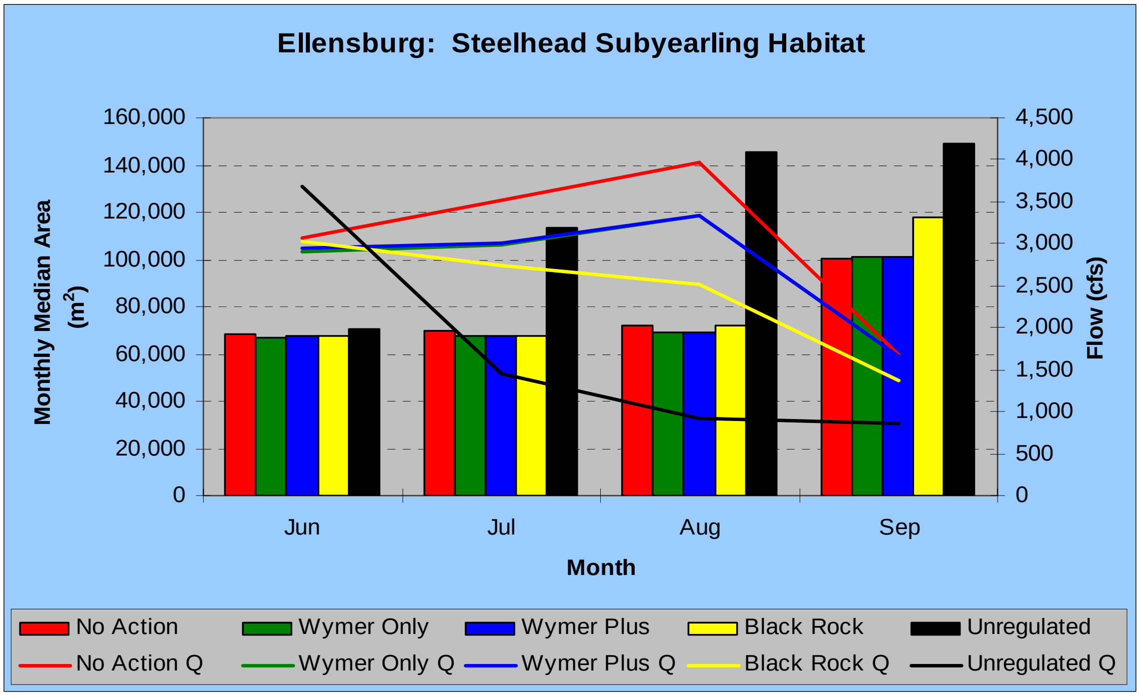


Figure S24. Summary of the amount of monthly median steelhead subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

1.3.1.4 Management Considerations

- To achieve a meaningful gain in the amount of spring Chinook and steelhead summer subyearling habitat will require summer flows of less than 2,500 cfs (figures S17 and S18 (see red dashed line)). This was only achieved for all alternatives in September after flip-flop. Of the alternatives investigated, Black Rock was the closest to achieving this outcome in July and August.

- Notice that the unregulated flow pattern provides the least amount of habitat in June during snow melt, but continues to increase as flows decrease towards summer base flow. This represents a typical flow-to-habitat pattern for a floodplain reach located in a snow dominated basin (i.e. east of the Cascades).

- Notice that with the exception of September, monthly flows for all of the alternatives occur more in the high flow range, comparable to the unregulated June flow, than in the low summer flow range of 1,000 to 1,500 cfs.

- Presently it's not feasible to achieve this range of low flows, irrespective of the alternative, because of the need to convey stored irrigation water down river lower basin irrigation demand.

- Ways to improve salmonid fry and summer subyearling habitat include, 1) consider flow reduction below 2,500 cfs, 2) reconnect pinched-off side channels (where opportunities exist) and, 3) enhance instream habitat both in the main and side channels. These actions will improve channel complexity and result in increased habitat quantity and quality.

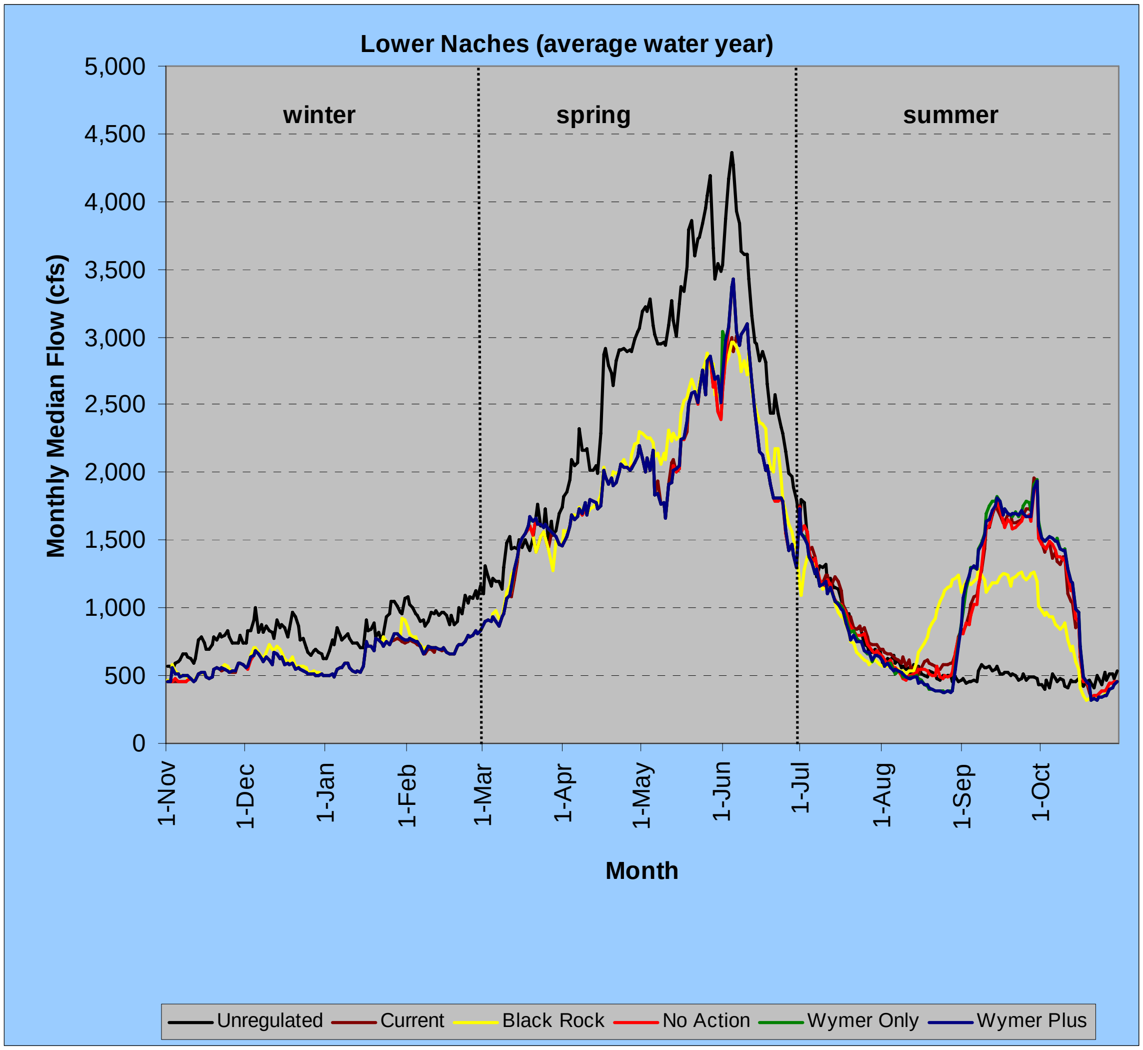
1.4 Lower Naches Floodplain Reach

1.4.1 Flow-to-Habitat Relationship

1.4.1.1 Spring Chinook and Steelhead Fry

- With the exception of the September flip flop operation that affects the Naches River downstream of the Tieton River, the lower Naches River generally emulates the unregulated flow regime for all of the alternatives, and the reduced spring flows compared to unregulated are due to snow-melt water being stored primarily in Rimrock reservoir (figure S25).

- For both species the amount of fry habitat increases from approximately 1,000 cfs to 3,000 cfs where it leveled off or began to decrease with increasing flow (figures S26 and S27).



FigureS25. RiverWare model simulated median daily flows for the 1981-2005 period of record for the Naches at Naches gage used to represent flows in the lower Naches floodplain reach.

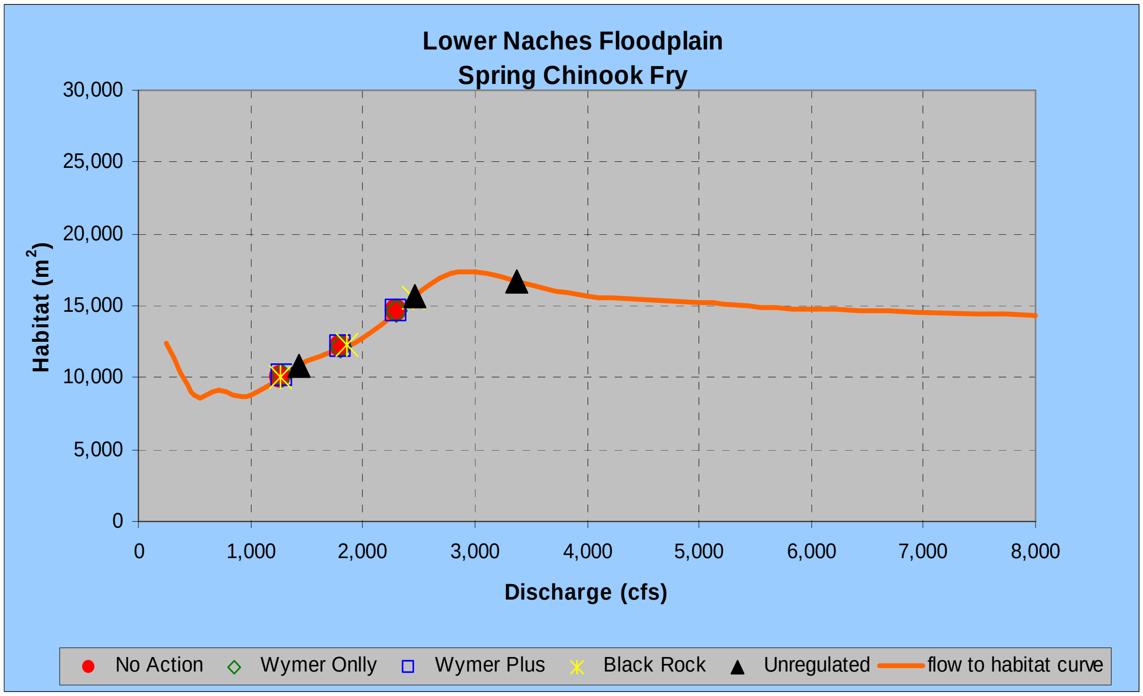


Figure S26. Flow-to-habitat curve for the spring Chinook fry lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the lower Naches floodplain.

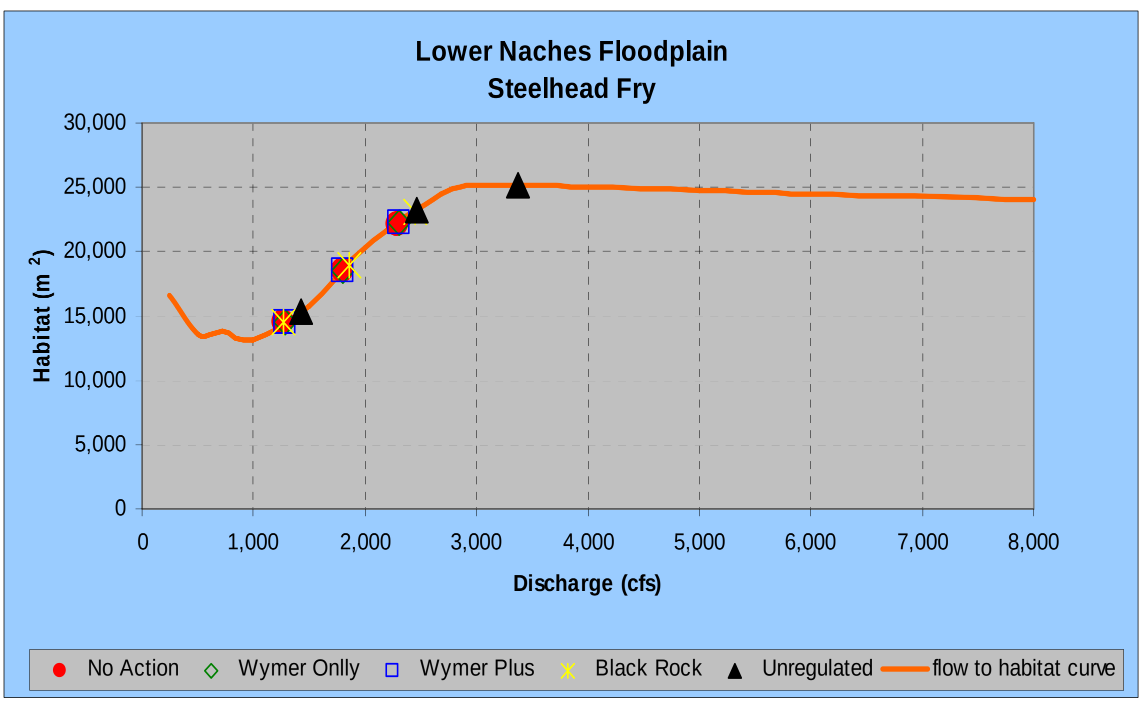


Figure S27. Flow-to-habitat curve for the steelhead fry lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the lower Naches floodplain.

For both species the percent of side channel is greatest off (~70% to 80%) and levels at flows greater than 2,000 cfs (figures S28 and S29).

1.4.1.2 Spring Chinook and Steelhead Summer Subyearling

- The least amount of spring Chinook and steelhead summer subyearling habitat occurred at approximately 1,500 cfs, and the amount of habitat continued to increase with increased flows (figures S30 and S31). And there was a less pronounced increase in the amount of habitat as flows decreased from 1,500 cfs to 250 cfs.

- The percent of summer yearling mainstem and side channel habitat was nearly equal at flows of approximately 2,700 cfs to 3,000 cfs (figures S32 and S33). At flows greater than 3,000 cfs side channel dominated and leveled off at about 80%. And at flows less than 2,000 cfs mainstem habitat was most prevalent (~70% to ~99%) as flows decreased to 250 cfs.

1.4.1.3 Alternative Accomplishments

- There was minimal difference between alternatives on a monthly basis in the amount of spring Chinook and steelhead fry habitat in the lower Naches; and monthly flows followed the unregulated flow pattern of increasing from March to May (figures S34 and S35).

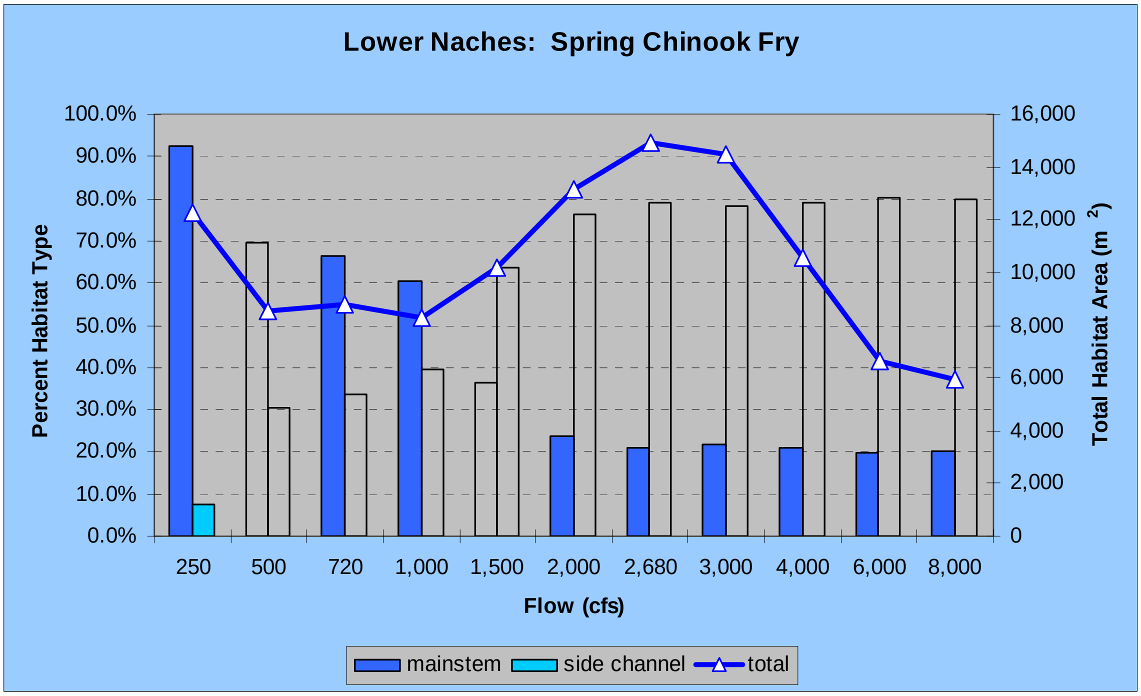
- There was not a substantive difference between alternatives in the amount of spring Chinook and steelhead summer subyearling habitat on a monthly basis for (figures S36 and S37).

1.4.1.4 Management Considerations

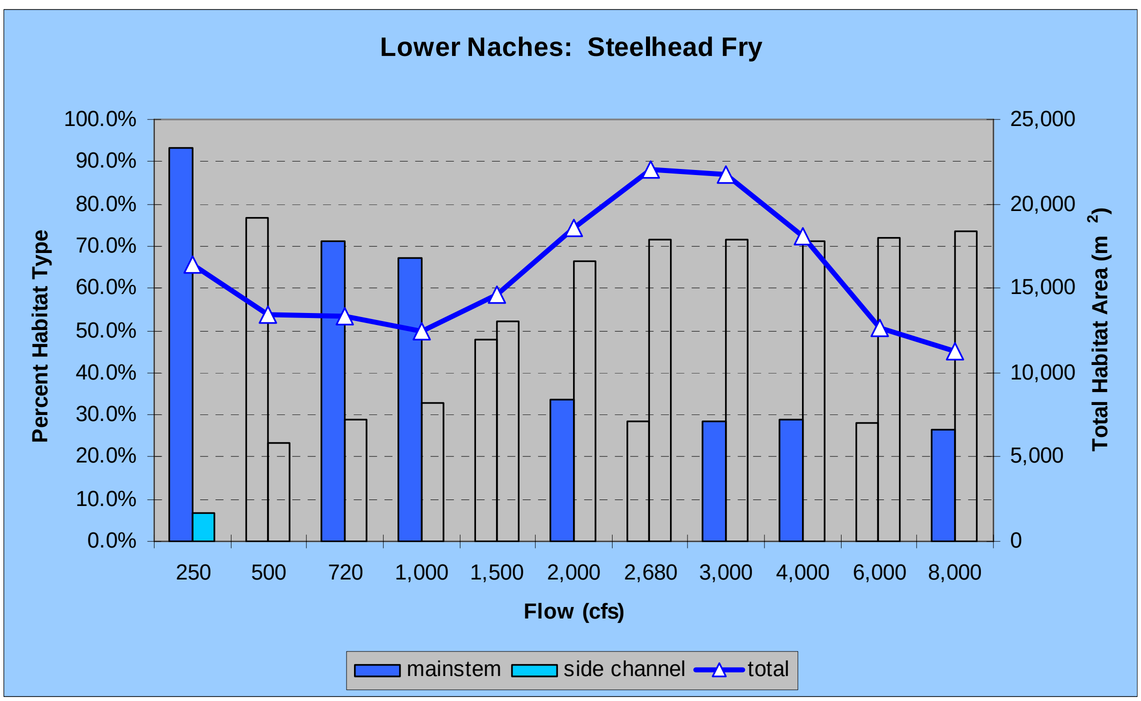
- Potential improvements to the lower Naches River flow regime should focus on reduction in the September flip flop operation; where flows ramp up from August to September and then ramp down from September to October coinciding with conclusion of the irrigation season, which would affect the summer subyearling lifestage for spring Chinook and steelhead (also steelhead yearlings).

- It is apparent from the fry flow-to-habitat curves that increased spring flow in April and May would increase the amount of fry habitat for spring Chinook and steelhead, which would also benefit smolt outmigration.

- With the exception of flip flop, flows for the spring Chinook and steelhead summer subyearling lifestage approximate the unregulated flows (especially in July and August) for all the alternatives.



FigureS28. Flow-to-habitat curve for spring Chinook fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the lower Naches floodplain.



FigureS29. Flow-to-habitat curve for steelhead fry showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the lower Naches floodplain.

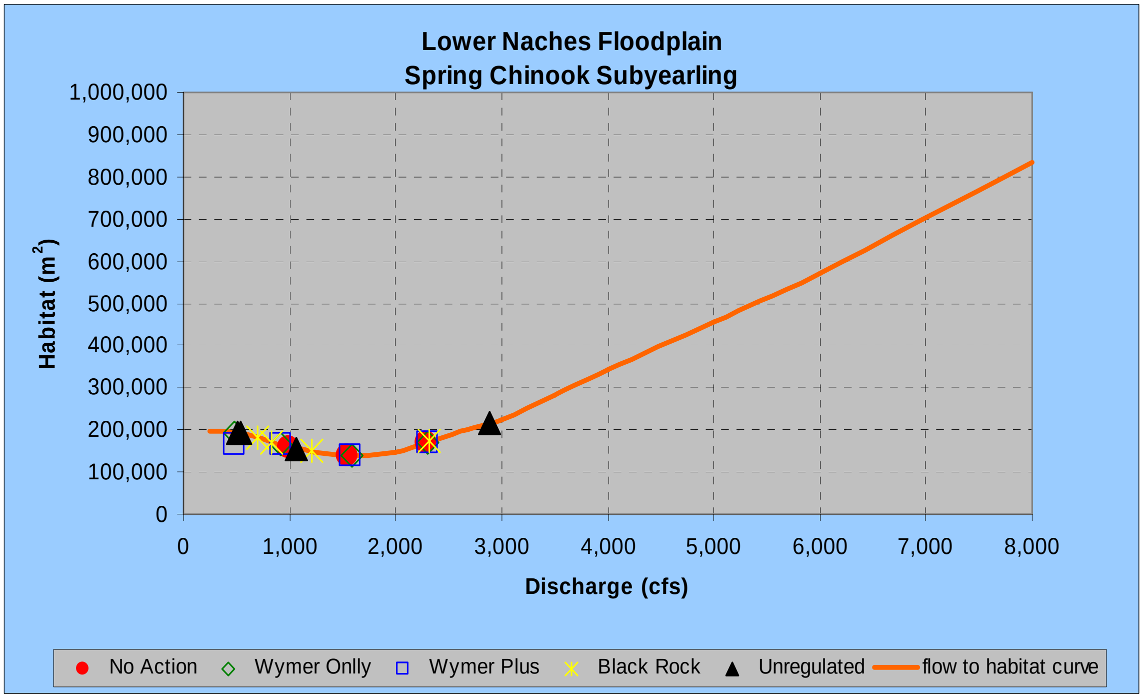


Figure S30. Flow-to-habitat curve for the spring Chinook summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the lower Naches floodplain.

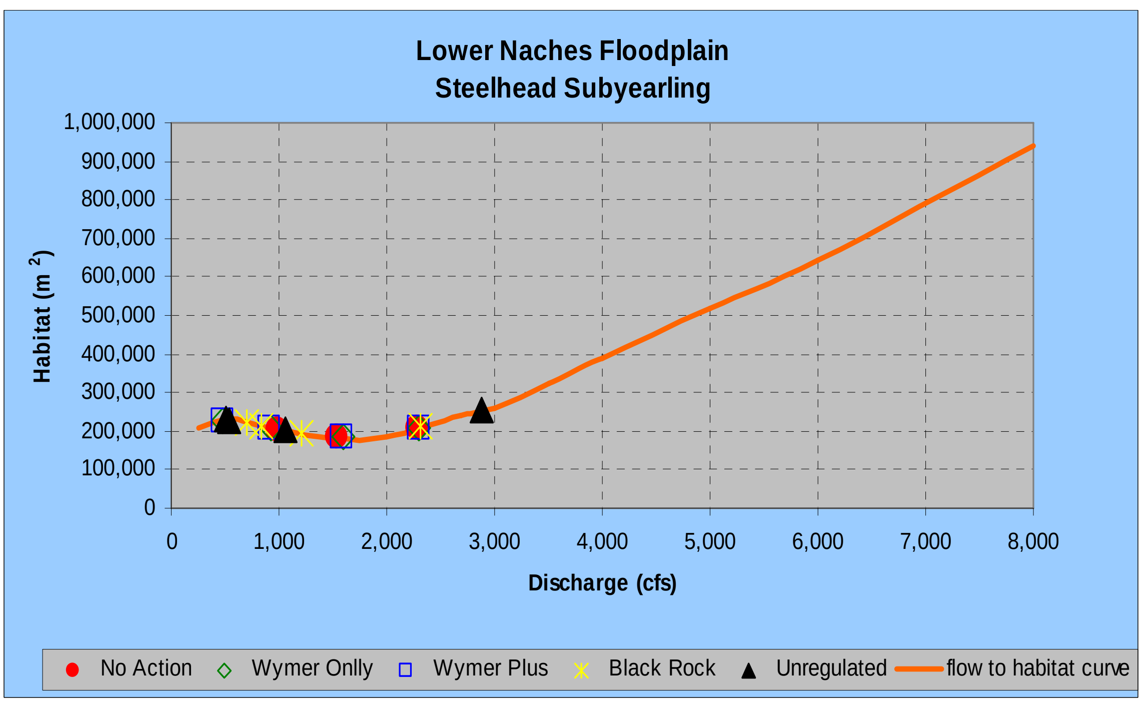


Figure S31. Flow-to-habitat curve for the steelhead summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the lower Naches floodplain.

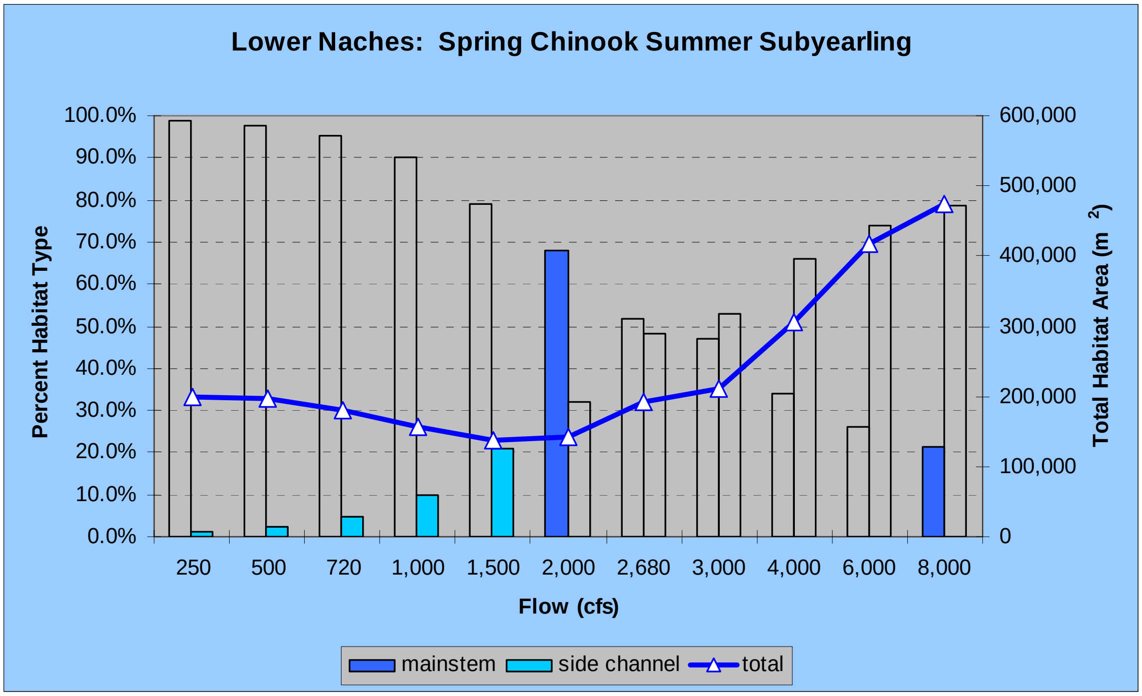


Figure S32. Flow-to-habitat curve for spring Chinook summer subyearling showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the lower Naches floodplain.

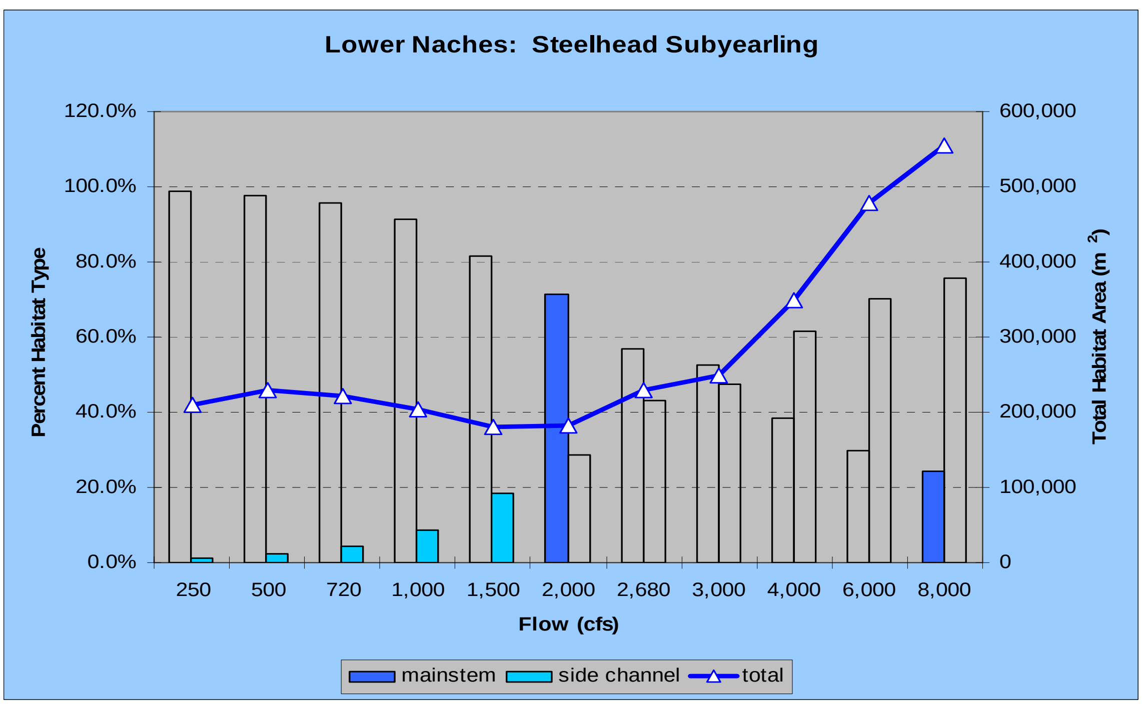


Figure S33. Flow-to-habitat curve for steelhead summer subyearling showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the lower Naches floodplain.

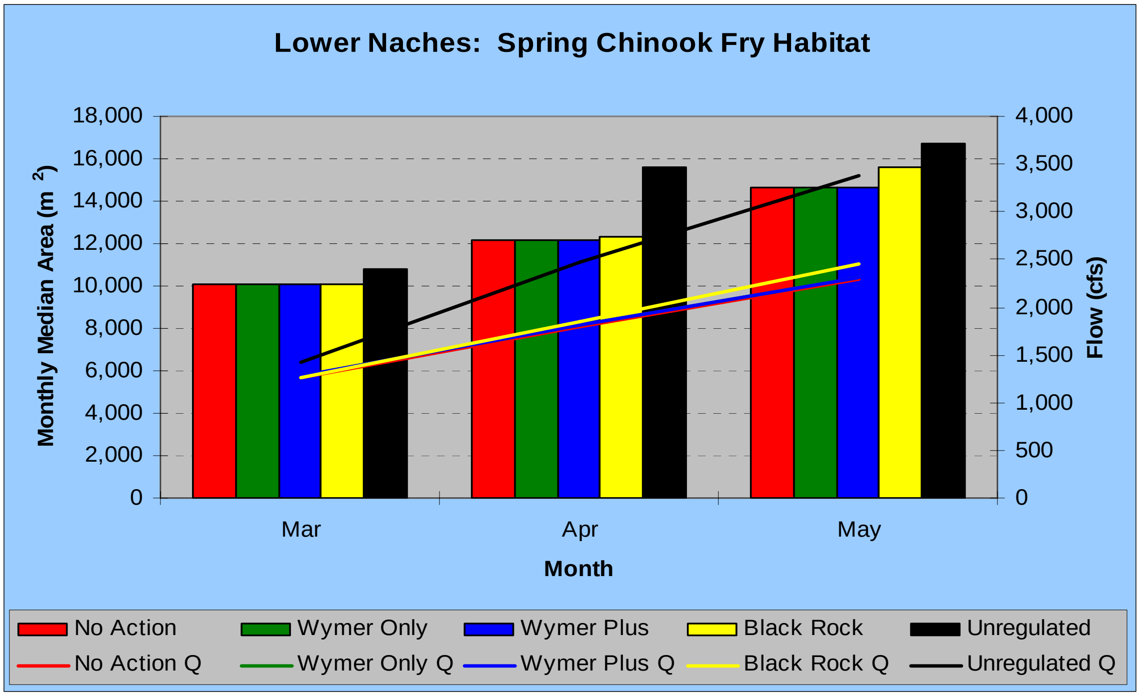


Figure S34. Summary of the amount of monthly median spring Chinook fry habitat and flow for each alternative for the lower Naches floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

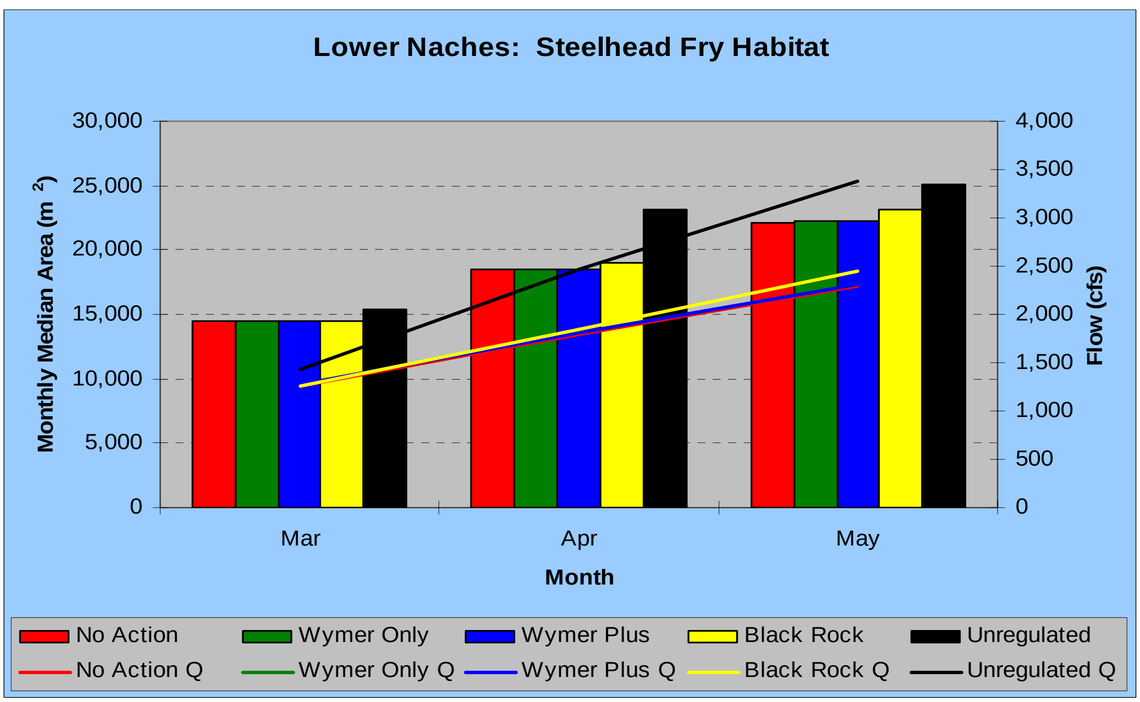


Figure S35. Summary of the amount of monthly median steelhead fry habitat and flow for each alternative for the lower Naches floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

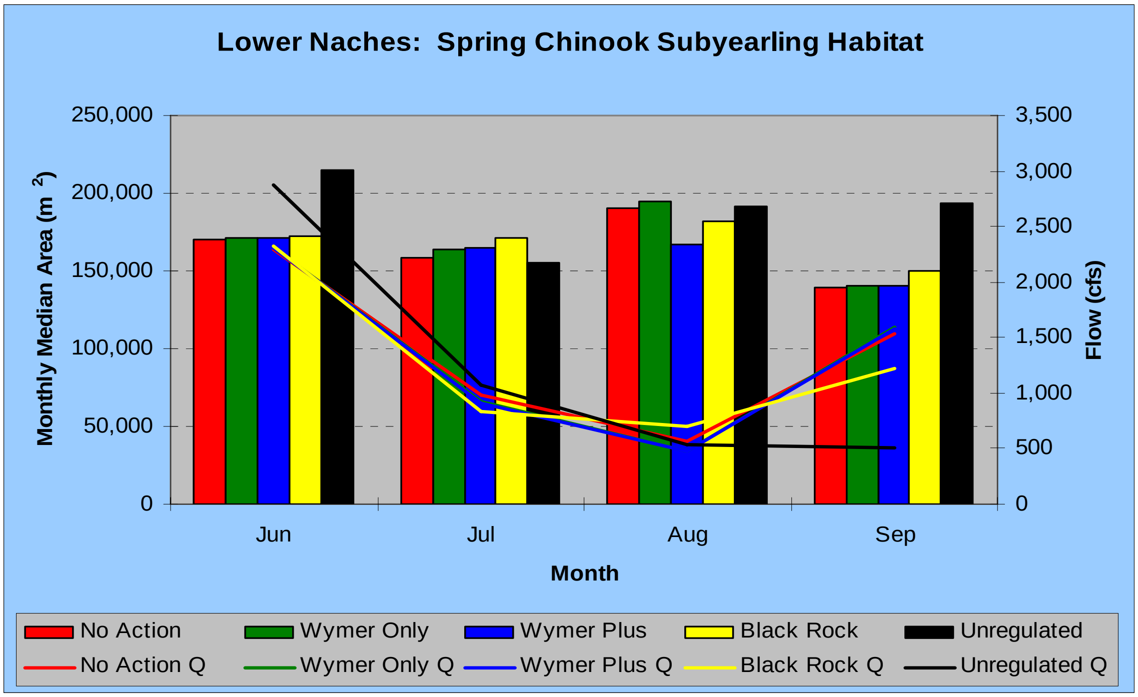


Figure S36. Summary of the amount of monthly median spring Chinook summer subyearling habitat and flow for each alternative for the lower Naches floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

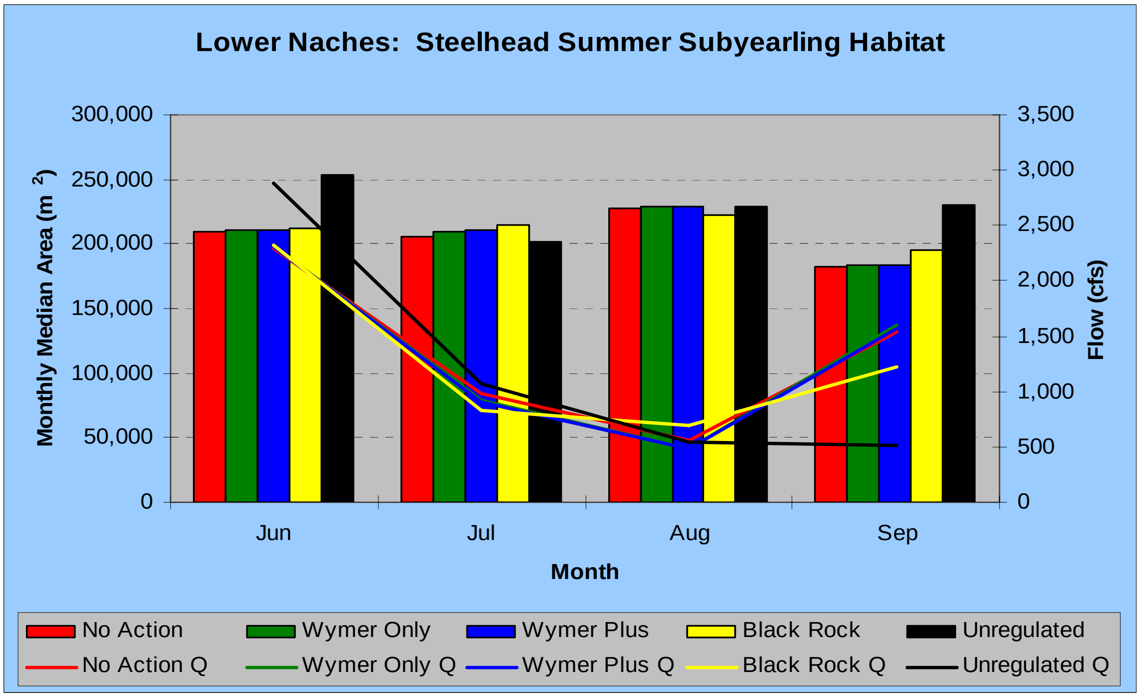


Figure S37. Summary of the amount of monthly median steelhead summer subyearling habitat and flow for each alternative for the lower Naches floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

- Non-flow actions that may be considered are preservation of existing high quality habitat from future development, as well as, to seek opportunities to improve existing floodplain habitat and to reconnect pinched-off side channels.

- It is recognized that the lower Naches River has elevated water temperatures in the summer months and this issue is currently being studied by the Washington State Department of Ecology.

1.5 Wapato Floodplain Reach

1.5.1 Flow-to-Habitat Relationship

The coho summer subyearling lifestage was chosen to evaluate the effect of summer flow on summer habitat in the Wapato because it is currently the primary salmonid species residing in this reach during the summer.

1.5.1.1 Coho Summer Subyearling

- The minimum amount of coho summer subyearling habitat occurred at approximately 750 cfs at around 240,000 m^2 and increases steadily to approximately 5,250 cfs, then levels off up to 7,000 cfs, and then begins to increase at higher flows (figure S38).

- The percent of mainstem and side channel habitat was nearly equivalent at approximately 2,500 cfs, and leveled off at about 70% at flows above 5,000 cfs. At flows less than 1,500 cfs the percent of side channel habitat declines rapidly (figure S39).

1.5.1.2 Alternative Accomplishments

The two main fishery concerns in the Wapato reach are reduced spring flows during the spring smolt outmigration period, and reduced summer flows downstream of Parker Dam.

Black Rock was the only alternative that exceeded the monthly median flow targets (table 1) for the entire spring season (March-June), and provided a flow pattern that most resembled the unregulated pattern (figure S40).

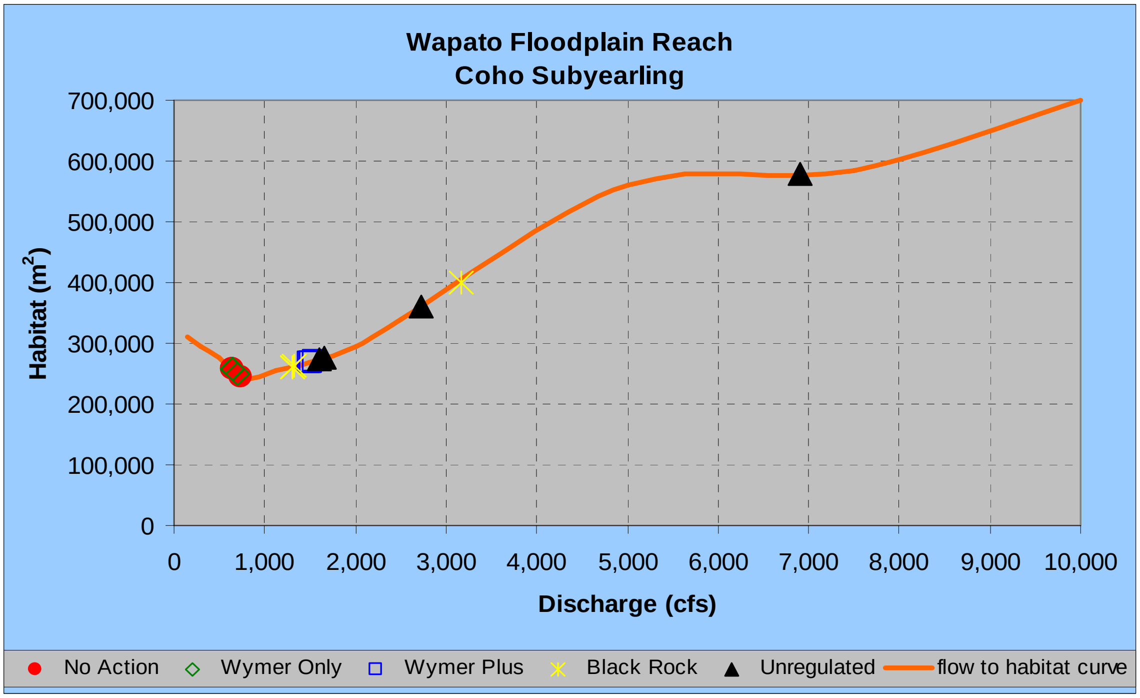


Figure S38. Flow-to-habitat curve for the coho summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Wapato floodplain.

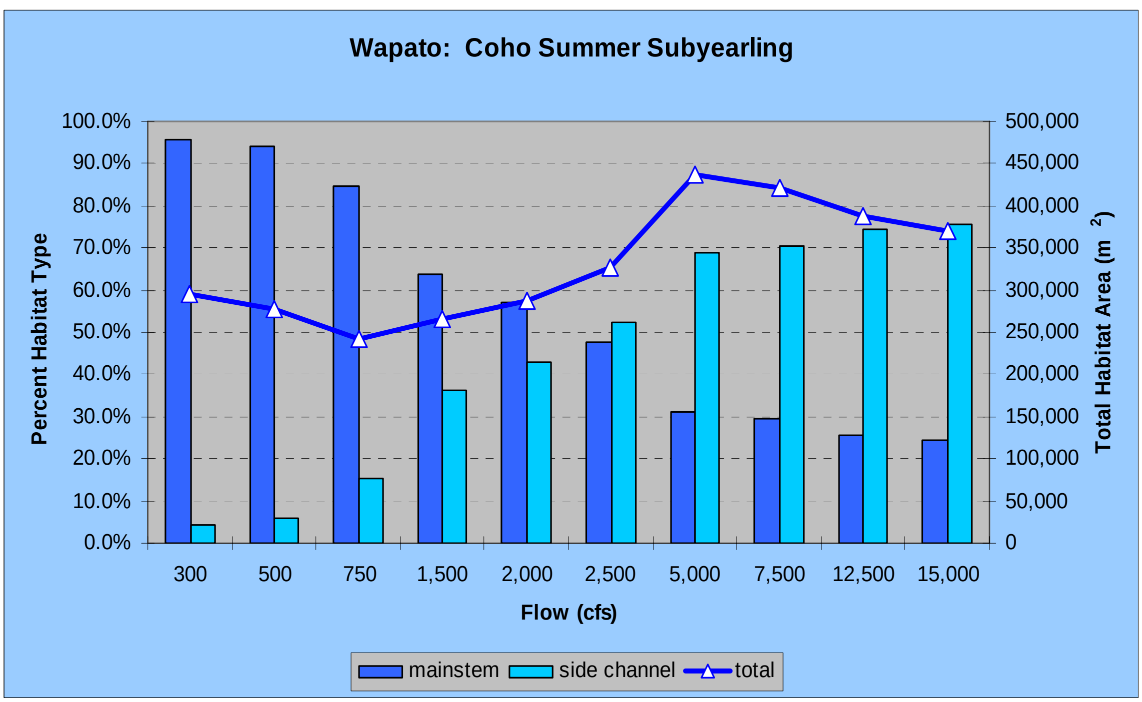


Figure S39. Flow-to-habitat curve for coho summer subyearling showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Wapato floodplain.

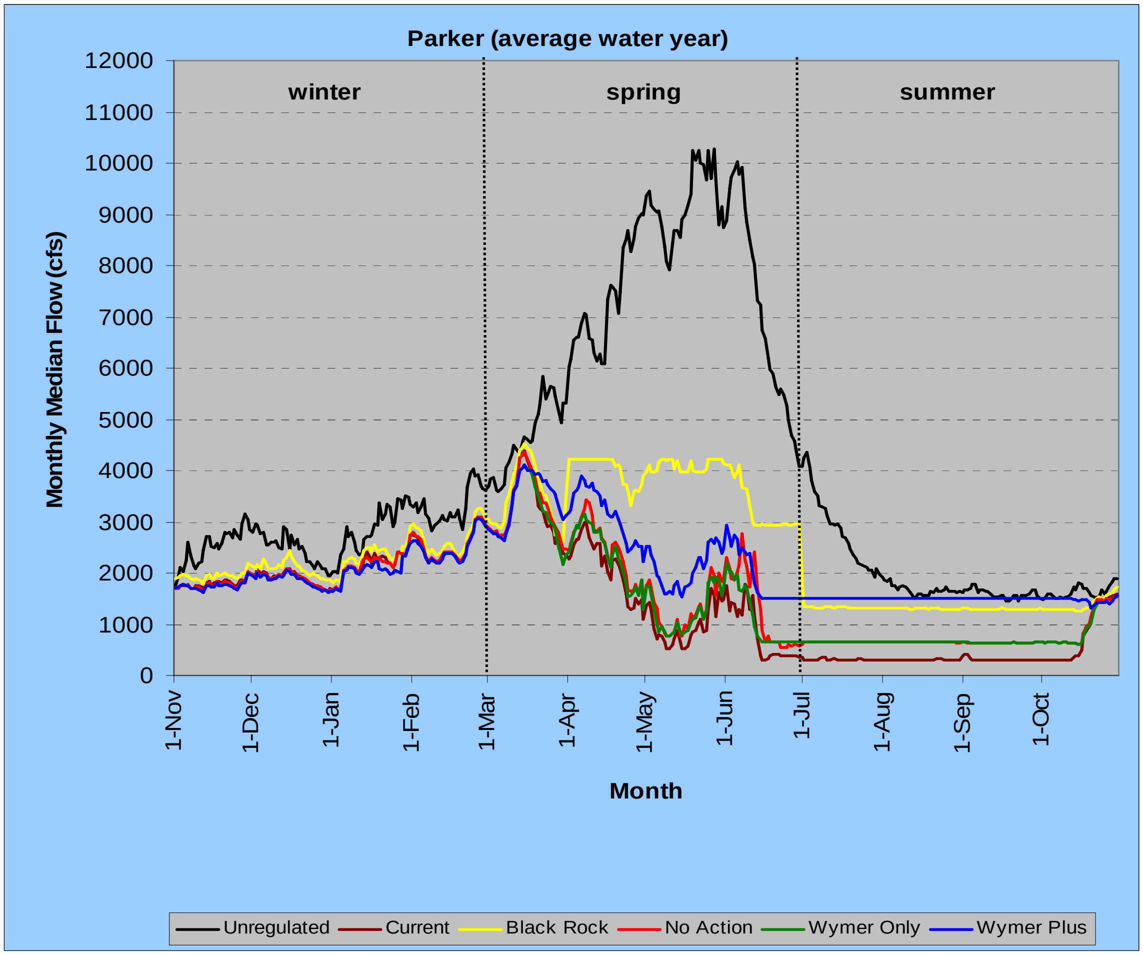


Figure S40. RiverWare model simulated median daily flows for the 1981-2005 period of record for the Parker gage used to represent flows in the Wapato floodplain reach.

Table 1. Percent difference in achieving the monthly target flow for an average water year by for the spring season (March-June) for the Storage Study alternatives.

Alternative	March	April	May	June
No Action	0.0%	-11.4%	-66.7%	-72.0%
Wymer Dam and Reservoir	-2.7%	-12.4%	-67.8%	-73.6%
Wymer Plus	8.0%	15.2%	-43.8%	-42.0%
Black Rock	9.7%	50.6%	15.0%	19.6%

- The No Action, Wymer Dam and Reservoir and Wymer Plus alternatives for March nearly met or exceeded the monthly target flow; for April No Action and Wymer Dam and Reservoir were below and Wymer Plus above; for May and

June all three alternatives were below (May: -44% to 67%; June: -42% to 74%). And none of these alternatives improved the spring flow regime pattern making more closely emulate unregulated.

- There was not a large percent difference in the amount of additional habitat (~0% to 8% depending on the month) provided by the action Storage Study alternatives compared to No Action (figure S41).

- The Wymer Plus alternative provided the most additional amount of coho summer subyearling habitat (~4% to 8% compared to No Action); the result of a July through September base flow of approximately 1,500 cfs.

1.5.1.3 Management Considerations

- Additional base flow does not significantly increase the amount of additional habitat above 1,500 cfs. For example, at 1,600 cfs the amount of habitat increased by about 2%; at 1,700 cfs, 3.7%; at 1,800 cfs 5.6% compared to the 1,500 cfs provided with Wymer Plus.

- Much of the remaining Wapato floodplain is in good condition and thus needs to be protected for the benefits of fish and wildlife and hydrologic function.

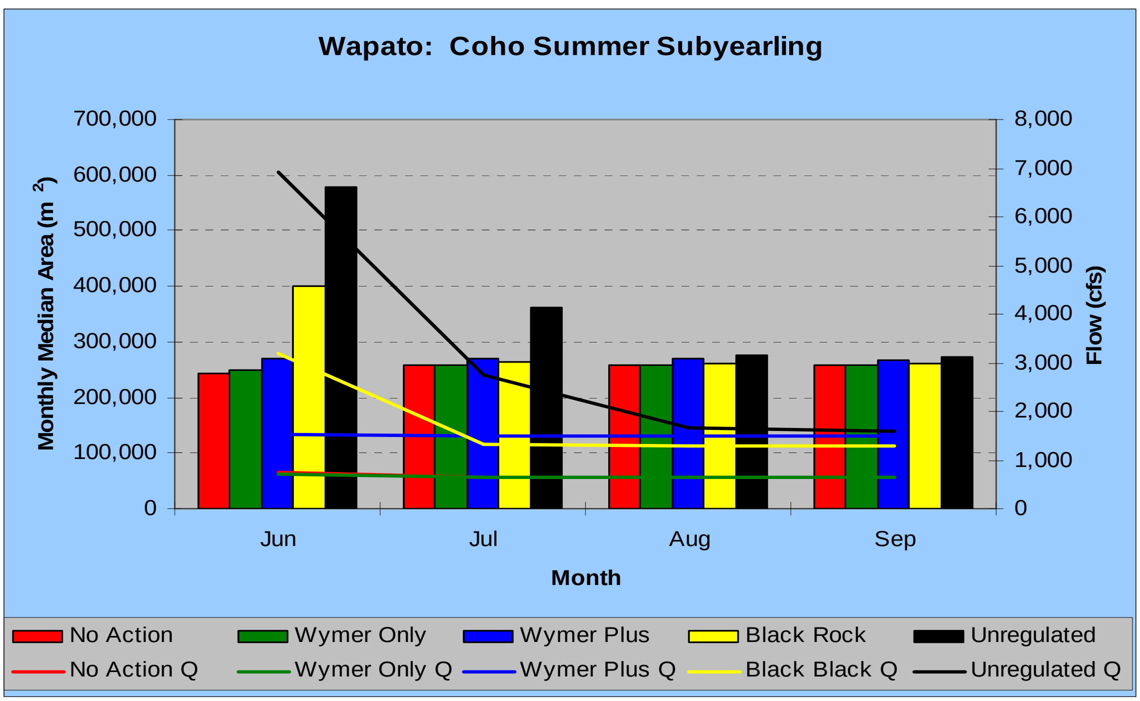


Figure S41. Summary of the amount of monthly median coho summer subyearling habitat and flow for each alternative for the Wapato floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by the lines.).

Chapter 2. METHODS

2.1 Overview

The fishery analysis study design was guided by input from the Storage Study Technical Work Group (SSTWG) at the inception of the Storage Study in 2003. Models used in the fishery analysis were classified as either a support model or an assessment model, and are presented in table 1.

The stream flow, habitat and physical models provided necessary data input to the EDT and DSS assessment models; and the DMS model managed data processing and input to the EDT model (figure 1). The EDT model was the primary fishery assessment model used to estimate anadromous salmonid (i.e. spring and fall Chinook, coho and steelhead) population equilibrium abundance, capacity and productivity for each alternative. The AHA model was used to estimate mean annual recruitment, harvest and spawner escapement for each anadromous salmonid population, inclusive of both the natural and hatchery populations. The DDS model was used to estimate changes in fisheries habitat, fish passage and bed scour for five floodplain reaches (i.e. Easton, Ellensburg, Union Gap, Wapato and lower Naches), and to report differences for important irrigation related parameters for each alternative.

2.2 Support Model Descriptions

2.2.1 RiverWare

The Yakima Project RiverWare (Yak-RW) model is a daily-time step reservoir and river operation simulation computer model for the Yakima Project created with the RiverWare software. The RiverWare software was developed at the Center for Advanced Decision Support for Water and Environmental Support (http://cadswes.colorado.edu/riverware/) at the University of Colorado, in cooperation with Reclamation and the Tennessee Valley Authority. The Yak-RW model was developed by Reclamation's Planning Group from the Upper Columbia Area Office.

The Yak-RW model was used in the Storage Study fishery assessment to simulate daily flows for the 1981-2005 period of record for each Storage Study alternative for all of the EDT model stream reaches downstream of the five storage reservoirs. Yak-RW model nodes correspond to one or more EDT stream reaches (table 2).

Table 1. List of support and assessment models used in the fishery analysis for the Storage Study.

Model Name	Model Category	Model Function
Support Models		
RiverWare (Yak-RW)	Stream flow	Daily time-step of stream flow
Sedimentation and River Hydraulic- Watershed (SRH-W)	Habitat	Flow to habitat relationship
River2D	Habitat	Flow to habitat relationship
Stream Network Temperature Model (SNTEMP)	Physical	Daily time-step of stream temperature
Sediment Impact Analysis Methods (SIAM)	Physical	Sediment transport
Hydraulic Engineering Center-River Analysis System (HEC-RAS)	Physical	Required for the SNTEMP and SIAM models; provides channel configuration and stream energy
Data Management System (DMS)	Data Management	Data processing and management for the EDT model
Assessment Models		
Ecosystem Diagnosis and Treatment (EDT) Model	Fisheries	Fisheries abundance, productivity and diversity
All H Analyzer (AHA) Model	Fisheries	Fisheries recruitment, harvest and escapement
Yakima River Decision Support System (YRDSS) Model	Fisheries and Irrigation	Quantifies fish habitat and irrigation related metrics to stream flow and/or water supply

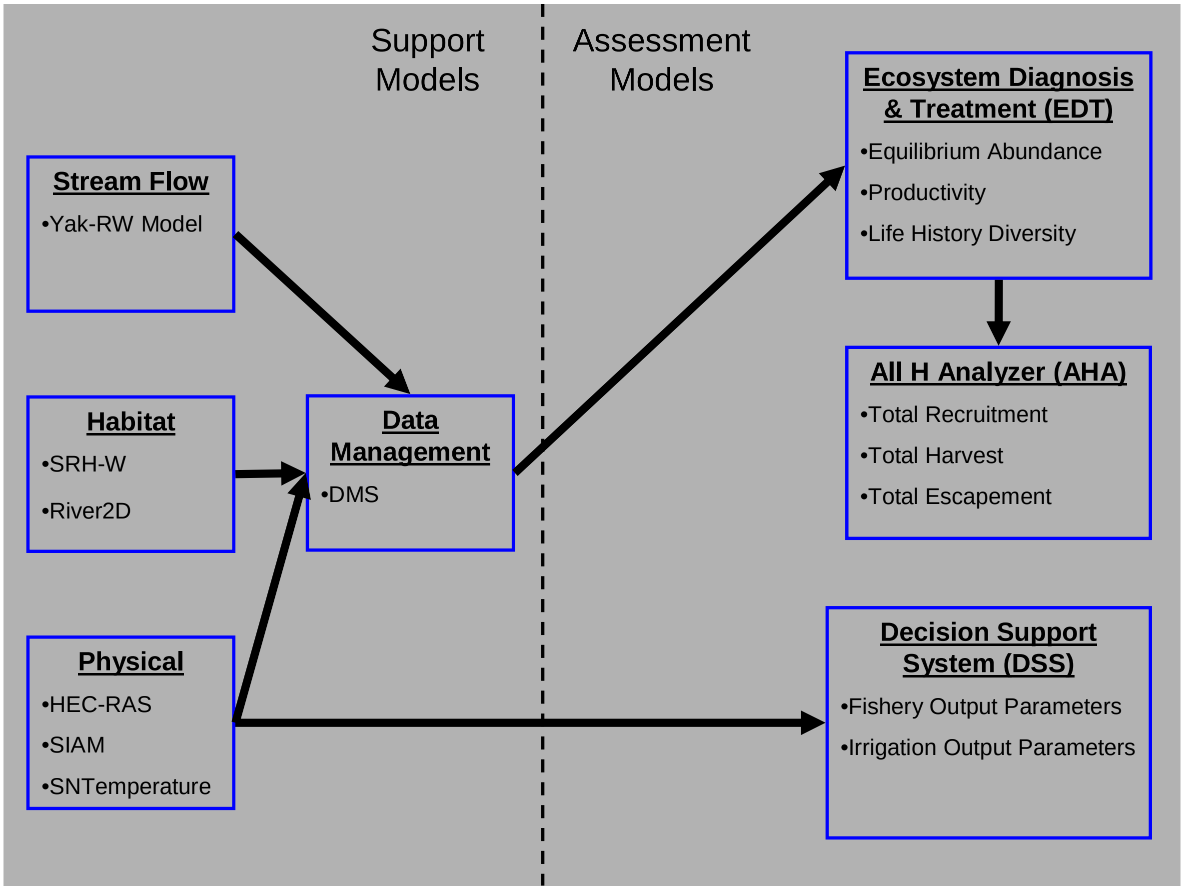


Figure 1. Data flow from the support models to the fishery assessment models.

Table 2. List of the mainstem EDT reaches and descriptions, and their association to the RiverWare nodes.

EDT Reach Name	EDT Reach Description	RiverWare Node to EDT Reach Association
Yakima River		
Yakima R.-1A	Yakima R: Yakima Delta (RM 0 to 2.1).	No association
Yakima R.-1B	Yakima R: Delta to Horn Dam (RM 2.1 to 18).	Yakima River From Kiona to Mouth.Outflow
Yakima R.-1D	Yakima R: Horn Dam to Benton Bridge (RM 18 to 29.8).	Yakima River at Kiona.Gage Outflow
Yakima R.-1E	Yakima R: Benton Bridge to Corral Canyon Cr. (RM 29.8 to 33.5).	Yakima River at Kiona.Gage Outflow
Yakima R.-1F	Yakima R: Corral Canyon Cr. to Prosser Powerplant Outfall (RM 33.5 to 35.8)	Yakima River at Kiona.Gage Outflow
Yakima R.-2	Yakima R: Chandler Powerplant Outfall to Snipes Cr. (RM 35.8 to 41.8).	Yakima River at Prosser.Gage Outflow
Yakima R.-2A	Yakima R: Snipes Cr. to Prosser Acclimation Site (RM 41.8 to 47.1).	Yakima River at Prosser.Gage Outflow
Yakima R.-2C	Yakima R: Prosser Dam to Mabton (RM 47.1 to 55).	Yakima 69_6 and Satus.Inflow1 + YGVW.RiverWare Local Flow*%
Yakima R.-2D	Yakima R: Mabton to Sulphur Cr. Wasteway (RM 55 to 61)	Yakima 69_6 and Satus.Inflow1 + YGVW.RiverWare Local Flow*%
Yakima R.-2E	Yakima R: Sulphur Cr. to Satus Cr. (RM 61 to 69.6).	Yakima 69_6 and Satus.Inflow1 + YGVW.RiverWare Local Flow*%
Yakima R.-3	Yakima R: Satus Cr. to Toppenish Cr. (RM 69.6 to 80.4).	Yakima 80_4 and Toppenish.Inflow1 + YGVW.RiverWare Local Flow*%
Yakima R.-4	Yakima R: Toppenish Cr. to Marion Drain (RM 80.4 to 82.6).	Yakima 80_4 and Toppenish.Inflow1 + YGVW.RiverWare Local Flow*%
Yakima R.-4A	Yakima R: Marion Drain to Granger Drain (RM 82.6 to 83.2)	Yakima River at Parker PARW.Gage Outflow
Yakima R.-5	Yakima R: Granger Drain to Sunnyside Dam (RM 83.2 to 103.8).	Yakima River at Parker PARW.Gage Outflow
Yakima R.-5B	Yakima R: Sunnyside Dam to Wapato Dam (RM 103.8 to 106.6).	Yakima River at Parker PARW.Gage Outflow + DIVERSION Sunnyside.Diversion
Yakima R.-5D	Yakima R: Wapato Dam to Ahtanum Cr. (RM 106.6 to 106.9).	Yakima 106_9 and Ahtanum.Outflow + PARW.RiverWare Local Flow*%
Yakima R.-6	Yakima R: Yakima R., Ahtanum Cr. to Wide Hollow Cr. (RM 106.9 to 107.4)	Yakima River at Terrace Heights YRTW.Gage Outflow + PARW.RiverWare Local Flow*%
Yakima R.-6A	Yakima R: Yakima R., Wide Hollow Cr. to Roza Powerplant Outfall (RM 107.4 to 113.3)	Yakima River at Terrace Heights YRTW.Gage Outflow + PARW.RiverWare Local Flow*%
Yakima R.-6B	Yakima R: Yakima R., Roza Powerplant Outfall to Naches R. (RM 113.3 to 116.3)	Yakima 116_3 and Naches.Inflow1 + PARW.RiverWare Local Flow*%
Yakima R.-7	Yakima R: Yakima R., Naches R. to Wenas Cr. (RM 116.3 to 122.4)	Yakima 122_4 and Wenas.Inflow1 + PARW.RiverWare Local Flow*%
Yakima R.-8	Yakima R: Yakima R., Wenas Cr. to Roza Dam (RM 122.4 to 127.9).	Yakima 127_98 at Roza Dam RBDW.Gage Outflow
Yakima R.-9B	Yakima R: Roza Dam to Umtanum Cr. (RM 127.9 to 139.8).	Yakima 139_8 at Umptanum UMTW.Gage Outflow
Yakima R.-10	Yakima R: Umtanum Cr. to Wilson Cr. (RM 139.8 to 147).	Yakima 139_8 at Umptanum UMTW.Gage Outflow
Yakima R.-11	Yakima R: Wilson Cr. to Bull Ditch outtake (RM 147 to 153.5).	Yakima 147_0 and Wilson.Inflow1 + UMTW.RiverWare Local Flow*%
Yakima R.-11A	Yakima R: Bull Ditch outtake to Reecer Cr. (RM 153.5 to 153.7).	Yakima 154_5 and Manastash.Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-11B	Yakima R: Reecer Cr. to Manastash Cr. (RM 153.7 to 154.5)	Yakima 154_5 and Manastash.Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-11C	Yakima R: Manastash Cr. To Town Ditch Diversion Dam (RM 154.5 to 161.3	Yakima 155_8 at Ellensburg ELNW.Gage Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-12	Yakima R: Town Ditch Diversion Dam to Taneum Cr. (RM 161.3 to 166.1).	Yakima 166_1 and Taneum.Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-13	Yakima R: Taneum Cr. to Clark Flat Acclimation Site (RM 166.1 to 167.7).	Yakima 169_9 and Swauk.Outflow + UMTW.RiverWare Local Flow*%

Yakima R.-13B	Yakima R: Clark Flats to Swauk Cr. (RM 167.7 to 169.9)	Yakima 169_9 and Swauk.Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-14	Yakima R: Swauk Cr. to Teanaway R. (RM 169.9 to 176.1).	Yakima 170_1 at Holick YRWW.Gage Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-14A		Yakima 176_1 and Teanaway.Outflow + UMTW.RiverWare Local Flow*%
Yakima R.-15	Yakima R: Teanaway R. to Cle Elum R. (RM 176.1 to 185.6).	Yakima 183_0 at Cle Elum YUMW.Gage Outflow
Yakima R.-16	Yakima R: Cle Elum R. to Little Cr. (RM 185.6 to 194.6).	Yakima 194_6 and Little.Outflow + YUMW.RiverWare Local Flow*%
Yakima R.-17	Yakima R: Little Cr. to Big Cr. (RM 194.6 to 195.8).	Yakima 195_8 and Big.Outflow + YUMW.RiverWare Local Flow*%
Yakima R.-17A	Yakima R: Big Cr. to Tucker Cr. (RM 195.8 to 199.9)	Yakima 202_0 at Eastion EASW.Gage Outflow
Yakima R.-17B	Yakima R: Tucker Cr. To Easton Acclimation Site (RM 199.9 to 201.9)	Yakima 202_0 at Eastion EASW.Gage Outflow
Yakima R.-18	Yakima R.: Easton Acclimation site to Easton Dam (RM 201.9 to 202.5)	Yakima 202_0 at Eastion EASW.Gage Outflow
Yakima R.-20	Yakima R: Kachess R. (upstream end of Lake Easton) to Cabin Cr. (RM 203.4 to 205).	Yakima 205_0 and Cabin.Outflow + EASW.RiverWare Local Flow*%
Yakima R.-21	Yakima R: Cabin Cr. to Keechelus Dam (RM 205 to 214.5).	Yakima River Below Keechelus Dam.Gage Outflow
Naches River		
Naches R.-1	Naches R: Mouth to Cowiche Cr. (RM 0 to 2.7)	Naches 0_1 at Yakima NRYW.Gage Outflow + PARW.RiverWare Local Flow*%
Naches R.-1a	Naches R: Cowiche Cr. to Buckskin Slough (RM 2.7 to 3.3)	Naches 2_7 and Cowiche.Inflow1
Naches R.-1b	Naches R: Buckskin Slough to S Naches Channel return (RM 3.3 to 9.8)	Naches 16_8 at Naches NACW.Gage Outflow
Naches R.-1c	Naches R: S Naches Channel return to S Naches Channel diversion (RM 9.8 to 14.0)	Naches 16_8 at Naches NACW.Gage Outflow
Naches R.-2A	Naches R: S Naches Channel diversion to Wapatox Dam (RM 14.0 to 17.1)	Naches 16_8 at Naches NACW.Gage Outflow
Naches R.-2C	Naches R: Wapatox Dam to Tieton (RM 17.1 to 17.5).	Naches 16_8 at Naches NACW.Gage Outflow
Naches R.-3	Naches R: Tieton R. to Rattlesnake Cr. (RM 17.5 to 27.8)	Naches 27_8 and Rattlesnake.Outflow + NACW.RiverWare Local Flow*%
Naches R.-4	Naches R: Rattlesnake Cr. to Nile Cr. (RM 27.8 to 29.4).	Naches 29_4 and Nile.Outflow + NACW.RiverWare Local Flow*%
Naches R.-5	Naches R: Nile Cr. to Little Naches/Bumping R. (RM 29.4 to 44.6).	Naches 36_0 at Cliffdale CLFW.Gage Outflow
Tieton River		
Tieton R.-1	Tieton R: Mouth to Oak Cr. (RM 0 to 1.8)	Naches 17_5 and Tieton.Inflow2
Tieton R.-2	Tieton R: Oak Cr. to Yakima/Tieton Diversion Dam (RM 1.8 to 14.2)	Tieton 1_8 and Oak.Inflow1
Tieton R.-3	Tieton R: Yakima/Tieton Diversion Dam to Wildcat Cr. (RM 14.2 to 20.7)	Tieton 20_8 Below Tieton Dam.Gage Ouflow
Tieton R.-4	Tieton R: Wildcat Cr. to Rimrock Dam (RM 20.7 to 21.3)	Tieton 20_8 Below Tieton Dam.Gage Ouflow
Bumping River		
Bumping R.-1	Bumping R: Mouth to American R. (RM 0 to 3.5).	Bumping 3_5 and American.Outflow
Bumping R.-2a	Bumping R: American R. to dam (RM 3.5 to 17).	Bumping River Below Bumping Dam.Gage Outflow

Yak-RW simulated daily flows for each Storage Study alternative was required data input to the habitat (i.e. SRH-W and River2D), physical (i.e. SIAM and SNTEMP), data management (DMS) and the DSS assessment models.

2.2.2 Sedimentation & River Hydraulic-Watershed (SRH-W) Model

The SRH-W (formerly GSTAR-W) is a two-dimensional depth-averaged hydrodynamic model developed by Reclamation's Sedimentation and River Hydraulics Group, Technical Service Center (http://www.usbr.gov/pmts/sediment/). A complete description of the SRH-W model can be found at Reclamation's website: http://www.usbr.gov/pmts/sediment/model/srh2d/Downloads/SRH-W%20v1.1%20User%20Manual%20June2007.pdf . The SRH-W model was used to simulate daily flow conditions (e.g. water depth and velocity, Froude Number, and channel width) for the Easton (RM 203.5 to 193), Ellensburg (RM 153.5 to 149) and lower Naches (RM 14 to 4) floodplain reaches. Simulated Yak-RW daily time-step flow data specific to each Storage Study alternative was used to relate stream flow to fishery habitat type (e.g. pool, riffle, glide, side channel, and wetland) and quantity (m^2). The Froude Number[1] was used to classify the pool, riffle and glide habitat types. Resulting flow-to-habitat type and quantity equations for each floodplain reach provided input to the DMS. The water depth and velocity grids from the SRH-W models were used in conjunction with the Delphi survey generated fish criteria to provide flow-to-species/lifestage specific equations that were used as data input to the DSS model. More about the Delphi survey and its application will be provided under the DSS model description.

Development of the two-dimensional hydrodynamic models and application of the Froude Number to classify habitat type is discussed in-depth in Reclamation's Technical Series report TS-YSS-12.

2.2.3 River2D Model

The River2D, like the SRH-W, is a two-dimensional depth-averaged hydrodynamic model that was developed by the University of Alberta for fish habitat evaluation studies. A brief description of the model can be found at the Web address: http://www.river2d.ualberta.ca/description.htm. And model documentation is located at Web address: http://www.river2d.ualberta.ca/download.htm. The River2D model was used to simulate daily flow conditions (e.g. water depth and velocity, Froude Number, and channel width) for the Union Gap (RM 111 to 107.5) and Wapato (RM 103 to 95)

[1] Froude Number is defined as, [$V/(\sqrt{g}*h)$]; where "*V*" is depth-averaged velocity, "*g*" is the gravitational constant and "*h*" is the flow depth..

floodplain reaches. Similar to the floodplain reaches modeled using the SRH-W model, the Froude Number was used to classify pool, riffle and glide habitat types. Bovee pers. comm. on information contained in the draft open file report, 2007) present a more in depth discussion of model development for these two floodplain reaches. Similar to the SRH-W models, flow-to-habitat type and quantity equations for the Union Gap and Wapato floodplain reaches provided input to the DMS model; and the water depth and velocity grids from the River2D models were used in conjunction with the Delphi survey generated fish criteria to provide flow-to-species/lifestage specific equations that were used as data input to the DSS model.

Development of the two-dimensional hydrodynamic models and application of the Froude Number to classify habitat type is discussed in detail by Bovee pers. comm. on information contained in the draft open file report, 2007) in Appendix 1 of the draft report for the Yakima DSS model[2].

2.2.4 Hydraulic Engineering Center-River Analysis System (HEC-RAS)

Hydraulic Engineering Center-River Analysis System (HEC-RAS) is a one-dimension step-back water model developed by the U.S. Army Corps of Engineers (http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html) that provides flow depth, channel top width, and cross-section averaged values of velocity (among others). Reclamation's Technical Service Center constructed a one-dimensional hydraulic (HEC-RAS) model for select reaches of the Yakima and Naches Rivers, which for clarification were not the same as for the 2-D hydrodynamic models (but may overlap)- Easton (~RM 202 to 191), Ellensburg (~RM 161 to 148), Selah to Sunnyside (Parker) Dam (~RM 125 to 104), Sunnyside Dam to Toppenish bridge (~RM 104 to 93), Toppenish bridge to Mabton bridge (~RM 93 to 60), Mabton bridge to Chandler Power Plant (~RM 60 to 36), and lower Naches River (~RM 13 to 0). A complete description of the Yakima basin one-dimensional model is provided by Hilldale and Mooney (2007a).

The HEC-RAS model was developed primarily for the Sediment Impact Analysis Methods (SIAM) and Steam Network Temperature (SNTEMP) models, which both require HEC-RAS to properly function. The seven stream reaches were selected based on the combined minimum reach needs of the SIAM and SNTEMP models.

2.2.5 Sediment Impact Analysis Methods (SIAM) Model

The Sediment Impact Analysis Methods (SIAM) model was developed by Reclamation's Sedimentation and River Hydraulics Group, Technical Service Center and simulates the

[2] A the time of this writing the USGS-FORT open file report for the Yakima DSS is under peer review and will be published spring 2008.

movement of sediment through a river basin to describe changes in channel morphology (http://www.usbr.gov/pmts/sediment/model/srhsiam/index.html). The SIAM model was applied to seven reaches of the Yakima basin: Easton, Ellensburg, Selah to Sunnyside (Parker) Dam, Sunnyside Dam to Toppenish Creek, Toppenish Creek to Mabton, Mabton to Chandler Power Plant, and Naches River. A complete description of the SIAM model used in the Yakima basin was prepared by Mooney and Hilldale (2007b). The SIAM model was used to estimate the average annual output for sand and gravel sediment transport, redd scour depth, incipient motion threshold and geomorphic work for each of the seven stream reaches.

Redd scour depth was used as input to both the DSS and EDT (i.e. Bed Scour attribute) models, and sand sediment transport, incipient motion (called armour disruption in the DSS model), and geometric work (called geomorphic adjustment in the DSS model) were used as input to the DSS model.

2.2.6 Stream Network TEMPerature Model (SNTEMP)

The Stream Network Temperature Model (SNTEMP) was developed by the USGS, Fort Collins Science Center and is described on their Website: http://www.fort.usgs.gov/Products/Software/SNTEMP/. A SNTEMP model was developed by the USGS-Washington Water Science Center for the Yakima River for the Roza Dam (RM 127.9) to Chandler Power Plant (RM 35.8) reach for the period of April 1 through October 31 (irrigation season). This particular stream reach and time period was selected because USGS through prior studies determined that this reach and time period was the only section of the Yakima River most likely to be influenced by changes in the flow regime, which is the objective of the Storage Study alternatives. The model was designed to estimate the relative difference in maximum daily water temperature between the Storage Study alternatives, which was used as input for the EDT Temperature Maximum attribute. Input to the SNTEMP model consisted of the Yak-RW simulated daily flows (April 1 – October 31 for the 25-year period of record) for each Storage Study alternative for each EDT stream reach from Roza to the Chandler Power Plant. Previously mentioned, the Yakima SNTEMP model requires the Yakima HEC-RAS model in order to run. An in-depth discussion of the Yakima SNTEMP model and model results is presented by Voss (personal communication on the USGS draft open file report for the Yakima Storage Study temperature model, 2007)[3].

Model output consisted of estimated daily water temperature for the 1981 – 2005 period of record by EDT reach (Roza Dam to Chandler Power Plant) for each Storage Study alternative. The water temperature datasets for each alternative were used to calculate the

[3] A the time of this writing the USGS-Tacoma open file report for the Yakima SNTEMP model is under peer review and will be published spring 2008.

EDT Temperature Maximum attribute rating and annual pattern for each modeled EDT reach, but was not used for the EDT Temperature Minimum or Temperature Spatial Variation attributes.

2.2.7 Wymer Reservoir Water Quality Model

The Storage Study contracted with Reclamation's Technical Service Center to assess Wymer Reservoir outlet water temperatures for the two Wymer alternatives. The purpose was to evaluate what potential impacts water released from the reservoir would have on Yakima River water quality downstream of the Lmuma Creek. A summary of the study design, methods, discussion and conclusions are presented in Appendix

2.2.8 Data Management System (DMS)

The Data Management System (DMS) is an EXCEL application developed by Reclamation's Technical Service Center to manage data transfer between the support models and the EDT model (figure 1). The primary function of the DMS is to calculate the EDT flow, habitat and temperature ratings, and associated annual patterns. And to write this information to the EDT model (a Microsoft ACCESS application) in the appropriate database tables.

Input to the DMS included the Yak-RW daily flows for the 25-year period of record, the flow-to-habitat algorithms for the EDT habitat attributes (i.e. Pools, Tailout, Backwater, Beaver Pond, Glide, Small Cobble Riffle and Large Cobble Riffle) for the five 2-dimensional hydrodynamic floodplain models (i.e. Easton, Ellensburg, Union Gap, Wapato and lower Naches), and the EDT flow and temperature maximum algorithms used to calculate the EDT flow and temperature ratings.

2.3 Assessment Model Descriptions

2.3.1 Ecosystem Diagnosis and Treatment (EDT) Model

Mobrand, Jones & Stokes describe the EDT model as "a system for rating the quality, quantity and diversity of habitat along a stream, relative to the needs of a focal species such as coho or Chinook salmon" (http://www.mobrand.com/MBI/pdfs/WhatisEDT.pdf).

A detailed description of the EDT model theory and structure is provided by Lestelle, Mobrand and McConnaha (2004). The standard EDT model as described on the Mobrand, Jones and Stokes website requires the user to rate 46 environmental attributes in four categories consisting of twelve sub-categories:

- Hydrologic Characteristics (7 total attributes)
  - Flow Variation (5 attributes)
  - Hydrologic Regime (2 attributes)
- Stream Corridor Structure (22 total attributes)
  - Channel Morphology (4 attributes)
  - Confinement (2 attributes)
  - Habitat Type (8 attributes)
  - Obstruction (1 attributes)
  - Riparian and Channel integrity (4 attributes)
  - Sediment Type (3 attributes)
- Water Quality (9 total attributes)
  - Chemistry (6 attributes)
  - Temperature Variation (3 attributes)
- Biological Community (8 total attributes)
  - Community Effects (7 attributes)
  - Macroinvertebrates (1 attributes)

The standard EDT model was modified to accommodate modeling requirements of the Storage Study fishery assessment by creation of additional environmental attributes. Three new attributes were added to the Hydrologic Characteristics category, these were Regulated Flow Decrease, Regulated Flow Increase and Hydrograph Month. Lestelle, Watson and Blair (2006) prepared a detailed description of these three new attributes and the rational for their creation.

Four new Stream Corridor Structure sub-categories totaling 16 new attributes were added. These sub-categories were: Off-Channel Morphometry (3 attributes), Off-Channel Habitat Type (3 attributes), Off-Channel Sediment Type (3 attributes) and Off-Channel Obstructions (7 attributes), that incorporated three new off-channel river features: ponds, groundwater channels and wetlands. For the Storage Study fishery assessment only the wetland related attributes were considered.

The Habitat Type sub-category was restructured to comprise the Habitat (i.e. Pools, Tailout, Backwater, Beaver Pond, Glide, Small Cobble Riffle and Large Cobble Riffle), Habitat Braids, Habitat Side Channel (which replaced the Off-channel Habitat Factor attribute) and Habitat Patterns. The Habitat Patterns attribute defines the monthly percent habitat composition of the Habitat attributes (i.e. Pools, Tailout, Backwater, Beaver Pond, Glide, Small Cobble Riffle and Large Cobble Riffle). Mobrand, Jones and Stokes (2005) describe these new attributes and how they were calculated using the support models.

The user is required to rate the environmental attributes for each EDT stream reach and dam (storage and diversion). The Yakima basin EDT model consists of approximately 400 stream reaches (mainstem and tributaries), diversion dams (e.g. Horn Rapids, Prosser, Parker, Wapato, Roza, Town Ditch, Easton, Wapatox and Yakima-Tieton) and hatchery acclimation sites. However, only the 53 streams reaches downstream of the five storage reservoirs (i.e. Keechelus, Kachess, Cle Elum, Bumping and Rimrock) in the Yakima, Naches, Bumping and Tieton Rivers, some of the diversion dams[4], and the five storage reservoirs were affected by the Storage Study, and therefore, were the only stream reaches and diversion dams that the EDT environmental attribute values were adjusted for specific to each alternative. The Flow Variation and Habitat environmental attribute categories were the main categories supplied with ratings by one of the support models (i.e. Yak-RW, SRH-W, River2D, SIAM and SNTEMP) automatically through the DMS model. The ratings for other attributes like Bed Scour and Obstruction, and other miscellaneous EDT attributes were modified by hand as needed for each alternative, meaning any changes to the EDT database were made by the user opposed to being automatically changed through the DMS model.

2.3.2 All H Analyzer (AHA) Model

The All H Analyzer (AHA) model was developed by Washington State fishery co-managers for the purpose to discuss salmon restoration strategies involving the four "Hs"- hatchery practices, harvest, hydroelectric dams and habitat restoration. An AHA model user's guide, which explains in more detail elements of the model, can be found at the USFWS Website: http://www.fws.gov/pacific/Fisheries/Hatcheryreview/documents/All-HAnalyzerDraftUsersGuideAug05.pdf .

For the Storage Study fisheries assessment the AHA model was used in conjunction with the EDT Productivity and Capacity output parameters for each anadromous salmon and steelhead population, plus any associated hatchery programs (i.e. Cle Elum Supplementation Program, Prosser Upriver Bright Fall Chinook Production Program and the Yakima Klickitat Fisheries Project Coho Program) to estimate the mean annual adult recruitment, harvest and spawner escapement for each alternative. These mean annual

[4] Only the following major diversion dams: Horn Rapids, Prosser, Parker, Wapato, Roza, Town Ditch, Easton, Wapatox and Yakima-Tieton were considered in the EDT fishery assessment for each alternative.

values were based on a 100-year simulation period that considered the effect of the Pacific Decadal Oscillation cycle on adult ocean survival by species.

For consistency in how spawner escapement was calculated for Reclamation's draft Kennewick and Columbia Irrigation Districts Pump Exchange Planning Report and Draft Environmental Impact Statement the in-basin (Yakima) smolt survival parameter in the AHA model was adjusted based on the median spring flow at Prosser for each Storage Study alternative according to the derived Pyper and Smith (2005) flow-to-smolt survival relationship for each salmonid species. A detailed discussion of how the Pyper and Smith (2005) flow-to-smolt survival relationship was incorporated into the AHA model analysis is presented in Appendix A.

2.3.3 Yakima River Decision Support System (YRDSS) Model

The Yakima River Decision Support System (YRDSS) model is an Microsoft EXCEL application developed by the USGS, Fort Collins Science Center for the Storage Study as an, "integrated water management/habitat response tool that would allow USBR to quantify the feasibility, effectiveness, and risks associated with various water management alternatives." (Bovee, pers. comm. on information contained in the draft open file report, 2007).

A Delphi survey was the first step in the development of the YRDSS. A Delphi survey[5] was conducted by the USGS, Fort Collins Science Center to determine, 1) critical salmonid lifestages to be considered, 2) suitable habitat defined by water depth and velocity, and 3) preferred mesohabitat, which were needed for development of the YRDSS model. A panel of 15 local fishery biologists, from nine different entities (i.e. Yakima Nation, Yakima County, Washington Department of Fish and Wildlife, Joint Board, National Marine Fisheries Service, Bureau of Reclamation, U.S. Fish and Wildlife Service, US Forest Service, and US Geological Survey) were invited to participate in the Delphi survey. Four survey rounds[6] were conducted before there was convergence in all three survey categories. Bovee (pers. comm. on information contained in the draft open

[5] The **Delphi method (or survey)** is a systematic interactive forecasting method for obtaining forecasts from a panel of independent experts. The carefully selected experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, participants are encouraged to revise their earlier answers in light of the replies of other members of the group. It is believed that during this process the range of the answers will decrease and the group will converge towards the "correct" answer. Finally, the process is stopped after a pre-defined stop criterion (e.g. number of rounds, achievement of consensus, stability of results) and the mean or median scores of the final rounds determine the results (from Wikpedia).

[6] The number of responses received by round were as follows: 1st round 10, 2nd round 6, 3rd round 6, and 4th round 5.

file report, 2007) present a discussion of the Delphi survey process and the resulting suitable habitat criteria for spring and fall Chinook, coho, steelhead, resident trout and bull trout.

Input to the DSS model comes from several of the support models (i.e. Yak-RW, SRH-W, River2D, SIAM and SNTEMP). The DSS includes:

- RiverWare model input: Daily mean flows for 25-year period of record (1981-2005) for the five floodplain reaches- Easton, Kittitas, Union Gap, Wapato and lower Naches for the four Storage study alternatives.

- SRH-W and River2D model input: Flow-to-species/lifestage algorithms for the Easton, Ellensburg, Union Gap, Wapato and lower Naches floodplain reaches. These algorithms were based on the suitable habitat criteria specific to each species/lifestage developed through the YRDSS Delphi survey.

- SIAM model input: Algorithms derived by the SIAM model for the decision variables- Fine Material Transport, Geomorphic Adjustment and Armor Disruption, for each of the five floodplains were incorporated into the YRDSS. Yak-RW generated daily flow specific to each alternative was the independent variable used to estimate the three decision variables for each alternative for the five floodplains for a specific daily flow.

- SNTEMP model input: Estimated daily maximum water temperature for the 23 year period of record (1981-2003) for each alternative for the Union Gap, Wapato and lower Naches floodplain reaches was used.

YRDSS model outputs called, Decision Variables (table 3) are divided into four categories, for the purposes of this report only the Biological and Sediment transport and geomorphology categories are discussed since these were germane to this technical report:

- Biological

- Overbank flow and floods

- Management and delivery

- Sediment transport and geomorphology

Table 3. List of decision variables and categories incorporated into the Yakima River Decision Support System (YRDSS).

Category	Decision Variables	Description
Biological	Redd Scour	Maximum depth of redd scour during incubation for the 25-year period of record
	Habitat Time Series	Amount (acres) of habitat for the following lifestages: fry, juvenile summer and winter rearing, and adult holding.
	Spawning-Incubation	Persistence of suitable spawning and incubation habitat (acres).
	Stream Temperature	Maximum daily temperature during specific lifestage time periods.
	Bull Trout Outmigration	Frequency of suitable inflows and reservoir (i.e. Keechelus, Kachess and Rimrock) elevation to support up migration of bull trout spawners.
	Cle Elum Reservoir Smolt Outmigration	Frequency of suitable reservoir elevation to support smolt outmigration.
Overbank Flow and Floods	Overbank Flows	Frequency of overbank flows
	Potential Flood Damage	Frequency of potentially damaging flood events.
Management and Delivery	Total Deliverable Water Supply	TWSA by month
	Total Deliverable to junior water right holders	Proration rate to junior water right holders
	Reservoir Carryover	End-of-year (September 30) total reservoir storage.
Sediment Transport and Geomorphology	Fine Sediment Transport	Total mass transport of sand, silt and clay.
	Armor Disruption	Frequency of events capable of erosion of armor layer.
	Geomorphic Adjustment	Maximum 15-day sum of geomorphic work performed in a water year.

The Biological category consists of the fisheries related decision variables- Redd Scour, Habitat Time Series, Spawning-Incubation, Stream Temperature, Reservoir Outmigration and Bull Trout Passage. The Redd Scour decision variable records the annual and overall (for the 25-year period of record) estimated maximum bed scour in the floodplain reach during the spawning/incubation lifestage, which is user defined. Redd scour for each floodplain reach represents the average bed scour based on all of the reach cross sections comprising the HEC-RAS model.

The Habitat Time Series decision variable averages the species/lifestage suitable area calculated daily for the 25-year period of record based on daily mean flows that occur during the user defined species/lifestage temporal window (i.e. summer rearing spring Chinook is June 1 – September 30) and species/lifestage flow-to-habitat algorithms.

The Spawning-Incubation decision variable calculates the amount of suitable spawning and incubation habitat that overlaps (or persists) throughout the spawner/incubation lifestage window (defined by the user).

The Stream Temperature decision variable is designed to tally the number of days annually and overall for the 23 year period of record that exceed a critical maximum water temperature threshold for a given species/lifestage. And the critical threshold values were determined by review of the fishery literature. Though this decision variable is functional in the DSS model, model output for this variable is not suitable for its intended use of recording the number of days the critical maximum stream temperature is exceeded. There are several reasons for this. First, the SNTEMP model is accurate for measuring the relative change in daily water temperature between Storage Study alternatives, but not as accurate for predicting the absolute daily maximum stream temperature for each alternative. Second, the spatial and temporal boundaries of the SNTEMP model only incorporated the Union Gap and Wapato floodplain reaches during the irrigation season (April through October).

The bull trout spawner upmigration decision variable tallies the number of days annually and overall for the 25-year period of record that does not meet the adult tributary upmigration criterion for bull trout populations residing in the Keechelus, Kachess and Rimrock reservoirs. Adult upmigration criteria were based on a combination of reservoir elevation and combined tributary inflow into the reservoir. It should be noted that individual tributary flow is not measured, and that total tributary inflow to each reservoir is calculated indirectly from the reservoir elevation-to-capacity curve and the reservoir outflow. Bovee (pers. comm. on information contained in the draft open file report, 2007) provides a more in-depth description of this decision variable using Keechelus Reservoir as an example.

Chapter 3. RESULTS AND DISCUSSION

Flow-to-habitat curves presented in the results section represent the under present day habitat conditions the approximate amount of expected habitat for a specific species and lifestage for a given stream flow. To the extend instream structure exists (i.e. large woody debris, boulders, overhanging vegetation) creating additional micro-habitat, this is not represented by the 2-D hydrodynamic models since they represent habitat conditions based on stream flow and channel configuration and channel roughness.

3.1 Hydrographs

Figures 2-5 present the median daily flows for the Easton, Umtanum, Parker and Naches at Naches USBR gages from November 1 through October 31 for the 1981-2005 period of record, that were simulated by the RiverWare model. Each hydrograph show the median daily flows for the No Action, Wymer Dam and Reservoir, Wymer Plus, Black Rock Alternatives, and the unregulated flow regime. These hydrographs are presented as background information that the reader can refer to as needed throughout the Results section.

3.2 Upper Yakima Summer Flows and Habitat for Spring Chinook and Steelhead

A map of the Yakima basin showing the location of the floodplain reaches can be found at the beginning of Appendix B.

3.2.1 Easton Reach

The flow-to-habitat curves[7], for spring Chinook and steelhead fry lifestages; and for spring Chinook and steelhead summer subyearling lifestages were similar (figure 6). And the amount of steelhead habitat for both lifestages at any given flow was somewhat greater compared to spring Chinook. The amount of fry habitat for both species was relatively constant from 150 cfs to 2,000 cfs. Spring Chinook and steelhead summer subyearling habitat increased from 150 cfs to 300 cfs, and then decreased up to 1,100 cfs, after which the amount of habitat increased again.

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[7] All flow-to-habitat curves presented in this technical report were derived from the DSS model, which relied on the Delphi survey criteria to define the specific species and lifestage habitat correspondence to a particular flow (cfs).

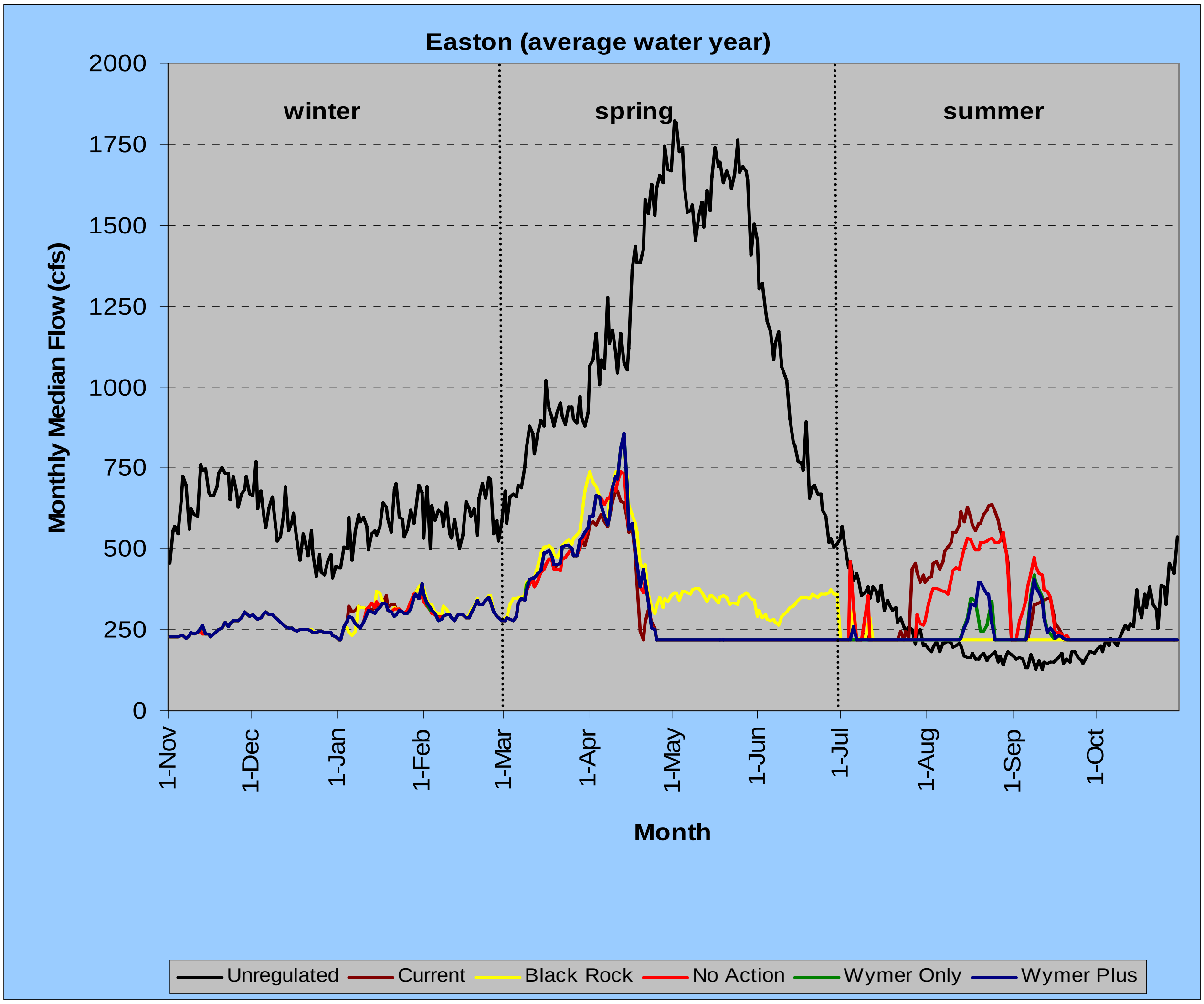


Figure 2. RiverWare model simulated median daily flows for the 1981-2005 period of record for the Easton gage used to represent flows in the Easton floodplain reach.

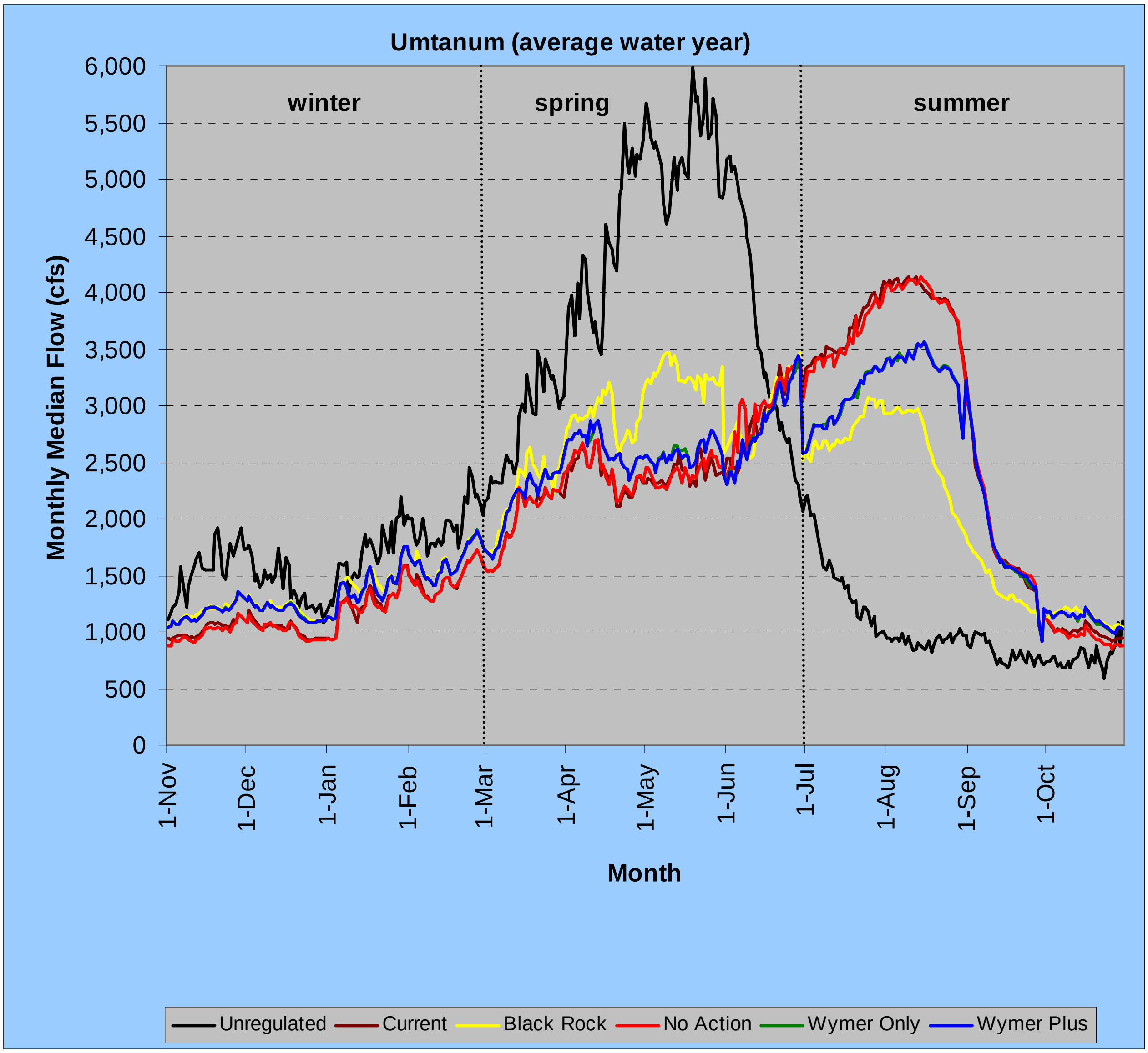


Figure 3. RiverWare model simulated median daily flows for the 1981-2005 period of record for the Umtanum gage used to represent flows in the Ellensburg floodplain reach.

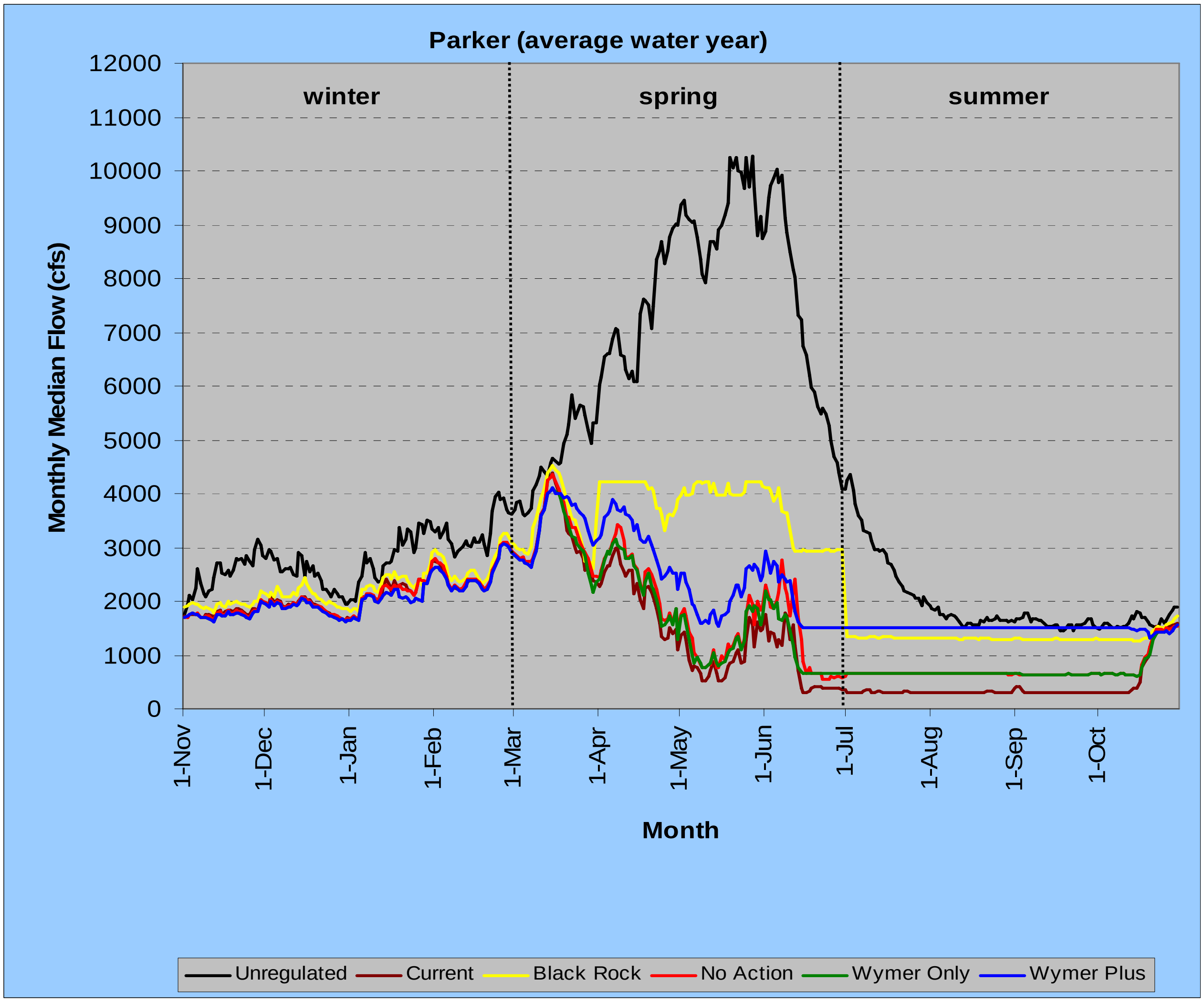


Figure 4. RiverWare model simulated median daily flows for the 1981-2005 period of record for the Parker gage used to represent flows in the Wapato floodplain reach.

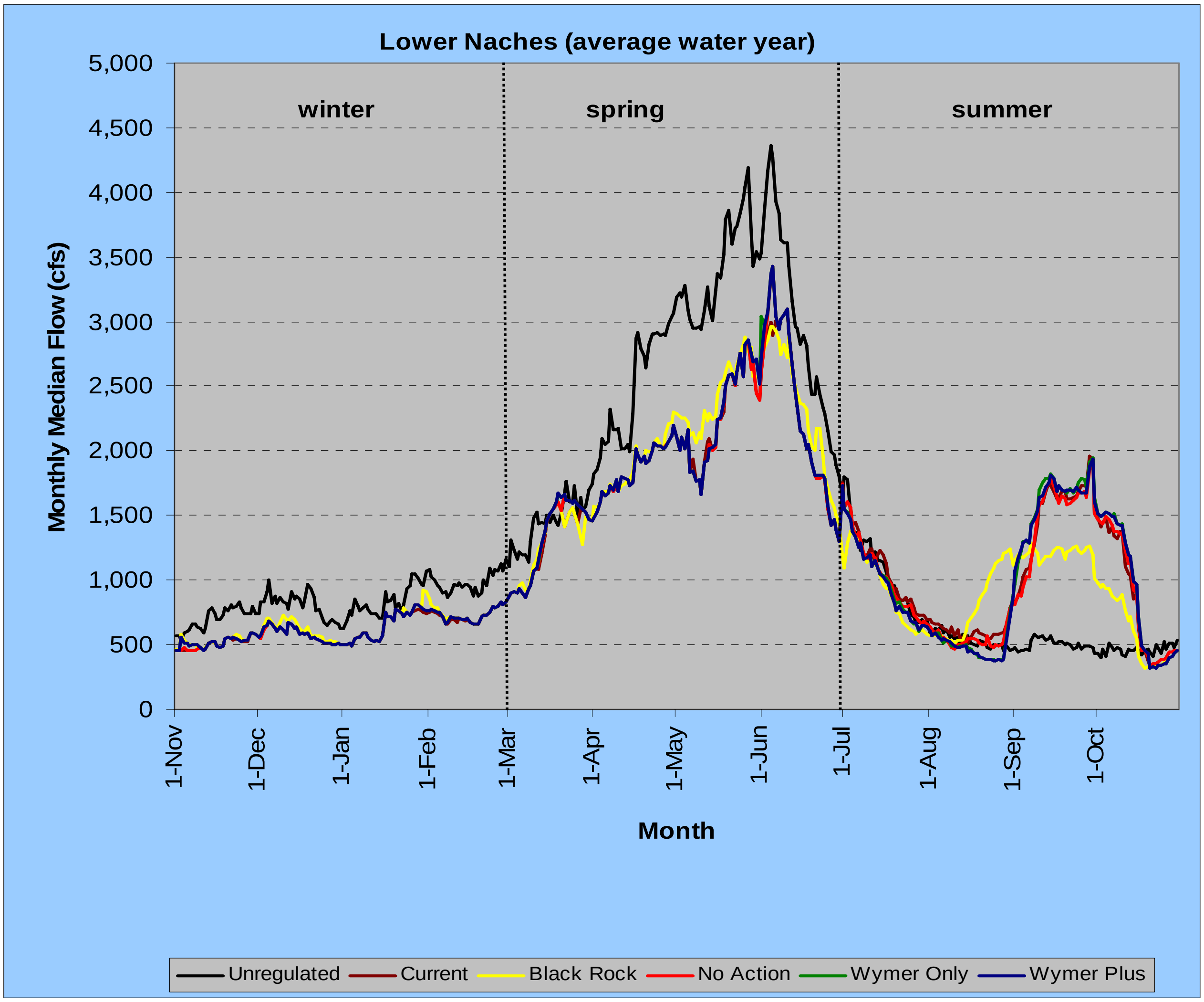


Figure 5. RiverWare model simulated median daily flows for the 1981-2005 period of record for the Naches at Naches gage used to represent flows in the lower Naches floodplain reach.

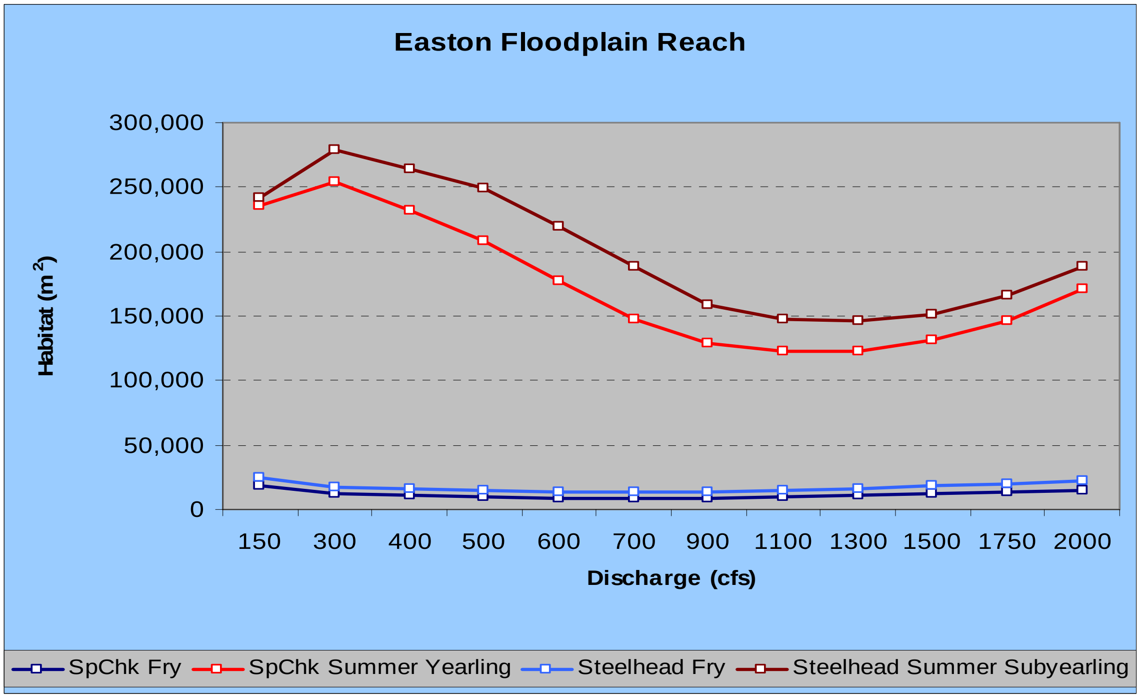


Figure 6. Flow-to-habitat curves for spring Chinook and steelhead for the fry and summer subyearling lifestages for the Easton floodplain reach.

3.2.1.1 Fry Habitat

Except for the month of May, there were minimal variation in the amount of monthly spring Chinook and steelhead fry habitat between the four alternatives, which is expected since there was little change in the amount of habitat from low to high flow (figures 7 and 8). Compared to No Action the monthly variation in the amount of fry habit for the Joint Alternatives (i.e. Wymer Dam and Reservoir, Wymer Plus and Black Rock) was -26.8% to 0.8% for spring Chinook and -20.9% to 1.1% for steelhead.

3.2.1.2 Subyearling Habitat

Except for the month of August, the amount of spring Chinook subyearling habitat was comparable for all alternatives for each month (figure 9). For August there was less (-9.5%) spring Chinook subyearling habitat for No Action compared to the Joint Alternatives.

The amount of steelhead subyearling habitat was nearly identical for all alternatives and for all months with the exception of Black Rock for June, which was approximately 6% greater than for the other alternatives (figure 10).

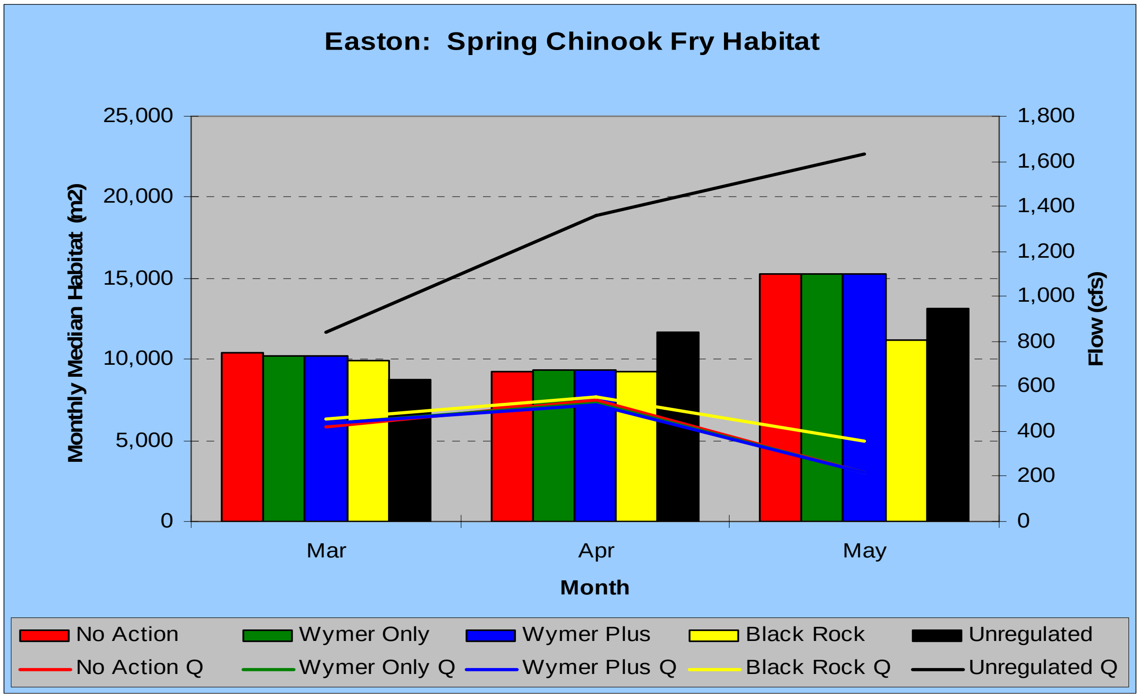


Figure 7. Summary of the amount of median monthly spring Chinook fry habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

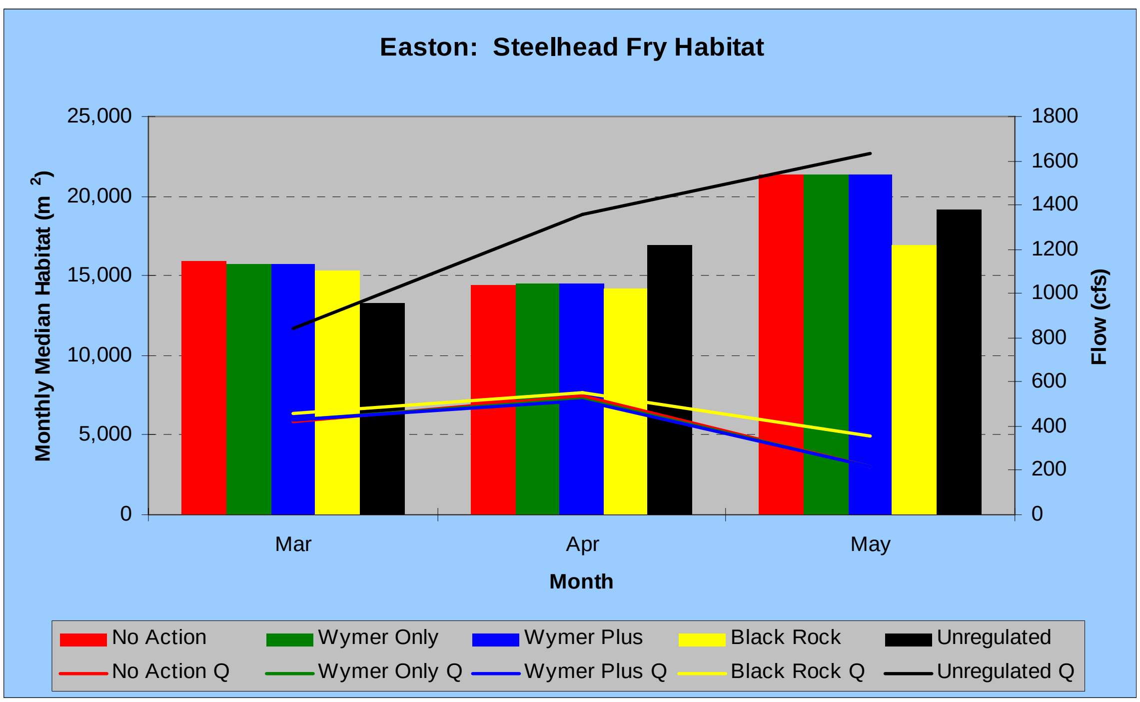


Figure 8. Summary of the amount of median monthly steelhead fry habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

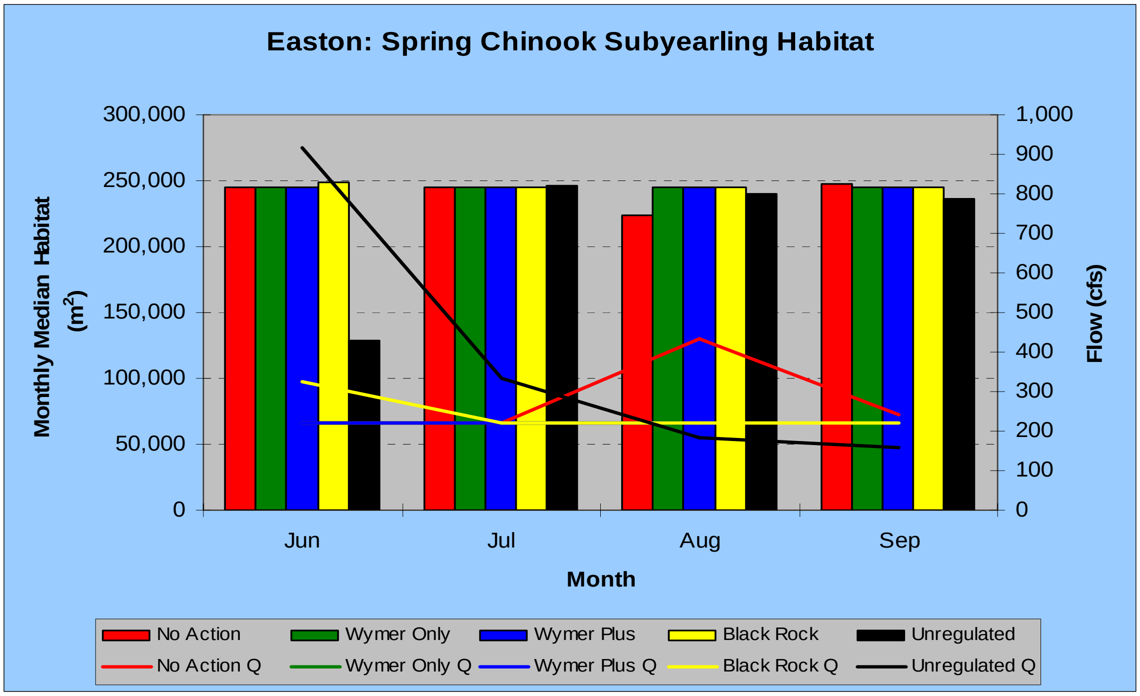


Figure 9. Summary of the amount of median monthly spring Chinook summer subyearling habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

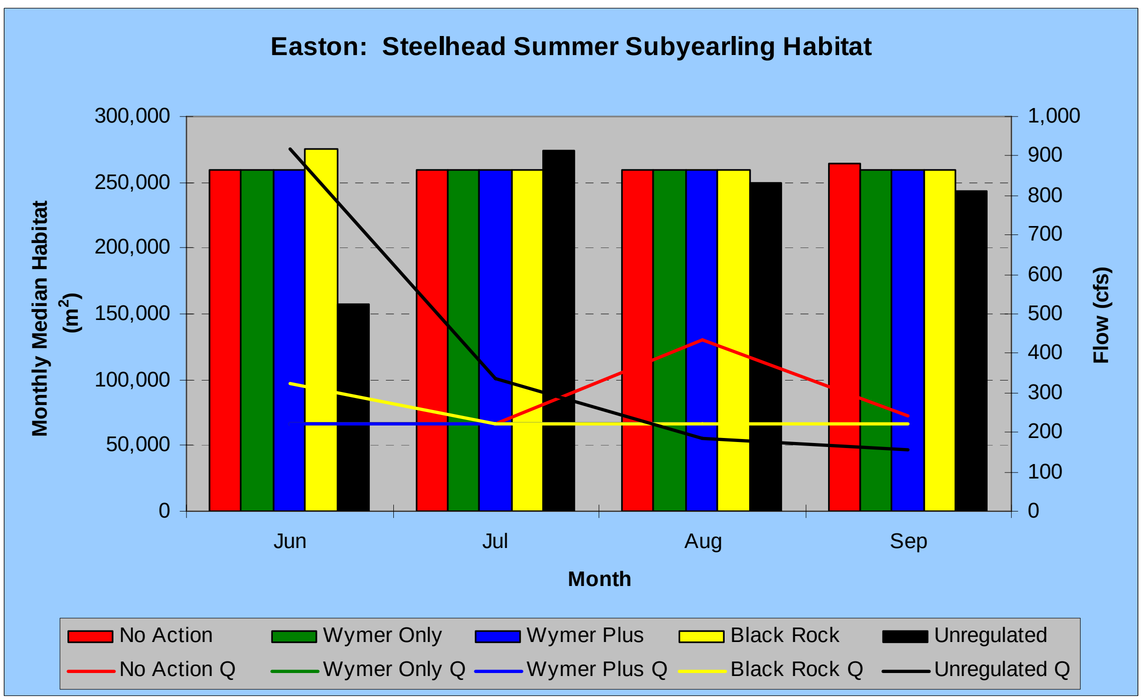


Figure 10. Summary of the amount of median monthly steelhead summer subyearling habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

3.2.1.3 Unregulated Condition

The unregulated flow regime for spring Chinook and steelhead fry habitat increased steadily from March through May as flow increased (figures 7 and 8). The amount of spring Chinook and steelhead fry habitat for the unregulated flow regime was less in March than for all the alternatives; in April it was greater than for all the alternatives; and in May it was greater than for Black Rock, but less compared to the remaining alternatives.

The amount of spring Chinook and steelhead summer subyearling habitat for the unregulated flow regime was similar to that of the other alternatives in July, August and September and lower than the other alternatives in June (figures 9 and 10).

3.2.2 Ellensburg Reach

For the Ellensburg 2-D hydrodynamic model 13 flows were simulated between 400 cfs to 10,000 cfs. In this discussion only simulated flows between 400 cfs to 6,500 cfs are presented since all monthly median flows for the alternatives occurred within this range. The flow-to-habitat curves were similar for spring Chinook and steelhead for both the fry and summer subyearling lifestages. And the amount of steelhead habitat for any given flow was consistently greater than for spring Chinook (figure 11).

There was not a substantial change in the amount of spring Chinook or steelhead fry habitat from low (400 cfs) to high (6,500 cfs) flow. The amount of spring Chinook summer subyearling habitat increased slightly from 400 cfs to 540 cfs then decreased slightly up to 800 cfs, then it decreased steadily up to 2,770 cfs, after which the amount of spring Chinook summer subyearling habitat slowly increased. Steelhead summer subyearling habitat increased from 400 cfs up to 800 cfs, then decreased steadily up to 2,770 cfs, after which the amount of habitat began to increase slowly as flow increased.

3.2.2.1 Fry Habitat

The percent difference in spring Chinook fry habitat comparing the Joint Alternatives to No Action varied from -3.7% to 6.9% depending upon the month (figure 12).

The percent difference in steelhead fry habitat for the Joint Alternatives compared to No Action varied from -5.6% to 4.9% depending on the month (figure 13).

3.2.2.2 Subyearling Habitat

With the exception of Black Rock for September (21.6%), the percent change in spring Chinook summer subyearling habitat varied between -7.3% to 0.9% for all alternatives compared to No Action depending on the month (figure 14).

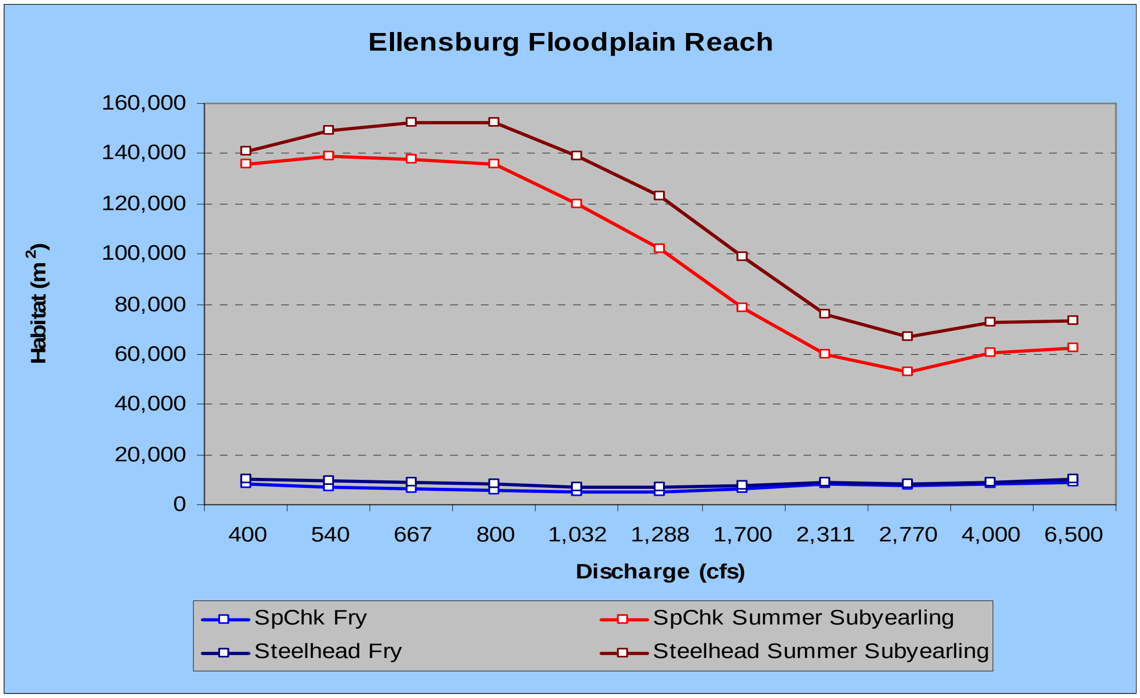


Figure 11. Flow-to-habitat curves for spring Chinook and steelhead for the fry and summer subyearling lifestages for the Ellensburg floodplain reach.

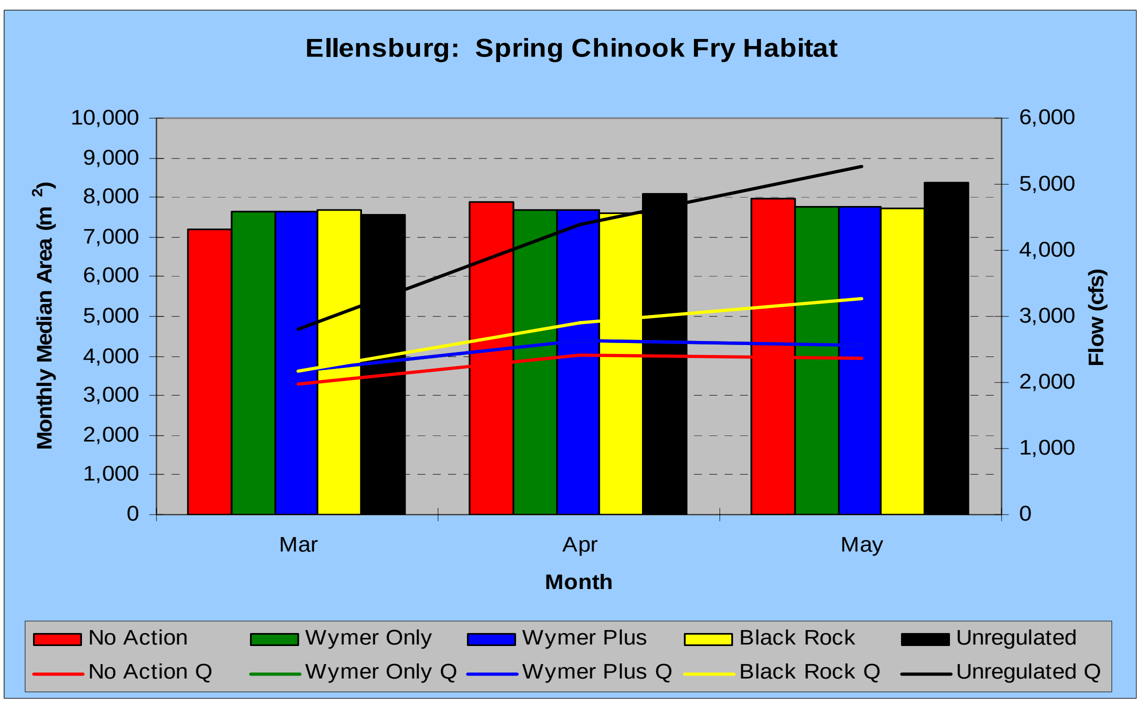


Figure 12. Summary of the amount of median monthly spring Chinook fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

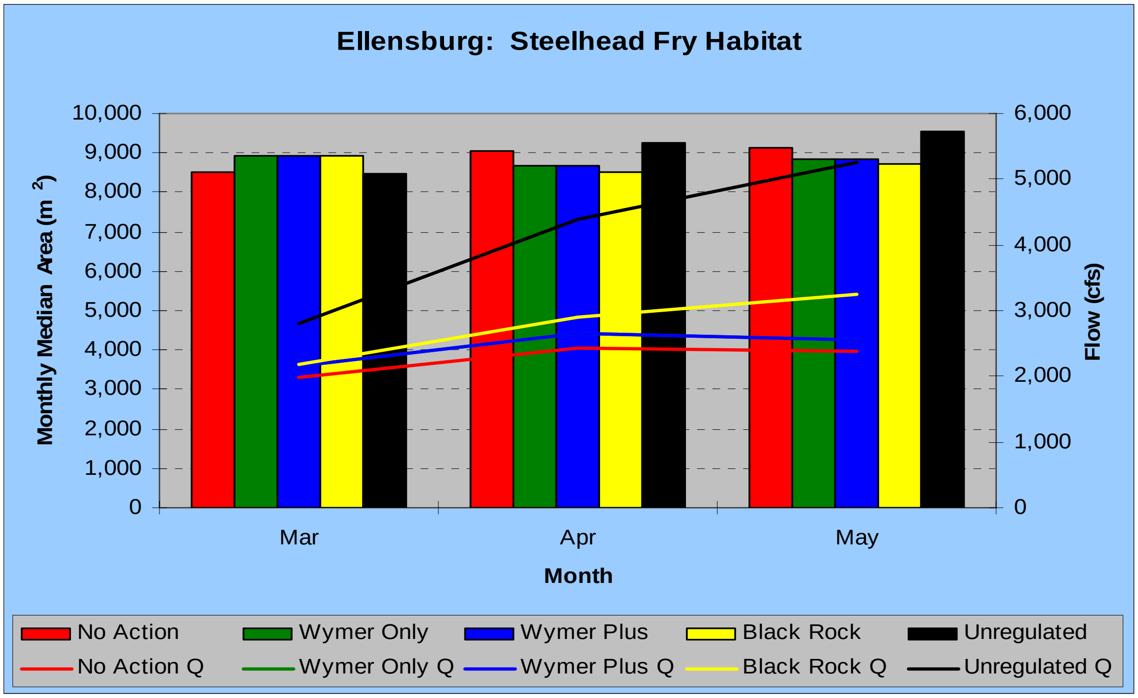


Figure 13. Summary of the amount of median monthly steelhead fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

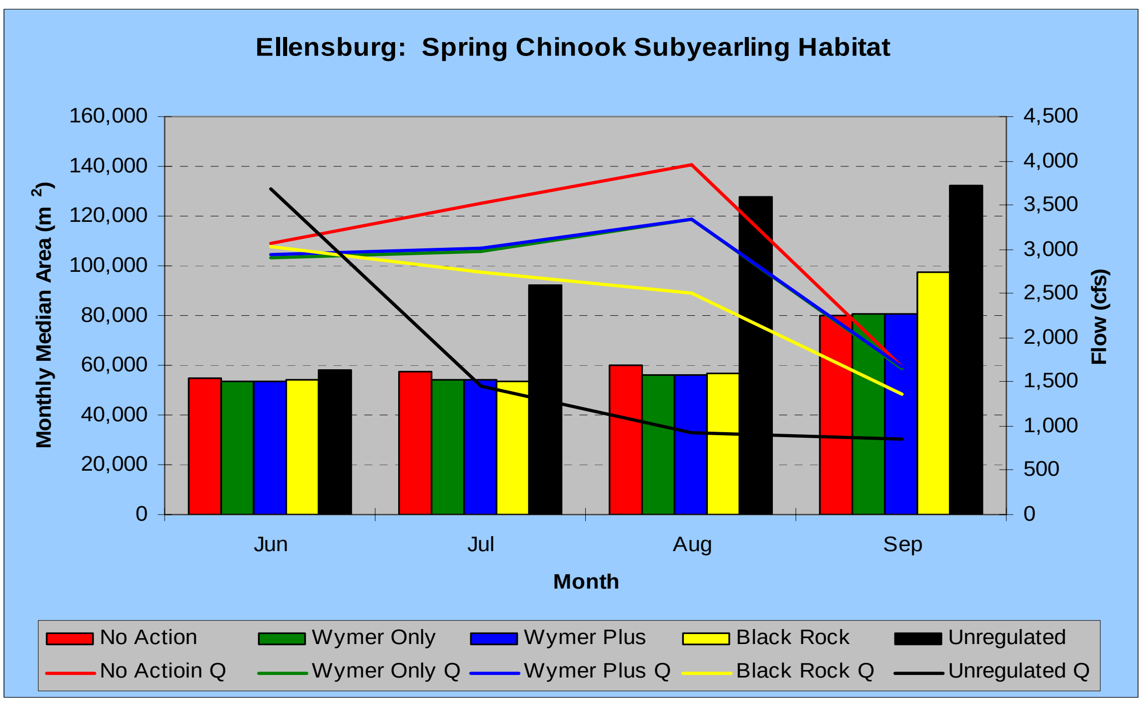


Figure 14. Summary of the amount of median monthly spring Chinook summer subyearling habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

Similar to spring Chinook the percent change in steelhead summer subyearling habitat (figure 15) changed minimally (-4.0% to 0.8%) between the Joint Alternatives and months compared to No Action, with the exception of Black Rock for September (17.6%).

3.2.2.3 Unregulated Condition

The unregulated flow regime for spring Chinook and steelhead fry habitat increased steadily from March through May as flow increased (figures 12 and 13). The amount of spring Chinook and steelhead fry habitat for the unregulated flow regime for March was comparable to the Joint Alternatives and greater than all alternatives for April and May.

The amount of spring Chinook and steelhead summer subyearling habitat for the unregulated flow regime was always greater on a monthly basis compared to all the alternatives, and steadily increased from March through September as flow declined (figures 14 and 15).

3.2.3 Lower Naches Reach

Both spring Chinook and steelhead for fry and summer subyearling lifestages had similar flow-to-habitat curves, and the amount of steelhead habitat for both lifestages was somewhat greater than for spring Chinook for a given flow (figure 16). There was not a substantial change in the amount of spring Chinook or steelhead fry habitat from low (250 cfs) to high (8,000 cfs) flow. Spring Chinook fry habitat ranged from 8,782 m^2 at 500 cfs to 17,361 m^2 at 3,000 cfs, which equates to a maximum percent difference in habitat of 98%. The amount of steelhead fry habitat was 15,742 m^2 at low flow (1,500 cfs) and was 24,079 m^2 at high flow (8,000 cfs). The quantity of spring Chinook summer subyearling habitat decreased slightly from 250 cfs to 1,500 cfs, and then continued to increase up to 8,000 cfs. Steelhead summer subyearling habitat increased from 250 cfs up to 500 cfs, then slowly decreased up to 1,500 cfs, and then increased steadily up to 8,000 cfs.

3.2.3.1 Fry Habitat

There was not much difference between alternatives in the amount of spring Chinook and steelhead fry habitat on a monthly basis, and the amount of habitat for all alternatives was greatest in May (figures 17 and 18). Compared to No Action the percent change in spring Chinook habitat for the Joint Alternatives ranged from 0.0% to 6.5% depending on the month, and for steelhead it was 0.0% to 4.4%.

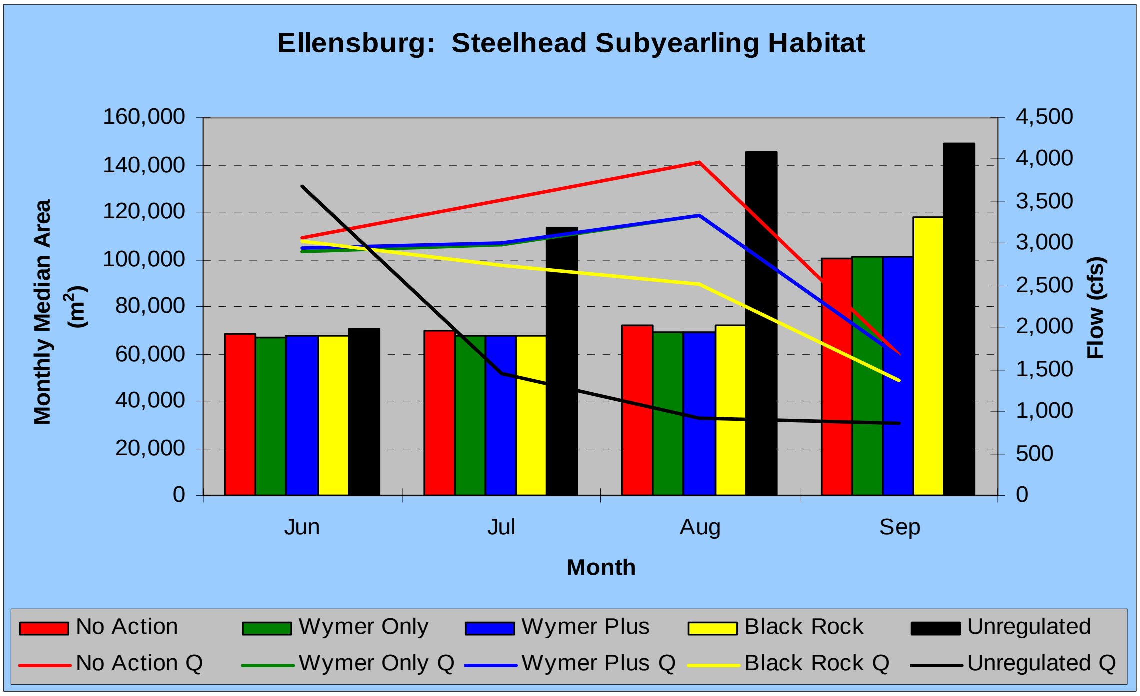


Figure 15. Summary of the amount of median monthly steelhead summer subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

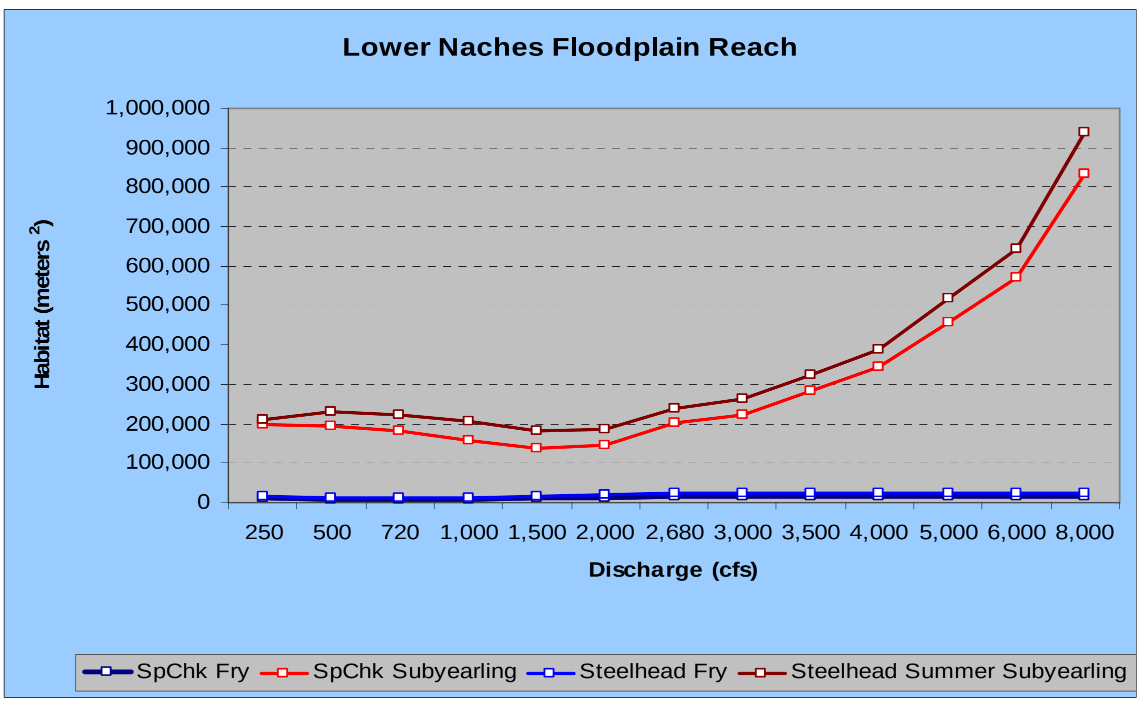


Figure 16. Flow-to-habitat curves for spring Chinook and steelhead for the fry and summer subyearling lifestages for the lower Naches floodplain reach.

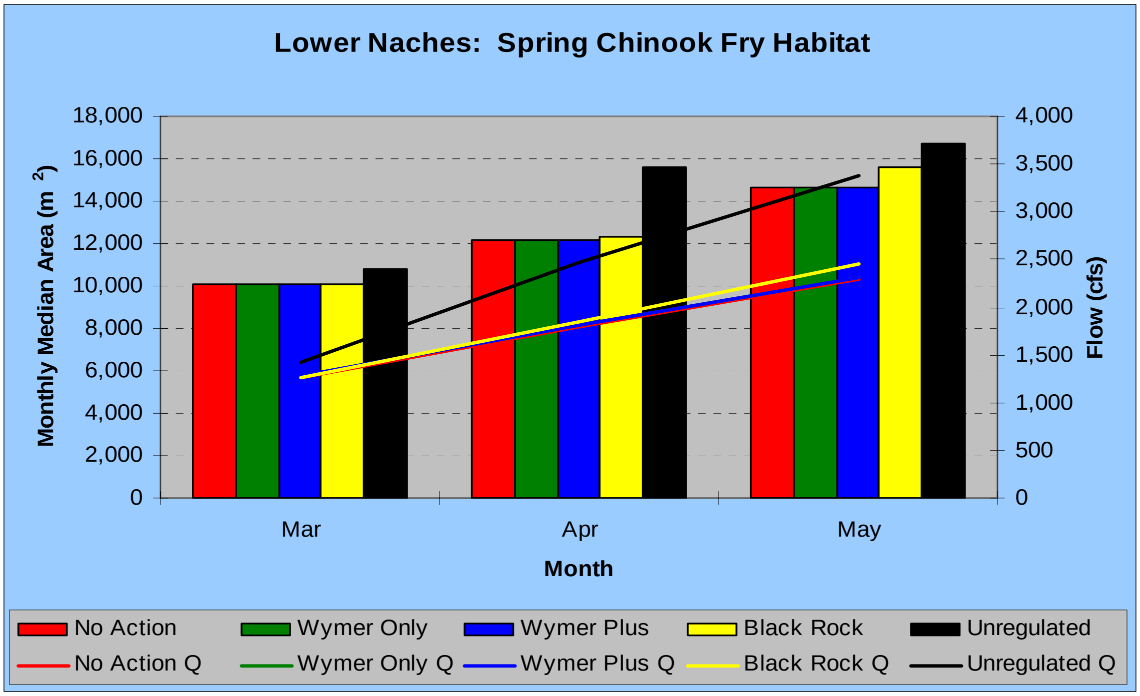


Figure 17 Summary of the amount of median monthly spring Chinook fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

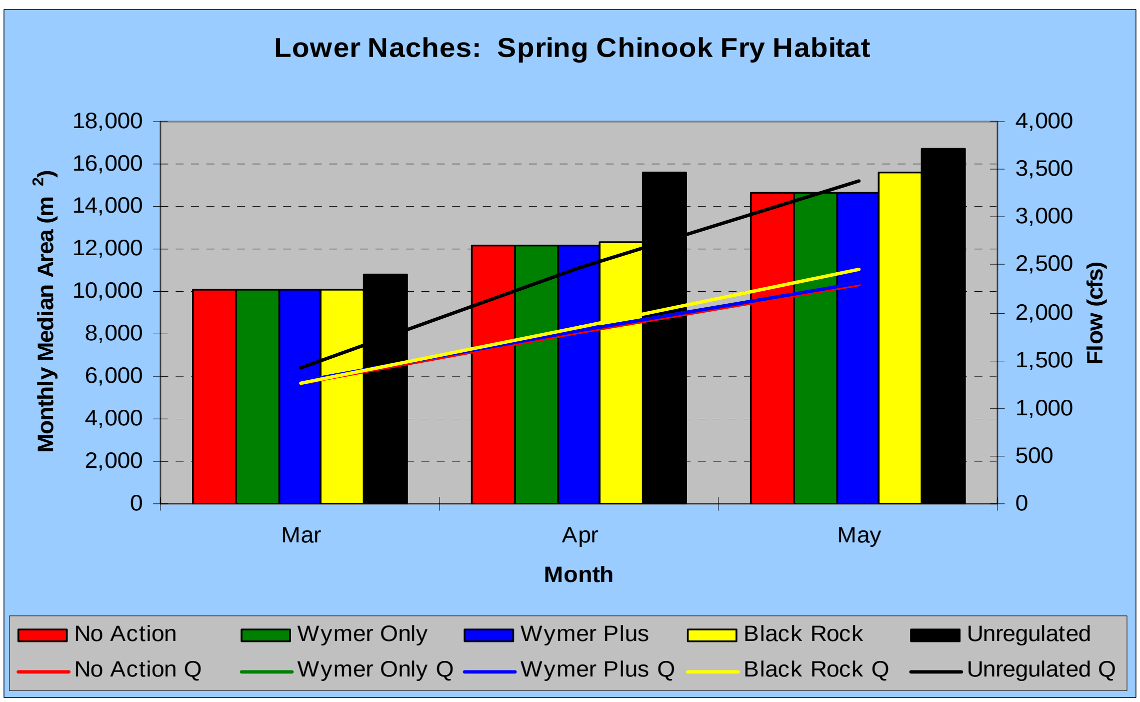


Figure 18. Summary of the amount of median monthly steelhead fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

3.2.3.2 Subyearling Habitat

On a monthly basis there was not a substantial difference in the percent change in spring Chinook and steelhead summer subyearling habitat between alternatives. The percent change in spring Chinook summer subyearling habitat varied from 0.0% to 6.5% depending on the month, and for steelhead it varied from -2.5% to 6.8% (figures 19 and 20).

3.2.3.3 Unregulated Condition

The unregulated flow regime for spring Chinook and steelhead fry habitat increased steadily from March through May as flow increased (figures 17 and 18). The amount of spring Chinook and steelhead fry habitat for the unregulated flow regime for all months was somewhat greater compared to all alternatives, and increased as a function of increasing flow.

The amount of spring Chinook subyearling habitat for the unregulated flow regime was greater for June (34.9% compared to No Action) and for September (39.3% compared to No Action) than for all of the alternatives; and was comparable for July and August; and for steelhead subyearling habitat it also was greater for June (23.0% compared to No Action) and for September (25.8% compared to No Action) than for all of the alternatives; and was comparable for July and August (figures 19 and 20).

3.3 Upper Yakima Summer Flows and Habitat for Resident Rainbow Trout and Bull Trout

3.3.1 Easton

The DSS model the bull trout fry lifestage was temporally defined to occur April through May and for the summer subyearling lifestage to occur June through September. The resident rainbow trout fry lifestage was temporally defined to occur July through August and the summer subyearling lifestage to occur in September.

Bull trout and rainbow trout both had near identical flow-to-fry habitat curves (figure 21). The amount of fry habitat for both species slowly decreased from 150 cfs up to 700 cfs, after which it slowly increased. Minimum and maximum fry habitat for bull trout and rainbow trout occurred at 700 cfs and at 900 cfs, and at 3,500 cfs and 3,500 cfs, respectively.

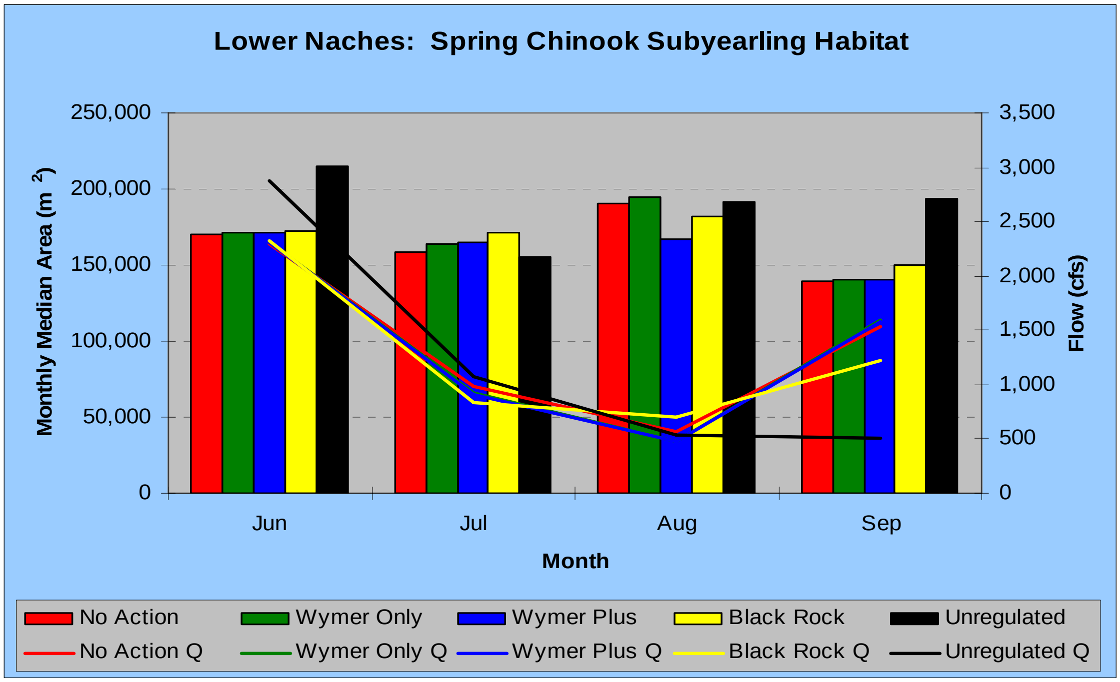


Figure 19. Summary of the amount of median monthly spring Chinook summer subyearling habitat and flow for each alternative for the lower Naches floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

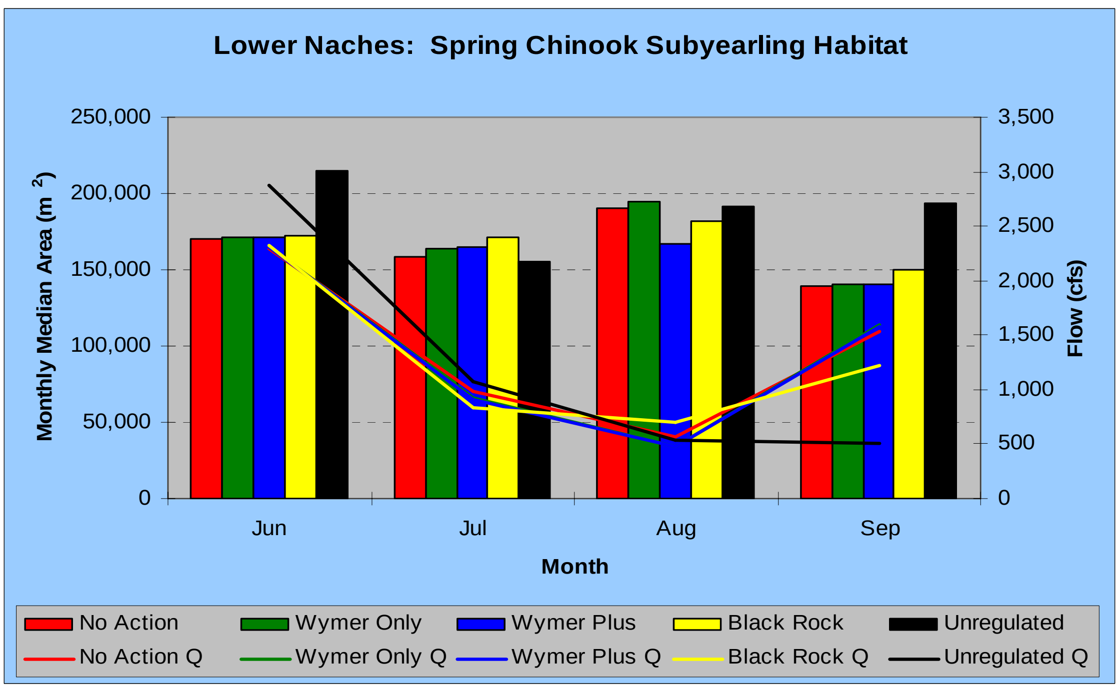


Figure 20. Summary of the amount of median monthly steelhead summer subyearling habitat and flow for each alternative for the lower Naches floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

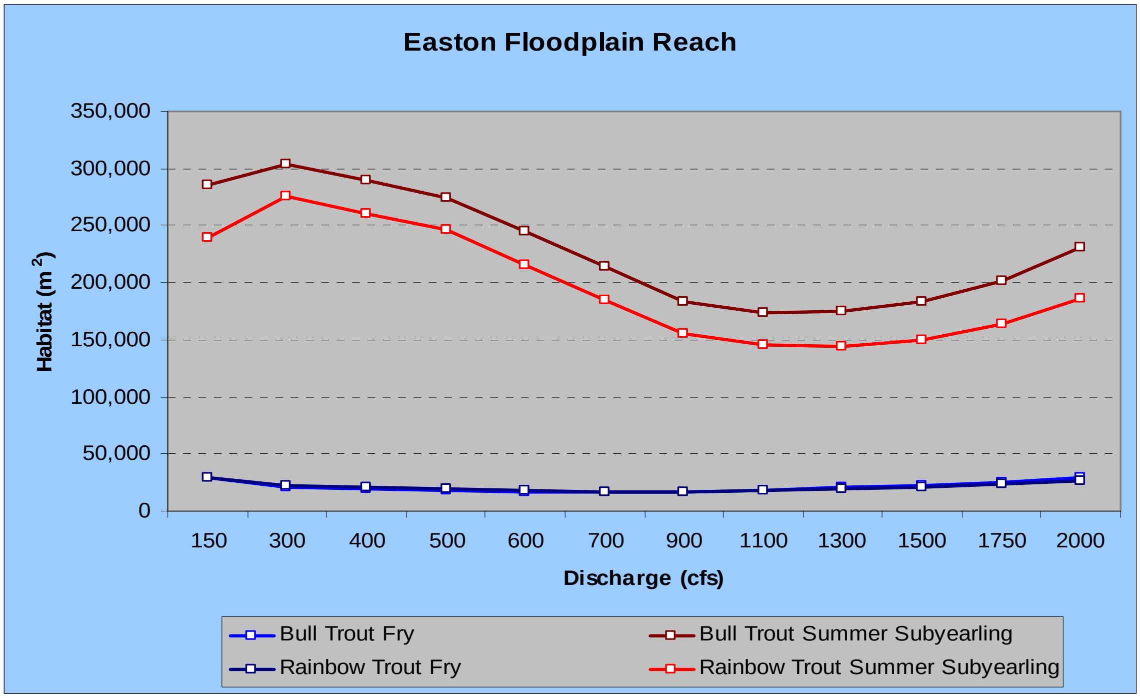


Figure 21. Flow-to-habitat curves for bull trout and resident rainbow trout for the fry and summer subyearling lifestages for the Easton floodplain reach.

The flow-to-summer subyearling habitat curves for bull trout and rainbow trout had similar patterns, and more bull trout habitat than rainbow trout habitat occurred at a given flow (figure 21). The amount of bull trout and rainbow trout summer subyearling habitat increased from 150 cfs to 300 cfs, then decreased up to 1,100 to 1,300 cfs, after which it began to increase.

3.3.1.1 Fry Habitat

The amount of bull trout fry habitat for April was nearly the same (~17,300 to ~17,500 m^2) for all alternatives, and in May it was the same (25,708 m^2) for all but the Black Rock Alternative, which was less (20,265 m^2) (figure 22).

The amount of rainbow trout fry habitat for July and August was identical (26,353 m^2) for all alternatives, with the exception of No Action for August (20,276 m^2) (figure 23).

3.3.1.2 Summer Subyearling Habitat

There was minimal difference (284,272 to 300,651 m^2) in the amount of bull trout summer subyearling habitat between the alternatives for every month (figure 24).

The amount of rainbow trout summer subyearling habitat was identical (256,325 m^2) for all but the No Action Alternative, which was somewhat greater (261,111m^2) (figure 25).

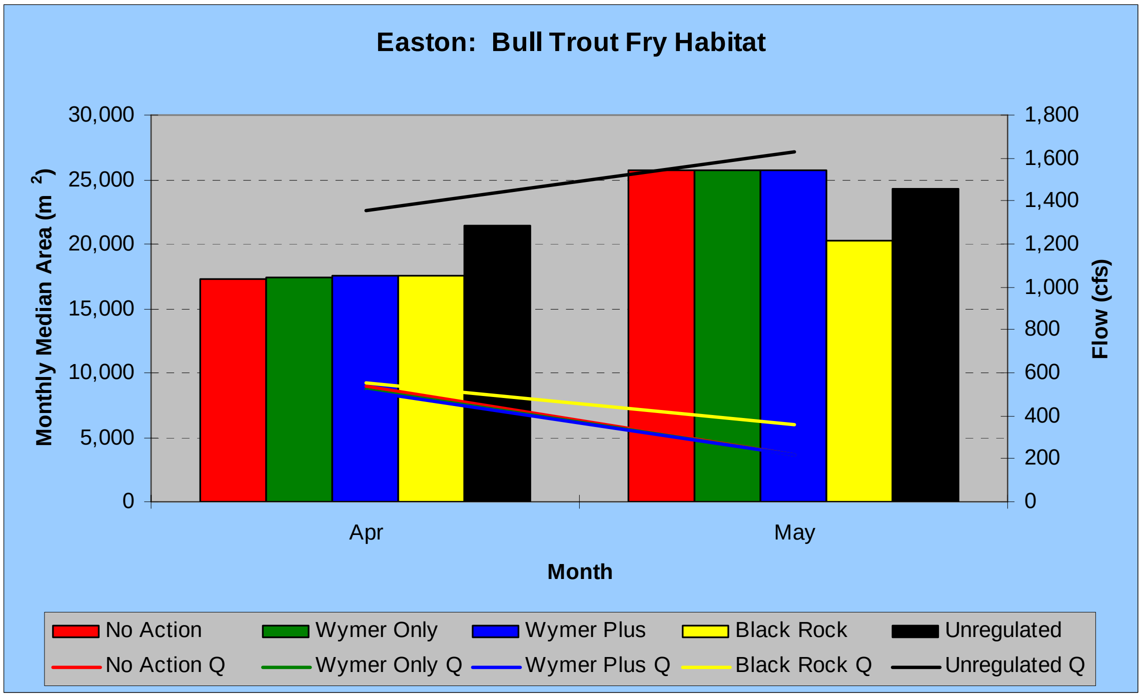


Figure 22. Summary of the amount of median monthly bull trout fry habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

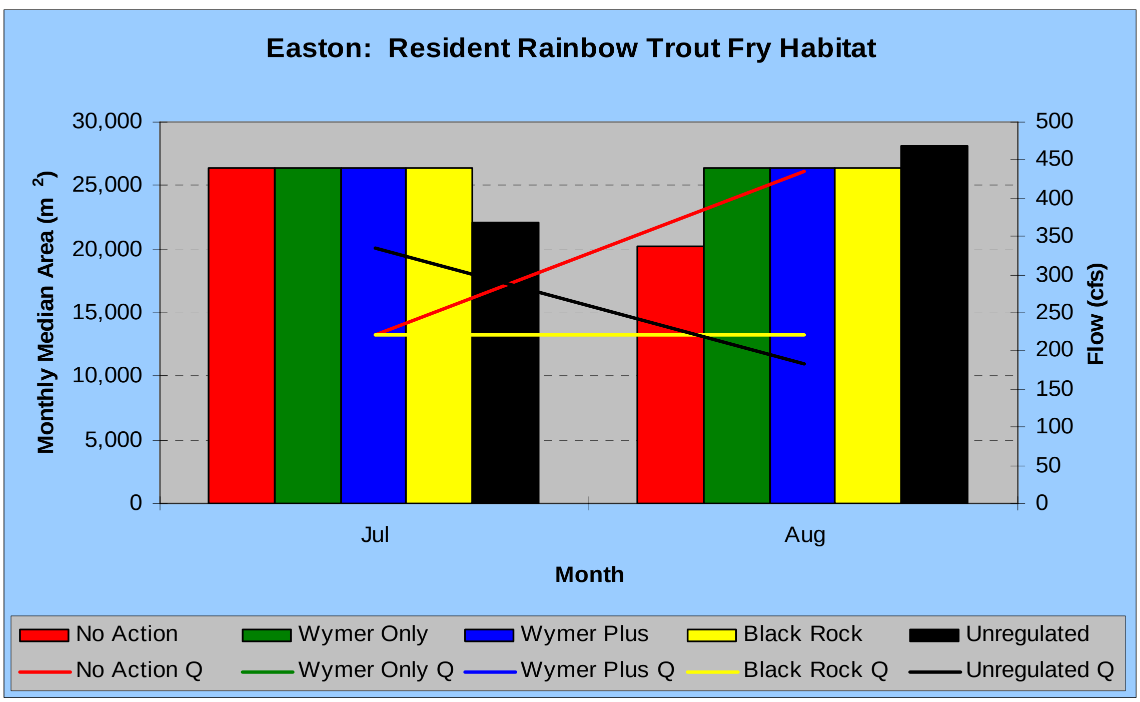


Figure 23. Summary of the amount of median monthly resident rainbow trout fry habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

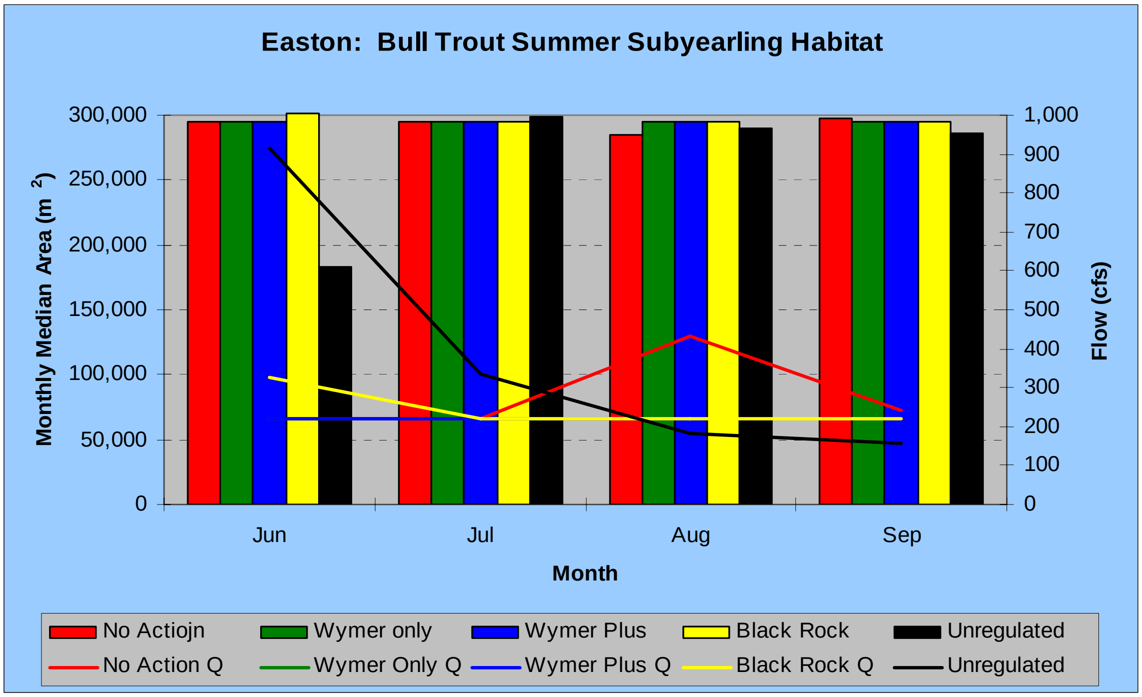


Figure 24. Summary of the amount of median monthly bull trout summer subyearling habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

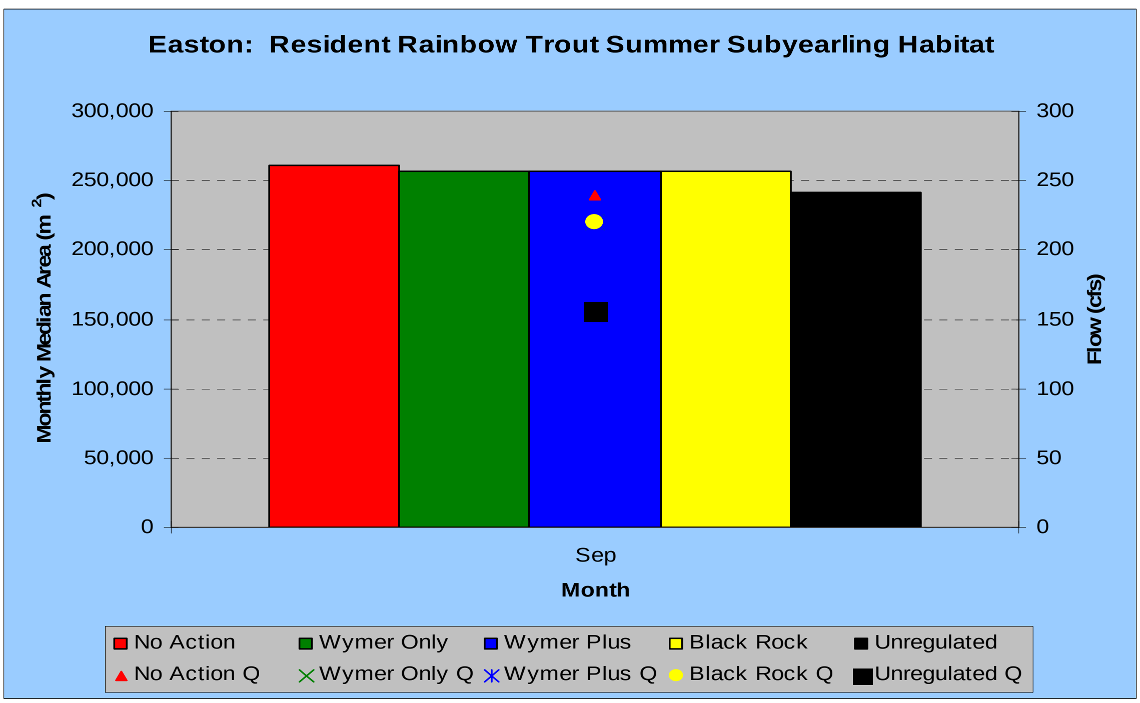


Figure 25. Summary of the amount of median monthly resident rainbow summer subyearling habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

3.3.1.3 Unregulated Condition

Under the unregulated flow regime bull trout fry habitat increased from April to May as flow increased; and rainbow trout fry habitat increased from July to August as flow decreased (figures 22 and 23).

Under the unregulated flow regime bull trout subyearling habitat was comparable to the other alternatives in July, August and September, and substantially less (-39.3% compared to No Action) in June; as flows decreased rapidly from June to July and then more gradually through September (figure 24). Rainbow trout subyearling habitat under the unregulated flow regime was less (-7.7%) compared to No Action) than for all the alternatives (figure 25).

3.3.2 Ellensburg

Bull trout and rainbow trout both had near identical flow-to-fry habitat curves (figure 26). The amount of fry habitat for both species decreased slowly from 400 cfs up to 1,288 cfs, after which it slowly increased. Minimum and maximum fry habitat for bull trout and rainbow trout occurred at 1,032 cfs and at 6,500 cfs, and at 1,288 cfs and 4,000 cfs, respectively.

The flow-to-summer subyearling habitat curves for bull trout and rainbow trout had similar patterns, and more bull trout habitat than rainbow trout habitat occurred at a given flow (figure 26). The amount of bull trout summer subyearling habitat increased from 400 cfs to 800 cfs then decreased up to 2,770 cfs, after which it increased. The amount of rainbow trout habitat increased from 400 cfs to 800 cfs, then decreased up to 2,311 cfs, and then slowly increased.

3.3.2.1 Fry Habitat

The amount of bull trout and rainbow trout fry habitat for April and May were similar (~10,400 m^2 to ~10,900 m^2) for all alternatives (figures 27 and 28). Compared to No Action the Joint Alternatives had a percent change in the amount of bull trout fry habitat ranging from -2.7% to 1.4%.

The amount of rainbow trout fry habitat for July and August was similar (~9,700 m^2 to 10,600 m^2) for all alternatives, and the percent change in habitat area for the Joint Alternatives compared to No Action was -18.2% to 0.2% depending on the month (figure 28).

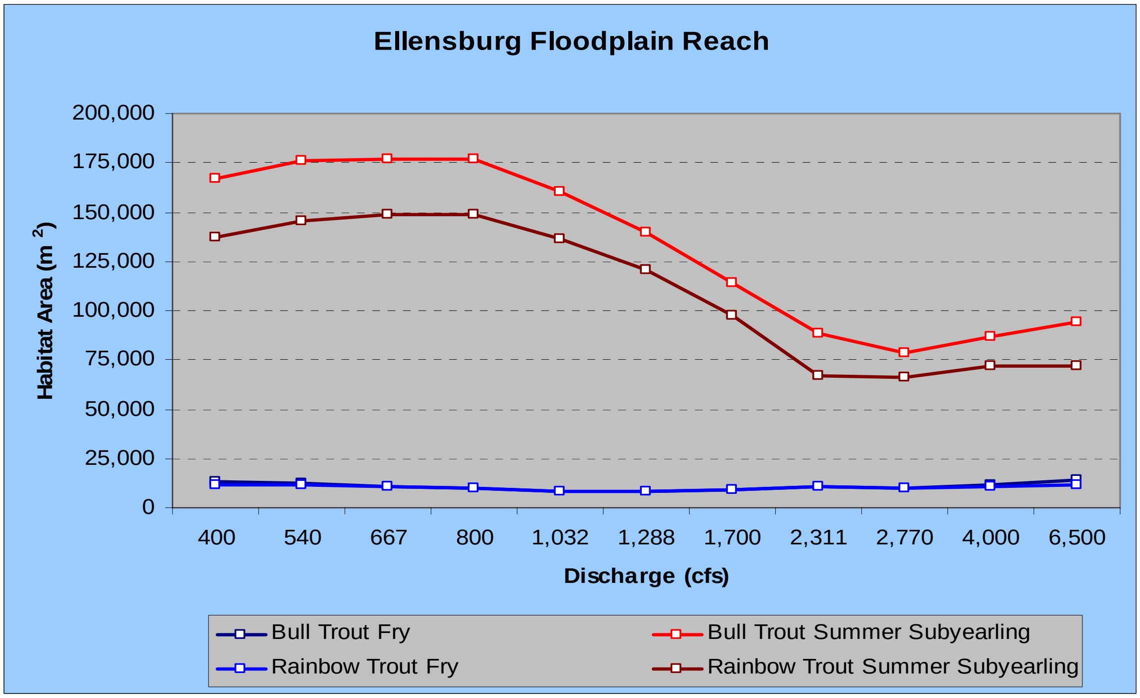


Figure 26. Flow-to-habitat curves for bull trout and resident rainbow trout for the fry and summer subyearling lifestages for the Easton floodplain reach.

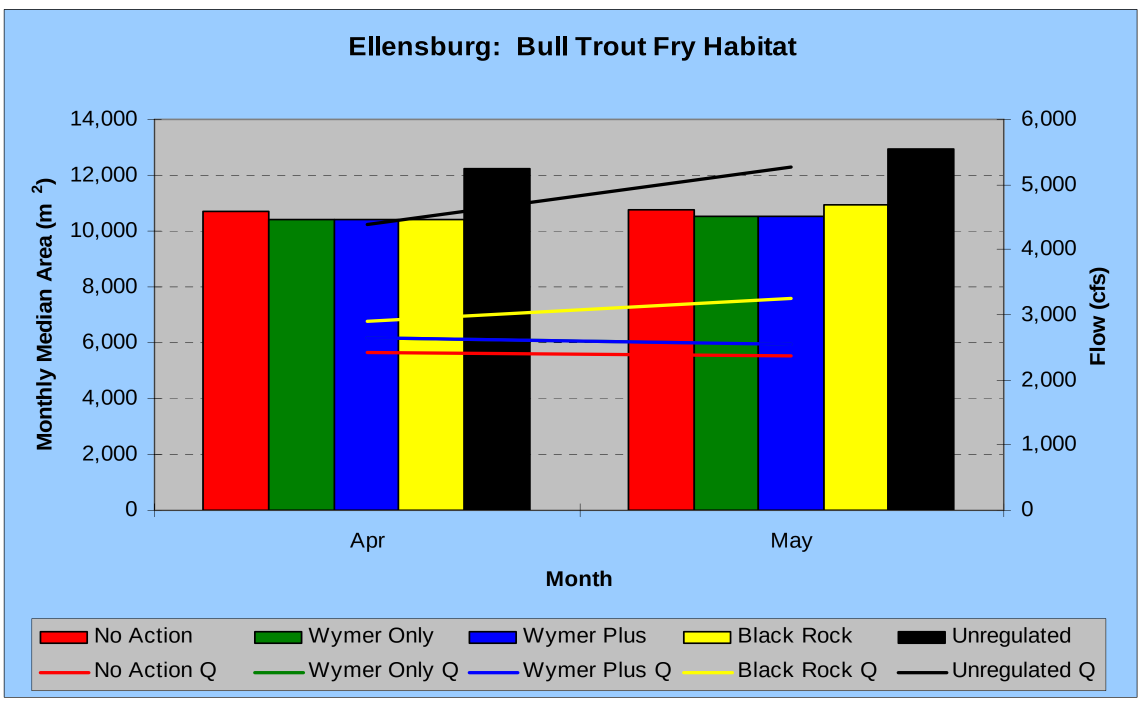


Figure 27. Summary of the amount of median monthly bull trout fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

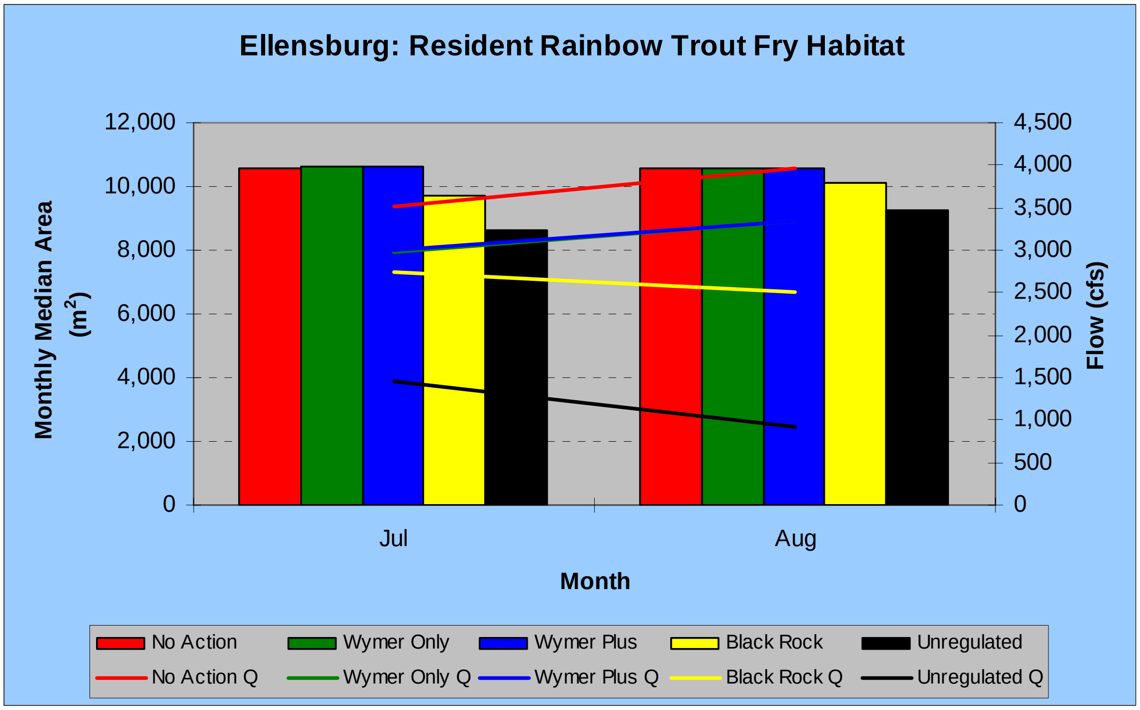


Figure 28. Summary of the amount of median monthly resident rainbow trout fry habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

3.3.2.2 Summer Subyearling Habitat

There was minimal difference (79,407 m^2 to 86,343 m^2) in the amount of bull trout summer subyearling habitat between the alternatives for June, July and August (figure 29). The amount of bull trout summer subyearling habitat in September was greater for all alternatives compared to the other months, and was similar (115,859 m^2 to 116,657 m^2) for all alternatives except Black Rock which was greater (134,522 m^2).

The amount of rainbow trout summer subyearling habitat was nearly the same (~99,000 m^2 to 99,700 m^2) for all but the Black Rock Alternative, which was somewhat greater (116,143 m^2) (figure 30).

3.3.2.3 Unregulated Condition

Under the unregulated flow regime bull trout fry habitat increased from April to May as flow increased; and rainbow trout fry habitat increased slightly from July to August as flow decreased (figures 27 and 28). The amount of fry habitat was greater than all the alternatives for bull trout and less than all the alternatives for rainbow trout for both April and May.

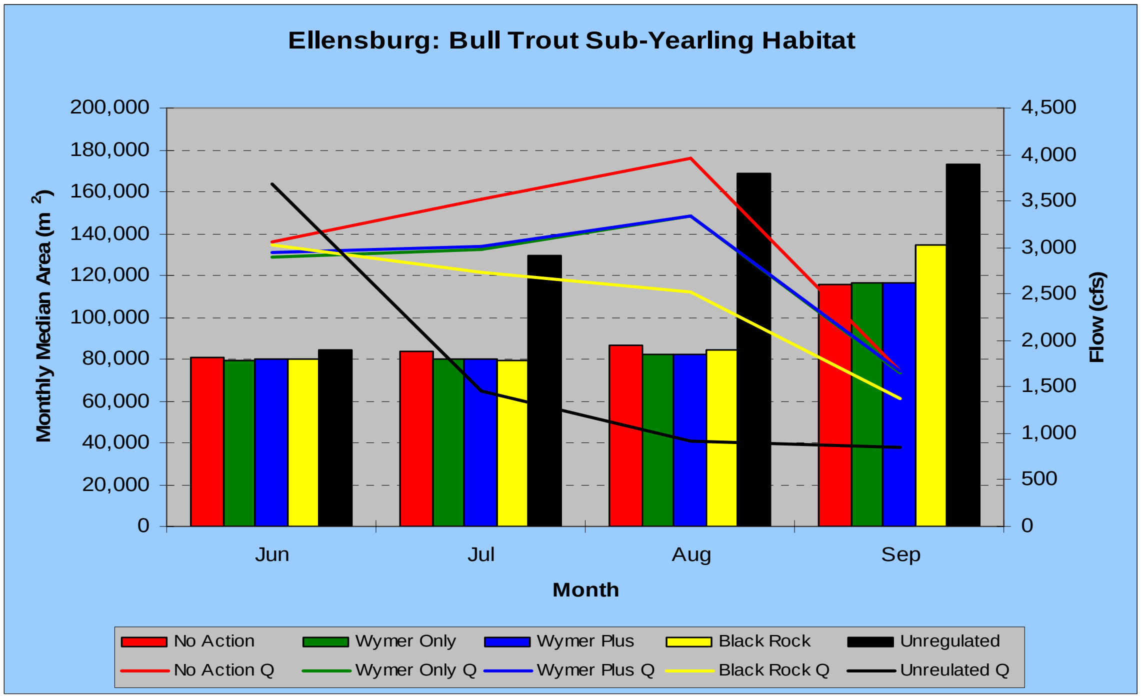


Figure 29. Summary of the amount of median monthly bull trout summer subyearling habitat and flow for each alternative for the Easton floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

Under the unregulated flow regime bull trout subyearling habitat increased from June to September and was always greater (4.9% to 95.1% compared to No Action) than the amount of habitat for the alternatives (figure 29); and flows decreased rapidly from June to July and then decreased slowly from July to September. Rainbow trout subyearling habitat under the unregulated flow regime was greater (47.2% compared to No Action) than for all the alternatives (figure 30).

3.4 Lower Naches Summer Flows and Habitat for Resident Rainbow Trout and Bull Trout

Bull trout and rainbow trout both had near identical flow-to-fry habitat curves (figure 31). The amount of fry habitat for both species was nearly constant from 250 cfs up to 1,500 cfs, then increased slightly up to 2,680 cfs, and then leveled off remained fairly constant. Minimum and maximum fry habitat for bull trout and rainbow trout occurred at 1,000 cfs and at 4,000 cfs, and at 1,000 cfs and 8,000 cfs, respectively.

The flow-to-summer subyearling habitat curves for bull trout and rainbow trout had similar patterns, and more bull trout habitat than rainbow trout habitat occurred at a given flow. The amount of summer subyearling habitat for both species increased from 250 cfs to 500 cfs, then decreased up to 1,500 cfs, and then steadily increased.

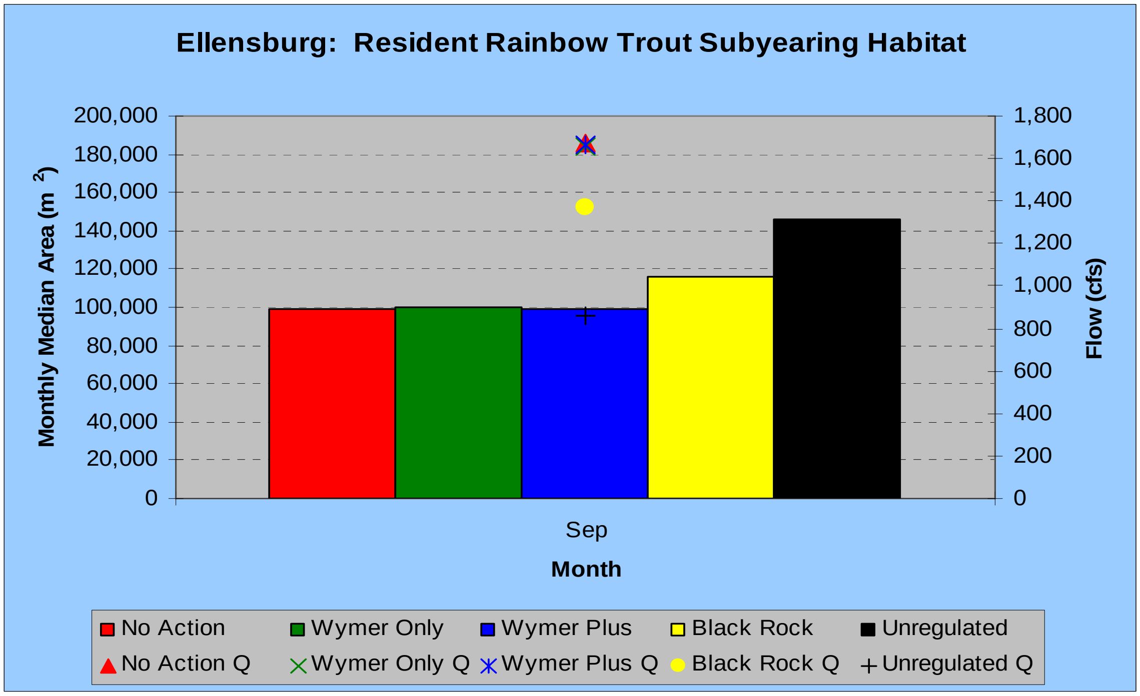


Figure 30. Summary of the amount of median monthly resident rainbow summer subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

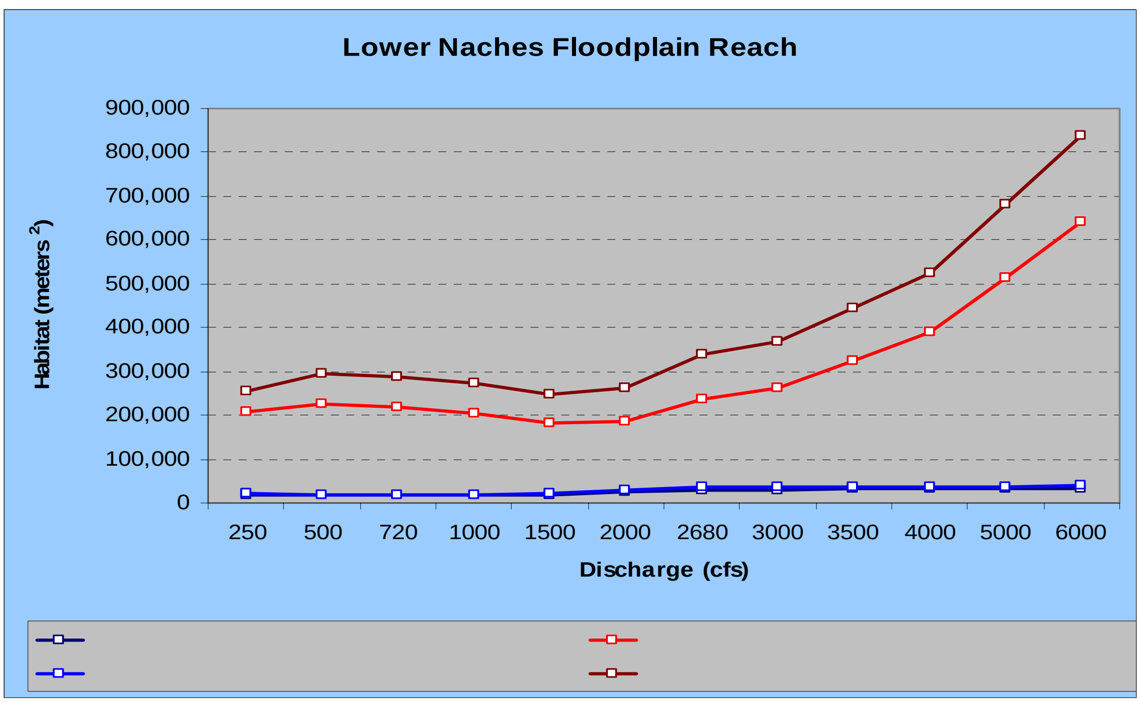


Figure 31. Flow-to-habitat curves for bull trout and resident rainbow trout for the fry and summer subyearling lifestages for the lower Naches floodplain reach.

3.4.1 Fry Habitat

The amount of bull trout fry habitat (~26,200 m^2 to ~27,000 m^2) for April was comparable for all alternatives, as was the case in May (~31,700 to ~33,100 m^2 (figure 32).

The amount of rainbow trout fry habitat for July was least for No Action (17,652 m^2) and increased for the Joint Alternatives (figure 33). The amount of rainbow trout fry habit for August was greater than for July for all alternatives (~18,600 m^2 to 18,800 m^2) and did not vary much between alternatives.

3.4.2 Summer Subyearling Habitat

There was little variation on a monthly basis in the amount of bull trout summer subyearling habitat between the alternatives, and the amount of habitat ranged from a low of approximately 250,000 m^2 for September to a high for June of approximately 300,000 m^2 (figure 34).

The amount of rainbow trout summer subyearling habitat (~250,000 m^2) was nearly the same for all the alternatives, except Black Rock, which was somewhat greater (~260,000 m^2) (figure 35).

3.4.3 Unregulated Condition

Under the unregulated flow regime bull trout fry habitat increased from April to May as flow increased; and rainbow trout fry habitat increased from July to August as flow decreased (figures 32 and 33). The amount of bull trout fry habitat was greater than the amount for all the alternatives for July and August (figure 32). The amount of rainbow trout subyearling habitat for April was greater than that for No Action, Wymer Dam and Reservoir and Wymer Plus, and for May it was less than that for all of the alternatives.

Under the unregulated flow regime bull trout subyearling habitat decreased from June to July and remained fairly constant to September, and was greater than the amount of habitat for the alternatives in June and September and comparable in July and August (figure 34); and flows decreased rapidly from June to July and then decreased slowly from July to September. Rainbow trout subyearling habitat under the unregulated flow regime was greater (18.6% compared to No Action) than for all the alternatives (figure 35).

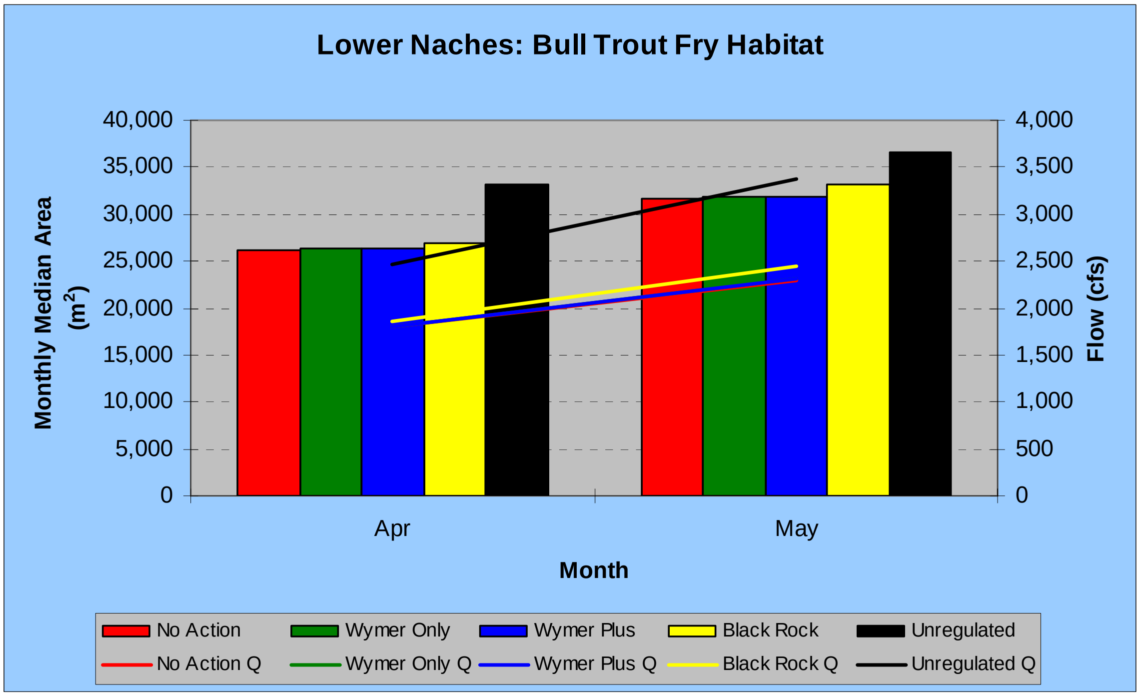


Figure 32. Summary of the amount of median monthly bull trout fry habitat and flow for each alternative for the lower Naches floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

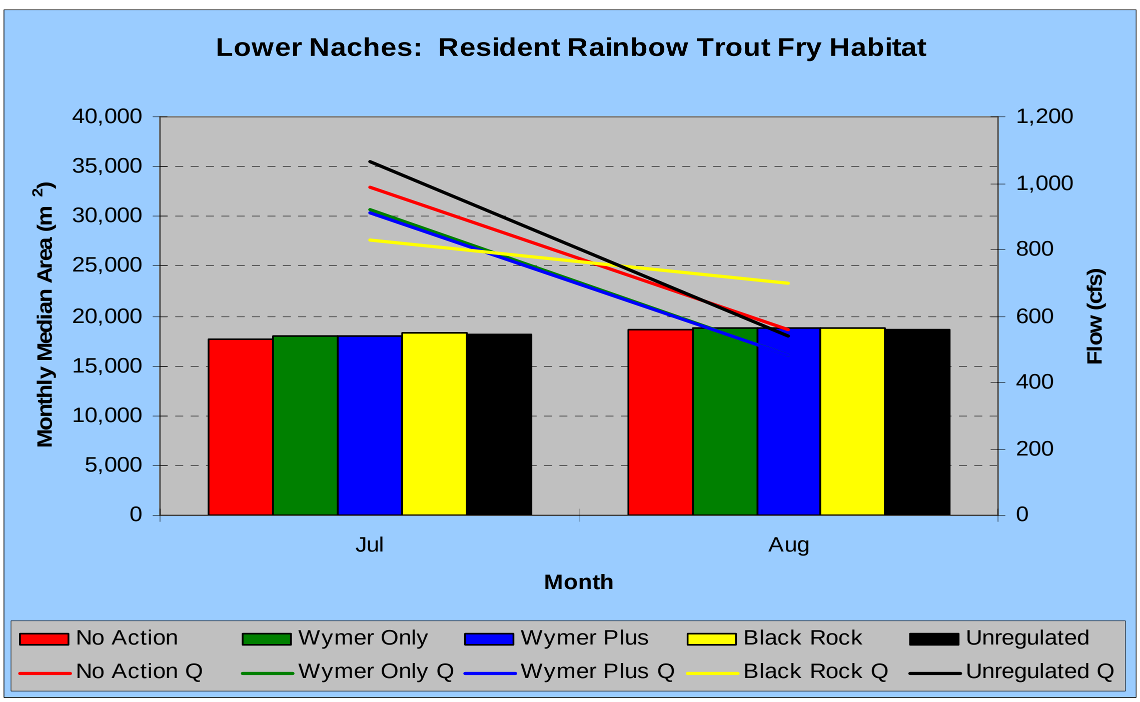


Figure 33. Summary of the amount of median monthly resident rainbow trout fry habitat and flow for each alternative for the lower Naches floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

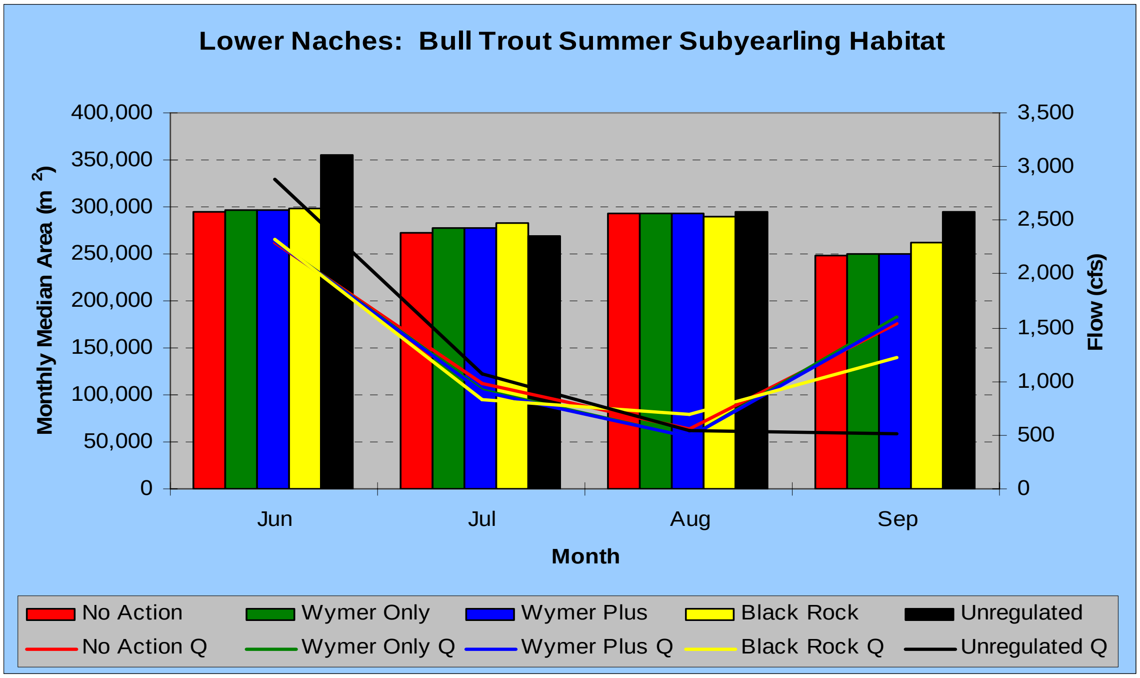


Figure 34. Summary of the amount of median monthly bull trout summer subyearling habitat and flow for each alternative for the lower Naches floodplain reach (Note: the left Y-axis is habitat represented by the columns; the right Y-axis is flow represented by lines.).

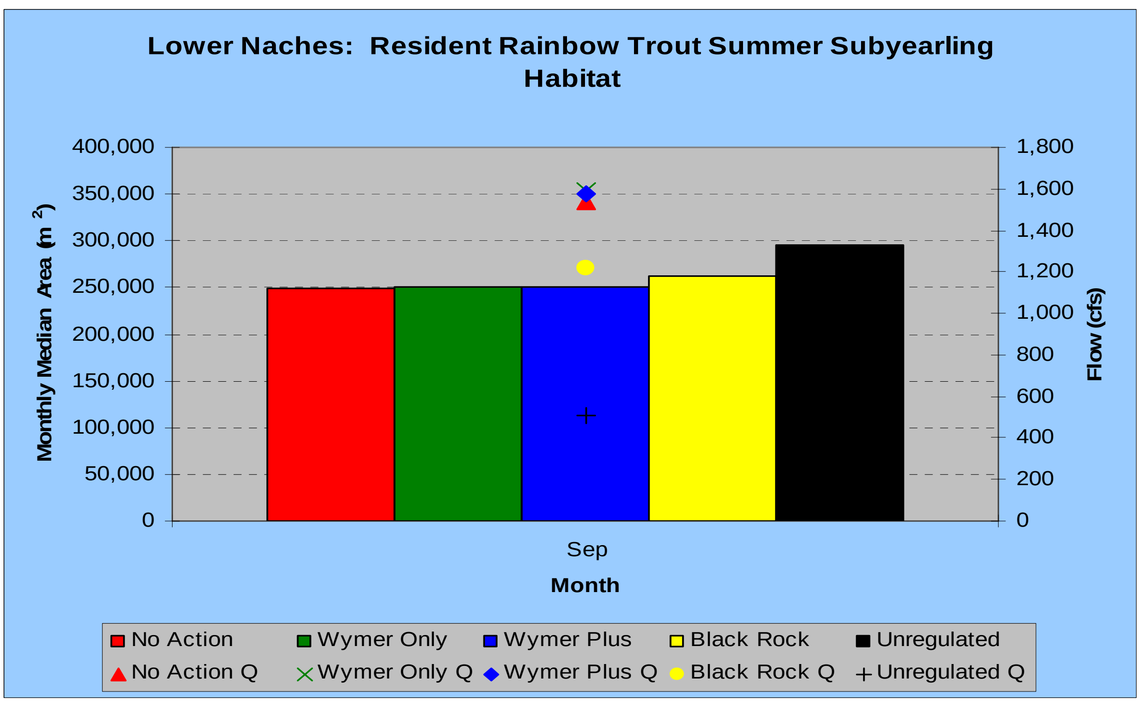


Figure 35. Summary of the amount of median monthly resident rainbow summer subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by lines.).

3.5 Upper Yakima and Lower Naches Flip Flop Operation

3.5.1 Ellensburg Reach

Table 3 presents the median pre and post flip flop flows and difference in flow; and the percent of pre and post flip flop spring Chinook summer subyearling habitat for the Ellensburg reach for each Storage Study alternative and unregulated.

Table 3. Median flow (cfs) for pre (August 1-15) and post (September 15-28) flip flop, and the percent of pre and post flip flop spring Chinook summer subyearling habitat in the Ellensburg reach (Based on Yak-RW model simulated flows for the 1981-2005 period of record.).

Period	Unregulated	No Action	Black Rock	Wymer Dam and Reservoir	Wymer Plus
Aug 1-15	998	3,860	2,774	3,208	3,229
Sep 15-28	834	1,506	1,239	1,507	1,493
Flow Difference	-164	-2,354	-1,535	-1,722	-1,715
Pre Flip Flop Percent Side Channel spring Chinook Summer Subyearling Habitat	18.0%	67.6%	51.8%	58.1%	58.4%
Pre Flip Flop Percent Side Channel spring Chinook Summer Subyearling Habitat	14.7%	25.1%	21.1%	25.1%	24.9%
Pre and Post Flip Flop Absolute Percent Difference	-3.3%	-42.5%	-30.7%	-33.0%	-33.5%

Unregulated flows were the lowest for pre and post flip flop, and had a flow differential of 164 cfs (table 3). For all the alternatives because of much higher flows the percent of pre flip flop side channel spring Chinook summer subyearling habitat was No Action, 67.6%; Black Rock, 51.8%, Wymer Dam and Reservoir, 58.1%; and Wymer Plus, 58.4%. The percent of post flip flop spring Chinook summer subyearling habitat was considerably lower: No Action, 25.1%; Black Rock, 21.1%, Wymer Dam and Reservoir, 25.1%; and Wymer Plus, 24.9%. For the alternatives the absolute percent difference between pre and post flip flop spring Chinook summer subyearling habitat was No Action, -42.5%; Black Rock, -30.7%, Wymer Dam and Reservoir, -33.0%; and Wymer Plus, -33.5%. If the post flip flop flow for Black Rock was similar to the other alternatives (~1,500 cfs) then the absolute percent difference between pre and post flip flop would be reduced from -30.7% to -26.8%.

None of the alternatives are able to reduce the effect of flip flop on side channel (and mainstem) habitat that is comparable to unregulated (-3.3%). Because of this, to the extent that spring Chinook summer subyearling fish are displaced as flow declines during the flip flop operation, there still exists a fairly high potential for displacement of juvenile fish to occur for all the alternatives. Figure 36 illustrates for a small section of the Ellensburg floodplain how spring Chinook summer subyearling habitat shifts from the side channels to the mainstem during flip flop for all of the Storage Study alternatives. In this example the green areas show suitable habitat at 4000 cfs and yellow areas at 540 cfs. Notice that most of the spring Chinook summer subyearling habitat occurs in the main channel at low flows and in the side channels at high flows, and that there is few areas (blue) where habitat overlaps at both flow levels.

3.5.2 Lower Naches Reach

Table 4 presents the median pre and post flip flop flows and difference in flow; and the percent of pre and post flip flop spring Chinook summer subyearling habitat for the lower Naches reach for each Storage Study alternative and unregulated.

Table 4. Median flow (cfs) for pre (August 1-15) and post (September 15-28) flip flop, and the percent of pre and post flip flop spring Chinook summer subyearling habitat in the lower Naches reach (Based on Yak-RW model simulated flows for the 1981-2005 period of record.).

Period	Unregulated	No Action	Black Rock	Wymer Dam and Reservoir	Wymer Plus
Aug 1-15	695	689	621	572	578
Sep 15-28	533	1628	1220	1691	1670
Flow Difference	-163	978	599	1120	1092
October Base Flow (approximate)	400	400	400	400	400
Pre Flip Flop Percent Side Channel spring Chinook Summer Subyearling Habitat	4.7%	3.7%	3.8%	3.2%	3.3%
Pre Flip Flop Percent Side Channel spring Chinook Summer Subyearling Habitat	2.8%	23.8%	14.9%	25.2%	24.7%
Pre and Post Flip Flop Absolute Percent Difference	-1.9%	20.1%	11.1%	22.0%	21.4%

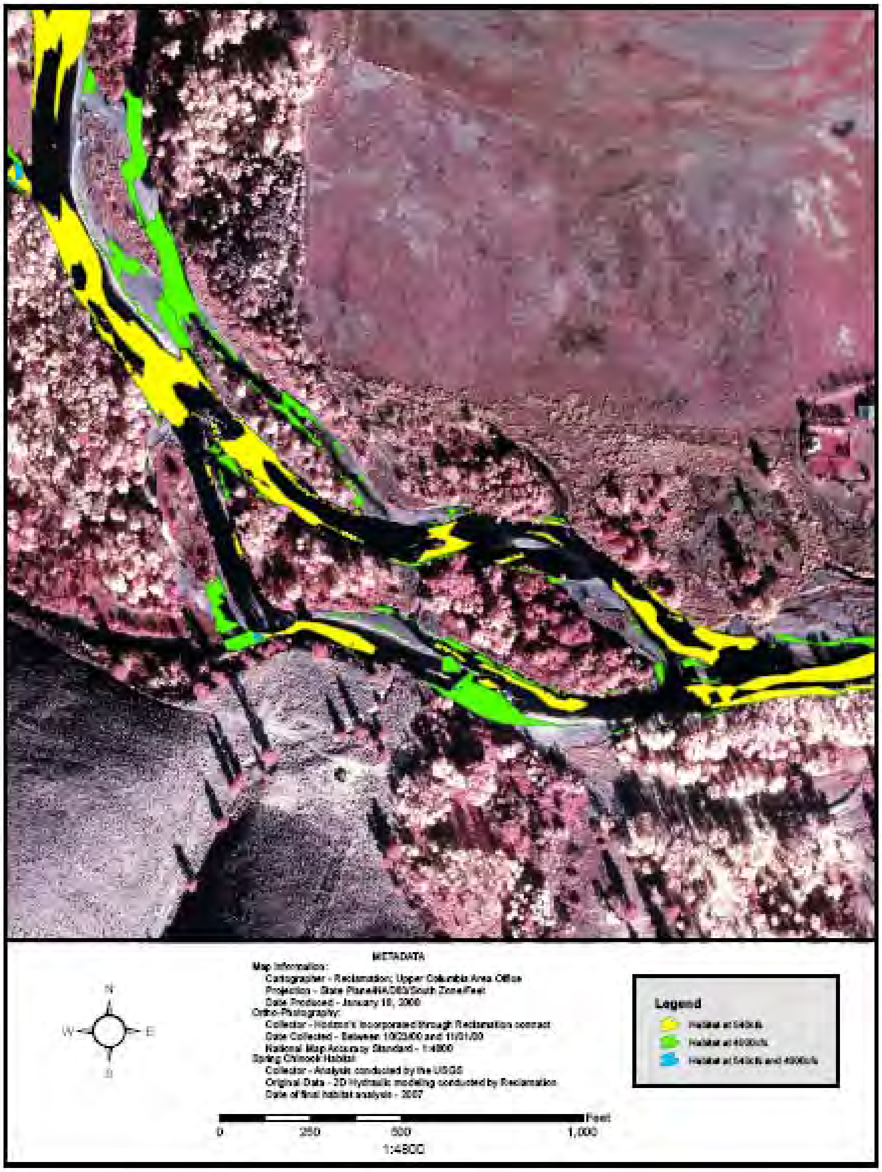


Figure 36. A reach segment located in the Ellensburg floodplain reach showing the location of spring Chinook summer subyearling habitat at 4000 cfs (green) and at 540 cfs (yellow).

The pre flip flop flows were comparable for all the Storage Study alternatives and unregulated (572 cfs to 695 cfs) (table 4). The percent of pre flip flop side channel habitat for spring Chinook summer subyearling was No Action, 3.7%; Black Rock, 3.8%, Wymer Dam and Reservoir, 3.2%; and Wymer Plus, 3.3%.; and the percent of post flip flop side channel habitat for spring Chinook summer subyearling was No Action, 23.8%; Black Rock, 14.9%, Wymer Dam and Reservoir, 25.2%; and Wymer Plus, 24.7%. The absolute percent difference between pre and post flip flop side channel habitat for spring Chinook summer subyearling was No Action, 20.1%; Black Rock, 11.1%, Wymer Dam and Reservoir, 22.0%; and Wymer Plus, 21.4%. Note, however, that for all Storage Study alternatives across all pre, post and October base flow the majority (75% to 98%) of spring Chinook summer subyearling habitat occurs in the mainstem.

Unlike in the upper Yakima River where flows decrease, and remain so, as a result of flip flop; in the lower Naches flows increase as a result of flip flop, and then decrease once the irrigation season is over in late September. Therefore, the potential negative effect of flip flop on spring Chinook summer subyearlings (and other fishes) may be greater. Figure 37 illustrates for a small section of the lower Naches floodplain how spring Chinook summer subyearling habitat shifts from the mainstem at pre flip flop flows, to the side channels at higher post flip flop flows, and then back to the mainstem when flows are reduced once irrigation season ends. Notice under unregulated flows, which represent the normative pattern, there is a steady and gradual (i.e. pre flip flop, ~700 cfs; post flip flop, ~500 cfs; and October base flow, ~400 cfs) there is a corresponding gradual decrease in the percent of spring Chinook summer subyearling habitat.

3.6 Wapato Reach Summer Flows and Habitat

The flow-to-habitat results for the Wapato reach; unlike for the other previously discussed reaches, used the coho summer subyearling lifestage, since it's the only anadromous salmonid lifestage residing at present in the Wapato reach during the summer period.

For the Wapato 2-D hydrodynamic model 12 flows were simulated between 300 cfs to 15,000 cfs, and habitat area was extrapolated for the flows of 150 and 50,000 cfs, and interpolated for 10,000 cfs flow (Bovee pers. comm. on information contained in the draft open file report, 2007). Only simulated, extrapolated or interpolated flows between 150 cfs to 10,000 cfs are presented since all monthly median flows between the alternatives occurred within this range.

Coho summer subyearling habitat decreased from 150 cfs up to 750 cfs, and gradually increased up to 2,500 cfs, after which the amount of habitat increased rapidly as flow increased to 10,000 cfs (figure 38).

3.6.1.1 Summer Subyearling Habitat

With the exception of Black Rock for June, there was little difference between alternatives and months in the amount of summer subyearling coho habitat (figure 39). The percent difference in the amount of coho summer subyearling habitat comparing the Joint Alternatives to No Action were June, 2.4% to 63.8%; July, 0.0% to 4.8%; August, -0.1% to 4.6%; and September, -0.1% to 3.9%.

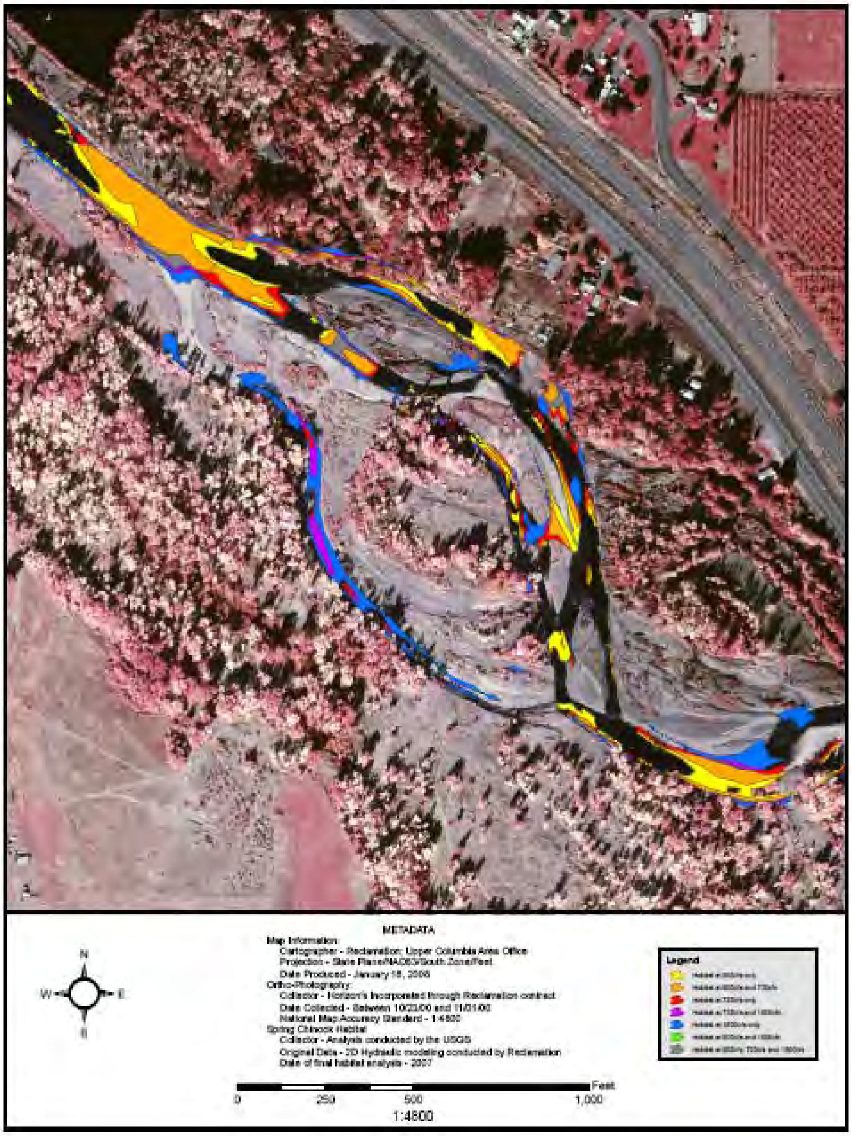


Figure 37. A reach segment located in the lower Naches floodplain reach showing the location of spring Chinook summer subyearling habitat at 1,500 cfs (blue), at 720 cfs (red), and at 500 cfs (yellow). Habitat areas of overlap at multiple flows, Orange, 500 cfs and 720 cfs; purple, 720 cfs and 1,500 cfs; green, 500 cfs and 1,500 cfs; and grey, 500 cfs, 720 cfs and 1,500 cfs.

3.6.1.2 Unregulated Condition

Under the unregulated flow regime coho subyearling habitat decreased from June to August and remained constant in September. Flow decreased rapidly from June to July and continued to decrease slowly to base flow in August and September (figure 4). The

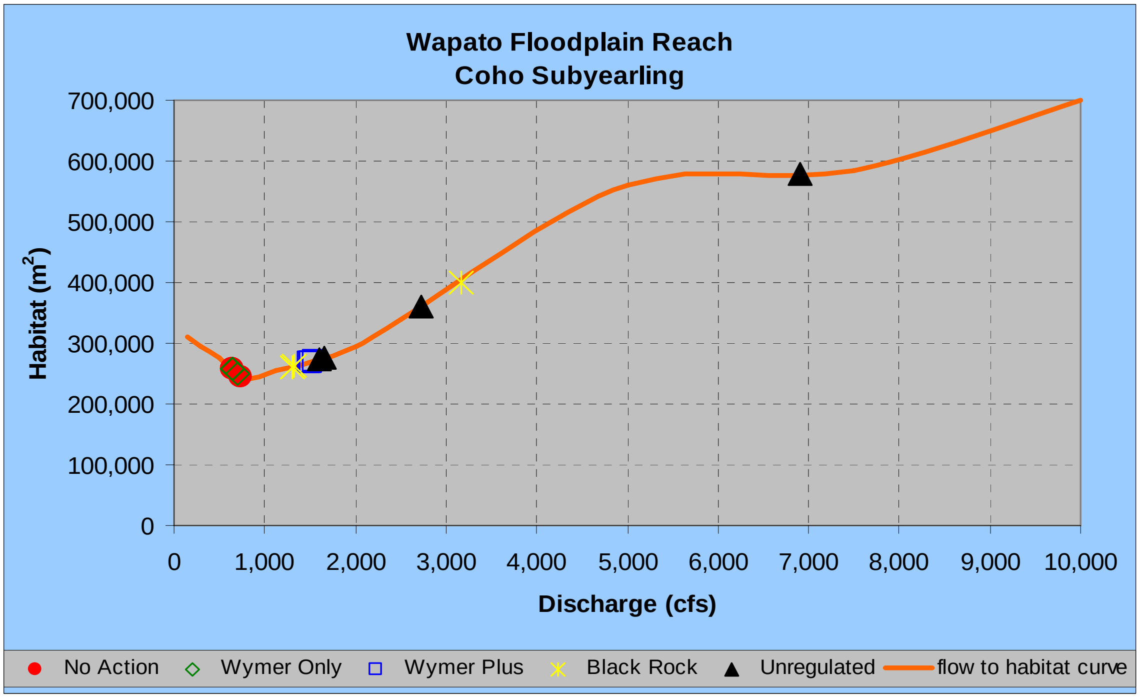


Figure 38. Flow-to-habitat curve for the coho summer subyearling lifestage depicting the flow-to-habitat location of each Storage Study alternative and unregulated for the Wapato floodplain.

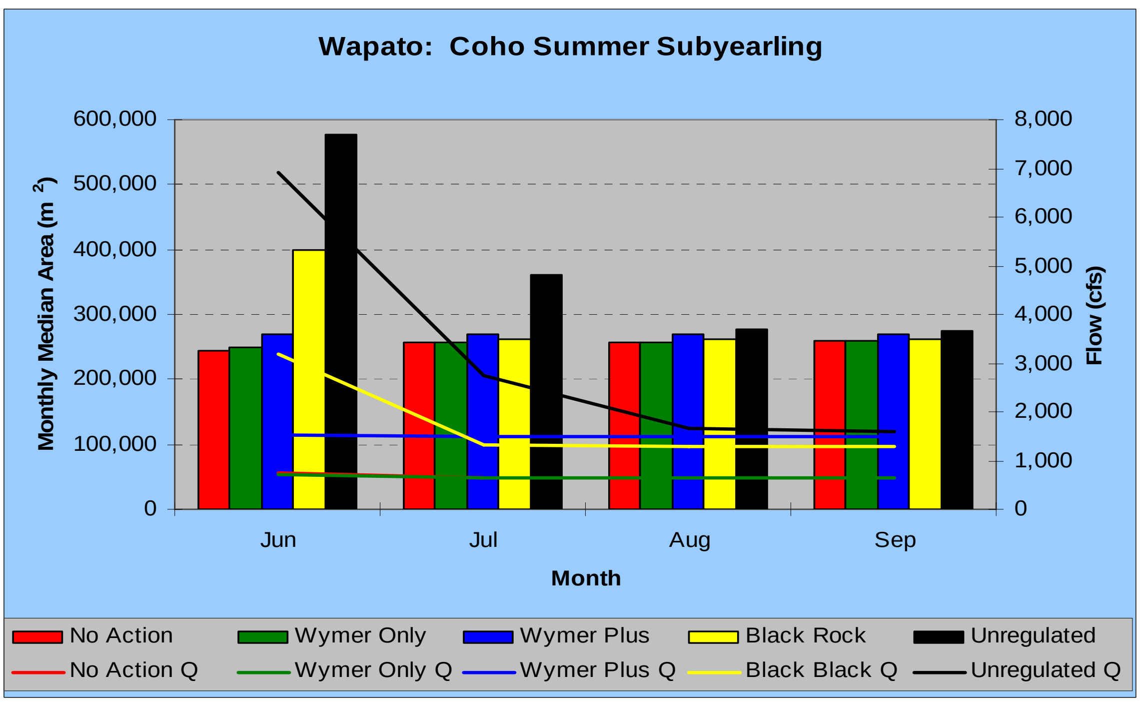


Figure 39. Summary of the amount of median monthly resident rainbow summer subyearling habitat and flow for each alternative for the Ellensburg floodplain reach (Note- the left Y-axis is habitat represented by the columns and the right Y-axis is flow represented by lines.).

amount of coho subyearling habitat was always greater (6.1% to 119.9% compared to No Action) than the amount for all the alternatives for all months (figure 39).

3.6.1.3 Flow-to-Habitat: Main Channel vs. Side Channel

Figure 40 shows the relationship of coho summer subyearling habitat in the main channel compared to channel as a function of flow for the Wapato floodplain. Mainstem summer subyearling habitat remained fairly constant at 30,000 m2 from 300 cfs to 2,500 cfs, and then steadily decreased from 2,500 cfs to 15,000 cfs (15,000 m^2). Side channel summer subyearling habitat increased from 300 cfs to 2,500 cfs, and then decreased from 2,500 cfs to 15,000 cfs (30,000 m^2).

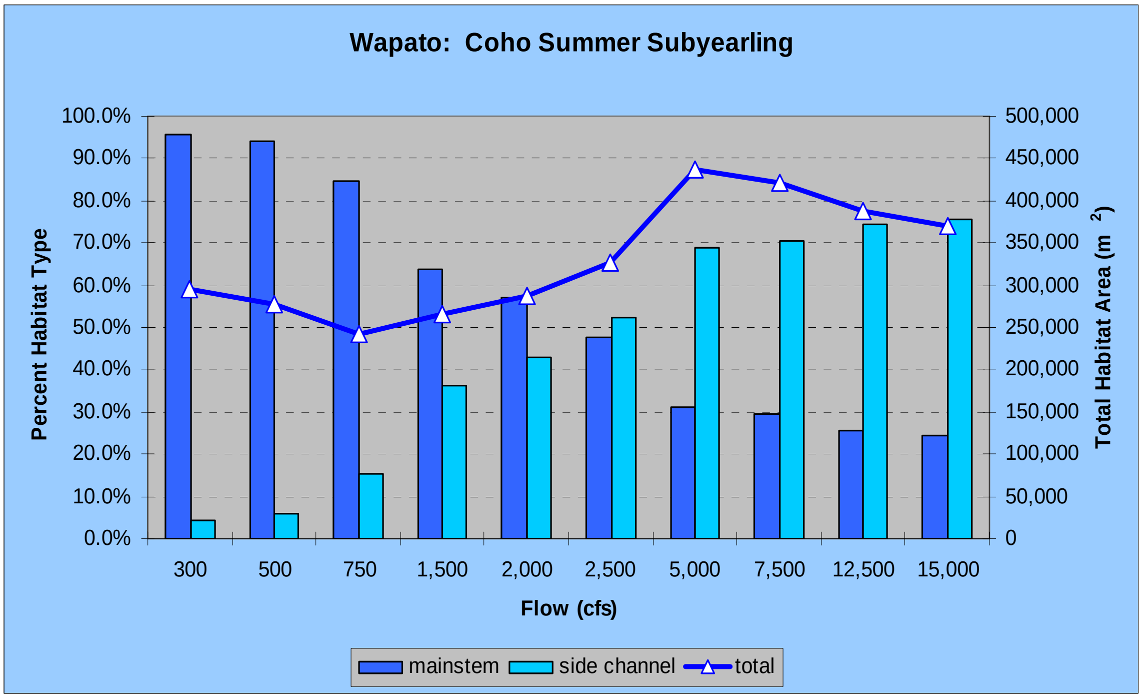


Figure 40. Flow-to-habitat curve for coho summer subyearling showing the total amount of habitat (line) by flow, and the percent of main channel and side channel habitat (columns) by flow for the Wapato floodplain.

3.7 Bull Trout Spawner Upmigration into Tributaries Flowing into the Reservoirs

There was little difference between alternatives in the number of days bull trout spawner upmigration into tributaries flowing into the Keechelus, Kachess and Rimrock reservoirs was deemed impassable (table 4). The maximum difference in numbers of days for the Joint Alternatives compared to No Action was Keechelus, 1 day; Kachess, 3 days; and Rimrock, 2 days. Furthermore, with the exception of Black Rock at Rimrock reservoir, reservoir surface elevations for the Joint Alternatives were more or less equal or greater than compared to No Action.

Table 4. Number of days bull trout spawner upmigration into spawning tributaries was deemed impassible for Keechelus, Kachess and Rimrock reservoirs for each Storage Study alternatives; based on the 1981-2005 period of record.

Reservoir	No Action	Wymer Dam and Reservoir	Wymer Plus	Black Rock
Keechelus	37	37	37	38
Kachess	18	18	17	15
Rimrock	3	1	1	3

In summary compared to No Action the Joint Alternatives neither significantly improve nor worsen conditions for bull trout spawner upmigration.

3.8 Anadromous Salmonid Fish Abundance for each Alternative

3.8.1 Overview

There are three general purposes to this section:

1. To summarize the predicted performance of Yakima salmon and steelhead under each scenario.

2. To demonstrate that the performance values estimated for each population are reasonable.

3. To explain as succinctly as possible the reasons for differences in performance among populations and storage alternatives.

The best estimates of the performance of Yakima salmon and steelhead under the storage alternatives entail the use of the AHA and the EDT models and a flow-survival relationship demonstrated in an earlier study (Pyper and Smith, 2005). It is assumed that the reader is already familiar with the AHA and EDT models and that a lengthy description is not necessary. However, those who are unfamiliar with the basic nature of these two models are encouraged to read Appendix A, "Application of the All H Analyzer Model in concert with the Ecosystem Diagnosis & Treatment Model and the Yakima River Flow-to-Smolt Outmigration Survival Rates to Estimate the Anadromous Fisheries Numeric Benefits for the Storage Study Alternatives", and for the EDT model the paper by Lestelle, Mobrand and McConnaha (2004) At this point it is necessary only to make a few specific points.

The AHA model is necessary to assess the true impact of the four scenarios on adult production whenever a hatchery program is associated with a natural population of the same species and run. This is so because EDT only estimates productivity and carrying capacity for natural populations in the absence of any hatchery impact. Given estimates of the proportion of natural origin fish in hatchery broodstock (pNOB), the proportion of hatchery origin spawners (pHOS), the relative genetic fitness of naturally spawning hatchery fish, etc, the AHA model estimates the equilibrium production of natural origin recruits (NORs), hatchery origin recruits (HORs), and the numbers of fish harvested in all fisheries. Importantly, the natural production values estimated by the AHA model are adjusted for a genetic fitness impact attributable to interbreeding between natural and hatchery fish over many generations.

Because hatchery programs exist for all salmon populations in the basin, the bottom-line impacts of each scenario – the mean expected number of NOR and HOR spawners and the mean expected numbers of harvested adults – entail the sequential application of the EDT and AHA models. Thus, for spring Chinook, fall Chinook and coho, productivity and capacity parameters estimated by the EDT model were entered into the AHA model along with the quantitative details of hatchery and harvest operations. Expected NOR and HOR escapements and harvests were estimated by the AHA model.

Such, however, was not the case for summer steelhead because none of the populations of Yakima steelhead are impacted by a hatchery program. With one exception, the impacts of each scenario on Yakima steelhead populations were estimated directly from the harvest-adjusted output of the EDT model. The exception is the upper Yakima steelhead population, which interbreeds extensively with a large upper Yakima rainbow trout population. In the case of upper Yakima steelhead it is necessary to adjust EDT-based estimates of abundance and harvest under each scenario for the interaction with rainbow trout.

Regarding interbreeding resident and anadromous *O. mykiss* in the upper Yakima watershed (the Yakima mainstem and its tributaries above Roza Dam), it has been demonstrated adult rainbow trout and steelhead are genetically indistinguishable (Pearsons et al. 1998). It is also known that virtually all populations of steelhead and rainbow trout are capable of producing progeny of a life history type different from the parental type – that is to say, that at least some of the progeny of steelhead matings will become resident, and some of the progeny of rainbow trout matings will become anadromous (Kostow 2003). Indeed, to some degree, any population of *O. mykiss* in the Northwest can be considered to represent equilibrium between resident and anadromous life history types produced by a single genetic population. Usually, this equilibrium is skewed far enough in one direction that most populations can reasonably be characterized as a "rainbow trout" or "steelhead" population, and the interactions between life history types can be ignored. Although such is probably the case for the Satus, Toppenish, middle Yakima and Naches populations, which are predominantly anadromous, it clearly is not for the upper Yakima population. Although a large majority of upper Yakima *O. mykiss* exhibit the resident life history, a significant minority does not. Therefore, it is necessary to described how differences in relative productivity carrying capacity and fecundity push the resident/anadromous equilibrium of the upper Yakima population in one direction or the other, and how such factors might mediate the ultimate impact of a changed hydrograph.

The second issue – the demonstration that fish modeling results are reasonable – consists of more than simply showing the degree of similarity between modeled and observed estimates of mean escapement abundance under current conditions, although it does entail this comparison. When mean smolt-to-adult return rate (SAR) changes significantly from recent observations and from values incorporated in the model, a reasonable model can produce estimates that differ considerably recent observations. In such instances it is necessary to demonstrate a similarity between recent observations and predictions adjusted by the change in SAR.

The third and final purpose of this section is to explain why modeled results are as they are and in particular why one scenario was better than another for each population. This exercise does not consist of a proof of the correctness of predictions for each population under each of the four scenarios. Rather, it consists of a description of the logic at the core of the fish models that causes predictions to differ among populations.

3.8.2 Results and Discussion

3.8.2.1 Modeled and Observed Fish Production- Model Validation

3.8.2.1.1 Spring Chinook

Three populations of spring Chinook are recognized in the Yakima Subbasin: the upper Yakima population, the Naches population and the American River population. The Naches population spawns in the Naches River drainage exclusive of the American

River, the American River population spawns only in the American River and the upper Yakima population spawns in the mainstem Yakima and tributaries above Roza Dam (RM 129). These populations differ genetically and in terms of life history, with the American River population consisting primarily of age-5 fish, the Naches of a more equal mix of age-4 and age-5 and the upper Yakima being primarily age-4 (Fast et al. 1991). Table 5 summarizes the observed spawning escapement by population for natural and hatchery fish for the years 1982 – 2007, as well as the EDT/AHA equilibrium abundance estimates by population for current conditions. The upper Yakima population is the largest (mean adult escapement = 2,488 from 1982 – 2007) followed by the Naches population (mean adult escapement = 1,640 from 1982 -2007) and the American River population (mean adult escapement = 754 from 1982 -2007). Juveniles from all three populations are characterized by a gradual downstream rearing migration during their first spring and summer, followed by a more directed movement downstream to overwintering locations in the lower Yakima mainstem in the late fall and winter. It should be noted that the downstream migration of pre-smolts in the fall and winter is not exclusive to spring Chinook, but is also seen in coho and steelhead. Juveniles at this point in their life cycle are referred to as "winter migrants".

Table 5 shows that escapement increased substantially in all spring Chinook populations beginning about the year 2000: mean escapement for the years 2000-2007 for the Upper Yakima, Naches and American River populations was 4,371, 3,620 and 1,572, respectively. This change is at least partly due to an increase in smolt-to-adult return rate (SAR) that began in 1998, the migration year for four-year-olds returning in 2000. The Yakama Nation estimated an average SAR of 2.03% for the migration years 1982 –

Table 5. Estimated adult escapement of adult spring Chinook salmon, 1982 – 2007, upper Yakima, Naches and American River populations. Figures include only adults and include fish that were removed for broodstock or for other purposes. EDT/AHA values are equilibrium abundance. (Based on Yakama Nation Fisheries Resources data.)

Brood Year	Upper Yakima NOR Escapement	Upper Yakima HOR Escapement (YKFP only)	Naches NOR Escapement	American HOR Escapement
1982	1,181		79	20
1983	978		112	86
1984	1,551		404	196
1985	2,436		560	276
1986	3,672		2,635	1,440
1987	1,929		1,123	548
1988	1,292		1,352	835
1989	2,359		1,025	541
1990	2,258		936	417
1991	1,664		682	400
1992	3,004		802	315
1993	1,851		1,141	718
1994	564		467	227
1995	289		89	71
1996	1,602		821	147
1997	1,416		763	372
1998	743		461	380
1999	934		227	39
2000	11,313		3,513	227
2001	5,296	6180	7,805	3,824
2002	2,434	6298	5,409	3,431
2003	867	1151	2,026	1,725
2004	7,183	2985	4,966	720
2005	4,904	726	1,923	629
2006	1,906	1851	2,455	1,050
2007	1,067	879	860	965
Mean 1982-2007	**2,488**	**---**	**1,640**	**754**
Mean 1982-1999	**1,651**	**---**	**760**	**390**
Mean 2000-2007	**4,371**	**2,867**	**3,620**	**1,572**
EDT/AHA Current	**2,601**	**3,068**	**726**	**215**
Observed / Estimated (2000-2007 reference)	**1.68**	**0.93**	**4.99**	**7.31**

1997, and 4.22% for migration years 1998-2004[8] (see file SpCkDatabase.xls). The Washington Department of Fish and Wildlife (WDGW) recently developed a procedure using differences in allozyme frequencies among the populations to estimate the proportion of the annual outmigration at Prosser Dam comprised of upper Yakima, Naches and American River smolts. Combined with estimates of the age-composition of spawners by population and brood year, these population-specific smolt counts allow SAR to be estimated for each population for outmigration years 2000, 2002 and 2003, and for a Naches/American aggregate and the upper Yakima population for the years

[8] SAR computed at Prosser Dam, jacks excluded, winter migrants included in smolt count.

1998 and 1999. Population-specific SARs for the three Yakima spring populations in migration years 1998, 1999 and 2000, 2002 and 2003 are given in Table 6.

Modeled estimates of current abundance compare reasonably well with observed abundances for upper Yakima spring Chinook, for both natural hatchery fish. Although the mean observed abundance over the entire period of record is especially close to predicted abundance, such a comparison is not appropriate. The abundance and SAR increases seen since the 1998 outmigration year are almost certainly the result of a shift of climatic conditions in the North Pacific which has resulted in an increase in marine survival. This climatic shift is a reflection of a long term cycle – the Pacific Decadal Oscillation or PDO – with a period of roughly 20 years (Mantua, N. J., and S. R. Hare, et al. 1997). That is to say, there is reason to believe that the improved marine survival rates responsible for the increases in abundance seen since 2000 will persist until approximately the year 2020. Therefore, the proper observational mean to compare to the EDT/AHA estimate is the mean for the years 2000 – 2007. Indeed, because the PDO-mediated increase in marine survival will affect all populations of salmon and steelhead, the appropriate observational standard is the mean abundance over the period of ~2000 - 2007 for all populations.

Modeled abundances compare reasonably well with observed means over the last eight years for the upper Yakima populations, but not for the Naches and American River populations. For naturally spawned upper Yakima NORs, observed means are 68% greater than modeled estimates, while the observed mean escapement of upper Yakima hatchery fish is 7% less than the modeled estimate. This level of congruence is arguably good enough to demonstrate that model predictions are "in the ballpark" and reasonable. Observed means for Naches and American fish, however, are five and seven times larger than modeled predictions.

It is not easy to in the context of this report it is suggested that all results be interpreted primarily in a relative sense. Specifically, it is suggested that the focus should be on the percent change in a performance parameter from one scenario to another and from current mean observations. Equilibrium abundance (N_{eq}) is a mathematical function of both productivity (p) and capacity (C): $N_{eq} = C - C/p$. Therefore, it is suggested that most attention be focused on the percent difference in predicted equilibrium abundance between the No Action Alternative and the three alternatives in which the hydrograph is substantially modified (Wymer Dam and Reservoir, Wymer Dam Plus Yakima River Pump Exchange and Black Rock). To the degree that some accounting of absolute abundance is necessary, it is suggested that the percent change from current for fish production under a storage alternative be multiplied by the observed mean abundance for the population.

Table 6. Estimated SAR for upper Yakima, Naches and American River spring Chinook smolts, migration years 1998, 1999, 2000, 2002 and 2003. Data courtesy Yakama Nation Fisheries Management.

Migration Year	Naches Population	American River Population	Upper Yakima Population	Naches/American Aggregate
1998			8%	6%
1999			5%	6%
2000	15%	9%	11%	
2002	14%	0%	3%	
2003	5%	1%	5%	
Mean	**11%**	**4%**	**6%**	

Despite the argument that undue importance should not be given to absolute numbers, the size of the difference between predicted and observed abundance is large enough for Naches and American River spring Chinook to cast doubt on the reasonableness of the results. In the section that follows, a case will be made that the difference between observed and modeled abundance for Naches and American spring Chinook under Current conditions is largely attributable to changes in SAR that have occurred since 1998.

When EDT estimates of Neq are compared with observations in terms of absolute numbers of adults, the comparison should be made in terms of brood year recruitment, and the EDT predictions should be adjusted to reflect the actual SAR associated with the population and brood year. EDT recruitment estimates can be adjusted for an SAR different from the assumed value as follows. If p_{EDT} is the EDT estimate of productivity and C_{EDT} is the EDT estimate of capacity, the Beverton Holt recruitment function is used to estimate recruitment for brood year i as follows:

$$\text{EDT estimate of recruitment for brood year i} = p_{EDT} * S_i / (1 + S_i * p_{EDT}/C_{EDT})$$

Where S_i is the number of spawners for brood year i. This recruitment estimate is modified for an SAR that differs from the value assumed by EDT by computing SAR-adjusted productivity (p’) and capacity (C’) values as follows:

$$P' = p_{EDT} * (SAR_{OBS,\,i}/SAR_{EDT}) \text{ and } C' = C_{EDT} * (SAR_{OBS,\,i}/SAR_{EDT}),$$

where SAR_{EDT} is the constant smolt-to-adult survival rate incorporated in the EDT model and $SAR_{OBS,\,i}$ is an observed SAR for a specific population in brood year i. Therefore, the SAR-adjusted EDT estimate of recruitment for brood year i (migration year i+2) is:

$$\text{SAR-adjusted EDT estimate of recruitment for brood year i} = p' S_i/(1 + S_i * p'/C').$$

Table 7 applies these procedures for comparing observed and EDT-based recruitment to the case of Naches Spring Chinook for brood year 1998.

Table 7. Procedures applied for comparing observed and EDT-based recruitment to the case of Naches Spring Chinook for brood year 1998.

	Naches Spring Chinook		
	Smolt Year 2000, Brood Year 1998		
	SAR_{EDT} =	2.99%	
	$SAR_{Naches\ BY\ 98}$ =	15.00%	
	p_{EDT} =	2.46	
	C_{EDT} =	1,944	
	p'=	2.46*(0.15/0.0299) =	12.3
	C'=	1,944*(0.15/0.0299) =	9,753
	Naches Spawners 1998 = 461		
	adjusted EDT estimate of Recruitment for BY 1998 = 461*12.3/(1 + (9,753*461)/12.3)		
	adjusted EDT estimate of Recruitment for BY 1998 =	**3,593**	
	Naches age-3 2001 =	194	
	Naches age-4 2002 =	1,191	
	Naches age-5 2003 =	1,038	
Observed recruitment for Naches spring Chinook, BY 1998:		**2,422**	

The constant SAR for Yakima spring Chinook assumed by the EDT model is 2.99%. Table BW2, however, shows that the actual SAR for Naches spring Chinook for BY 1998 (migration year 2000) was approximately 15%. When EDT productivity and capacity values are modified to reflect SAR_{OBS} /SAR_{EDT}, the initial EDT productivity increases from 2.46 to 12.3, and the initial EDT capacity increases from 1,944 to 9,753. These revised productivity and capacity values, when combined with the observed spawning escapement of 461 in the Beverton-Holt recruitment function, produce a recruitment estimate of 3,593 fish. This figure compares reasonably well with the observed recruitment for BY 98 Naches spring Chinook of 2,422. The actual congruence is closer than 3,593 vs 2,422 because the estimate of Naches SAR for migration year 2000 counted smolts at Prosser Dam and not the mouth of the Yakima River. It is thus likely, given the known smolt losses in the lower Yakima River, that the 15% SAR represents an overestimate. If the observed SAR is reduced 25% to account for lower Yakima smolt losses, to 11.5%, the adjusted EDT estimate of recruitment becomes 2,695.

This example of a comparison of observed recruitment and the EDT-based recruitment model is intended to illustrate why EDT and AHA results should be used in a relative sense – as the performance ratio between alternatives, to guide management choices. It is also hoped that this particular example, focusing as it does one of the larger discrepancies between modeled predictions and observations, will convince the reader that EDT and AHA results are reasonable and useful when used appropriately.

3.8.2.1.2 Fall Chinook

The Yakima Subbasin supports two populations of upriver Bright fall Chinook, the lower mainstem population, spawning in the Yakima mainstem between a point near the Columbia confluence and Sunnyside Dam, and the Marion Drain population which spawns exclusively inside Marion Drain[9]. Table 8 summarizes the estimated spawning escapement of the two populations of fall Chinook in the Yakima Subbasin over the years 1998 – 2006, as well as the ADT and AHA equilibrium abundance estimates for each population. The data in Table BW4 covers only the years 1998 – 2006 because those are the only years for which the proportion of spawning occurring above and below Prosser Dam can be determined. Although fall Chinook are accurately counted at Prosser Dam, the proportion that spawns below the dam varies widely from year to year, and total escapement cannot be estimated with knowing the spawning distribution relative to Prosser Dam.

Combined EDT-AHA estimates of total return (NOR + HOR) of the Yakima mainstem population match the mean estimate relatively well, but are about half of the estimated

Table 8. Estimated escapement of adult fall Chinook salmon, 1998 – 2007, Yakima mainstem and Marion Drain.

Year	Prosser Dam Adult Count[a] (NOR + HOR)	Estimated Percent Escapement Above Prosser Dam[b]	Estimated Escapement to Entire Yakima River	Marion Drain Redd Count[c]	Marion Drain Escapement at 5.9 adults/redd[d]	Estimated Escapement Yakima Mainstem
1998	1,064	61%	1,742	22	130	1,613
1999	1,876	46%	4,056	24	142	3,914
2000	1,371	30%	4,552	no data	*171*[e]	4,381
2001	3,651	62%	5,885	34	201	5,684
2002	6,146	46%	13,435	56	330	13,105
2003	4,796	48%	10,073	86	507	9,566
2004	2,862	50%	5,779	100	590	5,189
2005	1,920	61%	3,168	56	330	2,837
2006	1,499	65%	2,299	23	136	2,163
1998 - 2006 Mean	**2,798**	**52%**	**5,666**	**50**	**282**	**5,384**
EDT/AHA Current					**134**	**6,068**
Ratio Observed/Estimated (1998 - 2006 reference)					**2.10**	**0.89**

a Data courtesey Yakama Nation Fisheries Resoirces
b Data courtesy Paul Hoffarth, WDFW
c Data courtesey Yakama Nation Fisheries Resources
d Data from Seiler 1992
e Mean of escapements in 1999 and 2001

[9] Marion Drain is a deep, ~18-mile-long drainage ditch constructed in 1910 that enters the Yakima River at RM 83. The ditch bottom intercepts alluvial gravels and a considerable amount of groundwater draining out of irrigated lands to the north and west. Local residents claim it has supported a population of fall Chinook since at least the last 1940s.

mean for Marion Drain. The Marion Drain population, however, is an unusual population for which escapement is difficult to estimate, and it is possible that the empirical escapement figures are overestimated. Marion Drain escapement cannot be determined by a direct count and must be estimated as the product of redds and a spawners/redd estimate. The existing spawners/redd estimate for Marion Drain is unusually high- 5.9 adults/redd – and is based on a single year[10]. It is not known whether the 5.9 spawners/redd figure accurately characterizes the typical condition, or if it was an aberration. If a more typical spawners/redd ratio of 2.5 is applied to the mean redd deposition in Marion Drain over the period of record, the empirical estimate becomes 125, a figure which matches modeling result s quite well.

3.8.2.1.3 Summer Steelhead

There are at least four and possibly five genetically distinct steelhead populations in the Yakima Subbasin:

- The upper Yakima population, spawning above Roza Dam in the Yakima mainstem and most accessible tributaries.

- The Naches population, spawning throughout the Naches watershed.

- The middle Yakima population, spawning in the Yakima mainstem between Ahtanum Creek and Roza Dam, as well as throughout Ahtanum and Wide Hollow Creeks.

- The Toppenish Creek population, spawning exclusively in Toppenish Creek and its tributaries above and inclusive of Simcoe Creek.

- The Satus Creek population, spawning exclusively in Satus Creek and its tributaries.

Table 9 summarizes the estimated natural escapement by population and lists EDT-based mean abundance estimates for each population. The figures in Table BW5 are only approximate, and are based on Prosser Dam counts, the relative spawning distribution by population indicated by an adult radiotagging study over the years 1989 – 1993

[10] In 1992, an adult trap was installed on lower Marion Drain and the entire run was counted, sexed and aged (Seiler 1992). A total of 412 fish entered the drain, 14% of which were adult females, 42% of which were adult males and 44% of which were jacks.

Table 9. Estimated adult escapement of summer steelhead, 1985 – 2007, upper Yakima, Naches, Satus Creek, and Toppenish Creek. Complete estimates of mid-Yakima steelhead escapements do not exist. EDT values are equilibrium abundance. Data courtesy of Yakama Nation Fisheries Resources

Brood Year	Satus Creek Population	Naches Drainage Population	Toppenish Creek Population	Upper Yakima Population	Ahtanum Creek Escapement[a]	TOTAL
1985	1052	694	291	157	no data	2194
1986	1072	707	297	160	no data	2235
1987	1182	780	327	176	no data	2465
1988	1362	898	377	203	no data	2840
1989	557	368	154	83	no data	1162
1990	350	350	57	57	no data	814
1991	309	334	108	83	no data	834
1992	1222	588	339	113	no data	2263
1993	604	398	167	15	no data	1184
1994	272	179	75	28	no data	554
1995	466	307	129	23	no data	925
1996	213	141	59	92	no data	505
1997	560	369	155	22	no data	1106
1998	548	362	152	51	no data	1113
1999	435	360	261	14	no data	1070
2000	492	533	539	14	33	1611
2001	430	996	1498	140	24	3089
2002	1915	1447	886	238	39	4525
2003	448	707	922	134	24	2235
2004	1031	854	621	213	36	2755
2005	1093	1082	1002	227	48	3451
2006	932	642	311	117	3	2005
2007	567	434	274	58	12	1345
1985 - 2007 Mean	**744**	**588**	**391**	**105**	**27**	**1,838**
2001 - 2007 Mean	**917**	**880**	**788**	**161**	**27**	**2,772**
EDT Current	**789**	**553**	**659**	**186**[b]		
Ratio Observed/EDT (2001 - 2007 reference)	**1.16**	**1.59**	**1.20**	**1.0**[c]		

a. Ahtanum Creek is part of the mid-Yakima population: the Yakima mainstem between Ahtanum Creek and Roza Dam including Ahtanum and Wide Hollow Creeks.

b. The 2002 - 1986 mean was used for the upper Yakima for consistency with earlier estimates and because 2002 - 2006 also is within the new PDO cycle.

c. The observd/estimated ratio is 1.0 because the rainbow/steelhead adjustment procedure entailed adjusting upper Yakima mean steelhead abundace to the observed mean of 186.

(Hockersmith et al. 1995), and the relative numbers of redds deposited in Satus and Toppenish Creeks since 1985. With the caveat that the empirical data are only approximate, the correspondence between EDT predictions and observed means are relatively good. As is the case for all populations of anadromous salmonids in the Yakima Subbasin, the appropriate period of record to compare to EDT estimates is the last seven or eight years, during which the effects of improved ocean survival on adult returns have become evident. In this analysis, the empirical comparison period of 2001-2007 has been chosen.

3.8.2.1.4 Coho

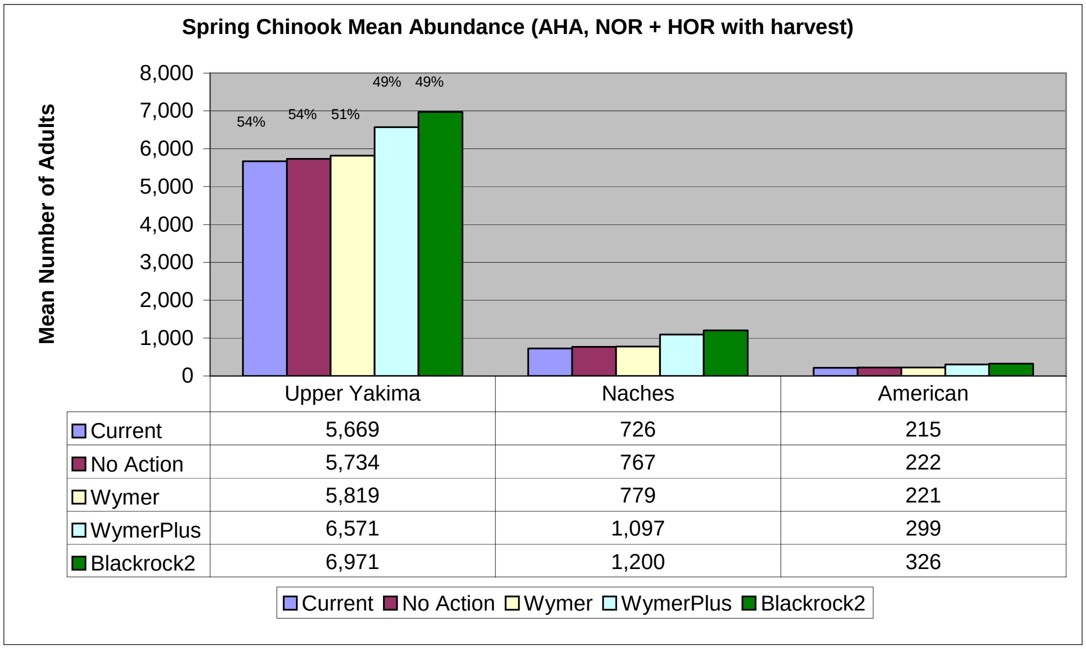
It is not possible to assess the reasonableness of EDT and AHA estimates of Yakima coho production, because the endemic population was extirpated around 1980 and natural production is currently being re-established by naturalized coho of a lower-Columbia stock (Yakima Subbasin Plan 2004). Because of the location of hatchery releases since 1983 and probably because of a lack of stamina in the lower Columbia stock released, most natural production now occurs in mid-Yakima tributaries (Ahtanum and Wide Hollow Creeks) and in the middle and lower Yakima mainstem, between the Naches confluence and Marion Drain. These areas are below the major historical coho production areas in the Naches River and tributaries below the Tieton confluence and the upper Yakima mainstem above Roza Dam, especially in the Easton reach (between the Cle Elum confluence and Easton Dam) and in such upper Yakima tributaries as Umtanum Creek and Taneum Creek (Yakima Subbasin Summary 2001). EDT and AHA estimates of mean coho abundance by population must therefore be considered predictions of the future abundance of a locally-adapted stock.

3.8.2.2 **Impact of Scenarios on Adult Production by Population**

3.8.2.2.1 Spring Chinook

Figure 41 summarizes the results of modeling the Black Rock, Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir, and No Action storage alternatives for Yakima spring Chinook populations. Modeling results are also presented for the current condition. The figures represent mean adult escapement (jacks excluded) as predicted by the AHA model incorporating productivity and capacity values generated by the EDT model. Total exploitation rates of 22.9% and 27.4% were assumed for NORs and HORs, respectively. The figures for upper Yakima adult escapement represent the sum of NOR and HOR escapement.

Over all populations, adult escapement is greater under any of the storage alternatives than under current conditions. Escapement also differs among storage alternatives, with the Black Rock Alternative being largest, followed by Wymer Plus (Wymer exchange), Wymer Dam and Reservoir, and No Action.



	Upper Yakima	Naches	American
Current	5,669	726	215
No Action	5,734	767	222
Wymer	5,819	779	221
WymerPlus	6,571	1,097	299
Blackrock2	6,971	1,200	326

Figure 41. Mean abundance of spring Chinook salmon adults in the upper Yakima, Naches and American River populations as estimated by the AHA model under Current, No Action, Wymer, Wymer Dam Plus Yakima River Pump Exchange and Black Rock scenarios. The percentages above the bars for Upper Yakima spring Chinook represent the predicted percent of hatchery-origin fish in the escapement.

Figure 42 summarizes the degree to which the Black Rock, Wymer Dam Plus Yakima River Pump Exchange and Wymer Dam and Reservoir Alternatives improve Yakima spring Chinook performance over the No Action Alternative. Spring Chinook performance is expressed in terms of equilibrium abundance, productivity (maximum adult returns/spawner), carrying capacity and life history diversity (proportion of self-sustaining life history patterns). Relative to the No Action Alternative, the Black Rock and Wymer Dam Plus Yakima River Pump Exchange Alternatives clearly outperform the Wymer Dam and Reservoir Alternative. The Black Rock Alternatives outperform the Wymer Dam Plus Yakima River Pump Exchange Alternative in terms of mean abundance and carrying capacity for all populations, but not for all performance parameters. For the Naches population, the Wymer Dam Plus Yakima River Pump Exchange Alternative results in a larger increase in productivity, and for both the Naches and upper Yakima populations, the Wymer Dam Plus Yakima River Pump Exchange Alternative improves life history diversity more than for the Black Rock Alternative.

3.8.2.2.2 Steelhead

Figure 43 summarizes the results of modeling the Black Rock, Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and No Action storage alternatives for Yakima summer steelhead populations. The numbers in Figure 43 are, with one exception, EDT outputs adjusted for a total exploitation rate of 13.4%. The exception is the upper Yakima population, which adjusted EDT output for interactions with interbreeding rainbow trout (see next section).

Over all populations, adult escapement is at least marginally greater under any of the storage alternatives than under current conditions. Escapement also differs among storage alternatives, with the Black Rock Alternative usually being largest, followed by Wymer Plus (Wymer exchange), the Wymer Dam and Reservoir and No Action Alternatives, which are essentially indistinguishable.

Figure 44 summarizes the degree to which the Black Rock, Wymer Dam Plus Yakima River Pump Exchange and Wymer Dam and Reservoir Alternatives improve Yakima summer steelhead performance over the No Action Alternative. Steelhead performance is expressed in terms of equilibrium abundance, productivity (maximum adult returns/spawner), carrying capacity and life history diversity (proportion of self-sustaining life history patterns). Relative to the No Action Alternative, the Black Rock and Wymer Plus Pump Exchange Alternatives clearly outperform the Wymer Dam and Reservoir Alternative. The Black Rock Alternative outperforms the Wymer Plus Pump Exchange Alternative in terms of mean abundance and carrying capacity for all populations, but not for all performance parameters. For the middle Yakima population, the Wymer Dam Plus Yakima River Pump Exchange Alternative produces a larger increase in life history diversity than the Black Rock Alternative, and for the Satus Creek population, the Wymer Dam Plus Yakima River Pump Exchange is slightly better than the Black Rock Alternative in improving productivity.

Estimation of Steelhead abundance in the upper Yakima Population: Adjusting for interactions with rainbow trout

The relative abundance of trout and steelhead in the interbreeding population of *O. mykiss* in the upper Yakima was viewed as the outcome of a competition to produce juveniles. In turn, relative juvenile production capacity was seen as a function of the relative productivity, carrying capacity and fecundity of the competing resident and anadromous life history types. At the core of the procedure is the magnitude of the product of productivity and relative fecundity. Productivity is the maximum number of returning adults per spawner, and fecundity is the average number of eggs per spawner. The product of these values, $adults_{max}$ * eggs/adult, is the maximum production of eggs. Assuming egg-to-fry survival is essentially identical for resident and anadromous life history types, maximum egg production is directly proportional to maximum juvenile production. At its core, the procedure used to estimate equilibrium abundances of resident trout and anadromous steelhead in the upper Yakima assumed that the life history type for which the product of productivity and relative fecundity was greatest would be the dominant life history type.

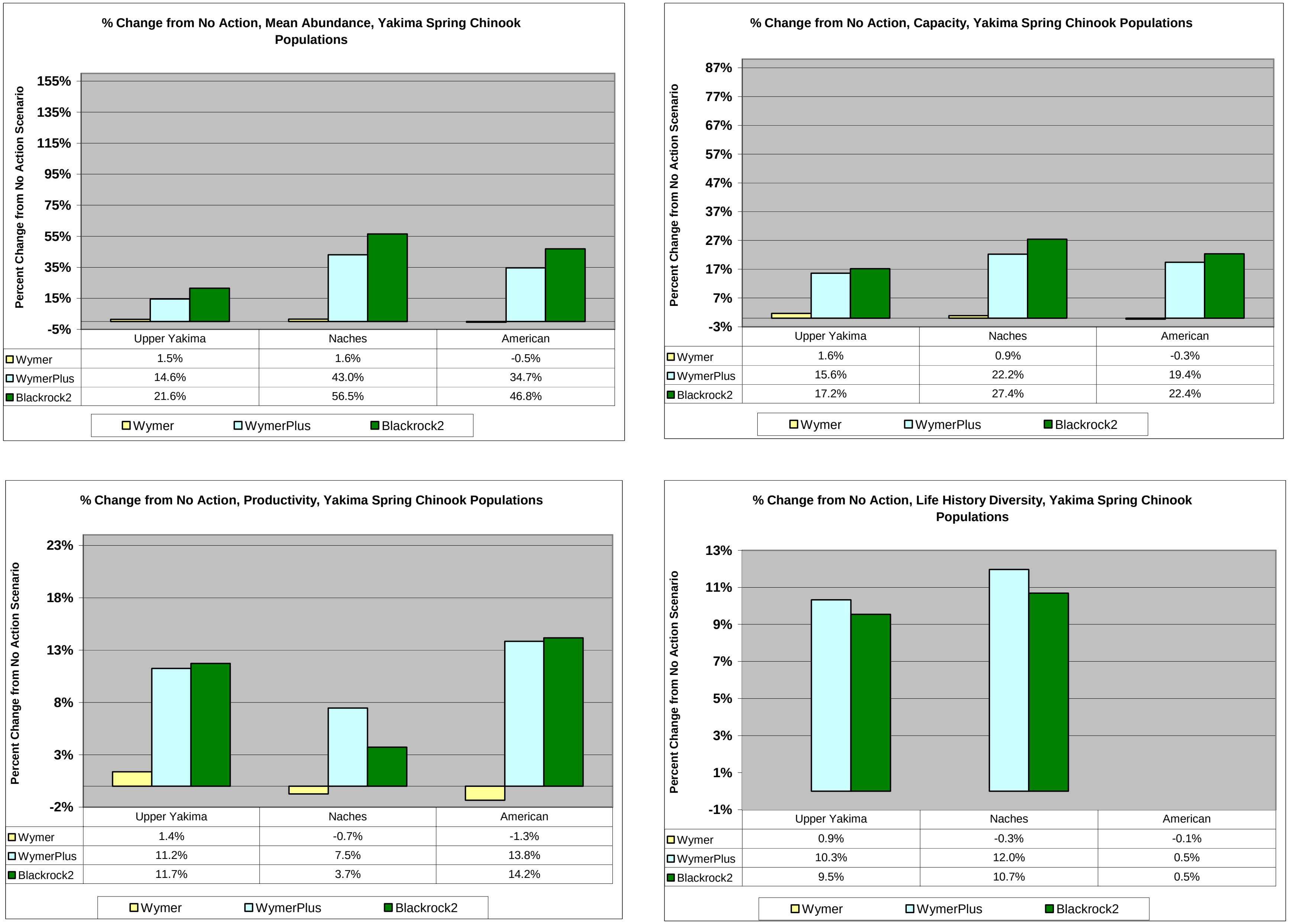
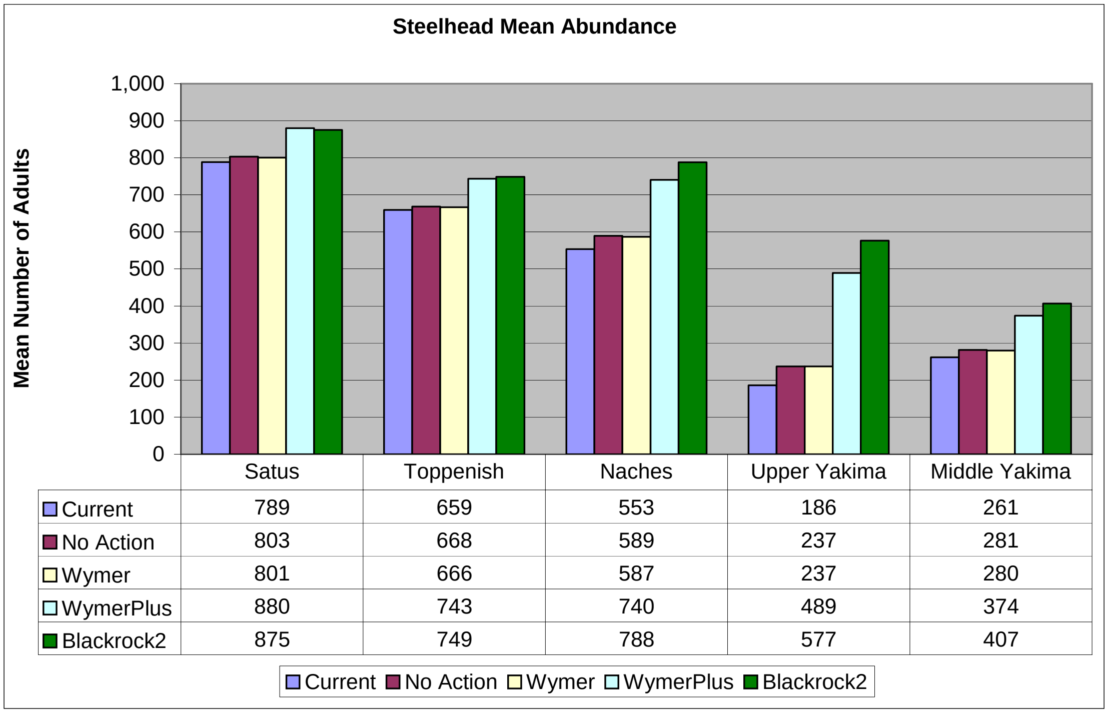
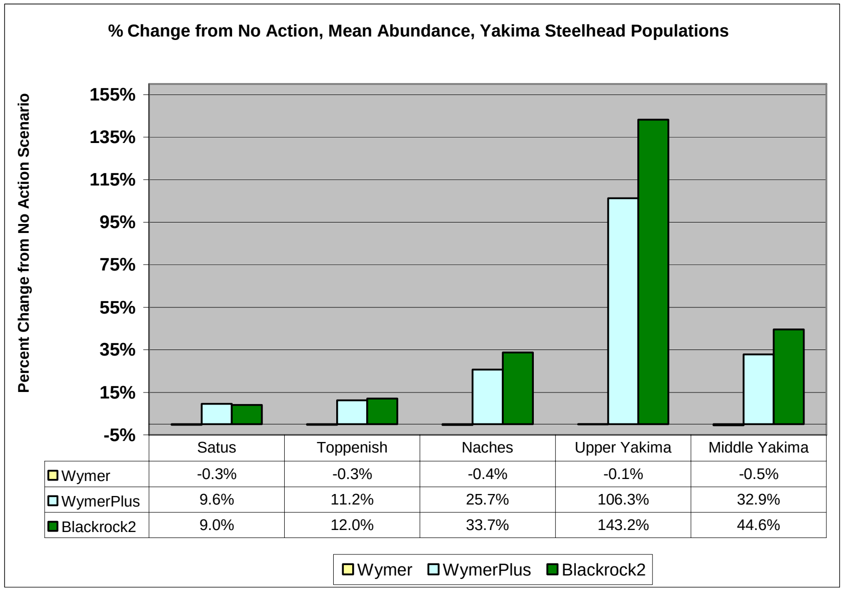


Figure 42. Percent change from No Action scenario for performance parameters for Upper Yakima, Naches and American River spring Chinook populations. Percent change in performance is calculated for Wymer, Wymer Plus and Black Rock scenarios, and is expressed in terms of productivity, carrying capacity, equilibrium abundance and life history diversity.

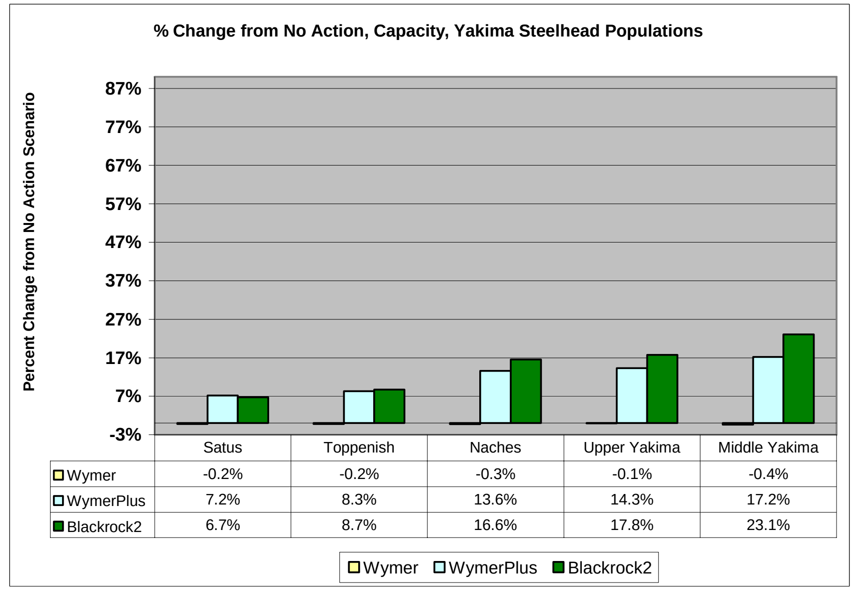


	Satus	Toppenish	Naches	Upper Yakima	Middle Yakima
Current	789	659	553	186	261
No Action	803	668	589	237	281
Wymer	801	666	587	237	280
WymerPlus	880	743	740	489	374
Blackrock2	875	749	788	577	407

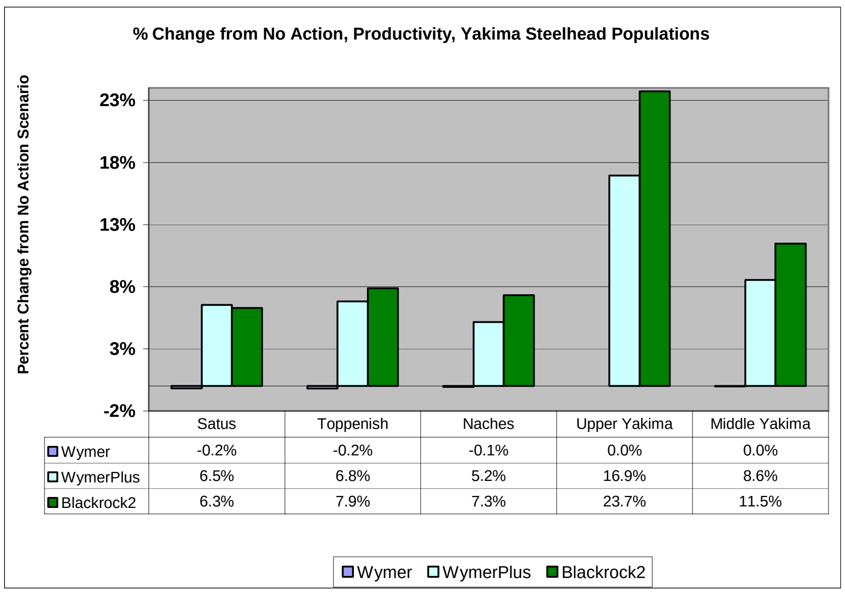
Figure 43. Mean abundance of summer steelhead adults in the upper Yakima, Naches, Satus Creek, Toppenish Creek and middle Yakima populations as estimated by the AHA model under Current, No Action, Wymer, Wymer Plus and Black Rock scenarios.



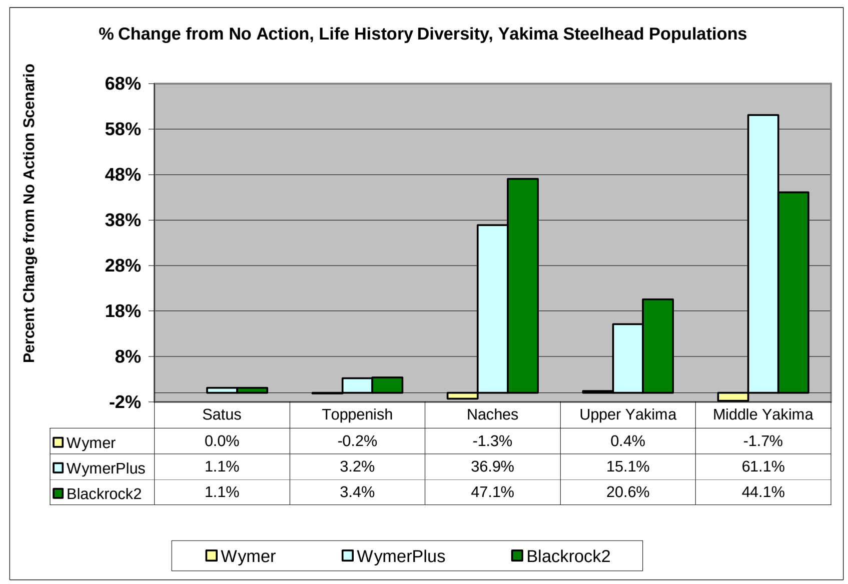
	Satus	Toppenish	Naches	Upper Yakima	Middle Yakima
Wymer	-0.3%	-0.3%	-0.4%	-0.1%	-0.5%
WymerPlus	9.6%	11.2%	25.7%	106.3%	32.9%
Blackrock2	9.0%	12.0%	33.7%	143.2%	44.6%



	Satus	Toppenish	Naches	Upper Yakima	Middle Yakima
Wymer	-0.2%	-0.2%	-0.3%	-0.1%	-0.4%
WymerPlus	7.2%	8.3%	13.6%	14.3%	17.2%
Blackrock2	6.7%	8.7%	16.6%	17.8%	23.1%



	Satus	Toppenish	Naches	Upper Yakima	Middle Yakima
Wymer	-0.2%	-0.2%	-0.1%	0.0%	0.0%
WymerPlus	6.5%	6.8%	5.2%	16.9%	8.6%
Blackrock2	6.3%	7.9%	7.3%	23.7%	11.5%



	Satus	Toppenish	Naches	Upper Yakima	Middle Yakima
Wymer	0.0%	-0.2%	-1.3%	0.4%	-1.7%
WymerPlus	1.1%	3.2%	36.9%	15.1%	61.1%
Blackrock2	1.1%	3.4%	47.1%	20.6%	44.1%

Figure 44. Percent change from No Action scenario for performance parameters for Satus, Toppenish, Naches, Upper Yakima and middle Yakima steelhead populations. Percent change in performance is calculated for Wymer, Wymer Plus and Black Rock scenarios, and is expressed in terms of productivity, carrying capacity, equilibrium abundance and life history diversity.

As will be seen, estimating equilibrium trout/steelhead abundances required estimating the productivity and carrying capacity of upper Yakima trout and steelhead under current conditions and under each storage alternative. The EDT model estimated steelhead productivity and capacity directly and also provided smolt productivity and capacity values that were used to estimate trout productivity and capacity by storage alternative. The essence of this procedure is described below.

Special EDT runs were made in which all upper Yakima steelhead smolts were assumed to be age-2 or age-3. The EDT-based smolt productivity values for these all-age-2- and all-age-3-smolt populations were assumed to be equal to the survival of trout to age 2 or 3. Then, assuming the survival of trout from age-3 to age-4 can be estimated as the ratio of the age-3/age-2 smolt productivity values, trout productivity was estimated as:

$$Prod_{trout} = F_{rel} * m_2 * p_2 + F_{rel} * m_3 * p_3 + F_{rel} * m_{4+} * p_3/p_2$$

where F_{rel} is the fecundity of trout relative to steelhead (here 789/4,495), $m_2 – m_{4+}$ are the estimated proportions of reproductively mature upper Yakima trout that are age-2, age-3 and age-4+ (here 14, 68 and 17%) and p_2 and p_3 are the EDT-derived estimates of all-age-2 and all-age-3 smolt productivities under current conditions and under No Action, Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and Black Rock storage alternatives.

Upper Yakima trout carrying capacity was also assumed to vary by storage alternative, just as steelhead capacity varies by alternative. The procedure for estimating trout capacity by alternative entailed estimating the mean abundance of reproductively mature upper Yakima trout under current conditions (~15,000 based on WDFW juvenile densities and the assumed age distribution of adults) and using EDT to estimate steelhead smolt N_{eq} (using the observed age distribution) for the upper Yakima under existing conditions. The ratio of adult trout abundance to estimated EDT smolt abundance, here 28%, was used to estimate trout abundance under the various storage alternatives. Specifically, the product of EDT estimates of steelhead smolt equilibrium abundance under each storage alternative and 0.28, the (adult trout)/smolt ratio under current conditions, was used to estimate trout equilibrium abundance by alternative. Trout carrying capacity was then estimated by re-arranging the formula for Beverton-Holt N_{eq} to solve for capacity as a function of N_{eq} and productivity (both of which are known).

The approach used to estimate equilibrium abundances of trout and steelhead in the upper Yakima approach makes no assumptions about the genetic factors involved in *O. mykiss* life histories. Rather, it assumes that the population produces smolts and residents in large enough numbers that an increase in egg-to-adult survival for either life history type will be converted, eventually, into additional spawners and juvenile progeny.

Before describing the details of the procedure for estimating equilibrium trout and steelhead abundance, it is necessary to reiterate that the AHA model was not used to estimate the mean abundance of steelhead by population and by storage alternative. Because no hatchery programs for steelhead exist in the Yakima Subbasin, mean abundance for all populations except the upper Yakima was estimated directly from EDT output adjusted to reflect a total exploitation rate of 13.4% (C. Frederickson, Yakama Nation, personal communication 2007). Specifically, EDT productivity and capacity estimates were multiplied by 1 - 0.134 to adjust for exploitation, and the adjusted parameters were then used to estimate N_{eq} as $C_{adj} – C_{adj}/p_{adj}$. For the upper Yakima steelhead population, EDT-derived productivity and capacity values were adjusted for the 13.4% exploitation and then incorporated into the resident/anadromous equilibrium procedure.

With this general overview, it is appropriate to discuss the procedure for estimating equilibrium trout and steelhead abundance in the upper Yakima in some detail.

Performance measures for both resident and anadromous forms are productivity (*P*), capacity (*C*), and equilibrium abundance (*Neq*). The purpose of this application is to estimate these measures for steelhead when resident rainbow compete for food and space resources.

Equilibrium abundance of first-time spawning resident rainbow trout when modeled independent of steelhead (as in allopatry) is computed as

$$Neq_{RI} = C_{RI}(1 - \frac{1}{P_{RI}})$$

Where C_{RI} is the estimated capacity for the resident life form modeled independent of steelhead, P_{RI} is the estimated productivity for the resident life form modeled independent of steelhead, and Neq_{RI} is the equilibrium abundance of the resident life form modeled independent of steelhead.

Similarly, equilibrium abundance of first-time spawning anadromous steelhead when modeled independent of rainbow is computed as

$$Neq_{AI} = C_{AI}(1 - \frac{1}{P_{AI}})$$

Where C_{AI} is the estimated capacity for the anadromous life form modeled independent of rainbow, P_{AI} is the estimated productivity for the anadromous life form modeled independent of rainbow, and Neq_{AI} is the equilibrium abundance of the anadromous life form modeled independent of rainbow.

Potential egg deposition (PED_{RI}) for the resident life form modeled independent of steelhead is estimated as

$$PED_{RI} = Neq_{RI} * \overline{F_R}$$

Where $\overline{F}_R$ is the average number of eggs per spawner (as the weighted average of age-specific fecundities) for the resident form.

Similarly, potential egg deposition (PED_{AI}) for the resident life form modeled independent of steelhead is estimated as

$$PED_{AI} = Neq_{AI} * \overline{F_A}$$

Where $\overline{F}_A$ is the average number of eggs per spawner (as the weighted average of age-specific fecundities) for the anadromous form.

It is assumed that O. mykiss are generally predisposed in the Pacific Northwest to be anadromous, unless mortality pressures cause residency to be more successful (produce more juveniles). This assumed predisposition is modeled by assigning additional weight to PED_{AI} (anadromous form modeled independent of rainbow) as shown below

$$WPED_{AI} = W_A * PED_{AI}$$

Where $WPED_{AI}$ is PED_{AI} weighted a constant W_A. For the current analysis, W_A was determined adjusted to a value that resulted in an equilibrium abundance for upper Yakima steelhead of 186, the mean adult steelhead count at Roza Dam for the period 2002 – 2006. This W_A value – 3.15 -- was applied to all estimates of steelhead production under the various storage alternatives.

Relative juvenile abundance was assumed to be a function of survival to reproductive maturity and relative potential egg deposition at equilibrium. The best measure of survival to reproductive maturity is productivity, and the best measure of potential egg deposition is the product of equilibrium adult abundance, mean fecundity, and the "anadromous bias" of West Coast O. mykiss represented by the weighting factor W_A. Therefore, relative steelhead potential egg deposition was estimated as:

$WPED_{AI} / (WPED_{AI} + PED_{RI})$

For resident rainbow, then, productivity in sympatry P_{RS} is estimated as follows:

If $P_{AI} * \left(\frac{WPED_{AI}}{PED_{RI} + WPED_{AI}} \right) \leq 1$ then (eq. 6)

$$P_{RS} = P_{RI}$$

else

$$P_{RS} = P_{RI} * \left(\frac{PED_{RI}}{PED_{RI} + WPED_{AI}} \right)$$

Sympatric rainbow productivity should be the same as allopatric rainbow productivity when eq. 1 is less than 1 because the steelhead competitors simply produce fewer juveniles – either because their productivity is too low, or their relative potential egg deposition is too low, or both.

If eq. 1 is *not* true, then some of the juveniles produced at equilibrium will be steelhead, and the two ecotypes will produce progeny in direct proportion to their relative weighted potential egg deposition.

Rainbow capacity in sympatry C_{RS} remains unchanged from capacity modeled independent of the anadromous form as shown below

$$C_{RS} = C_{RI}$$

Equilibrium abundance of the resident form in sympatry is then estimated using the equation described for residency modeled independently, though the terms are replaced with those given for allopatry.

Similarly, for the anadromous form, productivity in sympatry P_{AS} is estimated as follows

If $P_{RI} * \left(\frac{PED_{RI}}{PED_{RI} + WPED_{AI}} \right) \leq 1$ then (eq. 7)

$$P_{AS} = P_{AI}$$

else

$$P_{AS} = P_{AI} * \left(\frac{WPED_{AI}}{PED_{RI} + WPED_{AI}} \right)$$

and steelhead capacity in sympatry C_{AS} remains unchanged from capacity modeled independent of the resident form as shown below

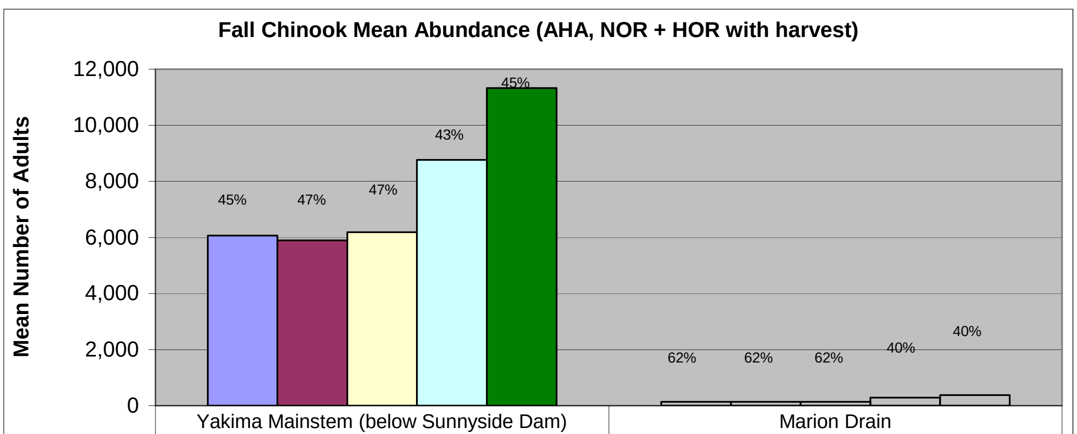
$$C_{AS} = C_{AI}$$

Equilibrium abundance of the anadromous form in sympatry is then estimated using the equation described for anadromy modeled independently, though the terms are replaced with those given for allopatry.

3.8.2.2.3 Fall Chinook

Figure 45 summarizes the results of modeling the Black Rock, Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and No Action storage alternatives for Yakima fall Chinook populations. Modeling results are also presented for the current condition. The figures represent mean adult escapement (jacks excluded) as predicted by the AHA model incorporating productivity and capacity values generated by the EDT model. Total exploitation rates of 37.9% were assumed for both NORs and HORs. The figures for adult escapement represent the sum of NOR and HOR escapement, and the percentages above the bars represent estimated proportion of hatchery fish in the escapement.

For both the lower Yakima and Marion Drain populations, adult escapement is clearly greater under the Wymer Plus (Wymer Dam Plus Yakima River Pump Exchange) and Black Rock Alternatives than under the Wymer Dam and Reservoir, No Action or Current scenarios. The Current, No Action and Wymer Dam and Reservoir scenarios are essentially indistinguishable.



	Yakima Mainstem (below Sunnyside Dam)	Marion Drain
Current	6,068	134
No Action	5,897	134
Wymer	6,185	140
WymerPlus	8,762	285
Blackrock2	11,327	377

Figure 45. Mean abundance of fall Chinook salmon adults in the lower Yakima mainstem and Marion Drain populations as estimated by the AHA model under Current, No Action, Wymer, Wymer Plus and Black Rock scenarios. Note that percents above bars represent the percent hatchery-origin fish in the escapement.

Figure 46 summarizes the degree to which the Black Rock, Wymer Dam Plus Yakima River Pump Exchange and Wymer Dam and Reservoir Alternatives improve Yakima fall Chinook performance over the No Action Alternative. Fall Chinook performance is expressed in terms of equilibrium abundance, productivity (maximum adult returns/spawner), carrying capacity and life history diversity (proportion of self-sustaining life history patterns). Except for the failure of the Wymer Dam and Reservoir Alternative to improve any measure of performance relative to the No Action Alternative, the only consistent relationship in Figure BW6 is the superiority of the Black Rock Alternative in improving mean abundance of both populations of fall Chinook.

3.8.2.2.4 Coho

Figure 47 summarizes the results of modeling the Black Rock, Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and No Action storage alternatives for Yakima coho populations. Modeling results are also presented for the current condition. The figures represent mean adult escapement (jacks excluded) as predicted by the AHA model incorporating productivity and capacity values generated by the EDT model. Total exploitation rates of 26.1% were assumed for both NORs and HORs. The figures for adult escapement represent the sum of NOR and HOR escapement, and the percentages above the bars represent estimated proportion of hatchery fish in the escapement.

As with fall Chinook, the analysis suggests essentially no difference in fall Chinook performance under the Current, No Action and Wymer Dam and Reservoir scenarios. And as was the case for all other populations except Satus steelhead, the Black Rock Alternative was superior to all other alternatives in improving mean abundance.

Figure 48 summarizes the degree to which the Black Rock, Wymer Dam Plus Yakima River Pump Exchange and Wymer Dam and Reservoir Alternatives improve Yakima coho performance over the No Action Alternative. Coho performance is expressed in terms of equilibrium abundance, productivity (maximum adult returns/spawner), carrying capacity and life history diversity (proportion of self-sustaining life history patterns). In terms of mean abundance and carrying capacity, it is quite clear that the Black Rock Alternative is superior to the Wymer Plus (Wymer Dam Plus Yakima River Pump Exchange) alternative, and that the Wymer exchange alternative is vastly superior to the Wymer Dam and Reservoir Alternative. The relative superiority of the Black Rock and Wymer Dam Plus Yakima River Pump Exchange Alternatives in terms of productivity and life history diversity varies by population.

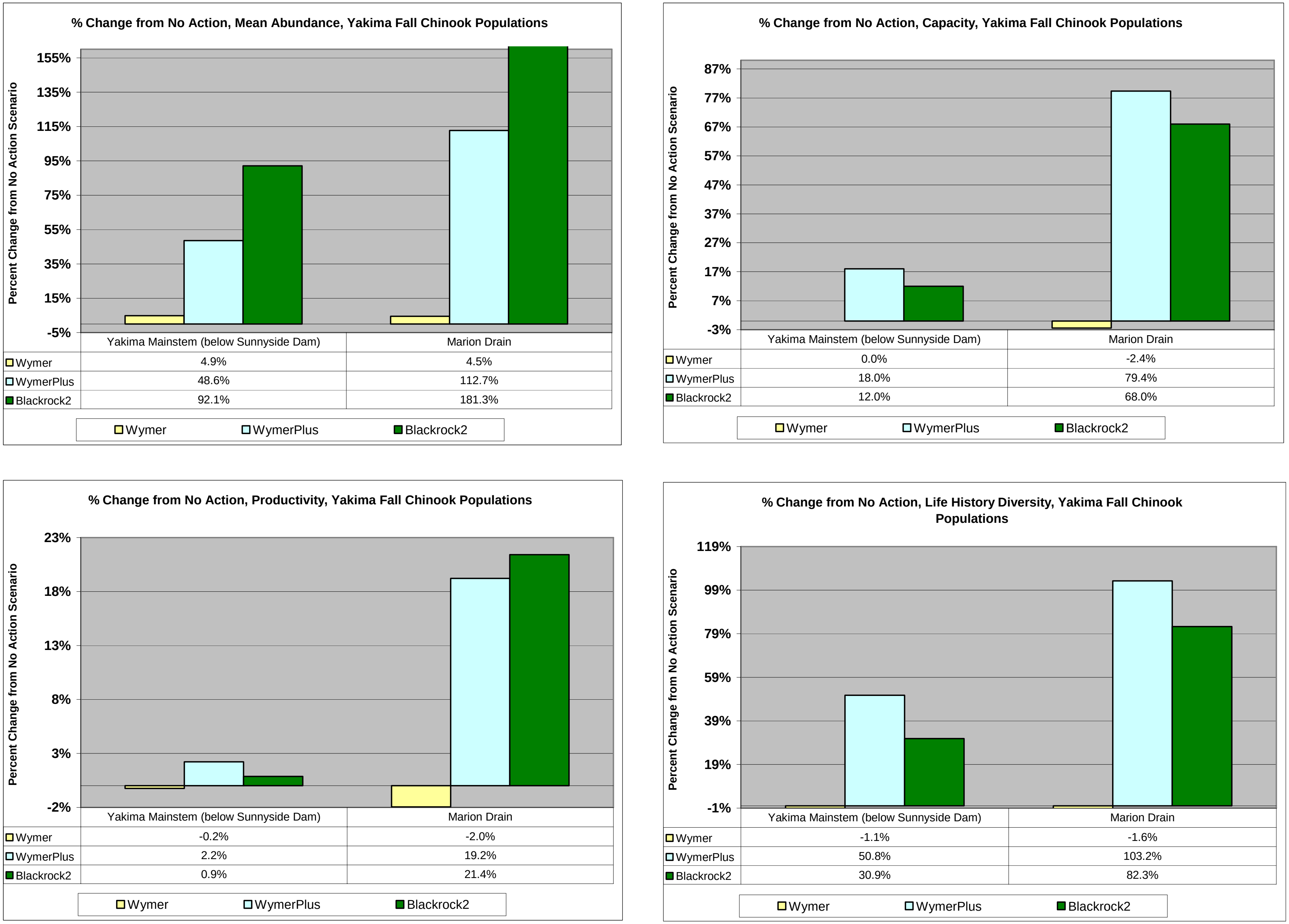
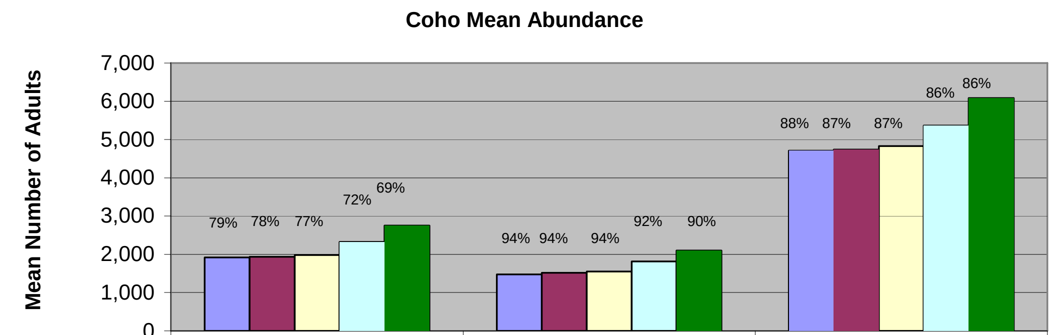


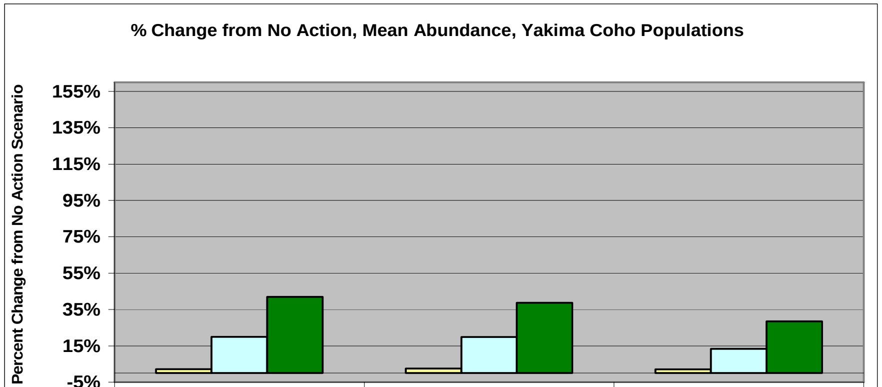
Figure 46. Percent change from No Action scenario for performance parameters for lower Yakima mainstem and Marion Drain fall Chinook populations. Percent change in performance is calculated for Wymer, Wymer Plus and Black Rock scenarios, and is expressed in terms of productivity, carrying capacity, equilibrium abundance and life history diversity.



	Upper Yakima (above Roza Dam)	Naches Drainage (including American)	Middle Yakima Coho (Toppenish to Roza Dam + Ahtanum + Wide Hollow)
Current	1,920	1,478	4,708
No Action	1,939	1,515	4,735
Wymer	1,980	1,554	4,830
WymerPlus	2,325	1,816	5,366
Blackrock2	2,751	2,101	6,083

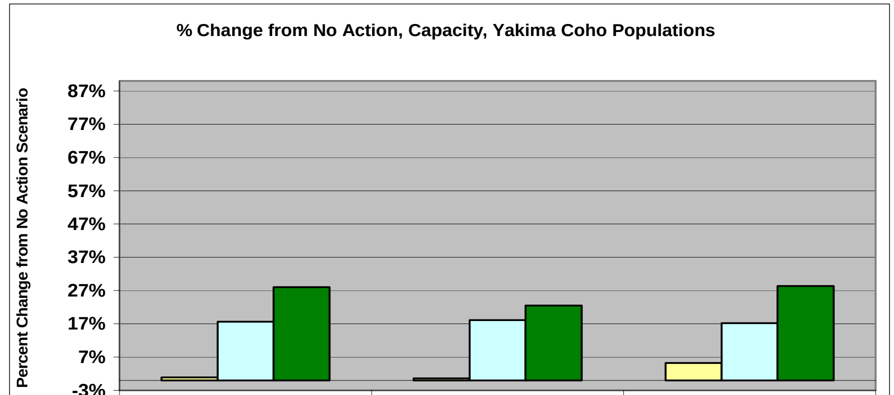
Current · No Action · Wymer · WymerPlus · Blackrock2

Figure 47. Mean abundance of coho salmon adults in the upper Yakima, Naches and middle Yakima populations as estimated by the AHA model under Current, No Action, Wymer, Wymer Plus and Black Rock scenarios. Note that percents above bars represent the percent hatchery-origin fish in the escapement.



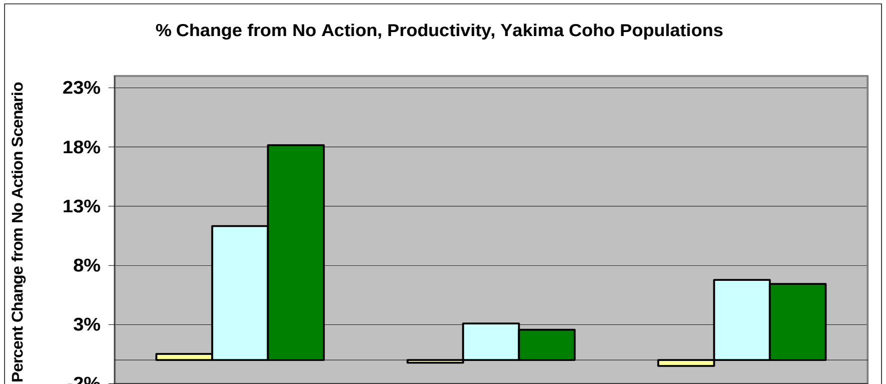
	Upper Yakima (above Roza Dam)	Naches Drainage (including American)	Middle Yakima Coho (Toppenish to Roza Dam + Ahtanum + Wide Hollow)
Wymer	2.1%	2.6%	2.0%
WymerPlus	19.9%	19.9%	13.3%
Blackrock2	41.9%	38.7%	28.5%

Wymer WymerPlus Blackrock2



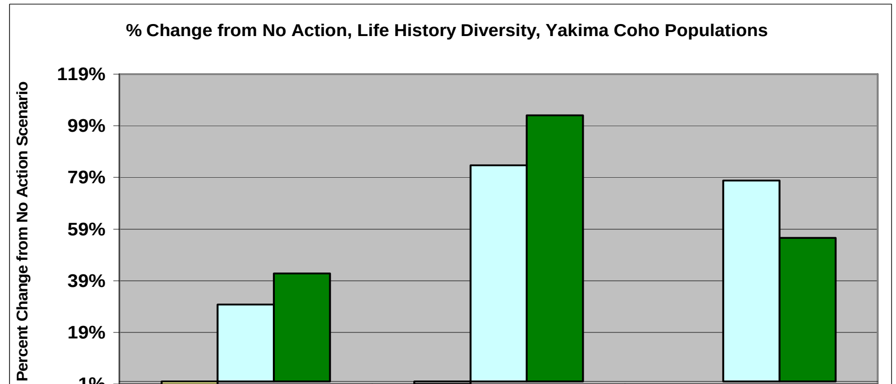
	Upper Yakima (above Roza Dam)	Naches Drainage (including American)	Middle Yakima Coho (Toppenish to Roza Dam + Ahtanum + Wide Hollow)
Wymer	0.9%	0.6%	5.2%
WymerPlus	17.7%	18.1%	17.2%
Blackrock2	28.0%	22.5%	28.4%

Wymer WymerPlus Blackrock2



	Upper Yakima (above Roza Dam)	Naches Drainage (including American)	Middle Yakima Coho (Toppenish to Roza Dam + Ahtanum + Wide Hollow)
Wymer	0.5%	-0.2%	-0.5%
WymerPlus	11.3%	3.1%	6.8%
Blackrock2	18.1%	2.6%	6.4%

Wymer WymerPlus Blackrock2



	Upper Yakima (above Roza Dam)	Naches Drainage (including American)	Middle Yakima Coho (Toppenish to Roza Dam + Ahtanum + Wide Hollow)
Wymer	-1.1%	-1.0%	0.0%
WymerPlus	29.8%	83.7%	77.8%
Blackrock2	41.8%	103.1%	55.6%

Wymer WymerPlus Blackrock2

Figure 48. Percent change from No Action scenario for performance parameters for upper Yakima, Naches and middle Yakima coho populations. Percent change in performance is calculated for Wymer, Wymer Plus and Black Rock scenarios, and is expressed in terms of productivity, carrying capacity, equilibrium abundance and life history diversity.

3.8.2.3 Explanation of Estimated Impacts

All of the predictions of Yakima salmon and steelhead performance were conditioned by the fact that the proximate physical impacts of each scenario were limited to alterations in the hydrograph and the "thermograph" – the seasonal profile of expected temperatures. As shown in Figures 2–5, the degree to which the historical hydrograph was restored by any of the storage alternatives was relatively small. In combination with the fact that none of the alternatives entailed restored access to the historical floodplain, the relatively modest restoration of the historical hydrograph largely explains why predicted salmon and steelhead performance did not approximate historical values.

In modeling the storage alternatives, the modest degree of hydrographic restoration was also responsible for the decision to limit substantial non-hydrographic physical impacts to changes in the thermograph. Specifically, it was considered unlikely that any of the storage alternatives entailed hydrographic changes large enough to affect bed scour, channel stability, sedimentation or turbidity significantly. Similarly, hydrographic changes were considered too small to cause substantial changes in such biotic factors as riparian function, large woody debris loading, predation, benthic macroinvertebrate abundance, and so on.

However, relatively small, indirect changes in a number of physical and biotic environmental factors were incorporated into the analysis. These indirect effects were attributable to the fact that flow, stream unit type composition (pool/riffle/glide ratios), and, especially, temperature can attenuate or exacerbate the impact of a number of environmental attributes. Temperature, for example, indirectly affects the severity of predation, sediment loading and pathogens, and flow affects the severity channel stability. It is nevertheless true that the only environmental attributes that were modeled differently between alternatives were those directly or indirectly associated with the hydrograph and the thermograph.

Within the context just described, differences in fisheries impacts among alternatives were entirely a function of the following specific factors, which are presented in rough order of their importance in determining overall impact:

1. Survival rates for subyearling and yearling migrants at diversion dam bypasses in the Yakima Subbasin.

2. Life history patterns, especially the life stage and month when most juveniles pass Yakima basin diversion dams.

3. Initial productivity of the population (productivity under current conditions).

4. Quantity of key habitat.

5. Predation risk, direct temperature effects, sediment loading and pathogens.

6. Flow (impact of high- and low-flow events and difference of mean monthly flow from historical/normative flows in terms of monthly means and variability.

In the following sections, the mechanism of impact for each of these ten factors will be described. The discussion will focus on spring Chinook and steelhead exclusively in the interest of limiting redundancy: all of the mechanisms driving differences in performance of Yakima salmon and steelhead can be illustrated with these two species.

3.8.2.4 Impacts of Diversion Dam Bypasses

A total of ten diversion dams and bypasses lie along the "project reaches" – the stream corridors in which flows would be affected by the storage alternatives. These diversions are: Easton Dam (RM 205 Yakima River), Town Dam (RM 161 Yakima River), Roza Dam (RM 129 Yakima River), Wapato Dam (RM 107 Yakima River), Sunnyside Dam (RM 103 Yakima River), Prosser Dam (RM 47 Yakima River), Horn Rapids Dam (RM 18 Yakima River), Cowiche Dam (RM 3 Naches River), Wapatox Dam (RM 17 Naches River) and the Yakima-Tieton Dam (RM 14 Tieton River). From a series of releases of PIT-tagged smolts released primarily in the vicinity of Prosser Dam beginning in 1991, it was learned that the survival of juvenile salmon through diversion dam bypasses declined significantly from early spring to summer, and that subyearlings fared worse than yearlings. At Prosser Dam, subyearling survival could be as low as ~40% in July and yearling survival could be below 50% in late June (Neeley 1992). These observations and a number of similar observations at Wapato, Sunnyside and Horn Rapids Dams led to the belief that predation by piscivorous birds and fish at bypass outfalls had a significant cumulative effect on Yakima salmon and steelhead production. Accordingly, a seasonally variable survival rate was assigned to virtually every diversion dam in the basin on the basis of perceived densities of predators congregating in the immediate vicinity of the bypass outfall. The severity of these bypass-related losses is highest and is best documented at lower river diversions -- Wapato, Sunnyside, Prosser and Horn Rapids Dams.

Figures 49 – 80 document the importance of diversion dam bypasses in differentiating the effects of storage alternatives on Yakima salmon and steelhead. These figures are also useful references when reach-specific impacts of other environmental factors are discussed. Figures 49 –80 are EDT outputs referred to as "tornado diagrams" because of their shape when ordered from the most to the least important reach. Tornado diagrams are an example of a "splice analysis" in EDT. In a splice analysis, a set of environmental conditions is substitute for current conditions is each reach, one at a time, for every reach used by a population. After each substitution or "splice," the EDT model recalculates performance to estimate the overall effect on the population of a specific kind of environmental change in each individual reach. In Figures 49-80, the environmental conditions spliced into each reach are those estimated to occur under one of the storage alternatives. The three vertical bar chars in each of these figures show reach-specific improvement (right-hand bars) or deterioration (left-hand bars) form current performance in terms of the mean abundance, productivity and life history diversity[11] of the population. Figure 49, the tornado diagram for upper Yakima spring Chinook under the Black Rock scenario, shows that the top four reaches in improving mean abundance are Sunnyside Dam (~5% increase), Prosser Dam (~4% increase), Horn Rapids Dam (~2% increase) and Wapato Dam (~1.5% increase). The top four reaches under the Black Rock scenario in terms of improving productivity and life history diversity are also these four dams. Although this is not always the case, Figure 49 indicates that the Black Rock scenario does not decrease performance for upper Yakima spring Chinook in any reach (there are no left-hand bars in any of the three bar charts). Figures 49-51 show reach-specific impacts of the Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and No Action Alternatives for upper Yakima spring Chinook. The dominance of diversion dams generally decreases in the sequence Black Rock, Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and No Action, as does the overall degree of improvement. A glance through the tornado diagrams for spring Chinook and steelhead populations and alternatives shows the same trend: diversion dams (and especially Sunnyside dam) top the list, especially for the Black Rock and Wymer Dam Plus Yakima River Pump Exchange Alternatives, under which flows during the outmigration months are higher at lower Yakima diversion dams. Although not shown, the tornado diagrams for fall Chinook and coho under the various storage alternatives show the same relationships seen for spring Chinook ands steelhead.

[11] Life history diversity is defined as the proportion of different life history pathways modeled that are viable – that on average produce at least one returning adult per spawner.

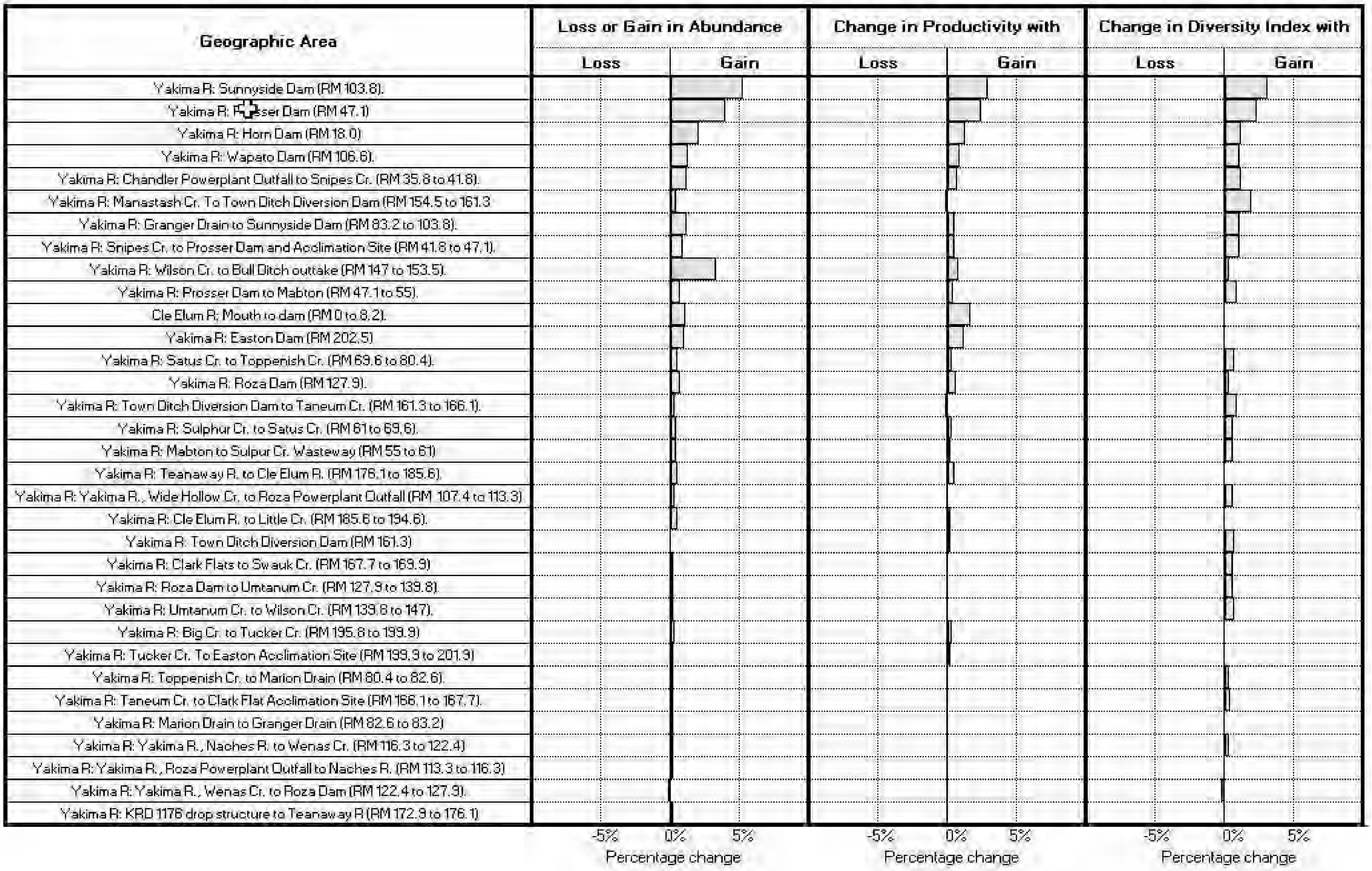


Figure 49. Upper Yakima spring Chinook tornado diagram, Black Rock Alternative.

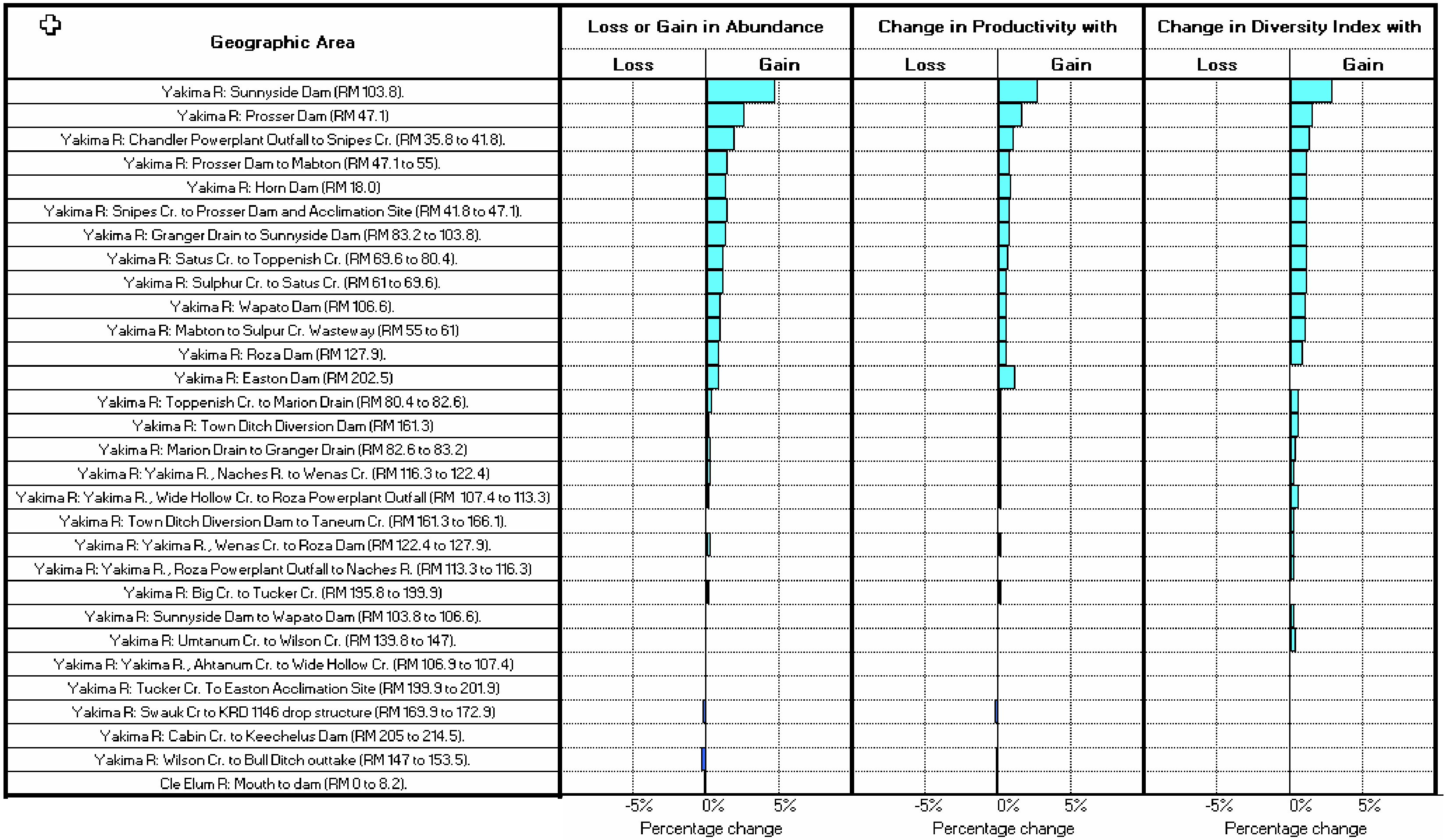


Figure 50. Upper Yakima spring Chinook tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

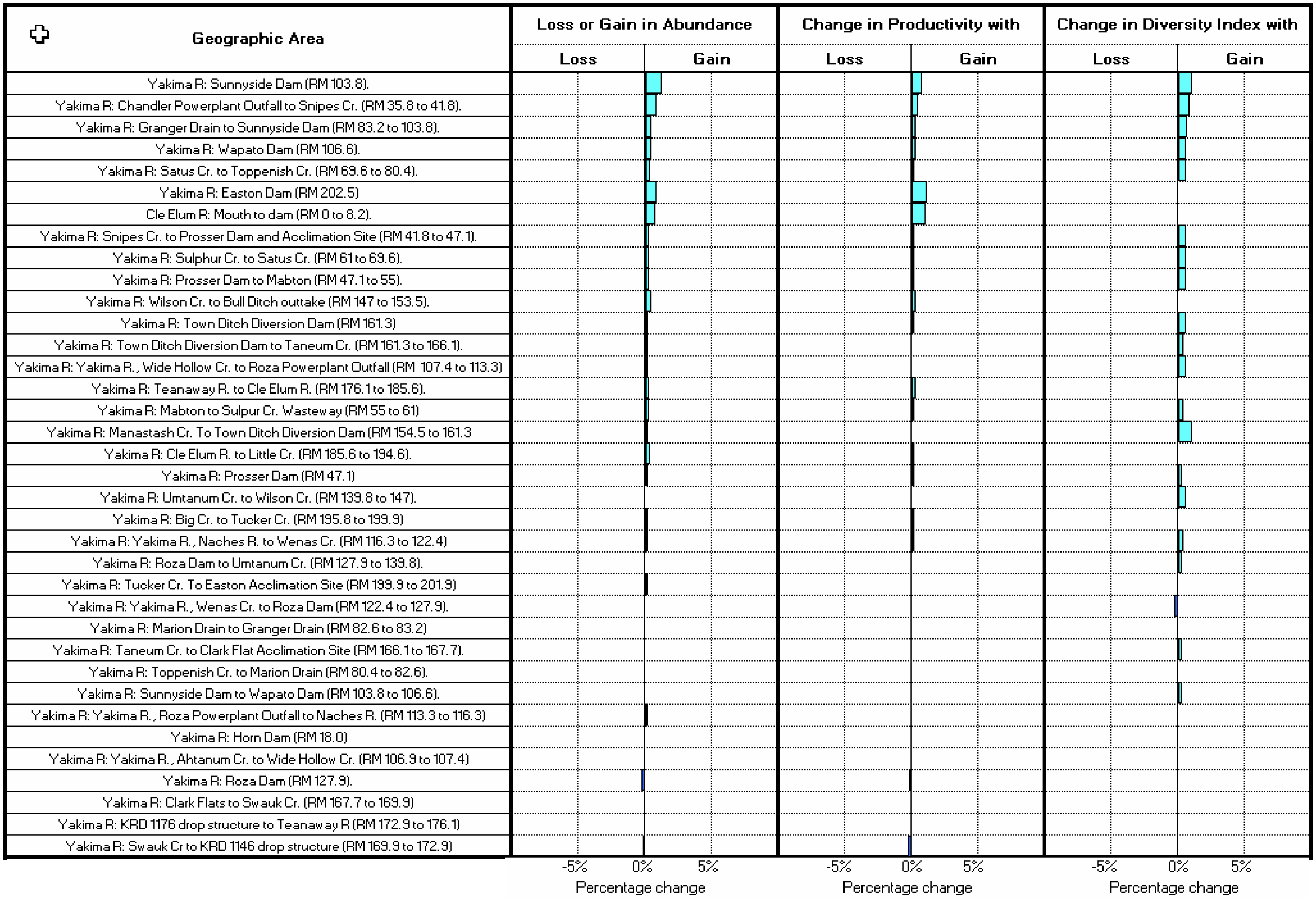


Figure 51. Upper Yakima spring Chinook tornado diagram, Wymer Dam and Reservoir Alternative.

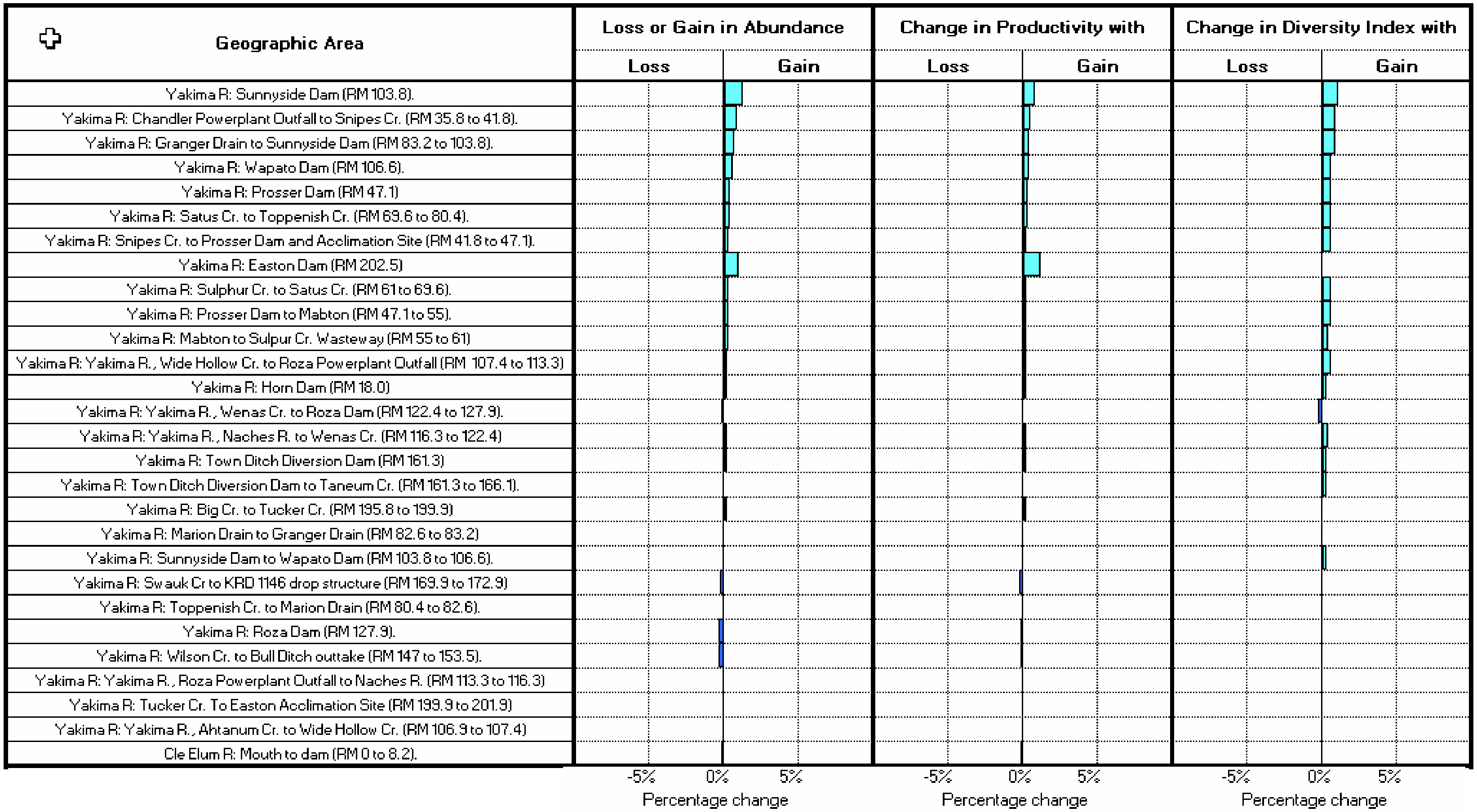


Figure 52. Upper Yakima spring Chinook tornado diagram, No Action Alternative.

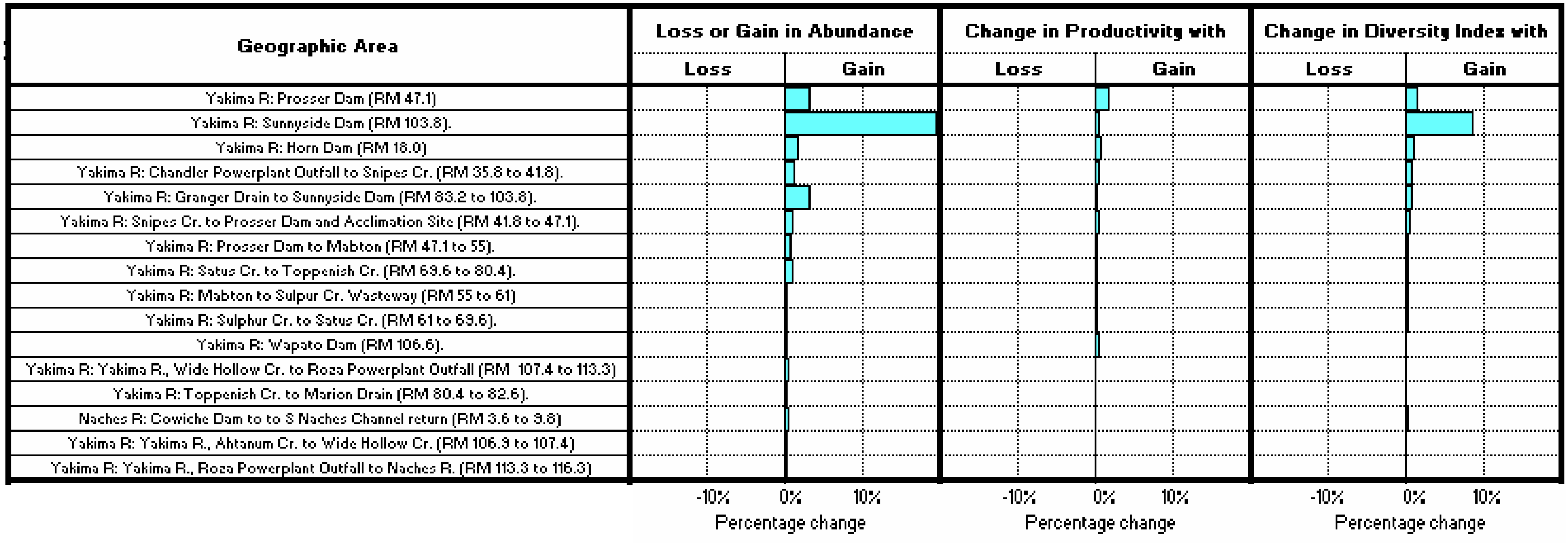


Figure 53. Naches spring Chinook tornado diagram, Black Rock Alternative.

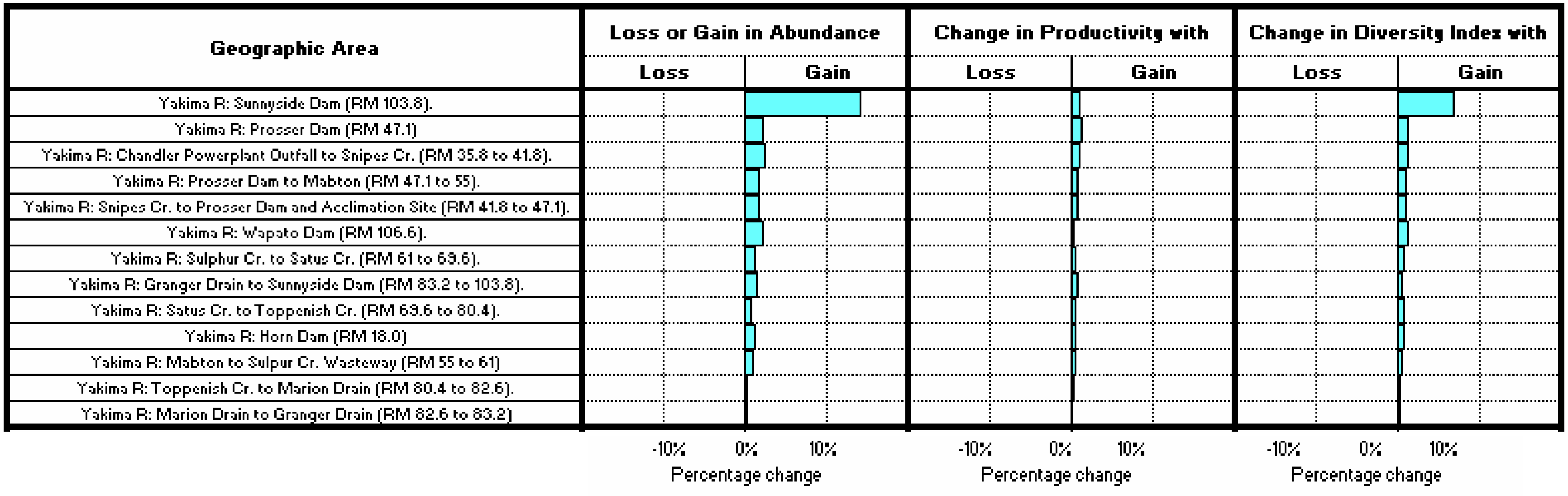


Figure 54. Naches spring Chinook tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

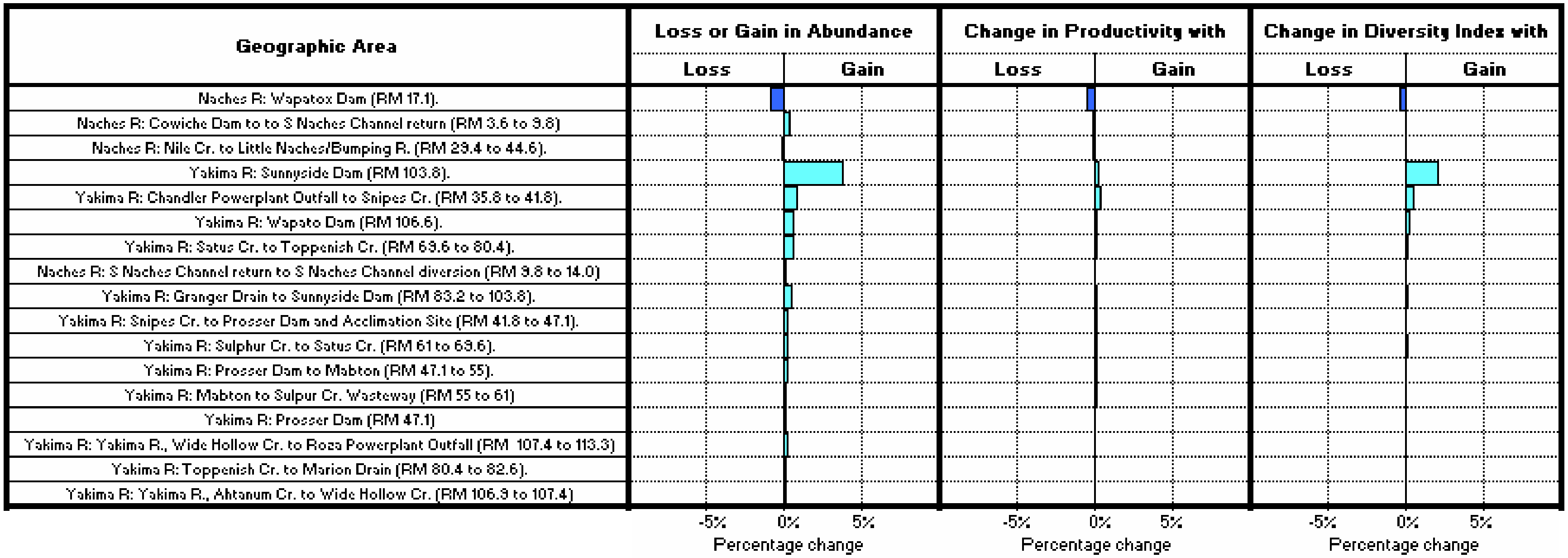


Figure 55. Naches spring Chinook tornado diagram, Wymer Dam and Reservoir Alternative.

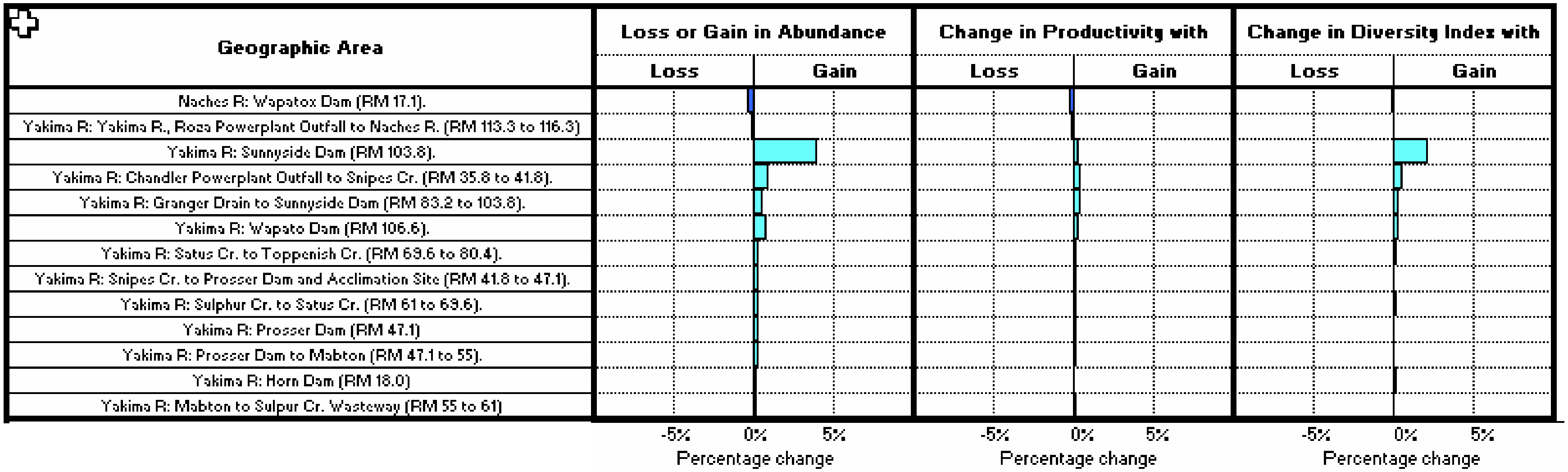


Figure 56. Naches spring Chinook tornado diagram, No Action Alternative.

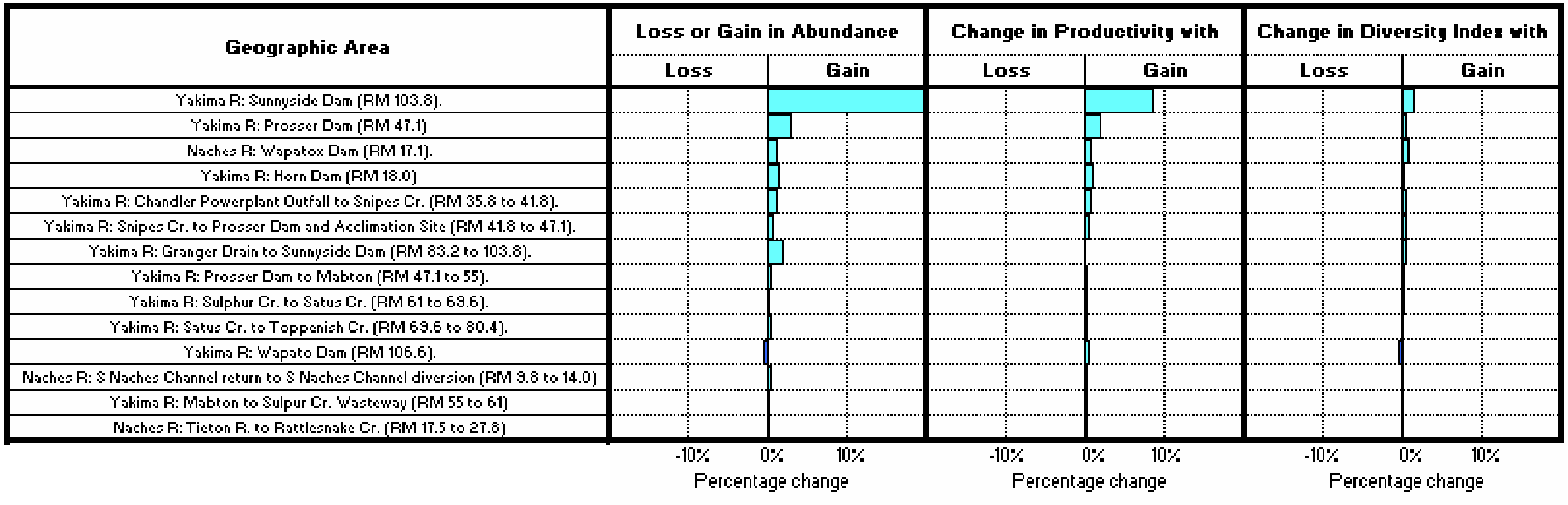


Figure 57. American River spring Chinook tornado diagram, Black Rock Alternative.

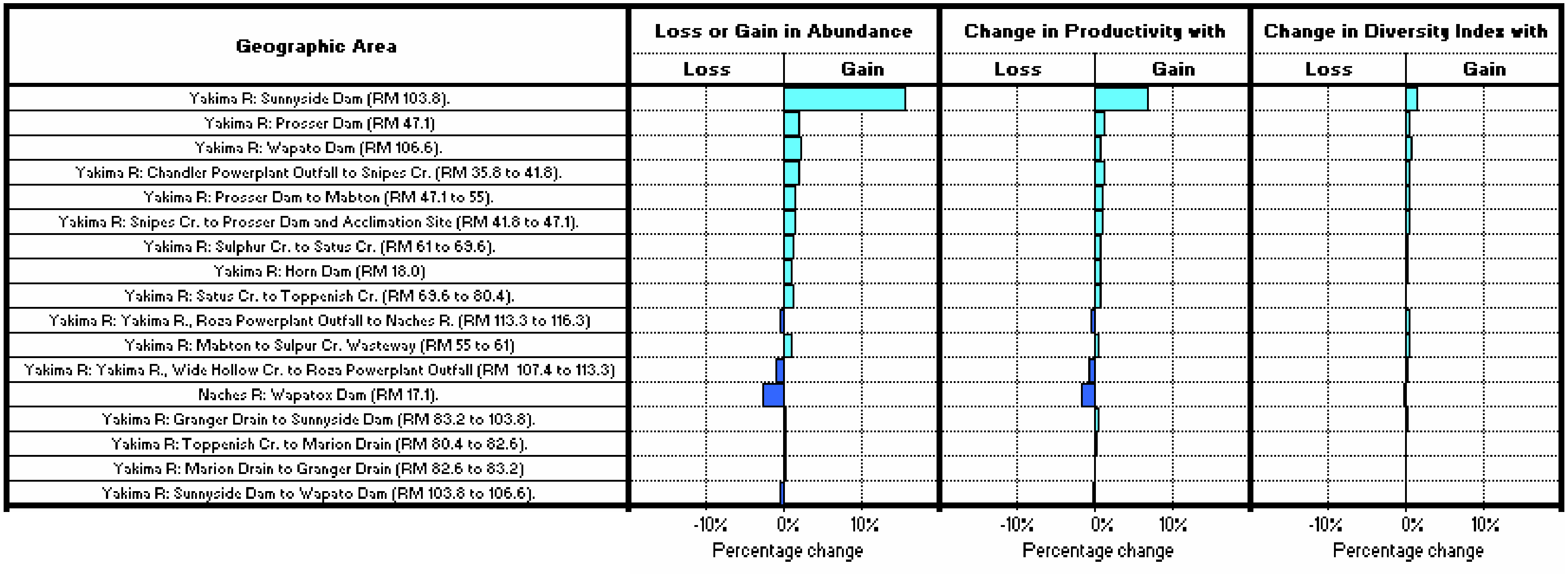


Figure 58. American River spring Chinook tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

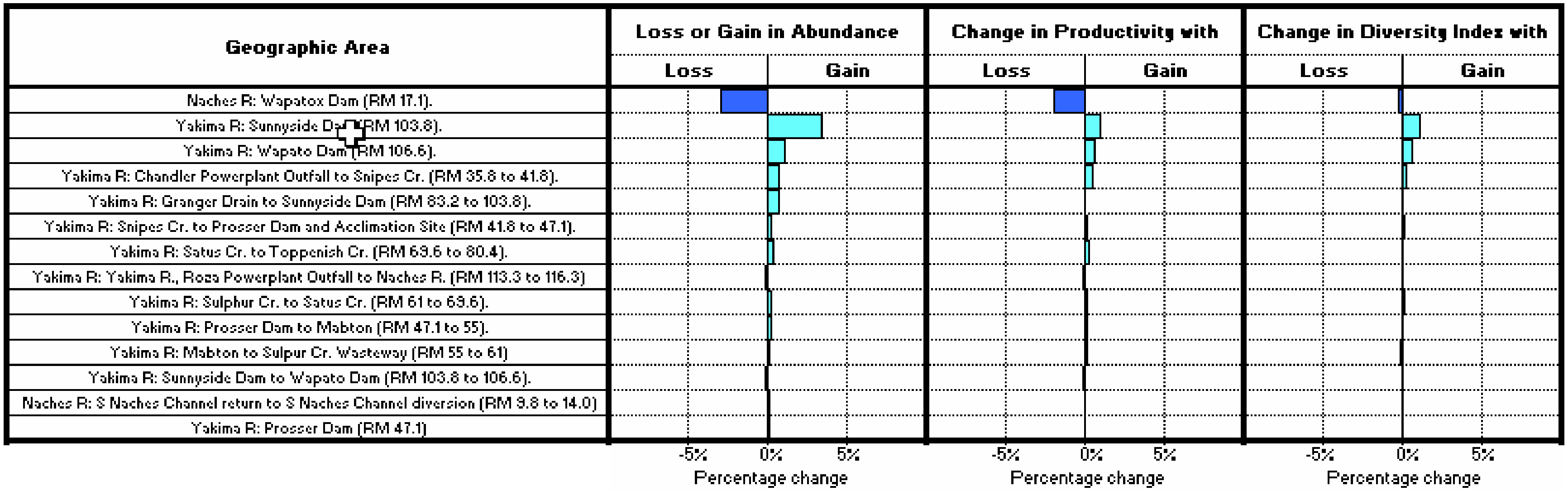


Figure 59. American River spring Chinook tornado diagram, Wymer Dam and Reservoir Alternative.

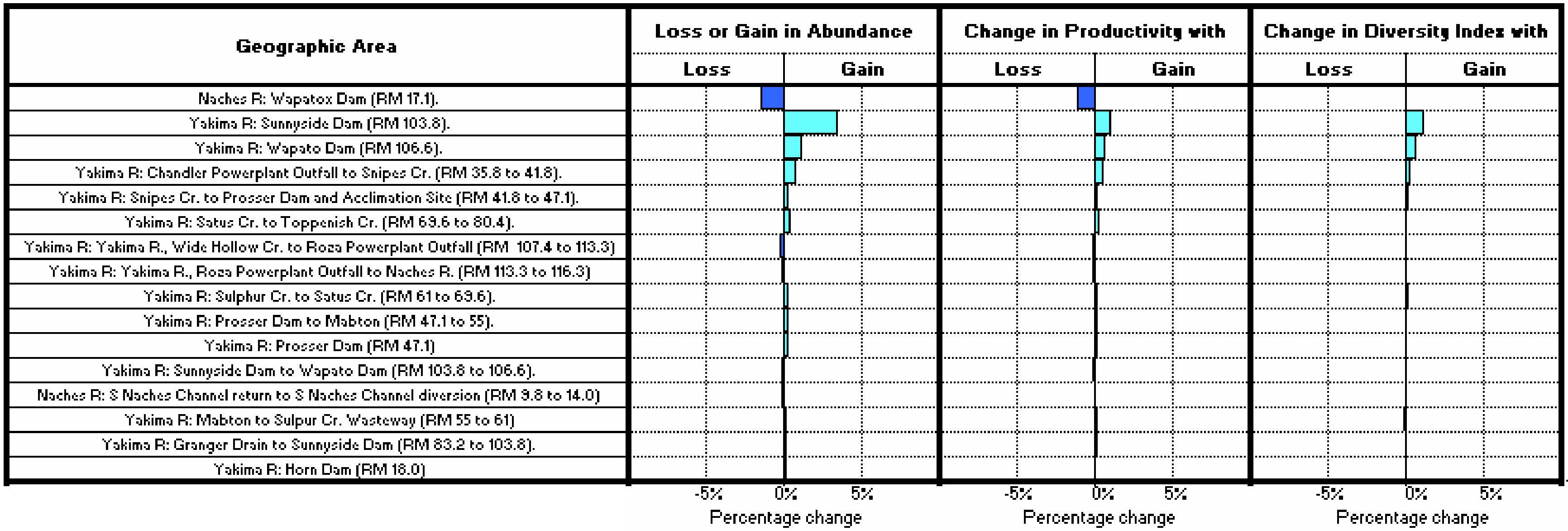


Figure 60. American River Spring Chinook Tornado Diagram, No Action Alternative.

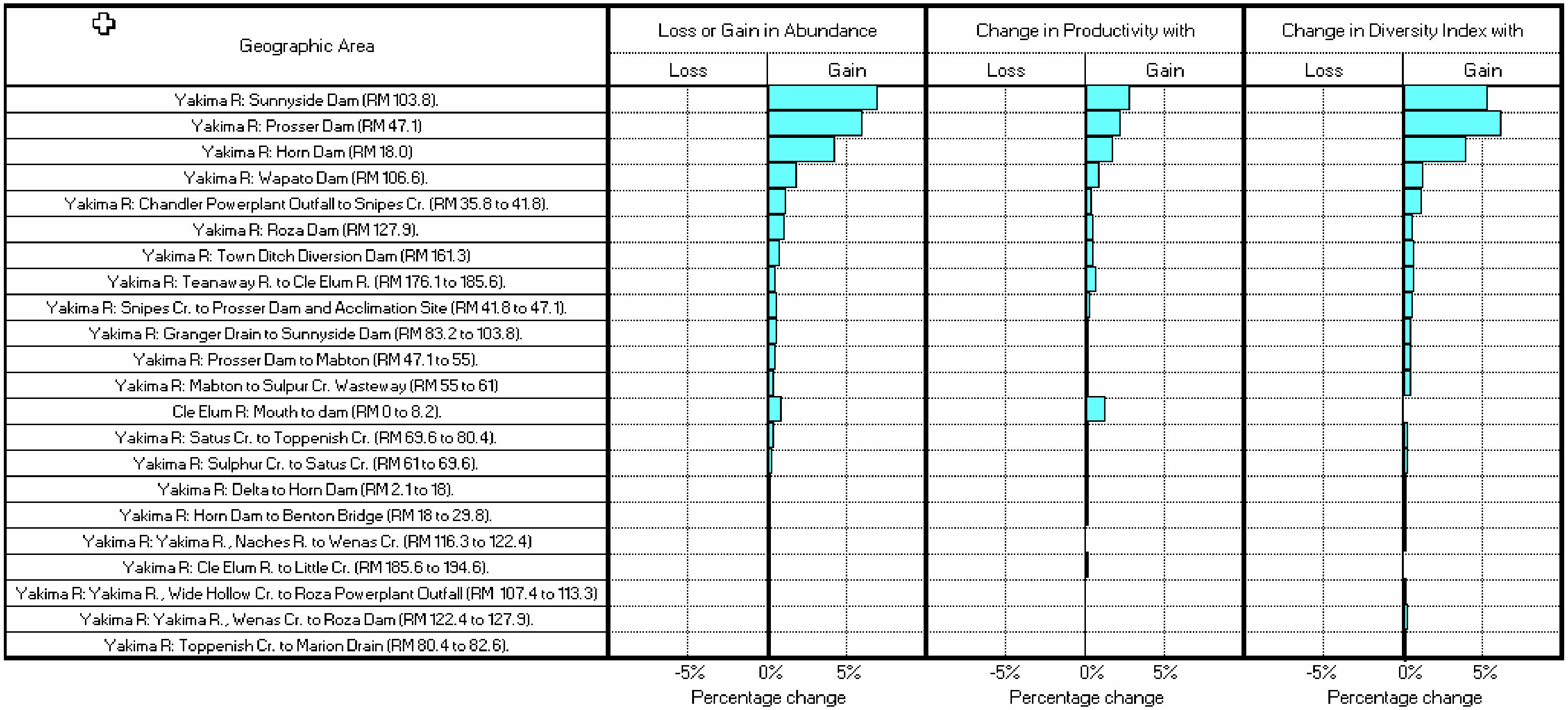


Figure 61. Upper Yakima steelhead tornado diagram, Black Rock Alternative.

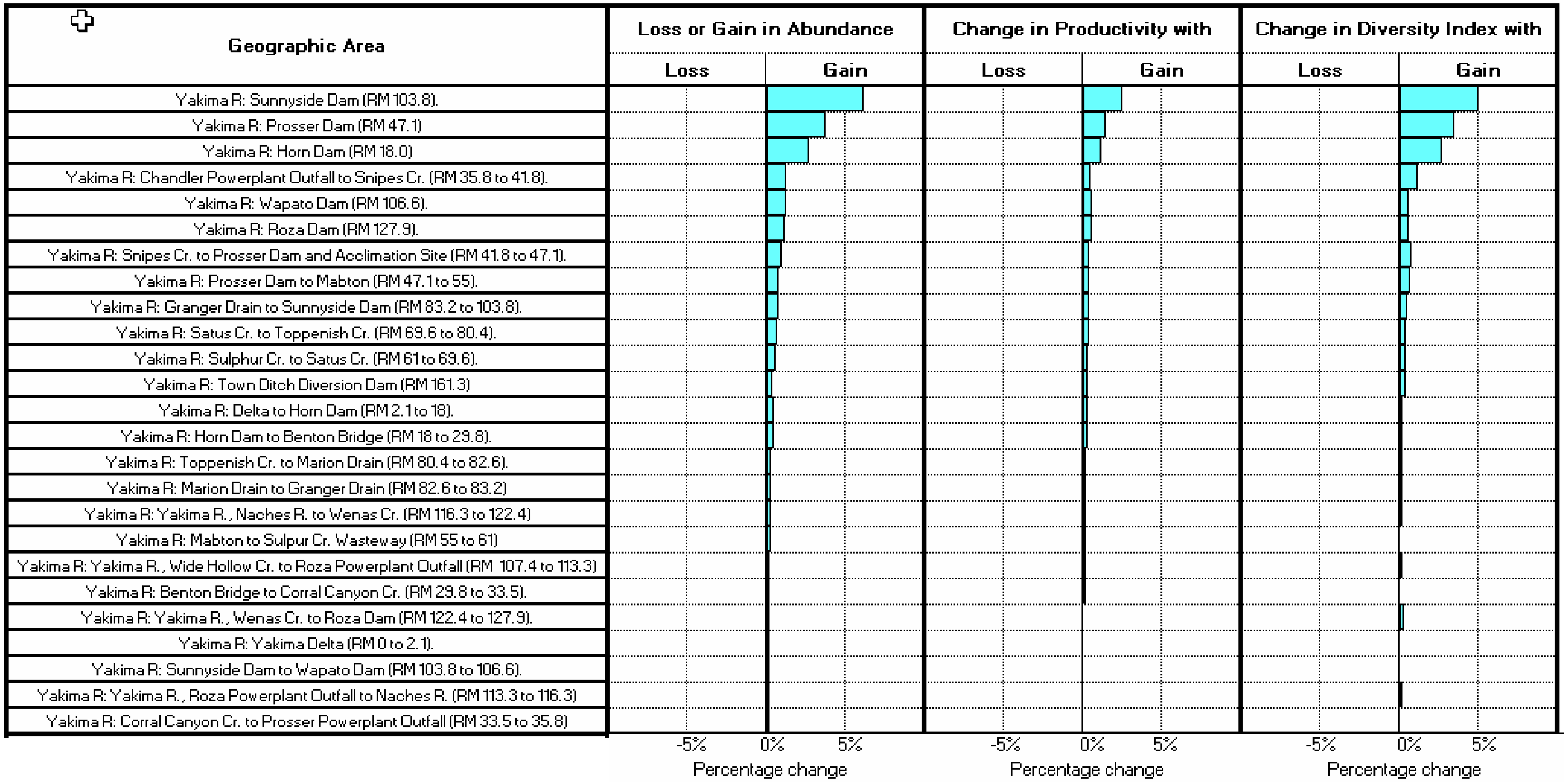


Figure 62. Upper Yakima steelhead tornado diagram, Wymer Dam Plus Yakima River Pump Exchanged alternative.

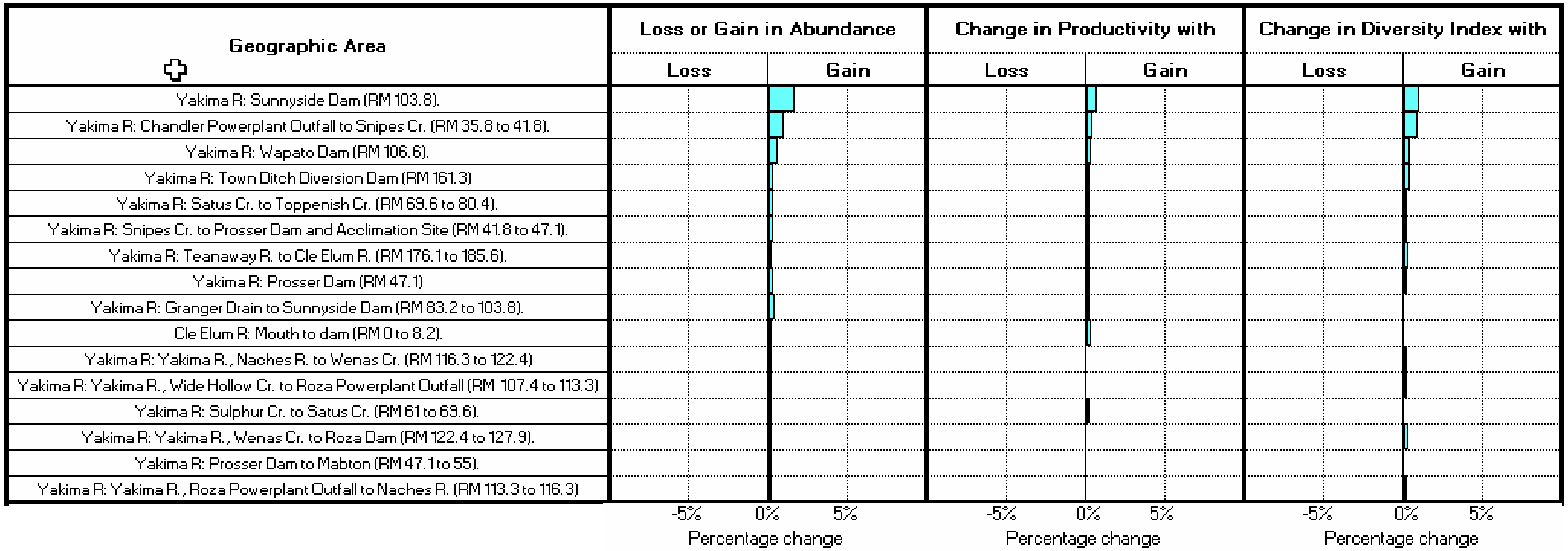


Figure 63. Upper Yakima steelhead tornado diagram, Wymer Dam and Reservoir Alternative.

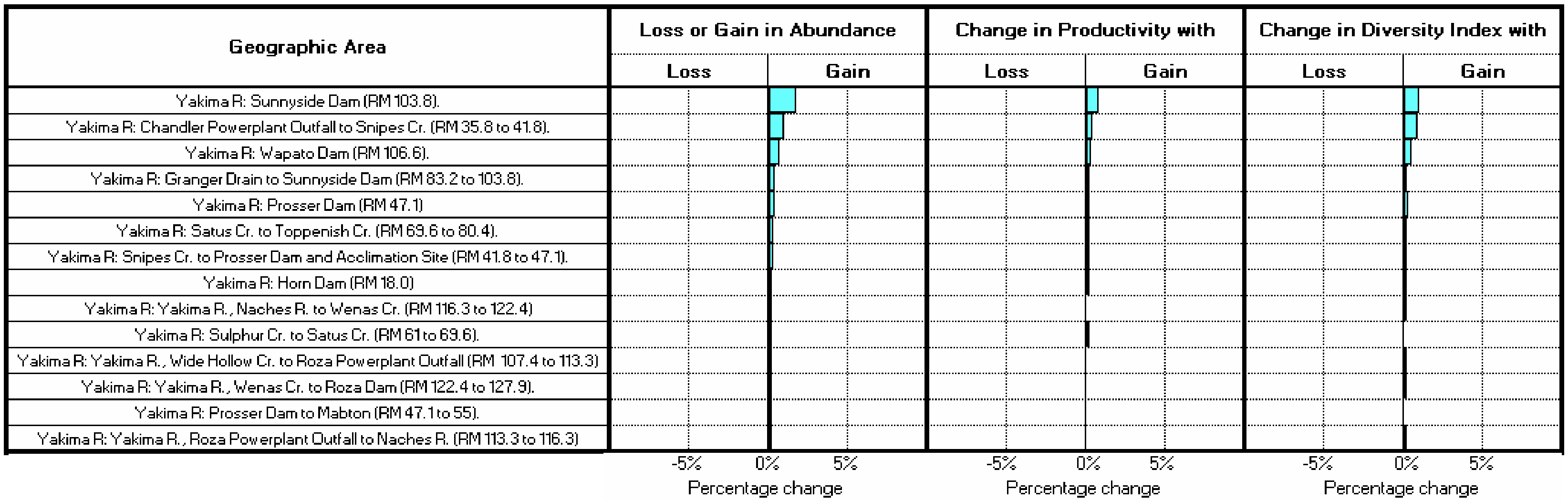


Figure 64. Upper Yakima steelhead tornado diagram, No Action Alternative.

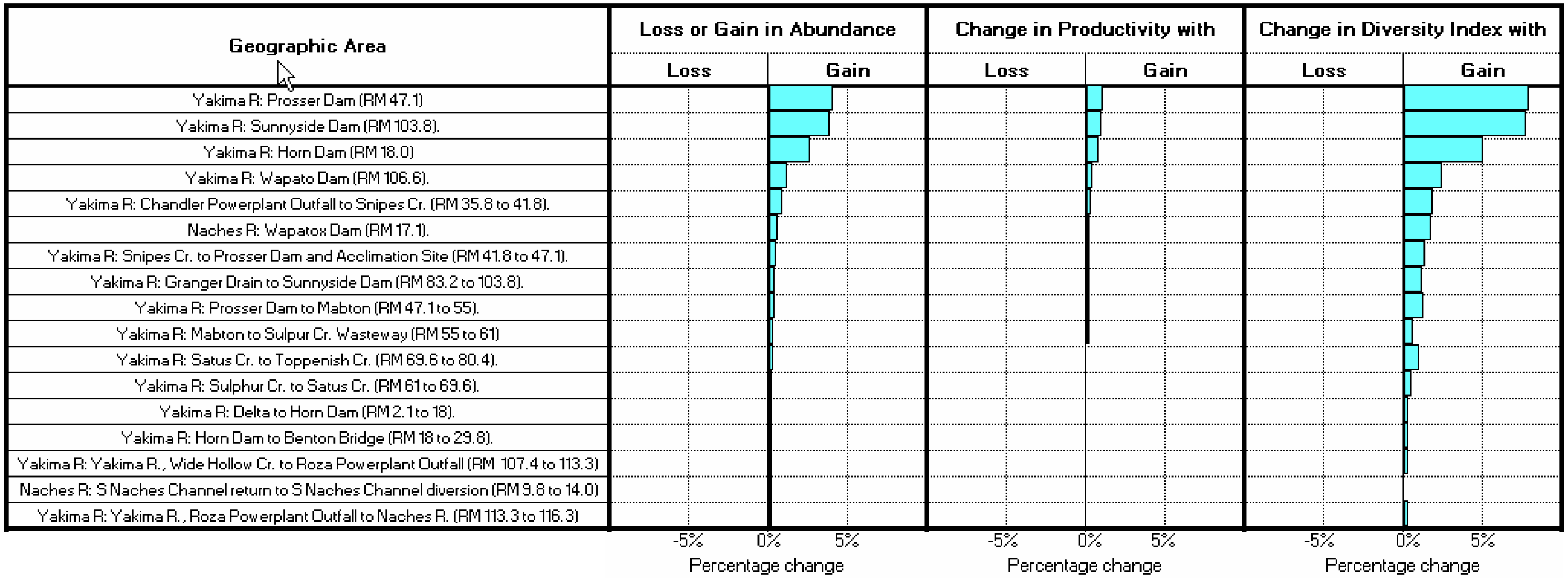


Figure 65. Naches steelhead tornado diagram, Black Rock Alternative.

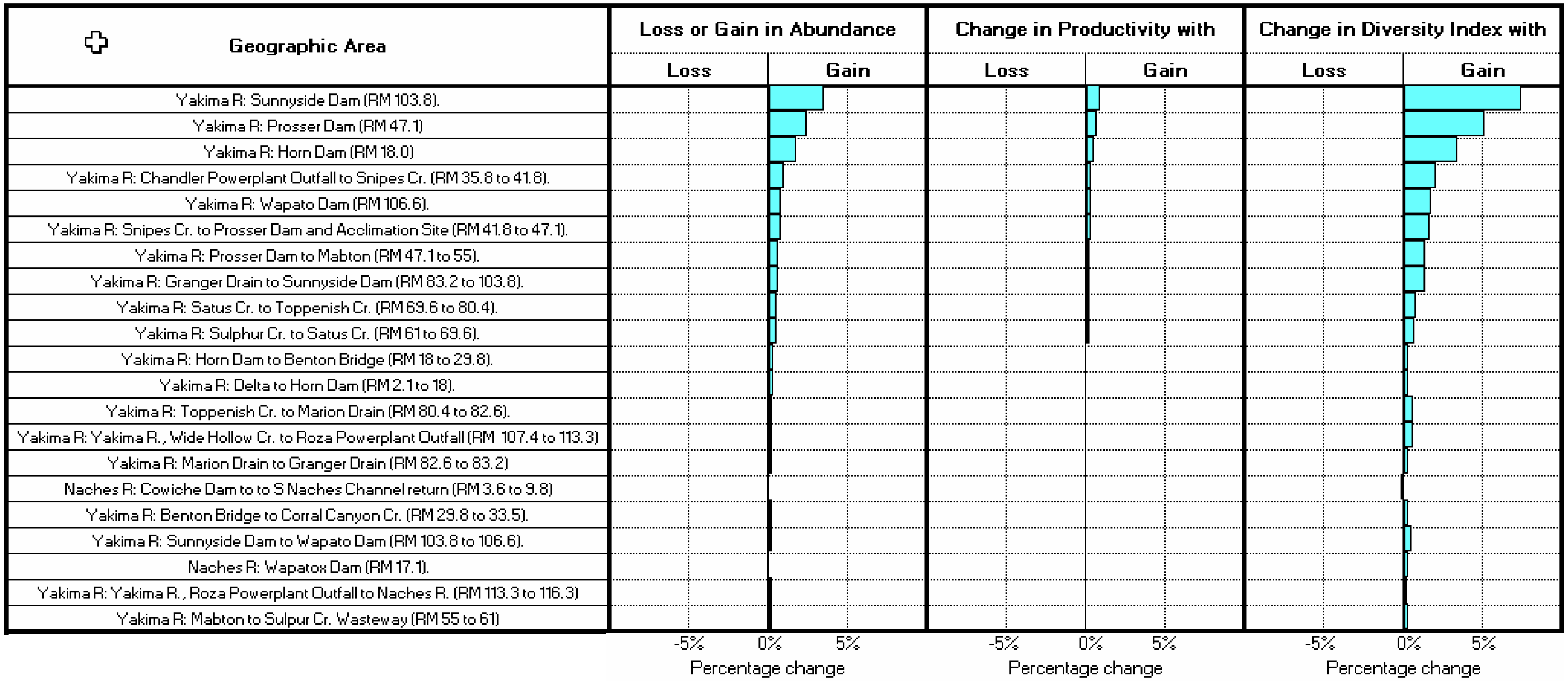


Figure 66. Naches steelhead tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

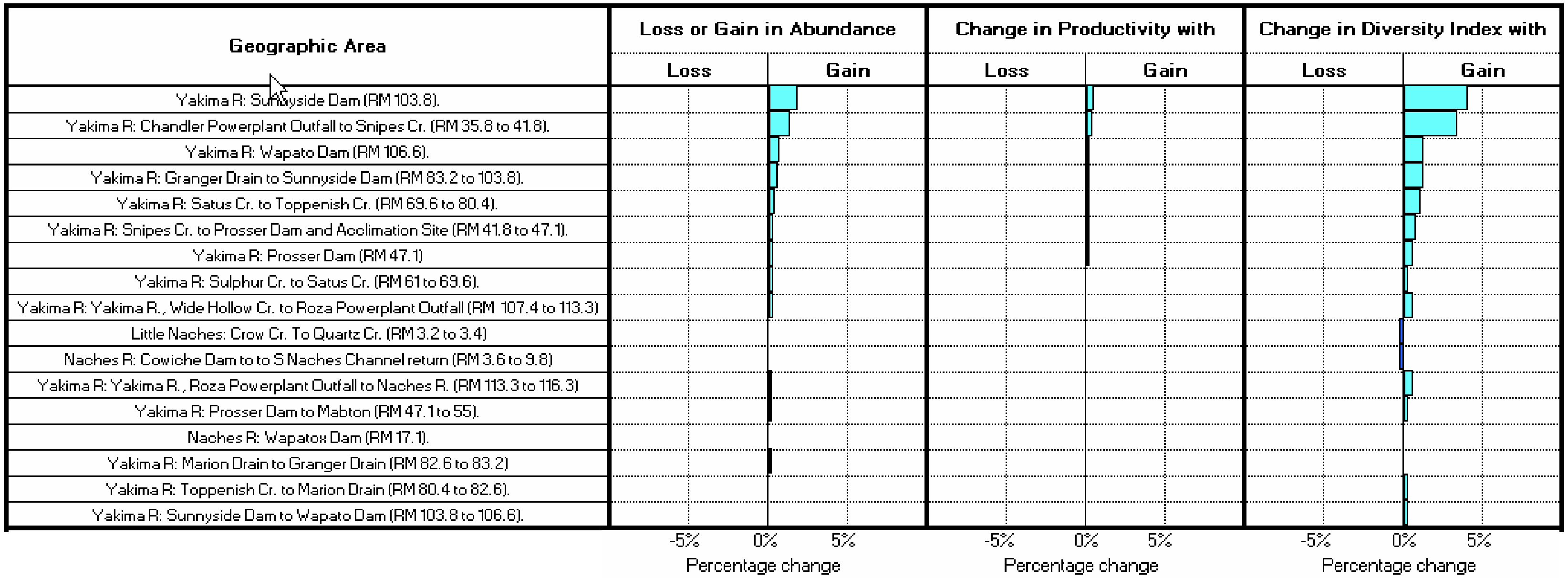


Figure 67. Naches steelhead tornado diagram, Wymer Dam and Reservoir Alternative.

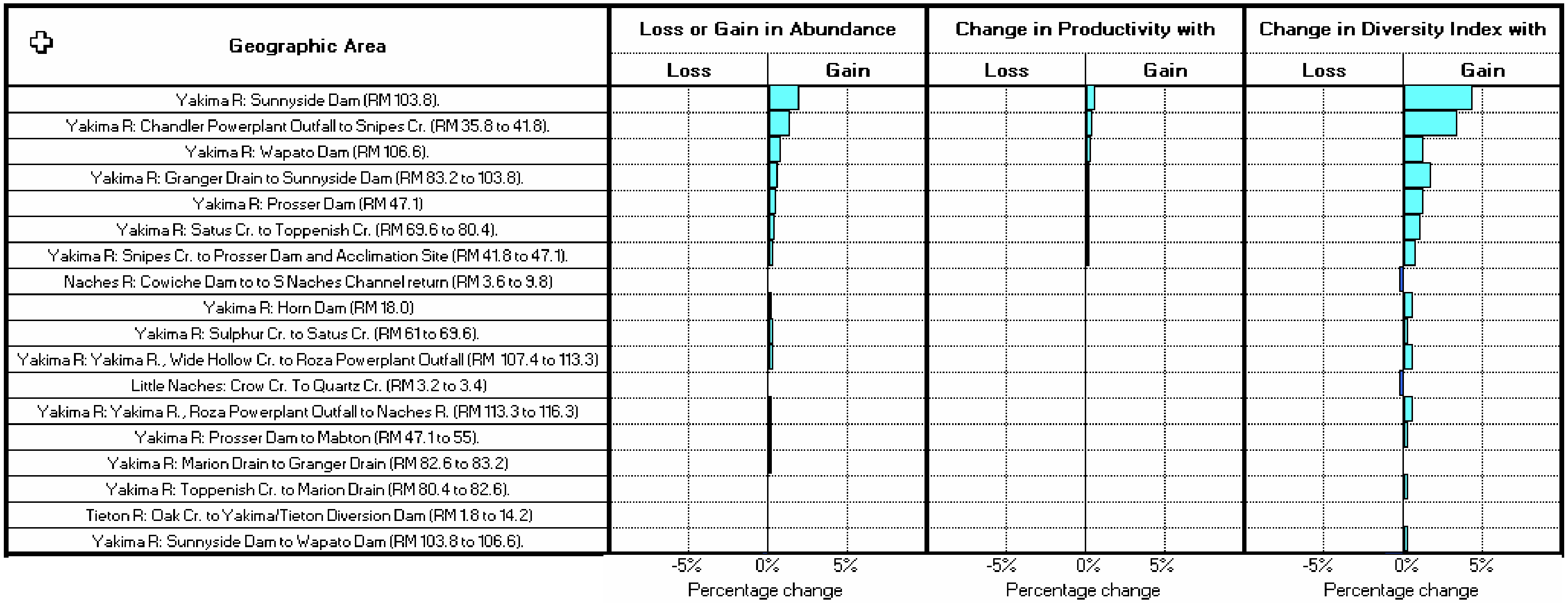


Figure 68. Naches steelhead tornado diagram, No Action Alternative.

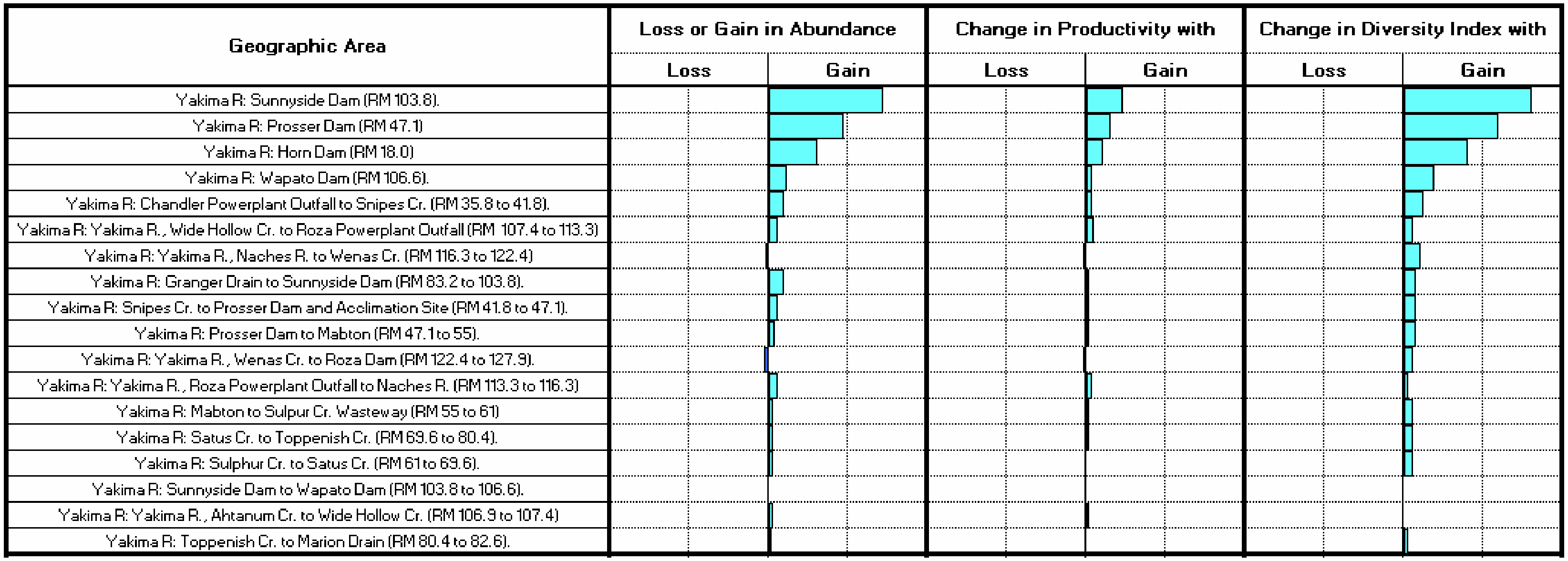


Figure 69. Middle Yakima steelhead tornado diagram, Black Rock Alternative.

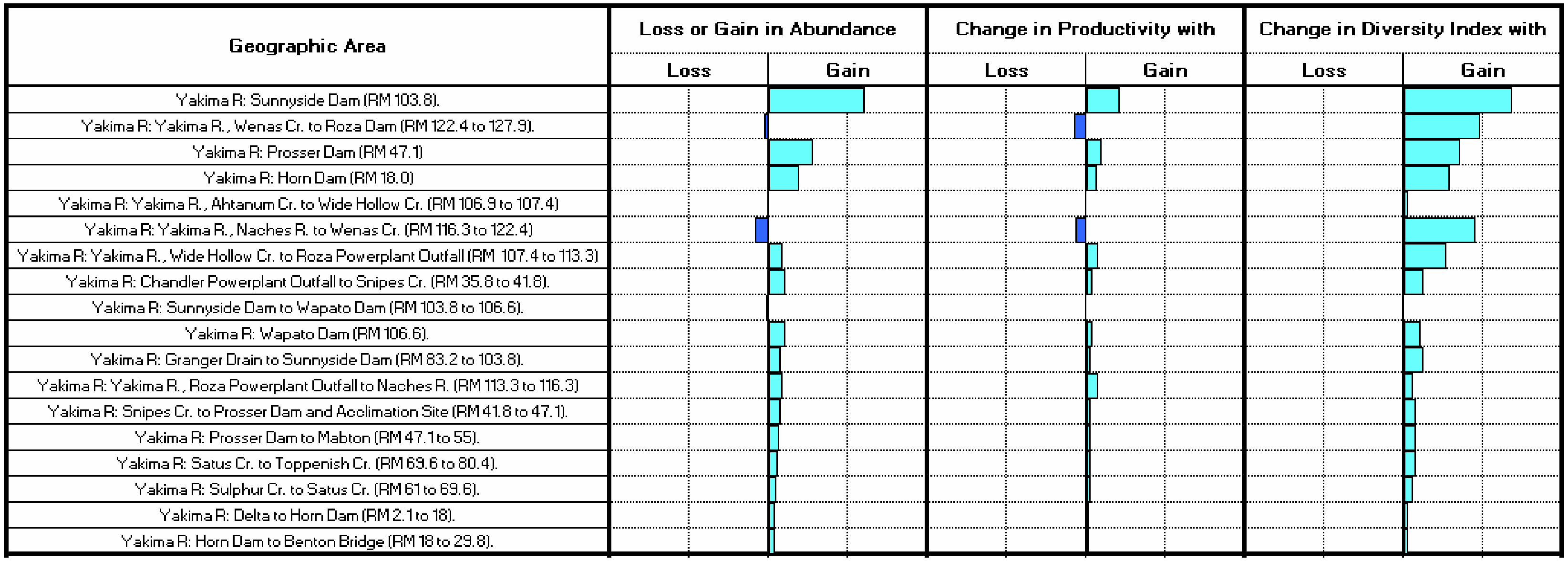


Figure 70. Middle Yakima steelhead tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

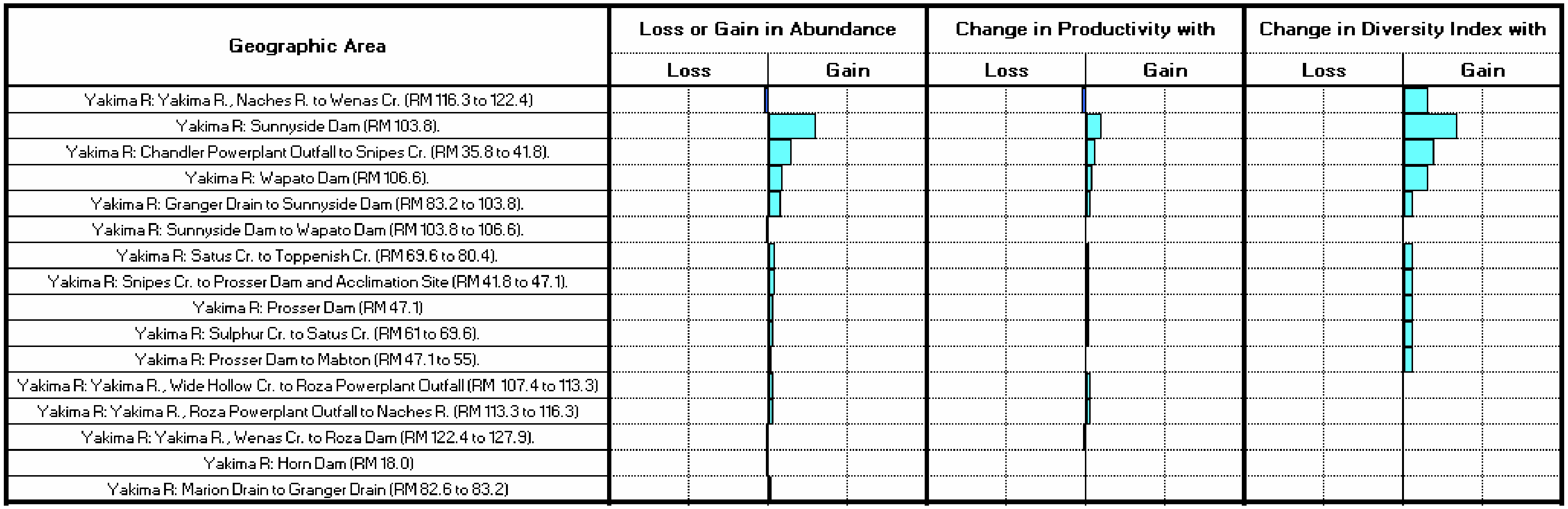


Figure 71. Middle Yakima steelhead tornado diagram, Wymer Dam and Reservoir Alternative.

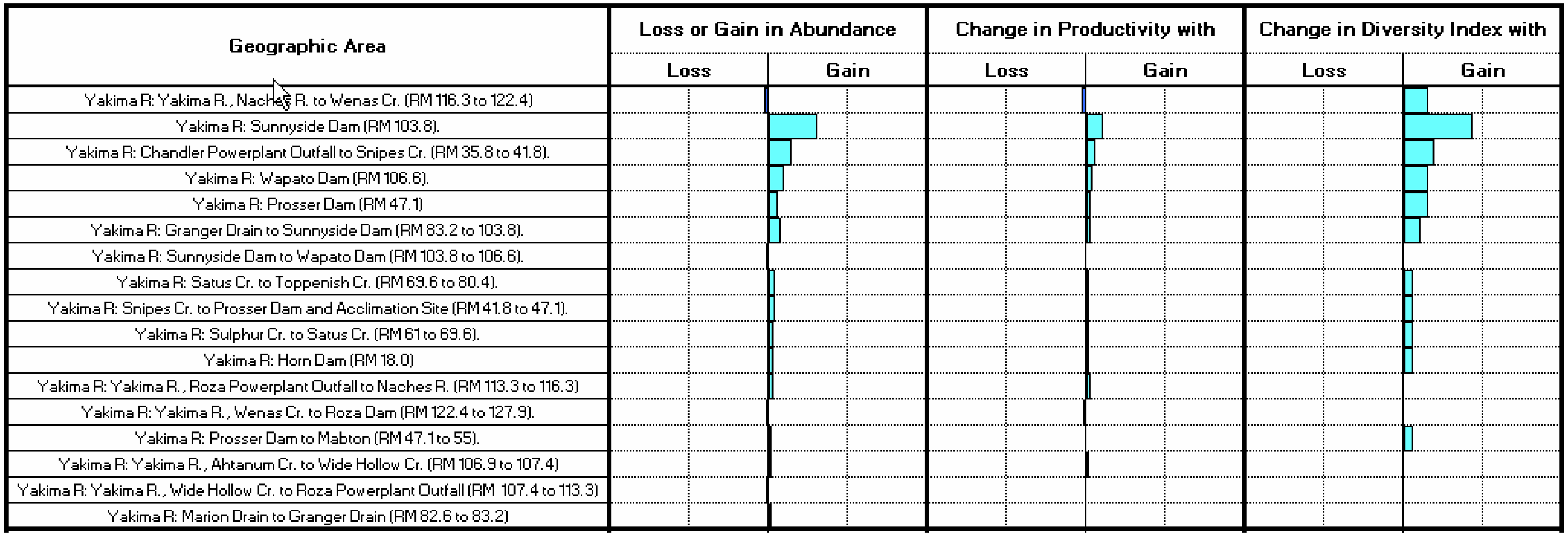


Figure 72. Middle Yakima steelhead tornado diagram, Wymer Dam and Reservoir Alternative.

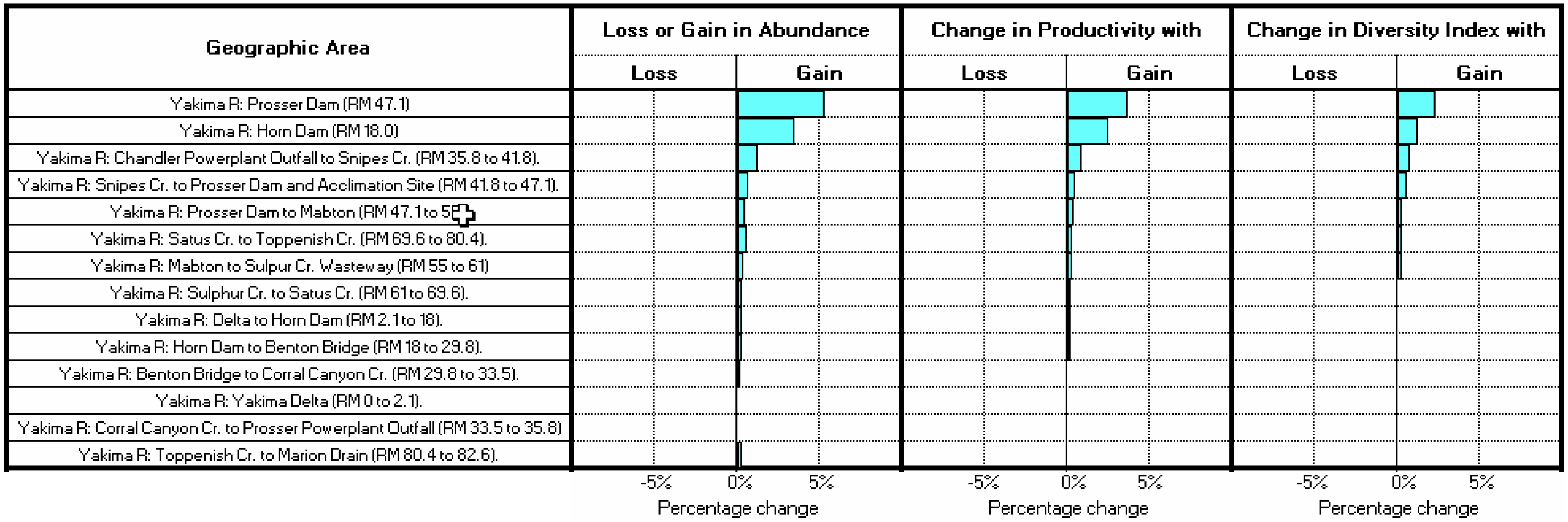


Figure 73. Toppenish steelhead tornado diagram, Black Rock Alternative.

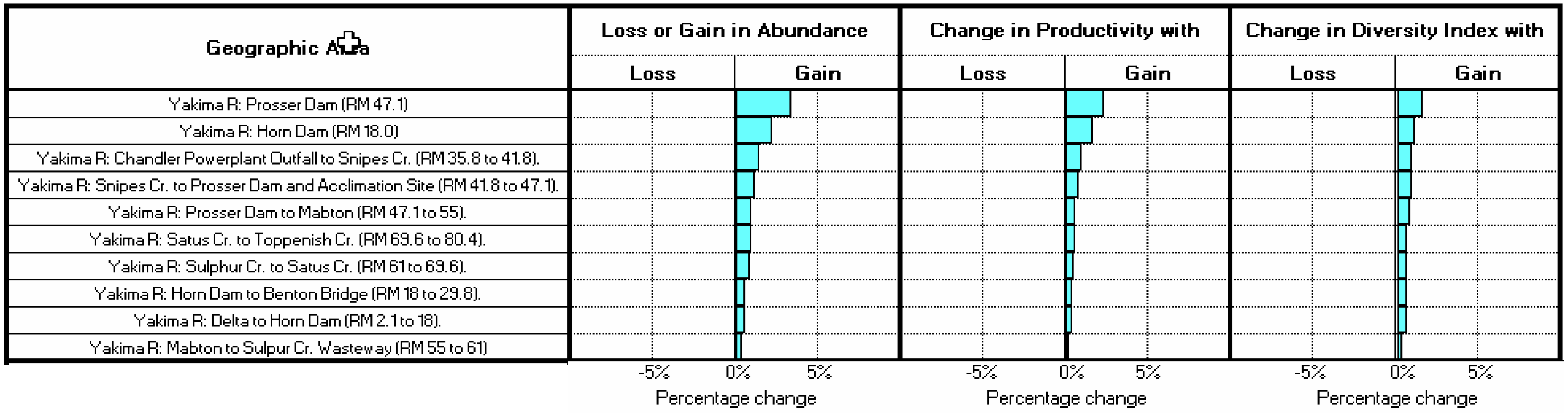


Figure 74. Toppenish steelhead tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

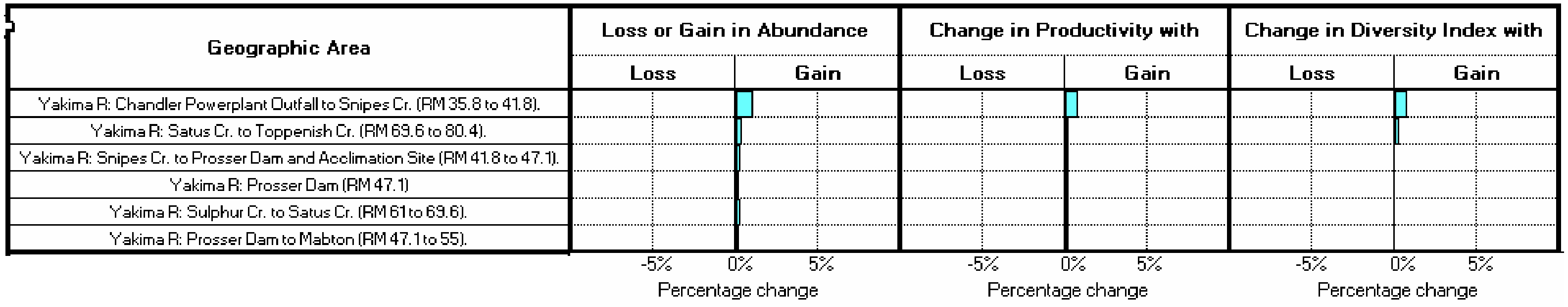


Figure 75. Toppenish steelhead tornado diagram, Wymer Dam and Reservoir Alternative.

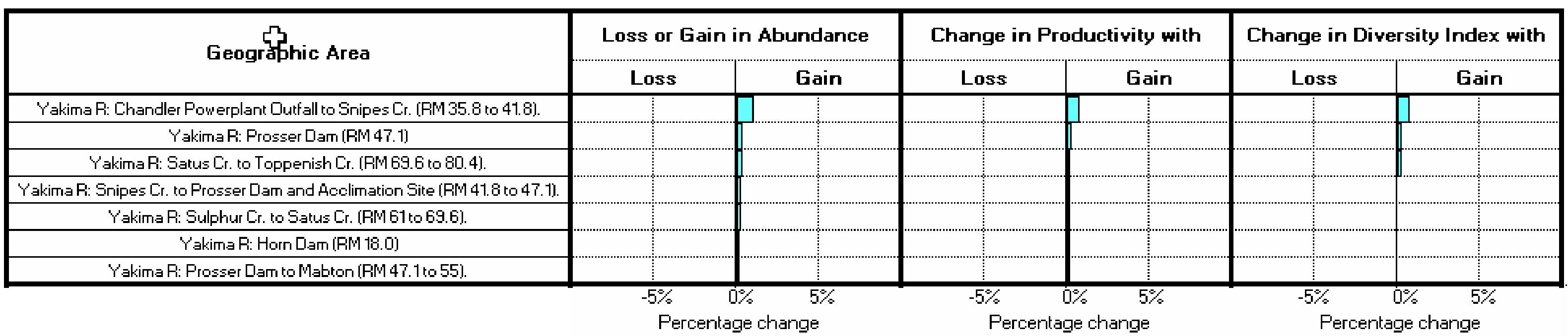


Figure 76. Toppenish steelhead tornado diagram, No Action Alternative.

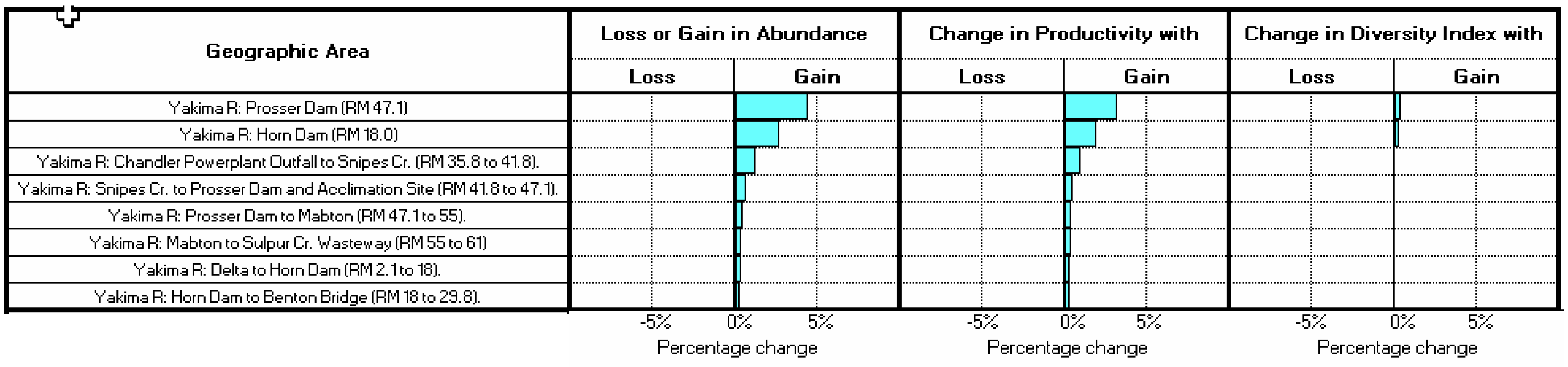


Figure 77. Satus steelhead tornado diagram, Black Rock Alternative.

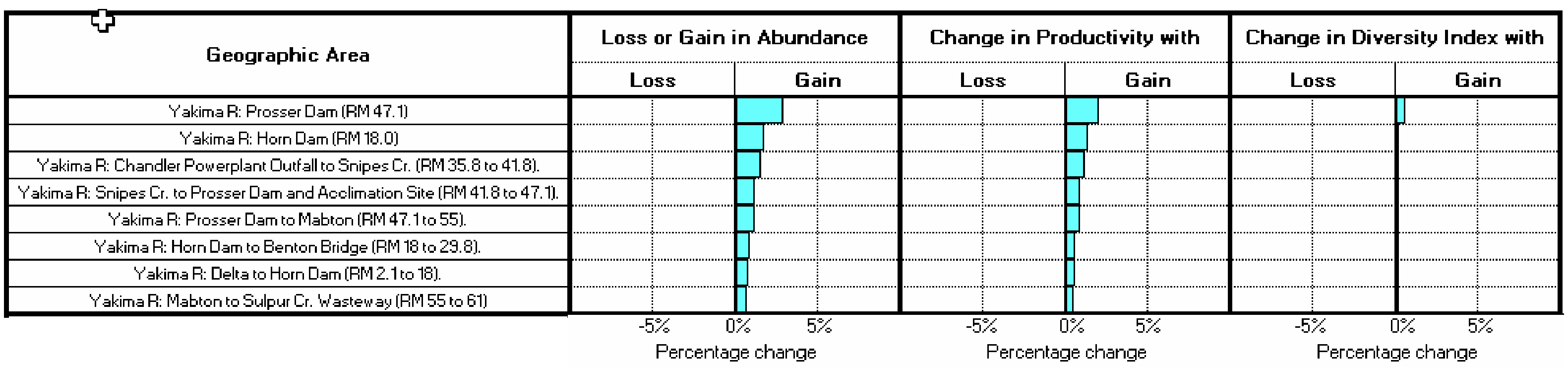


Figure 78. Satus steelhead tornado diagram, Wymer Dam Plus Yakima River Pump Exchange Alternative.

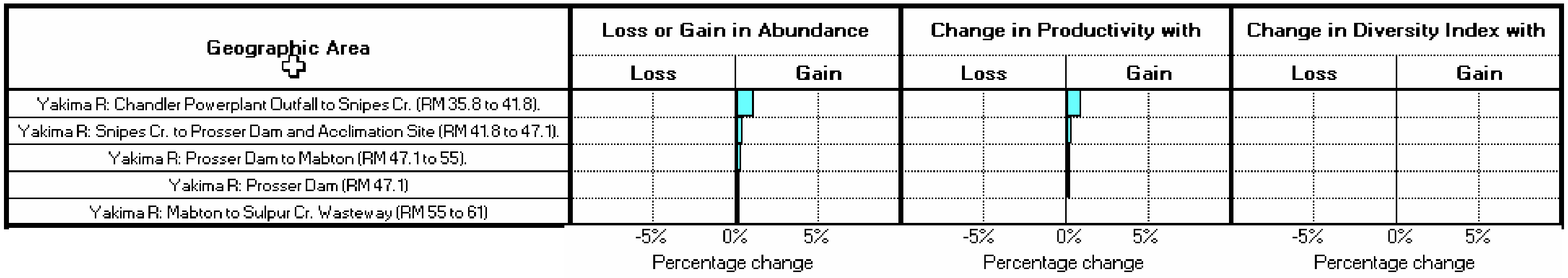


Figure 79. Satus steelhead tornado diagram, Wymer Dam and Reservoir Alternative.

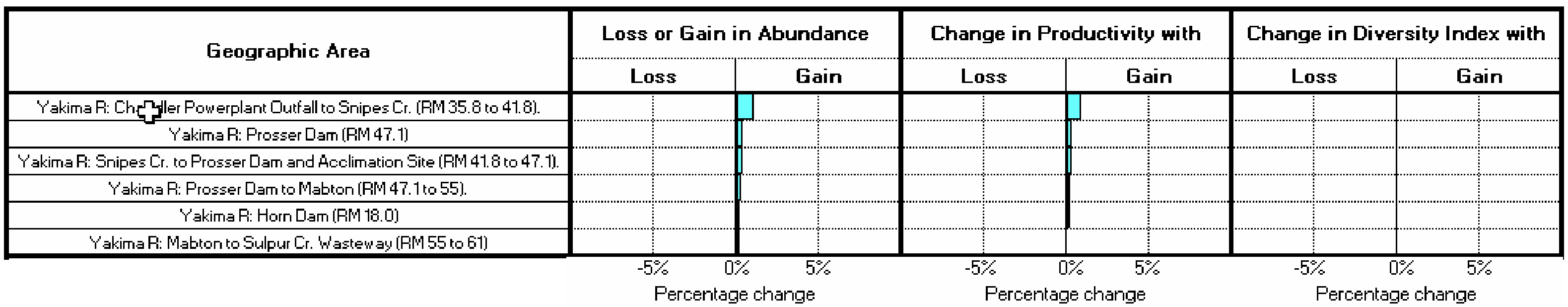


Figure 80. Satus steelhead tornado diagram, No Action Alternative.

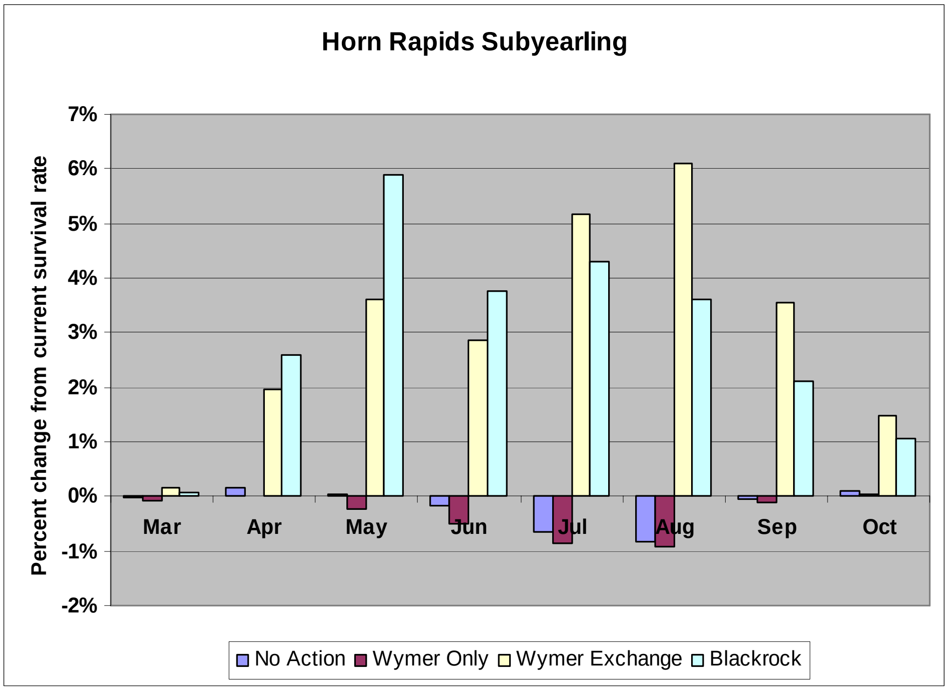
Monthly bypass survival in the existing EDT model is calculated as the product of an estimated or assumed monthly survival rate for bypassed fish and the proportion of fish bypassed in that month (survival of non-bypassed fish is assumed to be 100%). The proportion of bypassed juvenile migrants is assumed to be approximated by the percent discharge diverted. In almost all cases, the month-specific survival of subyearlings is assumed to be less than yearlings. Over the ten diversion dams arrayed along the project reaches, the maximum impact on subyearlings ranges from 7 to 62% mortality (August impacts for Easton Dam and Prosser Dam, respectively). Minimum impact is zero or near zero mortality, and is assigned to all diversions in early spring.

New bypass survival rates were assigned to each alternative on the basis of the change in the monthly percent discharge diverted:

$$S_{\text{month i , Alternative j}} = 1 - (PDD_{\text{month i, Alternative j}}/PDD_{\text{month i, Current}}) * (1 - S_{\text{month i, Current}})$$

where $S_{\text{month i , Alternative j}}$ is the monthly bypass survival rate under alternative j for subyearlings or yearlings, $PDD_{\text{month i, Alternative j}}$ is the mean percent discharge diverted for month i by Alternative j, $PDD_{\text{month i, Current}}$ is the current mean diversion rate for month i, and $S_{\text{month i, Current}}$ is the current monthly bypass survival rate.

Figures 81 – 89 show the percent change from current monthly bypass survival rates for each of the alternatives for all of the diversion dam bypasses along reaches affected by storage alternatives. Note that survival rates show significant improvement for the peak smolt outmigration months of April through June at all diversions for the Wymer Dam Plus Yakima River Pump Exchange and Black Rock Alternatives, and that survival under the Black Rock Alternative always exceeds survival under the Wymer Dam Plus Yakima River Pump Exchange Alternative. This difference is a major part of the reason fish production under the Black Rock Alternative exceeds the other alternatives for most species. Another part of the superiority of the Black Rock Alternative for Middle Yakima, upper Yakima and Naches populations is the fact that subyearling survival at Sunnyside Dam during the period July through October improves dramatically for the Wymer Dam Plus Yakima River Pump Exchange and, especially, the Black Rock Alternatives. Survival of subyearlings in the summer and fall at Sunnyside Dam is important because Naches and upper Yakima subyearlings move past Sunnyside Dam both during the summer, as parr, and during the late fall and winter, as “winter migrants” on their way to major overwintering areas in the mainstem Yakima near Toppenish (Fast et al. 1991). Subyearling survival rates at Wapato Dam are clearly also important for the same reasons. Similar benefits under the Black Rock Alternative are not seen at Wapato Dam, though, because Wapato Dam and the Wapato Irrigation Project have not been included in the water exchanges with Black Rock reservoir. The relative lack of subyearling survival benefits at Wapato Dam makes the benefits projected for Sunnyside even more important to Naches and upper Yakima populations.



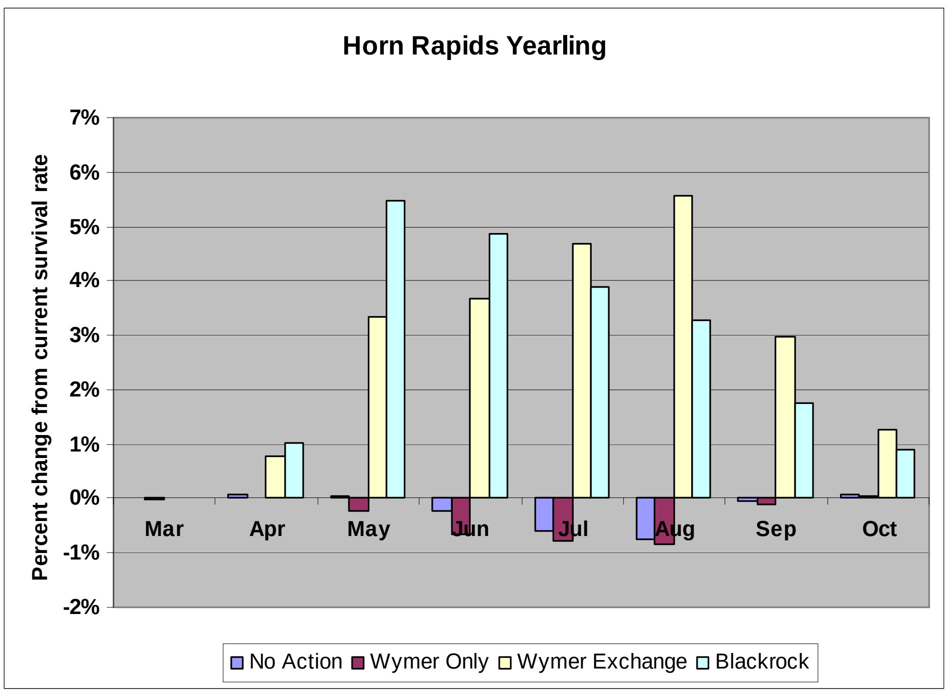
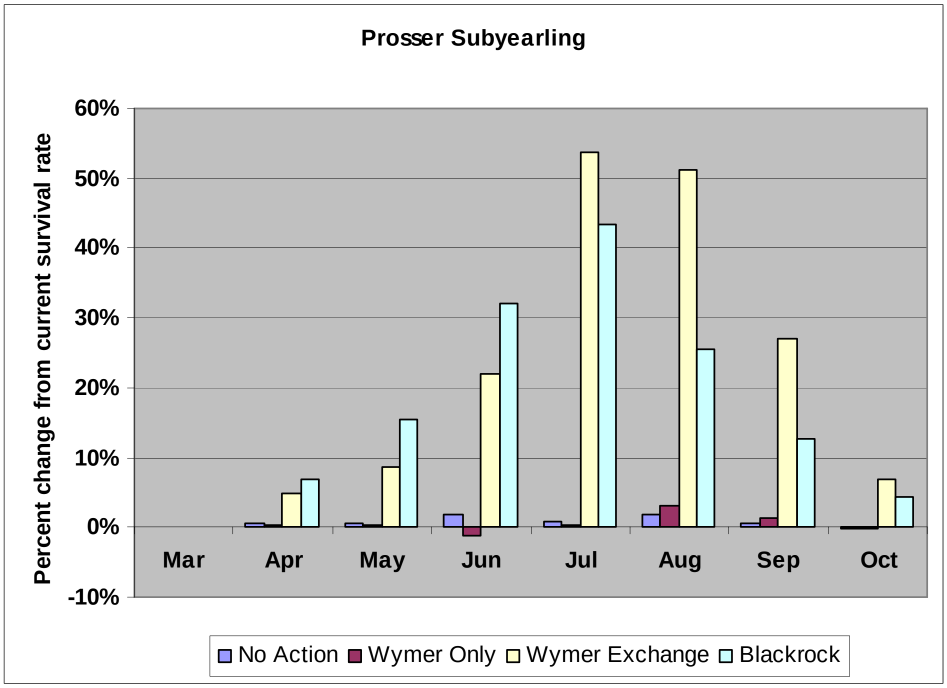


Figure 81. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Horn Rapids Dam bypass. Depicted survival rates were applied to all species.



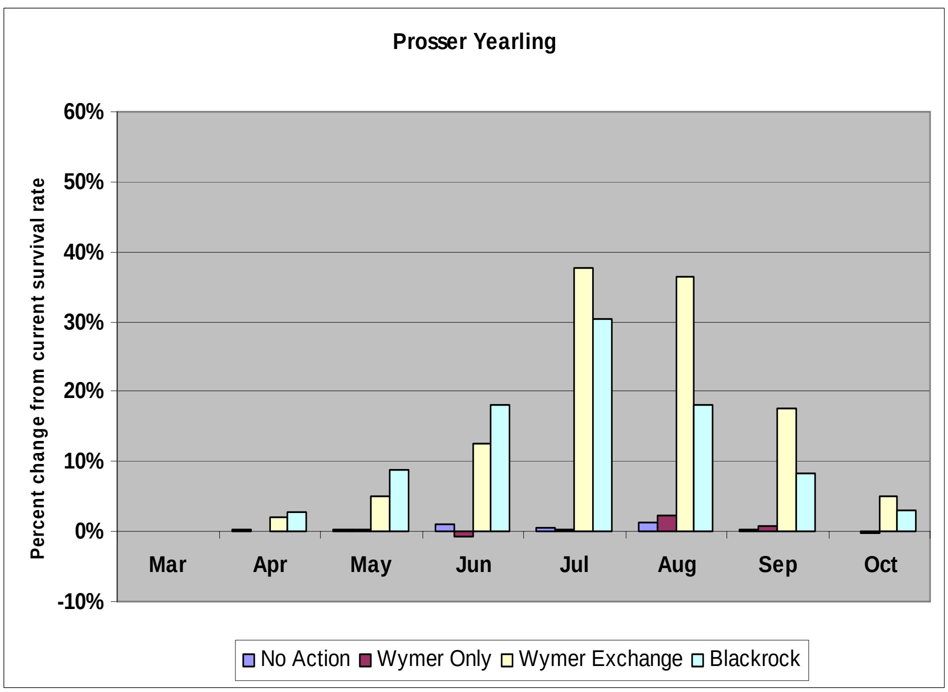
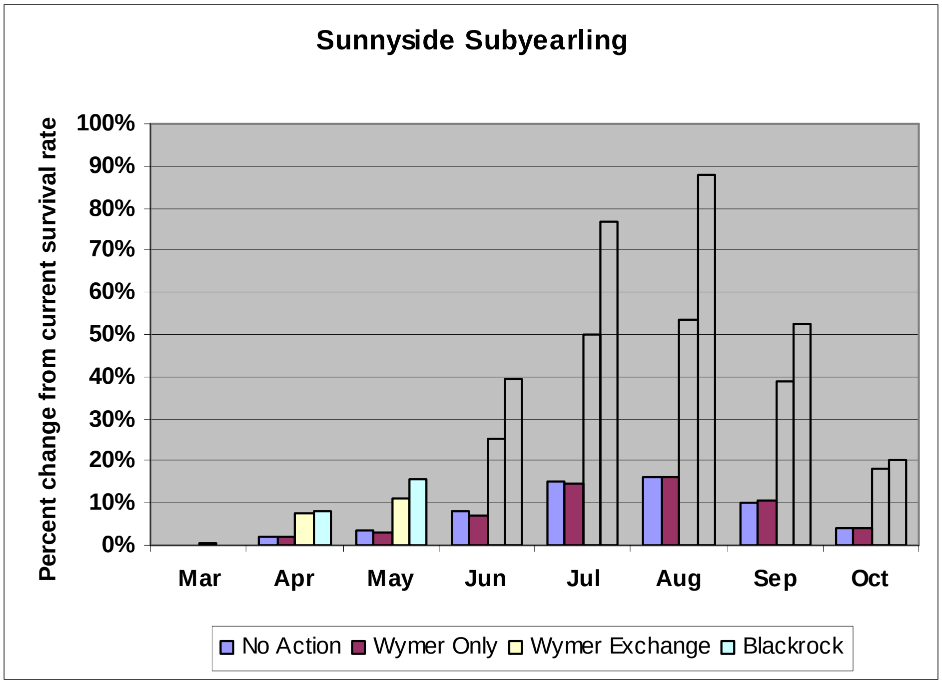


Figure 82. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Prosser Dam bypass. Depicted survival rates were applied to all species.



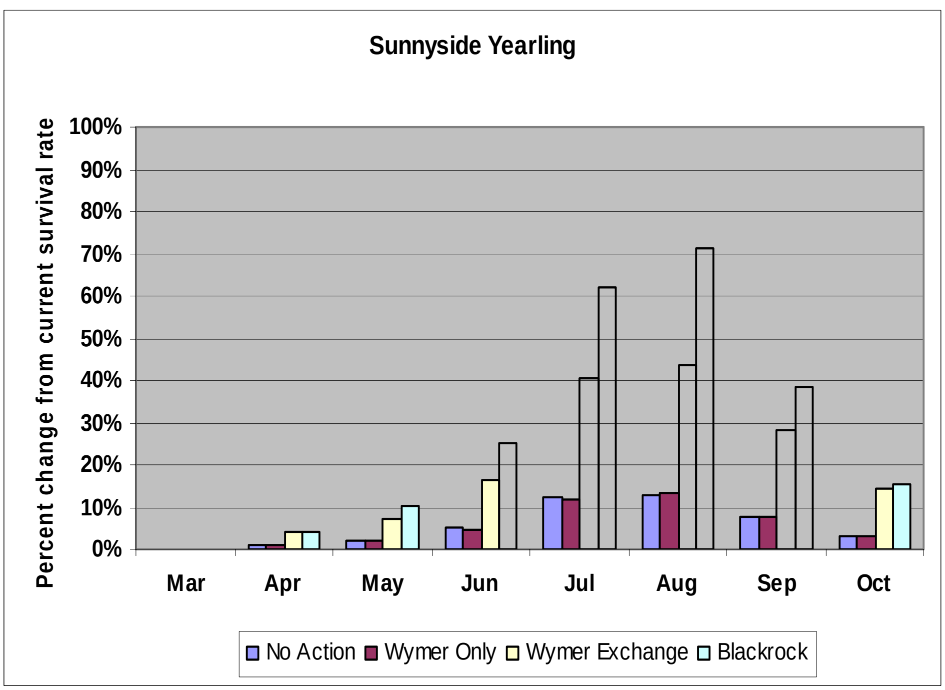
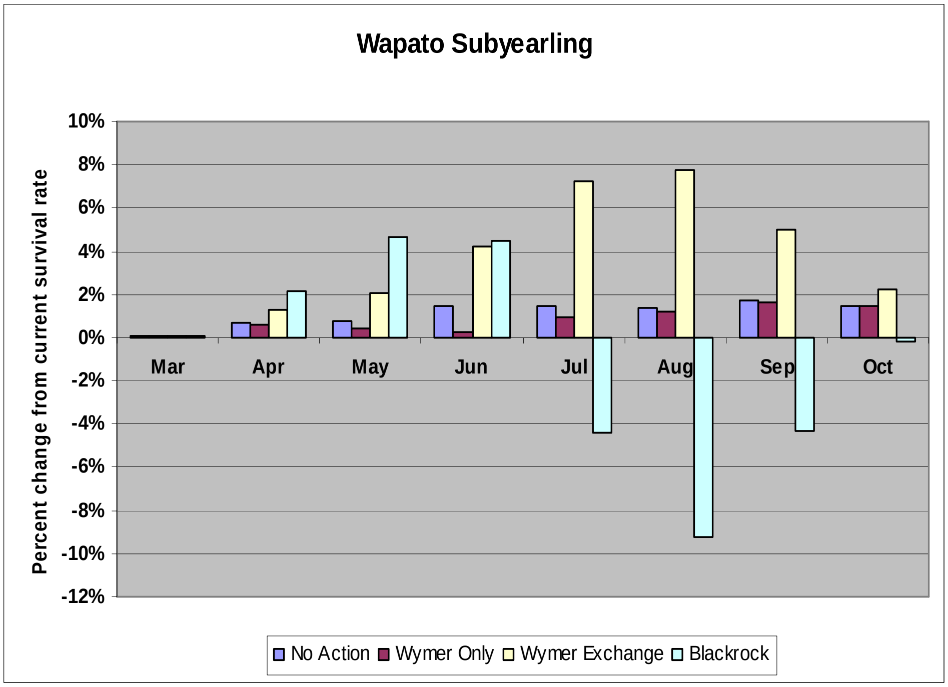


Figure 83. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Sunnyside Dam bypass. Depicted survival rates were applied to all species.



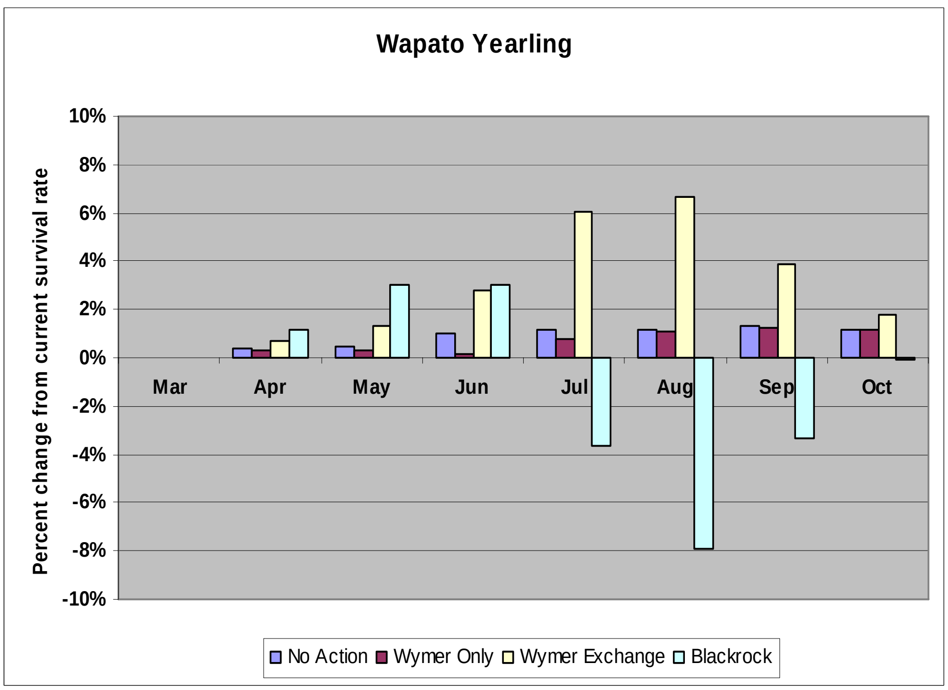
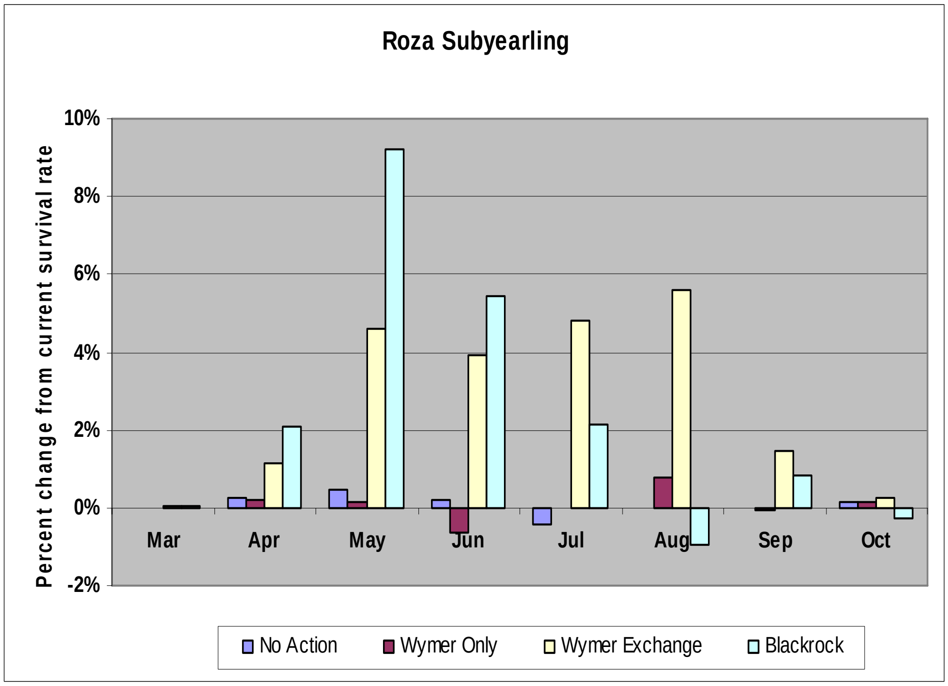


Figure 84. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Wapato Dam bypass. Depicted survival rates were applied to all species.



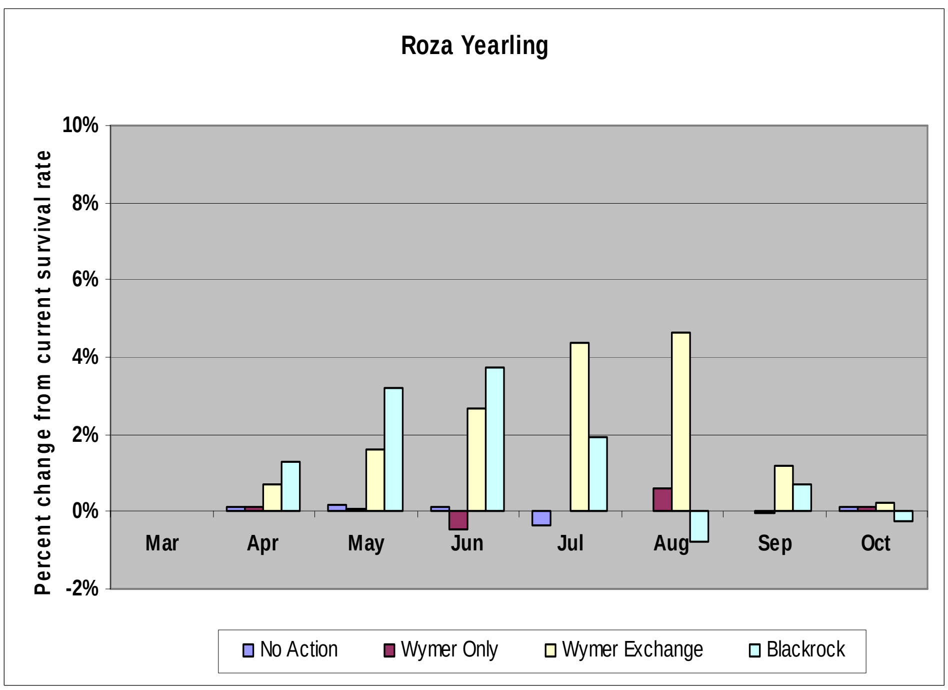


Figure 85. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Roza Dam bypass. Depicted survival rates were applied to all species.

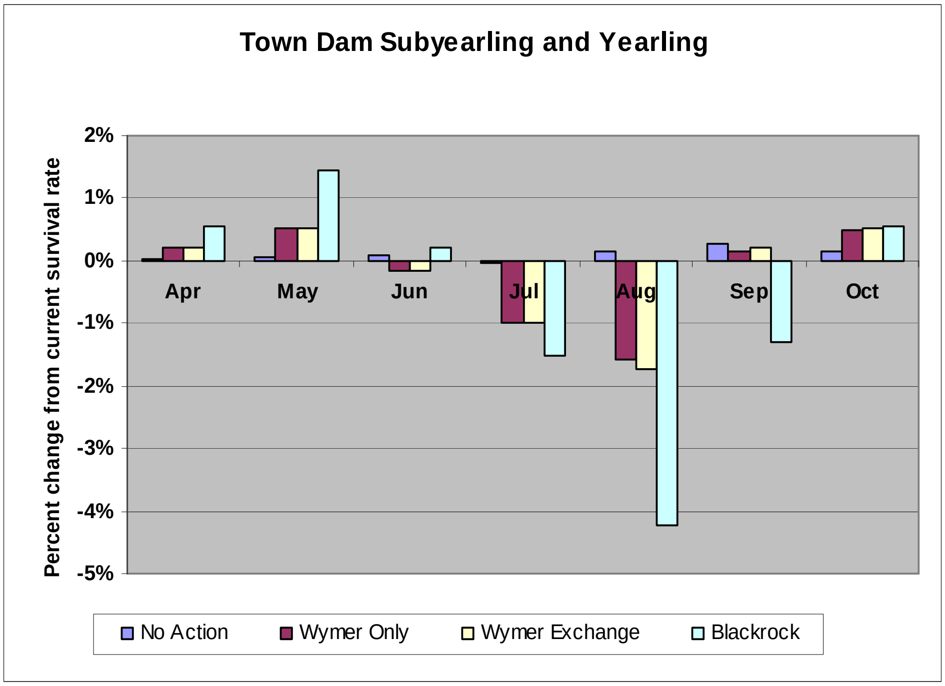


Figure 86. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Town Dam bypass. Depicted survival rates were applied to all species.

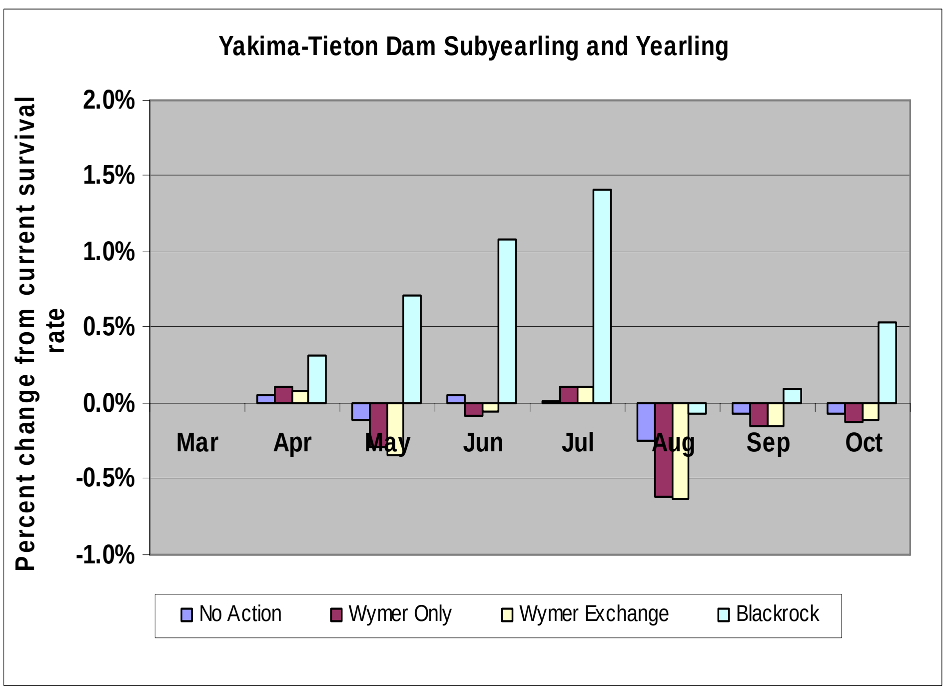
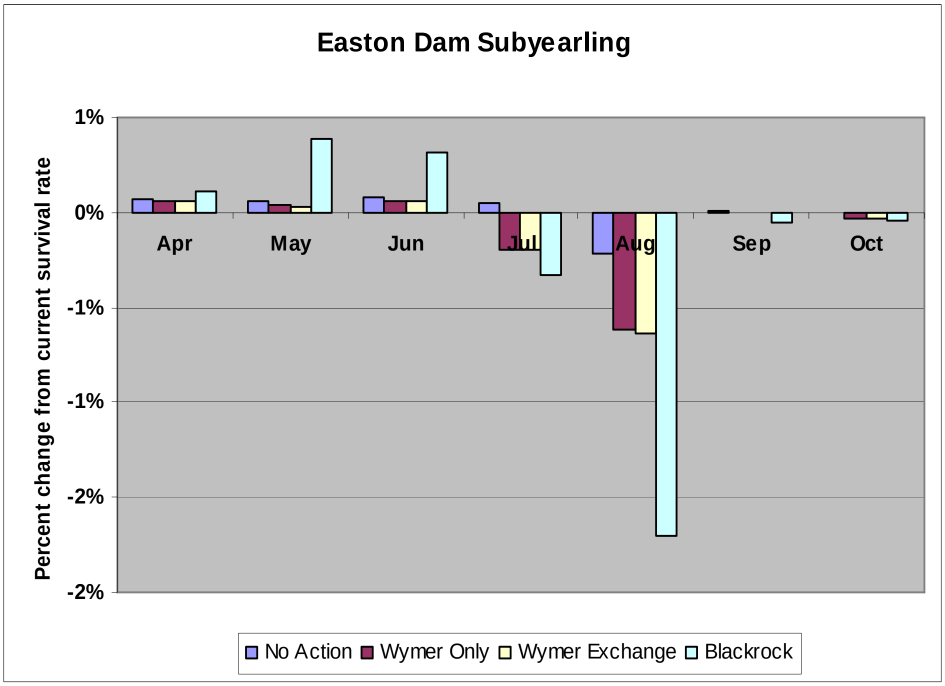


Figure 89. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Yakima-Tieton Dam bypass. Depicted survival rates were applied to all species.



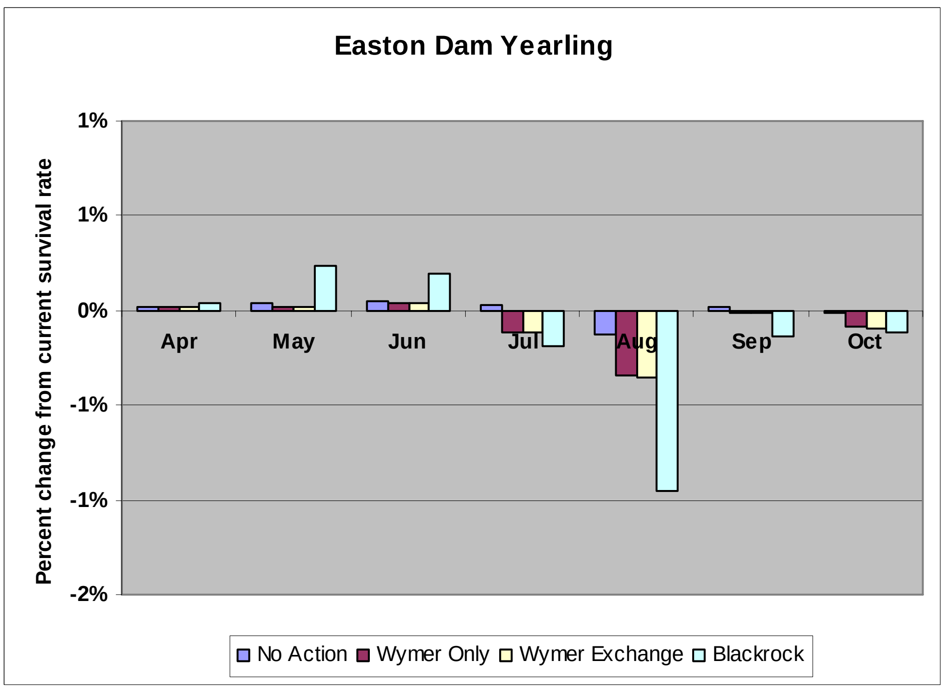


Figure 87. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Easton Dam bypass. Depicted survival rates were applied to all species.

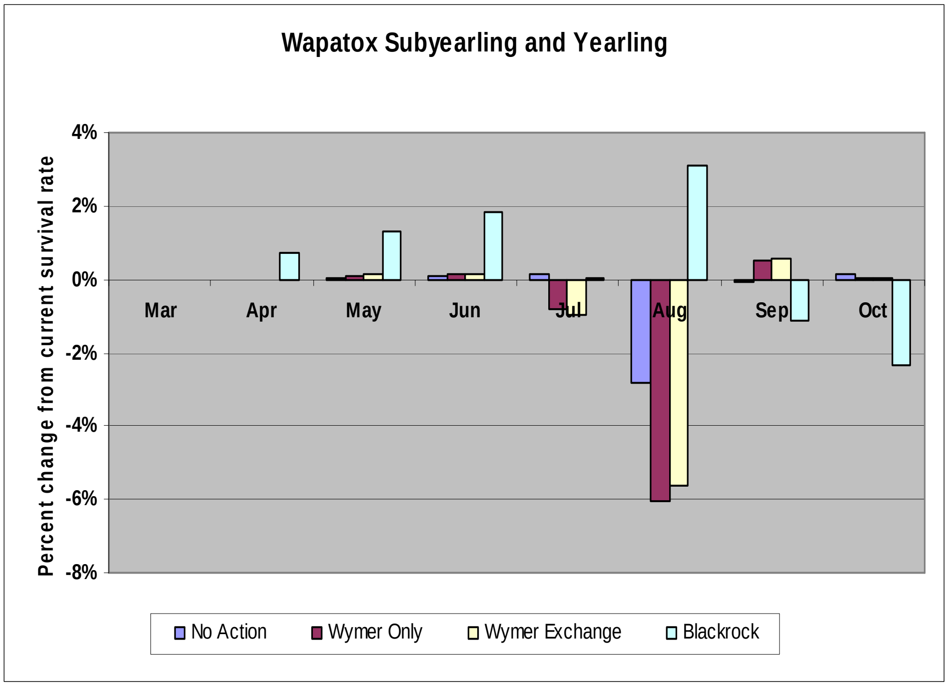


Figure 88. Percent change from current monthly bypass survival rates for subyearling and 1+ smolts at the Wapatox Dam bypass. Depicted survival rates were applied to all species.

3.8.2.5 Life History Patterns

Because the various Yakima salmon and steelhead populations spawn at very different locations and because all exhibit downstream rearing migrations as juveniles, the distribution of juveniles in time and space differ considerably among populations. These differences are quite important because conditions in a given reach, particularly in the lower mainstem, can change from favorable to very unfavorable depending on the season.

A useful index of the relative distributions of Yakima populations of salmon and steelhead is the distribution of life stages relative to Sunnyside Dam (Tables 10 and 11). The distribution of life stages relative to Sunnyside Dam is significant because, in terms of high water temperature and predation risk, Sunnyside Dam marks the upstream boundary of the lower Yakima mainstem. Moreover, as shown in the previous section, Sunnyside Dam itself has a survival impact that differs substantially by alternative.

Because the estimated survival of subyearlings at Sunnyside Dam differs so greatly among alternatives, those populations for which relatively more fish pass Sunnyside as subyearlings are more likely to benefit from the Wymer Dam Plus Yakima River Pump Exchange and Black Rock Alternatives. Figure 83 makes it clear that subyearling parr passing Sunnyside Dam in late August and September receive a major benefit from the

Black Rock and Wymer Dam Plus Yakima River Pump Exchange Alternatives as, to a somewhat lesser degree, subyearling winter migrants passing Sunnyside in October. The populations most benefiting from improved subyearling survival at Sunnyside under the Wymer Dam Plus Yakima River Pump Exchange and Black Rock Alternatives are American River spring Chinook, middle Yakima steelhead and coho and, to a lesser degree, Naches spring Chinook.

Table 10. Life stage distribution of Yakima spring Chinook populations with respect to Sunnyside Dam as modeled.

Lifestage	American River Spring Chinook		Naches Spring Chinook		Upper Yakima Spring Chinook	
	Proportion	Time	Proportion	Time	Proportion	Time
Fry (subyearling)	0%	---	0.2%	May	0%	---
Parr (subyearling)	45%	mid Sep	22.3%	late Jul	2%	early Sep
Winter migrant (subyearling)	39%	mid Oct	9.8%	mid Oct	3%	mid Oct
Smolt (yearling)	17%	late Mar	67.8%	late Mar	95%	late Mar

Table 11. Life stage distribution of upper Yakima, middle Yakima and Naches steelhead populations with respect to Sunnyside Dam as modeled.

Lifestage	Naches Steelhead		Upper Yakima Steelhead		Middle Yakima Steelhead	
	Proportion	Time	Proportion	Time	Proportion	Time
Fry (subyearling)	0%	---	0%		0	
Parr (subyearling)	0%	---	0%		0	
Winter migrant (subyearling)	1%	late Sep	0.1%	late Sep	10.4%	mid Sep
Smolt (yearling)	13%	early May	6.9%	late Apr	64.7%	mid Apr
Smolt (2+)	86%	early Apr	92.9%	early Apr	24.9%	early Apr

A proportion of all Yakima spring Chinook populations display (and were modeled as having) juvenile "rearing migrations" – slow, downstream movements of actively rearing fish with temporary territorial attachments. Half of the upper Yakima and Naches spring Chinook populations were assigned this "transient" life history but, because of the cold temperatures and low primary productivity of the American River, all of the American

River population were assumed to be transients. As a result of location and life history assumptions, 45% of American River spring Chinook were modeled as passing Sunnyside as parr, on average in mid-September, while 39% passed Sunnyside as winter migrants in mid-October and only 17% passed Sunnyside as yearling smolts in late March. The life stage distribution of middle Yakima steelhead was similar. For middle Yakima steelhead, the proportion of fish passing Sunnyside as fry, parr, winter migrants, age-1 smolts and age-2 smolts and smolts was 0%, 0%, 10.4% (in mid September) , 64.7% (in mid April) and 24.9% (in early April), respectively. None of the other populations Yakima salmon and steelhead received a comparable benefit from improved subyearling passage at Sunnyside Dam.

3.8.2.6 Baseline Productivity

It is mathematically true that the rate of change of equilibrium abundance increases in proportion to the square of productivity for Beverton-Holt production functions. This fact implies that the impact on the mean abundance of a specific change in productivity will be considerably larger for Yakima salmon and steelhead populations with lower initial productivity values. This relationship is illustrated in Figure 90 which shows the relative impact on abundance of improving productivity for populations with productivity values ranging from 1.1 to 3. Figure 90 shows that a doubling of productivity results in a five-fold abundance increase for a population with an initial productivity of 1.1 (like the upper Yakima steelhead population), but only a 25% increase for a population with an initial productivity of 3.0 (like upper Yakima spring Chinook). This mathematical relationship explains much of the interspecific differences among populations in terms of the relative impact of Storage Study alternatives on abundance. It does, of course, also apply to the relative efficacy of the alternatives within a species/run.

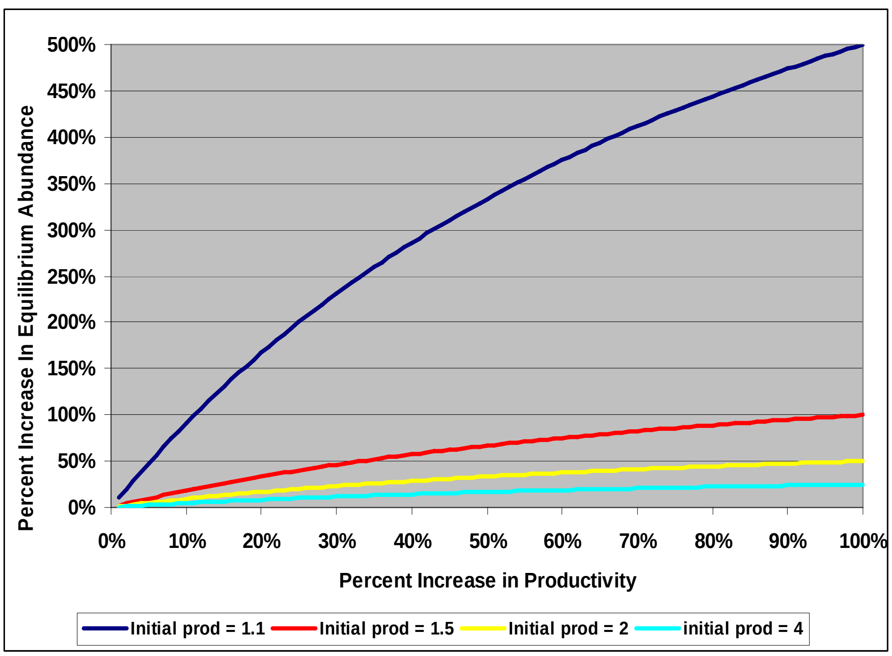


Figure 90. Relationship between initial productivity and the impact of an increase of productivity on equilibrium abundance for populations with a Beverton-Hold production function. The Beverton-Holt production function was applied to all populations of Yakima salmon and steelhead.

3.8.2.7 Quantity of Key Habitat

Tables 12 and 13 summarize the impact of the Black Rock, Wymer Dam Plus Yakima River Pump Exchange and Wymer Dam and Reservoir Alternatives on key habitat in selected geographic areas for the three populations of Yakima spring Chinook and the five populations of Yakima steelhead.

Table 12. Percent increase over current key habitat for Yakima spring Chinook under the four storage alternatives for selected unconfined reaches. Key habitat is expressed in terms of the proportion of the wetted area of a reach comprising key habitat for specified life stages.

			Blackrock	Wymer Exchange	Wymer Only
Upper Yakima Spring Chinook	Incubation Key Habitat	Easton Reach	-11.7%	-0.5%	-8.4%
		Kittitas Reach	-6.8%	1.0%	-1.1%
	Fry Key Habitat	Easton Reach	1.6%	0.2%	0.2%
		Kittitas Reach	1.4%	1.4%	1.4%
		Union Gap Reach	7.4%	1.9%	1.9%
	Subyearling Rearing Key Habitat	Easton Reach	6.2%	0.5%	5.2%
		Kittitas Reach	3.6%	-0.6%	-2.1%
		Union Gap Reach	20.0%	1.2%	8.6%
		Wapato Reach	59.9%	9.8%	25.8%
		Lower Yakima Reach	0.0%	0.0%	0.0%
	Subyearling Overwintering Key Habitat	Easton Reach	7.0%	0.1%	5.2%
		Kittitas Reach	7.4%	-0.8%	1.3%
		Union Gap Reach	15.6%	1.5%	8.6%
		Wapato Reach	30.5%	1.6%	13.7%
		Lower Yakima Reach	0.0%	0.0%	0.0%
Naches Spring Chinook	Incubation Key Habitat	Lower Naches Reach	-3.6%	0.0%	-3.9%
	Fry Key Habitat	Union Gap Reach	11.3%	0.6%	3.3%
		Wapato Reach	42.1%	2.6%	5.3%
		Lower Naches Reach	0.4%	-0.9%	-0.7%
	Subyearling Rearing Key Habitat	Union Gap Reach	19.7%	1.7%	9.3%
		Wapato Reach	44.2%	5.4%	18.8%
		Lower Yakima Reach	0.0%	0.0%	0.0%
		Lower Naches Reach	1.3%	-0.3%	2.9%
	Subyearling Overwintering Key Habitat	Union Gap Reach	19.1%	2.1%	10.2%
		Wapato Reach	30.8%	1.7%	13.9%
		Lower Yakima Reach	0.0%	0.0%	0.0%
		Lower Naches Reach	4.3%	0.5%	5.1%
American River Spring Chinook	Subyearling Rearing Key Habitat	Union Gap Reach	21.2%	1.2%	9.5%
		Wapato Reach	62.9%	10.7%	27.2%
		Lower Yakima Reach	0.0%	0.0%	0.0%
		Lower Naches Reach	3.9%	-0.4%	1.7%
	Subyearling Overwintering Key Habitat	Union Gap Reach	15.8%	1.4%	8.6%
		Wapato Reach	30.9%	1.8%	13.9%
		Lower Yakima Reach	0.0%	0.0%	0.0%
		Lower Naches Reach	0.0%	0.0%	0.0%

Table 13. Percent increase over current key habitat for Yakima steelhead under the four storage alternatives for selected unconfined reaches. Key habitat is expressed in terms of the proportion of the wetted area of a reach comprising key habitat for specified life stages.

Population	Life Stage Habitat	Reach	Blackrock	Wymer Exchange	Wymer Only
Upper Yakima Summer Steelhead Population	Incubation Key Habitat	Easton Reach	-8.8%	-1.1%	-7.6%
		Kittitas Reach	-3.7%	0.3%	-0.3%
	Fry Key Habitat	Easton Reach	-0.3%	0.0%	0.0%
		Kittitas Reach	0.0%	0.0%	0.0%
	Subyearling Rearing Key	Easton Reach	-1.8%	-0.6%	-1.8%
		Kittitas Reach	0.0%	0.0%	0.0%
	Overwintering Key Habitat	Easton Reach	0.9%	0.0%	0.6%
		Kittitas Reach	0.0%	0.0%	0.0%
		Union Gap Reach	5.7%	0.0%	0.0%
		Wapato Reach	11.1%	0.0%	1.2%
		Lower Yakima Reach	12.9%	-0.1%	1.2%
Naches Summer Steelhead Population	Incubation Key Habitat	Lower Naches Reach	-0.2%	0.0%	-3.7%
	Fry Key Habitat	Lower Naches Reach	-0.6%	0.0%	0.2%
		Union Gap Reach	0.0%	0.0%	0.0%
	Subyearling Rearing Key	Lower Naches Reach	0.0%	0.0%	0.0%
		Union Gap Reach	0.0%	0.0%	0.0%
	Overwintering Key Habitat	Lower Naches Reach	0.3%	0.2%	0.5%
		Union Gap Reach	6.0%	0.0%	0.0%
		Wapato Reach	11.2%	0.0%	1.2%
		Lower Yakima Reach	17.5%	0.2%	2.1%
Middle Yakima Summer Steelhead Population	Incubation Key Habitat	Union Gap Reach	6.2%	-0.8%	-7.2%
	Fry Key Habitat	Union Gap Reach	6.8%	0.0%	0.0%
	Subyearling Rearing Key Habitat	Union Gap Reach	6.4%	0.0%	0.0%
	Subyearling Overwintering Key Habitat	Union Gap Reach	7.0%	0.0%	0.0%
		Wapato Reach	11.2%	0.0%	1.2%
		Lower Yakima Reach	16.9%	0.1%	2.0%
Toppenish Creek Summer Steelhead Population	Fry Key Habitat	Lower Yakima Reach	6.8%	0.0%	0.0%
	Subyearling Rearing Key Habitat	Lower Yakima Reach	48.3%	0.0%	0.0%
	Subyearling Overwintering Key Habitat	Lower Yakima Reach	17.6%	0.5%	2.4%

The values in these tables are the percent differences between storage alternative scenarios and the current scenario in terms of an index of the quantity of key habitat in selected geographic areas. The index of key habitat being compared is the percent of the wetted area of a reach comprised of key habitat. This index is not the best possible measure of the effect of storage alternatives on habitat: the actual total area of key habitat, and its distribution among main channel, side channels and off-channel areas (i.e., seasonally inundated "wetlands") would be better. An analysis of effects of Storage Study alternatives on estimates of the actual area of key habitat will be presented in the final EIS. In this document, however, an alternative with a larger percent increase (over current) in key habitat index is assumed to produce more area of key habitat.

Habitat impacts were analyzed in six geographic areas, five in the mainstem Yakima River and one in the lower Naches River. The five Yakima reaches are: the Easton reach (between the confluence of the Cle Elum River and Easton Dam), the Kittitas reach (between the Wilson Creek confluence and the Bull Ditch diversion in Ellensburg), the Union Gap reach (between the Ahtanum Creek and Naches River confluences in the cities of Yakima and Union Gap), the Wapato reach (between Granger and Sunnyside Dam), and the lower Yakima reach (between the confluence of Satus Creek and Marion Drain, roughly between the cities of Wapato and Toppenish). The lower Naches reach extends from the Yakima confluence to the Tieton River. These reaches correspond to the major relatively unconfined areas in the Yakima watershed, and were the areas most intensively analyzed with two-dimensional river modeling and EDT. It should be noted that the extensive confined areas within the Yakima Subbasin – e.g., the Yakima Canyon between Yakima and Ellensburg, the Thorp Canyon between Ellensburg and Cle Elum, and most of the Naches River above the Tieton confluence - have distinct physical limits on the degree to which habitat can be expanded or transformed by flow, and were therefore excluded from this analysis

The information in Tables 12 and 13 suggests that habitat benefits under any of the storage scenarios are not extremely large, disproportionately benefit spring Chinook over steelhead, and are concentrated in the middle and lower Yakima mainstem. Of the eight areas and life stages showing more than a 30% improvement over current conditions, seven affected spring Chinook, and all of these affected juveniles (primarily actively rearing parr and overwintering pre-smolts) in the Wapato reach. The only life stage and area for which steelhead key habitat increased by 30% or more was parr rearing habitat for the Toppenish population in the lower Yakima. None of the storage alternatives increased key habitat to any degree in the Easton, Kittitas or lower Naches reaches for either spring Chinook or steelhead.

The impact on incubation key habitat in all of the reaches examined was negligible or marginally negative under all alternatives except for mid Yakima steelhead in the Union Gap reach under the Black Rock Alternative. It is currently unclear precisely why spring and fall spawners should be affected similarly by all alternatives in the upper Yakima and Naches Rivers. It is clear, however, that this response is an important reason why the benefits of the storage alternatives were not larger.

Among storage alternatives, the Black Rock Alternative clearly had the largest impact on key habitat and, except for incubation, an effect that was almost always positive or at least neutral. Both the Wymer Dam Plus Yakima River Pump Exchange and Wymer Dam and Reservoir Alternatives appeared to have little impact on key habitat for any life stage or population of steelhead, but the Wymer Dam and Reservoir Alternative appeared to have a marginally more positive impact across all reaches and life stages for spring Chinook.

In summary, the impact of storage alternatives on key habitat was usually modestly positive or neutral for all life stages except incubation, which appeared to suffer a minor loss of key habitat in the upper Yakima and Naches. The Black Rock Alternative clearly increased key habitat proportions more than the Wymer Dam Plus Yakima River Pump Exchange or Wymer Dam and Reservoir Alternatives, and benefited spring Chinook more than steelhead.

3.8.2.8 Predation, Sediment, Pathogens Temperature and Flow

Were it not for the fact that temperature varies between alternatives and modulates the effects of predation, sedimentation and pathogens, neither predation nor sediment nor pathogens would be included as factors contributing to differences in the effects of storage alternatives on fish production.

Because they are all thermally linked, it is not surprising that that impacts from predation, sediment, pathogens and temperature tend to co-occur. Reaches in which these temperature-related factors had their largest impacts included the Prosser bypass reach (the Yakima mainstem between Prosser Dam and the Chandler power plant return) and, to a lesser extent, the Yakima mainstem between Prosser Dam and Sunnyside Dam and the Yakima from the Naches confluence to Roza Dam. Although the impact of predation on mean abundance was determined to be slightly negative for spring Chinook in the Yakima River reach between Swauk Creek and the KRD drop structure (Black Rock Alternative), and in the reach between Granger Drain and Wide Hollow Creek (Wymer Exchange alternative), the overall impact of predation on spring Chinook abundance under these alternatives was positive. Similarly, the overall impact of temperature and predation on steelhead abundance was positive under the Wymer Dam Plus Yakima River Pump Exchange Alternative even though a small negative impact was predicted for the Yakima River between Wapato Dam and the Naches confluence. Table 14 indicates that temperature and predation contributed to a net positive increase in abundance for all populations of spring Chinook and steelhead under all storage alternatives.

EDT indicated that flow was responsible for modest increases in spring Chinook and steelhead abundance in scattered reaches in the upper Yakima (the Ellensburg area between Bull Ditch and Town Dam, the lower Cle Elum River, and the Yakima between Easton Dam and Cabin Creek), middle Yakima (Yakima between the Naches confluence and Roza Dam) and lower Yakima (Yakima from Mabton to the Toppenish Creek confluence). Table BW54 shows a positive impact of flow was usually detected only under the Black Rock Alternative, and that negative impacts were attributed to flow under the Wymer Dam Plus Yakima River Pump Exchange, Wymer Dam and Reservoir and No Action Alternatives in the lower Naches.

Almost all of the benefits to Yakima spring Chinook and steelhead under all four storage alternatives are due to diversion dam bypass effects, changes in key habitat area, flow, predation, sediment, pathogens and temperature. With a few exceptions, over 50% of the benefits are due to diversion dam bypass effects alone. However much of the impact is attributed to diversion dam bypasses, all of the remaining effects are due to key habitat, flow and the four temperature-related factors (pathogens, predation, sediment and temperature). For most populations and under most alternatives, most of the impact of the non-dam factors occurs in the lower Yakima mainstem- the Yakima River below Sunnyside Dam.

Table 14. Summary of dam-related and non-dam-related impacts to Yakima spring Chinook and steelhead populations under the four storage study alternatives. EDT model output. Note: red font indicates a factor caused a decrease in mean abundance relative to the current scenario.

Population	Alternative	% Abundance increase due to by-passes	% Abundance increase due to non-dam factors in lower Yakima mainstem	Life stage most benefitted	Major non-dam factors affecting abundance
Upper Yakima spring Chinook	Blackrock	54%	18%	Smolts	Flow, Predation, Temperature, Key Habitat
	Wymer Exchange	49%	48%	Smolts	Predation, Sediment, Temperature, Key Habitat
	Wymer Only	35%	31%	Smolts	Predation, Sediment, Temperature, Key Habitat
	No Action	43%	48%	Smolts	Predation, Sediment, Temperature, Key Habitat
Naches spring Chinook	Blackrock	71%	24%	Parr rearing	Flow, Predation, Temperature, Key Habitat
	Wymer Exchange	60%	40%	Parr rearing	Flow, Predation, Sediment, Temeprature, Key Habitat
	Wymer Only	54%	40%	Parr rearing	Flow, Predation, Temeprature, Key Habitat
	No Action	65%	30%	Parr rearing	Flow, Predation, Temeprature, Key Habitat
American spring Chinook	Blackrock	78%	20%	Winter Migrant	Predation, Temeprature, Key Habitat
	Wymer Exchange	65%	35%	Winter Migrant	Predation, Temeprature, Key Habitat
	Wymer Only	61%	37%	Smolts	Predation, Temeprature, Key Habitat
	No Action	69%	31%	Parr rearing	Predation, Temeprature, Key Habitat
Upper Yakima Steelhead	Blackrock	78%	16%	Parr rearing	Flow, Key Habitat, Temperature
	Wymer Exchange	67%	29%	Smolts	Predation, Sediment, Temperature, Key Habitat
	Wymer Only	49%	36%	Parr rearing	Flow, Predation, Temeprature, Key Habitat
	No Action	54%	32%	Parr rearing	Predation, Temerpature, Key Habitat
MiddleYakima Steelhead	Blackrock	78%	16%	Smolts	Flow, Predation, Temerpature, Key Habitat
	Wymer Exchange	66%	26%	Incubation	Predation, Sediment, Temperature, Key Habitat
	Wymer Only	53%	36%	Fry	Predation, Temperature, Key Habitat
	No Action	58%	38%	Fry	Predation, Temperature, Key Habitat
Naches Steelhead	Blackrock	79%	18%	Smolts	Flow, predation, temeprature, Key Habitat
	Wymer Exchange	62%	32%	Smolts	Predation, Sediment, Temeprature, Key Habitat
	Wymer Only	41%	44%	Parr rearing	Flow, Predation, Key Habitat
	No Action	46%	38%	Parr rearing	Predation, Temeprature, Key Habitat
Toppenish Steelhead	Blackrock	69%	31%	Smolts	Flow, Predation, Temperature, Key Habitat
	Wymer Exchange	51%	49%	Smolts	Predation, Sediment, Temperature, Key Habitat
	Wymer Only	8%	93%	Smolts	Predation, Temperature, Key Habitat
	No Action	20%	80%	Smolts	Predation, Temperature, Key Habitat
Satus Steelhead	Blackrock	73%	27%	Smolts	Flow, Predation, Sediment, Temeprature
	Wymer Exchange	52%	48%	Smolts	Predation, Sediment, Temeprature
	Wymer Only	8%	92%	Smolts	Predation,Temeprature
	No Action	20%	80%	Smolts	Predation,Temeprature

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Appendix A - Application of the All H Analyzer Model in concert with the Ecosystem Diagnosis & Treatment Model and the Yakima River Flow-to-Smolt Outmigration Survival Rates to Estimate the Anadromous Fisheries Numeric Benefits for the Storage Study Alternatives.

Introduction

The Reclamation is conducting the Yakima River Basin Water Storage Feasibility Study (Storage Study); and one of its fisheries assessment objectives is to estimate the 100-year mean population size and harvest of anadromous salmonids for each alternative. For consistency with the fisheries analysis conducted for the Kennewick and Columbia Irrigation Districts Pump Exchange project (Kennewick and Columbia Project), the Storage Study's analysis was carried out in similar fashion.

The Storage Study fisheries analysis utilized the Ecosystem Diagnosis and Treatment (EDT) model, Pyper and Smith's (2005) Yakima River anadromous salmonid flow-to-smolt survival equations (Prosser to McNary Dams reach) and the All H Analyzer (AHA) model to estimate the combined natural and hatchery anadromous salmonid population size and harvest increases for each alternative (figure A-1).

The purpose of this paper is to report the details on how data output from the EDT model, and the Pyper and Smith's (2005) anadromous salmonid flow-to-smolt survival equations were used as input to the AHA model to estimate population size (i.e. total recruitment and spawner escapement) and harvest for each Storage Study alternative (i.e. No Action, Black Rock, Wymer Dam and Reservoir, Wymer Dam Plus Yakima River Pump Exchange).

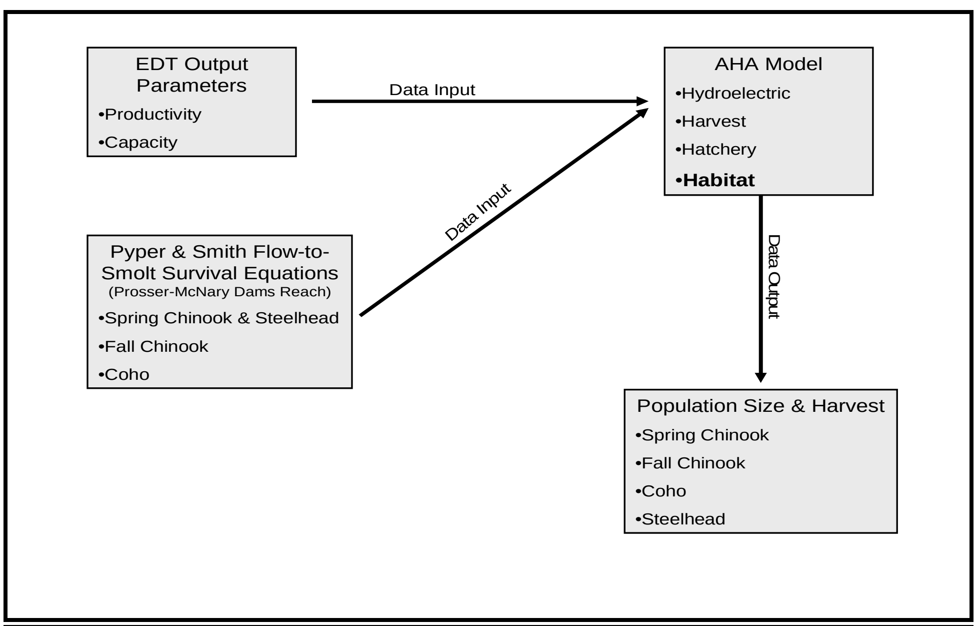

Figure A-1. A Schematic showing the data flow between the EDT model, Pyper and Smith (2005) flow-to-smolt survival equations and the AHA model to generate estimates of anadromous salmonid population size for each Storage Study alternative.

Integration of Models

The AHA model was used to estimate the annual and mean anadromous salmonid population size and harvest associated with each Storage Study alternative. The AHA model requires data input in four categories- **H**ydroelectric, **H**arvest, **H**atchery and **H**abitat which are called the "4-Hs" and will be discuss in more detail later. For this analysis data input into the AHA model for the Hydroelectric, Harvest and Hatchery categories remain constant across all Storage Study alternatives. Only data input to the AHA model Habitat category varied in accordance with each Storage Study alternative, and was provided by the EDT model (i.e. Productivity and Capacity parameters) and the Pyper and Smith (2005) lower Yakima River flow-to-smolt survival equations (i.e. spring and fall Chinook, coho and steelhead).

In addition, the AHA model allows the user (if necessary) to integrate both the natural and hatchery populations to estimate the overall integrated population size and harvest through data input to the Hatchery category. In the Yakima basin spring and fall Chinook and coho all have hatchery programs designed to supplement the natural population, while steelhead do not have an associated hatchery program. Specific Hatchery parameters (e.g. number of eggs, egg-to-smolt survival, and fitness factor) that quantitatively defined the spring and fall Chinook and coho hatchery programs were input into the AHA model to provide an estimate of the hatchery population size and harvest for each alternative. The AHA model then integrated both the natural and hatchery produced components to estimate the overall integrated population size and harvest by species.

EDT Model Description

Mobrand, Jones & Stokes describe the EDT model as "a system for rating the quality, quantity and diversity of habitat along a stream, relative to the needs of a focal species such as coho or Chinook salmon" (http://www.mobrand.com/MBI/pdfs/WhatisEDT.pdf). A detailed description of the EDT model will not be presented in this appendix, however, model theory and structure is provided in a paper by Lestelle, Mobrand and McConnaha (2004), which can be accessed through the Mobrand, Jones and Stokes website library: http://www.mobrand.com/MBI/library.html.

As stated above, the EDT model provided population specific productivity and capacity parameters as input to the AHA model.

The AHA Model Description

The AHA model was developed by Washington State fishery co-managers to facilitate the discussion of strategy options to restore and manage salmon populations in the Pacific

Northwest. The AHA model allows managers to explore the implications of different ways of balancing the “4-Hs”- habitat restoration, hatchery practices, harvest and the operation of hydroelectric dams. An introductory user’s guide, prepared by Mobrand, Jones and Stokes (2005) can be found at the following USFWS website: http://www.fws.gov/pacific/Fisheries/Hatcheryreview/documents/All-HAnalyzerDraftUsersGuideAug05.pdf . Details of parameter inputs to the AHA model for each 4-H category are discussed below.

AHA Model Inputs and Assumptions

Application of the AHA model for the Storage Study fisheries assessment relied upon the expertise of biologists from the Yakama Nation Fisheries Resources Program, and biologists from Reclamation who have experience working with data from the local anadromous salmonid stocks in the Yakima River basin. The Yakama Nation and Reclamation worked together to calibrate AHA model inputs for anadromous fish stocks in the Yakima River basin.

The AHA model partitions the anadromous salmonid life cycle into the 4-H components and requires the user to input several parameters for each one. Input parameters are species specific and in some cases, population specific where multiple, distinct populations occupy the same subbasin. These 4 H components include:

1. **Freshwater <u>Habitat</u> Production Potential**- Expressed as the habitat’s capacity and productivity represented by a density dependent, stock recruitment function.

2. **Yakima In-basin <u>Hatchery</u> Programs**- Includes the number of adults needed for broodstock and their origin (natural or hatchery), total juvenile release number, and returning adult destination (hatchery vs. natural spawning grounds).

3. **Total Exploitation (<u>Harvest</u>) Rate**- The cumulative harvest effect compounded over all fisheries occurring in the marine, Columbia mainstem and terminal fisheries.

4. **Outmigration & Ocean Survival (<u>Hydroelectric</u>)**- Expected smolt-to-adult return rate (SAR) on average which is expressed as the product of juvenile out migrant, ocean, and returning adult survival.

Freshwater <u>Habitat</u> Production Potential- AHA model inputs for freshwater habitat capacity and productivity specific to each anadromous salmonid population relied exclusively on population specific Capacity and Productivity output parameters from the EDT model specific to each Storage Study alternative. The EDT model Capacity and Productivity output parameters are summarized by species and population in Table A-1.

Table A-1. A summary of the EDT population capacity (Cap) and productivity (Prod) parameters for spring and fall Chinook, coho and steelhead populations for each Storage Study alternative. These parameters were used as input values to the AHA model for each salmonid population and alternative.

Yakima River Anadromous Stocks		No Action		Black Rock		Wymer Dam and Reservoir		Wymer Plus	
Species	**Population**	**Cap**	**Prod**	**Cap**	**Prod**	**Cap**	**Prod**	**Cap**	**Prod**
Spring Chinook	Upper Yakima	4,941	3.24	5,791	3.62	5,021	3.29	5,712	3.61
	Naches	1,944	2.46	2,477	2.56	1,962	2.45	2,376	2.65
	American	403	3.66	494	4.18	402	3.61	482	4.16
Steelhead	Satus	1,264	4.34	1,349	4.61	1,261	4.33	1,355	4.62
	Toppenish	1,093	3.93	1,188	4.24	1,091	3.92	1,184	4.20
	Naches	2,152	1.69	2,508	1.81	2,146	1.69	2,445	1.78
	Upper Yakima	186	1.14	421	1.30	216	1.16	359	1.25
	Mid Yakima	876	1.83	1,079	2.04	873	1.83	1,027	1.99
Fall Chinook	Mainstem	14,666	3.23	16,425	3.26	14,660	3.22	17,307	3.30
	Marion Drain	305	1.96	512	2.38	297	1.92	546	2.33
Coho	Upper Yakima	1,593	1.69	2,040	2.00	1,607	1.70	1,856	1.88
	Mid Yakima	1,435	1.33	1,843	1.41	1,509	1.32	1,720	1.38
	Naches	607	1.46	744	1.50	611	1.46	706	1.48

Yakima In-basin Hatchery Programs- Characterizing hatchery programs in the AHA model is a fairly straight forward process that uses readily available information describing a particular hatchery program including the number of fish used for broodstock, hatchery or natural origin, and the total smolt release number which is computed from the egg-to-smolt survival in the hatchery environment. These parameters are summarized by species in Table A-2. Among the four anadromous salmonid species currently existing in the Yakima subbasin, spring and fall Chinook, and coho have experienced some form of hatchery intervention with research, harvest and species reintroduction purposes in mind. Although each species' program has its own unique set of goals and objectives, they all are considered integrated hatchery programs, meaning that both natural and hatchery origin adult fish are allowed to spawn in the wild or are used as broodstock for the hatchery program. The four populations of steelhead residing in the Yakima currently have no supporting hatchery program; though there is an experimental spawner reconditioning program that has been in force for the past 5 or so years.

Table A-2. Hatchery input parameters by species for Yakima River hatchery programs.

Species	# Adults for Broodstock	% Wild Broodstock	# Smolts Released
Spring Chinook	~419	100%	673,261
Fall Chinook	~926	25%	2,027,176
Coho	~830	50%	881,040

Total Exploitation (<u>Harvest</u>) Rate- Yakima River anadromous salmonids are harvested in fisheries occurring in the ocean, and the Columbia and Yakima Rivers. The AHA model requires the user to input mean harvest rates for hatchery and natural origin fish in each individual fishery including the ocean, lower Columbia (Zones 1-5), mid Columbia (Zone 6) and terminal (Yakima River) fishery areas. Harvest rates and data sources are summarized by species and fishery in Table A-3. Ocean and Columbia River harvest rates established in the 2005-2007 Interim Management Agreement developed by Columbia River Fisheries (CRM) were used for stocks with anticipated changes in harvest rates compared to those observed prior to 2005. Harvest regimes established in the 2005-07 Interim Management Agreement are managed on a sliding scale in accordance to run size strength and status of ESA listed Evolutionary Significant Units (ESU's). For both selective and non selective fisheries, harvest of both hatchery and natural origin fish are regulated by the "incidental catch" of ESA listed stocks. Mean terminal harvest rates observed in the recent five year period for the combined tribal and sport fisheries were used to populate Yakima River harvest of spring Chinook, fall Chinook and coho. Due to the ESA listing status of all Yakima River steelhead, no terminal fishery has been permitted since the late 1980's. However, with these restrictions in place, both YN and WDFW biologists believe that illegal harvest of steelhead is occurring during the whitefish fishery in the lower Yakima River. The estimated, illegal harvest rate was included in the AHA modeling analysis for the purpose of capturing all sources of mortality effecting natural production and survival throughout the entire lifecycle.

Outmigration & Ocean Survival (<u>Hydroelectric</u>)- As stated earlier, for consistency with the Kennewick and Columbia Project's fisheries assessment, the Storage Study's assessment used the exact same methodology. The objective of the Kennewick and Columbia Project's fisheries assessment was to estimate the increase in population size and harvest (relative to the baseline) as a function of increased smolt outmigrant survival, which is correlated to increased spring flow in the lower Yakima River downstream of Prosser Dam resulting from each alternative. Kennewick Irrigation District contracted with Crammer Fish Sciences to analyze the relationship of Yakima River flow downstream of Prosser Dam (RM 47.1) to smolt outmigrant survival using PIT tag detections at the Chandler Juvenile Monitoring Facility (RM 47.1) and McNary Dam on the Columbia River.

Table A-3. Species exploitation broken down by fishery and natural vs. hatchery origin.

Spring Chinook			Source For Harvest Rate
Fishery	**Natural**	**Hatchery**	
Ocean	1.00%	1.00%	Ocean fisheries on CESRF spring Chinook ranged from 0 to 1.8% for brood years 1997-1999. Ocean fisheries have been minimal on upriver spring Chinook stocks averaging about 1% (RMIS database)
Zones 1-5	1.80%	7.70%	2001-2005 Zones 1-5 non-Indian harvest rate (2006 WDFW & ODFW Joint Staff Report)
Zone 6	8.80%	8.80%	2001-2005 Zone 6 Treaty Indian harvest rate (2006 WDFW & ODFW Joint Staff Report). This number also represents the maximum exploitation rate allowed on listed Upriver stocks (2005-07 Interim Management Agreement
Terminal	13.00%	13.00%	2001-2005 Terminal harvest rate average (YN database)
Steelhead			**Source For Harvest Rate**
Fishery	**Natural**	**Hatchery**	
Ocean	-	-	No ocean commercial or sport fishery targets summer run steelhead
Zones 1-5	-	-	Harvest of wild steelhead not allowed in fisheries, No hatchery program present in Yakima River
Zone 6	5.20%	5.20%	1996-2003 A-run steelhead average harvest rate (2005 Harvest Biop, Table 28)
Terminal	8.00%	8.00%	Total estimated terminal mortality rate from poaching and hook and release mortality in the Satus Bar area during the "White Fish" season (Tribal and state Biologist estimates)
Steelhead			**Source For Harvest Rate**
Fishery	**Natural**	**Hatchery**	
Ocean & Zones 1-5	8.25%	8.25%	Maximum URB fall Chinook exploitation rate for combined lower river sport and commercial fisheries (split 50/50 between Sport and Commercial) (2005-2007 Interim Management Agreement)
Zone 6	23.00%	23.00%	Maximum URB fall Chinook exploitation rate for Treaty tribe Commercial and C&S Fishery in Zone 6 (2005 -2007 Interim Management Agreement)
Terminal	12.00%	12.00%	2001-2005 Terminal harvest rate average (WDFW harvest database)
Coho			**Source For Harvest Rate**
Fishery	**Natural**	**Hatchery**	
Ocean	15.00%	15.00%	Maximum Lower River stock harvest rate occurring in Ocean Fisheries (2005 -2007 Interim Management Agreement)
Zones 1-5	7.50%	7.50%	Maximum Lower River stock harvest rate occurring in Lower River Fisheries (2005 -2007 Interim Management Agreement)
Zone 6	5.00%	5.00%	2001-2006 estimated Zone 6 Harvest rate (YN database)
Terminal	1.00%	1.00%	2001-2005 Terminal harvest rate average (YN database)

Pyper and Smith (2005), fishery scientists with Crammer Fish Sciences, used logistic regression to examine the potential effects of flow, as well as other variables, on smolt outmigration survival rates for Yakima spring and fall Chinook, coho and steelhead. The logistic regression coefficients and resulting flow-to-smolt outmigration survival equations for each species are presented in tables A-4 to A-6 and figure A-2, respectively.

Table A-4. Regression coefficients and standard errors for the spring Chinook and steelhead logistic model fit, based on values provided by Pyper by personnel communication (2007).

Spring Chinook & Steelhead		
Variable	**Coefficient**	**Standard Error**
Y-Intercept	6.620	0.554
Year = 1999	0	
2000	-0.409	0.175
2001	-0.346	0.188
2002	-0.745	0.181
2003	-0.870	0.177
2004	-1.303	0.186
Year Mean	-0.612	
Migration Day	-0.030	0.003
Travel Time	-0.101	0.014
Release Type = Hatchery	0	
Wild	0.236	0.066
Flow (<5,000 cfs)	0.000238	0.000039
Model Input Parameters		
Migration Day (Julian Date)	125	
Travel Time (Days)	6	
Release Type	1	

Table A-5. Regression coefficients and standard errors for the coho logistic model fit, based on values provided by Pyper by personnel communication (2007).

Coho		
Variable	**Coefficient**	**Standard Error**
Y-Intercept	6.029	1.706
Year = 1998	0	
1999	0.545	0.525
2000	0.176	0.434
2001	1.357	0.496
2002	0.797	0.508
2003	0.541	0.455
2004	-0.641	0.508
Year Mean	0.396	
Migration Day	-0.037	0.011
Travel Time	-0.280	0.094
Flow	0.000288	0.000090
Model Input Parameters		
Migration Day (Julian Date)	140	
Travel Time (Days)	4	

Table A-6. Regression coefficients and standard errors for the fall Chinook logistic model fit, based on values provided by Pyper by personnel communication (2007).

Fall Chinook		
Variable	**Coefficient**	**Standard Error**
Y-Intercept	10.344	2.049
Year = 1998	0	
1999	0.145	0.504
2000	0.377	0.929
2001	1.063	0.588
2003	-0.261	0.404
2004	-0.915	0.515
Year Mean	0.068	
Migration Day	-0.049	0.011
Travel Time	-0.148	0.042
Flow (<4,000 cfs)	0.000815	0.0000152
Model Input Parameters		
Migration Day (Julian Date)	150	
Travel Time (Days)	8	

$$\text{Smolt Survival}_{\text{spring Chinook \& steelhead}} = \frac{1}{1+EXP\,[-(6.620 - 0.612 + (-0.030*125) + (-0.101*6) + (0.236*1) + (0.000258*(Q-5000)))]}$$

$$\text{Smolt Survival}_{\text{fall Chinook}} = \frac{1}{1+EXP\,[-(10.344 + 0.068 + (-0.049*150) + (-0.48*8) + (0.000815*(Q-4000)))]}$$

$$\text{Smolt Survival}_{\text{coho}} = \frac{1}{1+EXP\,[-(6.029 +0.396 + (-0.037*140)+(-0.280*4)+(0.000288*Q))]}$$

Where Q = Median spring (April-June) flow (cfs) at Prosser gage.

Figure A-2. Yakima River derived flow-to-smolt outmigration survival from Prosser Dam to McNary Dam for spring and fall Chinook, coho and steelhead based on Pyper and Smith (2005)[12].

Application of the Pyper and Smith Equations

The smolt-to-adult survival rate in the AHA model is comprised of three metrics, 1) smolt outmigration survival, 2) ocean survival, and 3) adult upmigration survival, and is mathematically expressed as:

Smolt-to-Adult Survival (SAR) = (SmSur) * (OcSur) * (AdSur); Equation (1)

Where,

SmSur = Smolt Outmigration Survival (Yakima and Columbia);

OcSur = Ocean Survival, and

AdSur = Adult upmigration survival (Columbia and Yakima).

Smolt outmigration survival (SmSur) is further partitioned into Yakima and Columbia Rivers smolt outmigration survival metrics:

SmSurv = (YR-SmSur) * (CR-SmSur); Equation (2)

[12] The equations presented are not presented in the Pyper and Smith (2005) document, but are based on their analysis. These actual equations were provided through personnel communication with Brian Pyper (November 2007).

Where,

YR-SmSur = Yakima River smolt outmigration survival, and

CR-SmSur = Columbia River smolt outmigration survival.

For the fisheries assessment the smolt-to-adult survival rate (SAR), smolt outmigration survival (SmSur) and adult upmigration survival (AdSur) metrics were estimated based on observed or estimated data for each species, and ocean survival (OcSur) was solved for mathematically (equation 1). For spring Chinook, a robust time series of empirical data was available for estimating smolt-to-adult survival rates (SARs) for both natural and hatchery origin fish; for fall Chinook and coho coded wire tag data was used; and steelhead smolt-to-adult survival rate (AdSur) values were based on results from the EDT model. Values for the Yakima basin adult upmigration survival and smolt outmigration survival (SmSur) metrics for each species were taken for the 2004 BiOp document.

For this analysis only the Yakima River smolt survival (YR-SmSur) metric is effected by changes in flow attributed to the Storage Study alternatives; while the other metrics remained constant. The estimated No Action smolt-to-adult survival rate (SAR) specific to each species and origin (natural or hatchery) was increased by the estimated increase in survival for each Storage Study alternative, which was based only on the increase in Yakima River smolt outmigration survival (YR-SmSur). The percent increase in Yakima River smolt outmigration survival (YR-SmSur) for each species for each Storage Study alternative was calculated using Pyper and Smith's (2005) flow-to-smolt outmigrant survival equations and the estimated mean (for the 25-year period) spring flow benefit calculated from the RiverWare model (Figure A-2).

For all the Storage Study alternatives, the smolt-to-adult survival rates (SARs) were the only metric varied, while all other model metrics were held constant. The estimated percent increase in smolt outmigration survival (SmSur) and the estimated smolt-to-adult survival rates (SARs) for natural and hatchery fish as a function of increased flow in the lower Yakima River for each species and alternative are presented in Table A-7. Similar to the assumptions applied in Piper & Smith (2005) any increase in smolt outmigration survival (SmSurv) between Prosser and McNary Dams directly translated into a proportional increase in the smolt-to-adult survival rate (SAR) measured as the number of returning adults at Prosser divided by the number of smolt outmigrants at Prosser. This assumption implies that smolt-to-adult survival between Prosser and McNary Dams remains fixed regardless of the abundance of smolts that reached McNary Dam, the day of smolt arrival, or potential changes caused by a given Storage Study alternative that alters flow resulting in a change in smolt behavior or the habitat conditions they experienced (Pyper & Smith 2005). For example, if the average smolt outmigration survival rate (SmSur) increased by 4.3% for a given species, then the total smolt-to-adult survival rate (SAR) would also increased by 4.3%.

Table A-7. Projected mean smolt-to-adult return rates (SARs) for natural (NORs) and hatchery (HORs) origin Yakima spring and fall Chinook, coho and steelhead for the Storage Study alternatives.

Spring Chinook

Alternative	Survival Increase	Projected SARs	
		NORs	HORs
No Action	----	2.990%	0.588%
Black Rock	8.20%	3.235%	0.636%
Wymer Dam and Reservoir	0.50%	3.005%	0.591%
Wymer Plus	3.80%	3.104%	0.610%

Steelhead

Alternative	Survival Increase	Projected SARs	
		NORs	HORs
No Action	----	2.033%	-
Black Rock	8.20%	2.043%	-
Wymer Dam and Reservoir	0.50%	2.110%	-
Wymer Plus	3.80%	2.200%	-

Fall Chinook

Alternative	Survival Increase	Projected SARs	
		NORs	HORs
No Action	----	0.794%	0.260%
Black Rock	35.40%	0.980%	0.352%
Wymer Dam and Reservoir	2.40%	0.741%	0.266%
Wymer Plus	17.00%	0.847%	0.304%

Coho

Alternative	Survival Increase	Projected SARs		
		NORs	HORs$_1$	HORs$_2$
No Action	----	4.460%	0.808%	1.170%
Black Rock	12.20%	5.004%	0.907%	1.313%
Wymer Dam and Reservoir	0.80%	4.496%	0.814%	1.179%
Wymer Plus	5.60%	4.710%	0.853%	1.236%

Pacific Decadal Oscillation (PDO) Cycle

As stated above, the AHA model uses the smolt-to-adult survival rate (SAR) metric as an input parameter that is calculated in part using ocean survival (OcSur) metric (the other two metrics are smolt outmigration and adult upmigration survival rates) (equation 1). Environmental variability effecting ocean survival over a given time period is captured with an imbedded Pacific Decadal Oscillation (PDO) cycle. Application of the PDO cycle to model the variability in smolt-to-adult survival (SAR) follows the logic of Hare and Francis (1994) of whom demonstrated a correlation between the PDO cycle and ocean productivity. Ocean productivity has also been documented having consecutive periods transitioning from higher to lower productivity (Mantua et al. 1997). An example of the PDO cyclic behavior and its effects on adult recruitment can be viewed in Figure A-3. The model requires the user to input the observed species specific mean smolt-to-adult return rate (SAR) to be used for the analysis. Based upon the range of observed low, medium and high smolt-to-adult return rates (SARs) for an entire PDO cycle, the AHA model randomly assigns a smolt-to-adult rate (SAR) value from either the high, medium or low ocean survival category which correlates to the cyclic pattern of the PDO cycle.

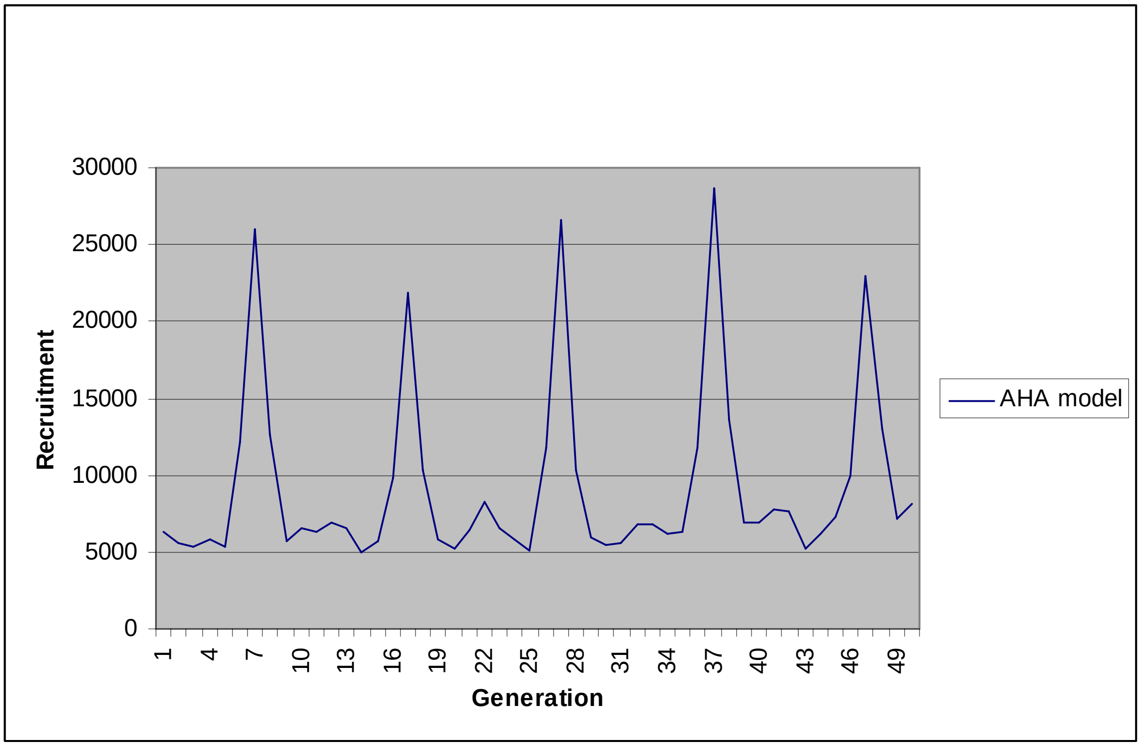

Figure A-3. AHA model behavior illustrating the PDO cycle influence on smolt to adult survival and adult recruitment over a 50 generation period.

Model Results

AHA model results showed a recurring pattern of alternately strong and weak returns of adult salmon and steelhead to the Yakima Basin that resulted, in large part, from the cyclical nature of ocean rearing conditions as illustrated in Figure A-3. Model results are summarized in Table A-5.

Table A-5. Projected increases for Storage Study alternatives for Yakima River anadromous species assuming current freshwater habitat conditions persist for the indefinite future.

				Spring Chinook					
Alternative	Mean Annual Run Size			Mean Annual Increase			100 Year Cumulative Benefit		
	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement
No Action	9,591	2,402	6,619	0	0	0	0	0	0
Black Rock	12,048	2,982	8,473	2,457	580	1,854	245,701	58,029	185,411
Wymer Dam and Reservoir	9,729	2,435	6,714	138	33	95	13,784	3,263	9,489
Wymer Plus	11,209	2,781	7,842	1,618	379	1,223	161,765	37,883	122,322
				Steelhead					
Alternative	Mean Annual Run Size			Mean Annual Increase			100 Year Cumulative Benefit		
	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement
No Action		0		-----	0	-----	-----	0	-----
Black Rock		0			0			0	
Wymer Dam and Reservoir					0			0	
Wymer Plus					0			0	
	0			**Fall Chinook**					
Alternative	Mean Annual Run Size			Mean Annual Increase			100 Year Cumulative Benefit		
	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement
No Action	11,093	4,200	6,146	-----	-----	-----	-----	-----	-----
Black Rock	17,908	6,780	11,128	6,815	2,580	4,235	681,514	258,038	423,476
Wymer Dam and Reservoir	11,445	4,334	7,112	352	133	219	35,245	13,344	21,900
Wymer Plus	15,000	5,680	9,321	3,907	1,479	2,428	390,736	147,942	242,794
				Coho					
Alternative	Mean Annual Run Size			Mean Annual Increase			100 Year Cumulative Benefit		
	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement	Total Recruitment	Harvest	Escapement
No Action	11,461	2,986	8,475	-----	-----	-----	-----	-----	-----
Black Rock	13,850	3,608	10,242	2,389	623	1,767	238,935	62,250	176,684
Wymer Dam and Reservoir	11,618	3,027	8,591	157	41	116	15,706	4,092	11,614
Wymer Plus	12,702	3,309	9,392	1,241	323	918	124,083	32,327	91,755

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Appendix B - Amount of Habitat Area for the Easton, Ellensburg, Lower Naches and Wapato Floodplain Reaches for Anadromous and Resident Salmonids.

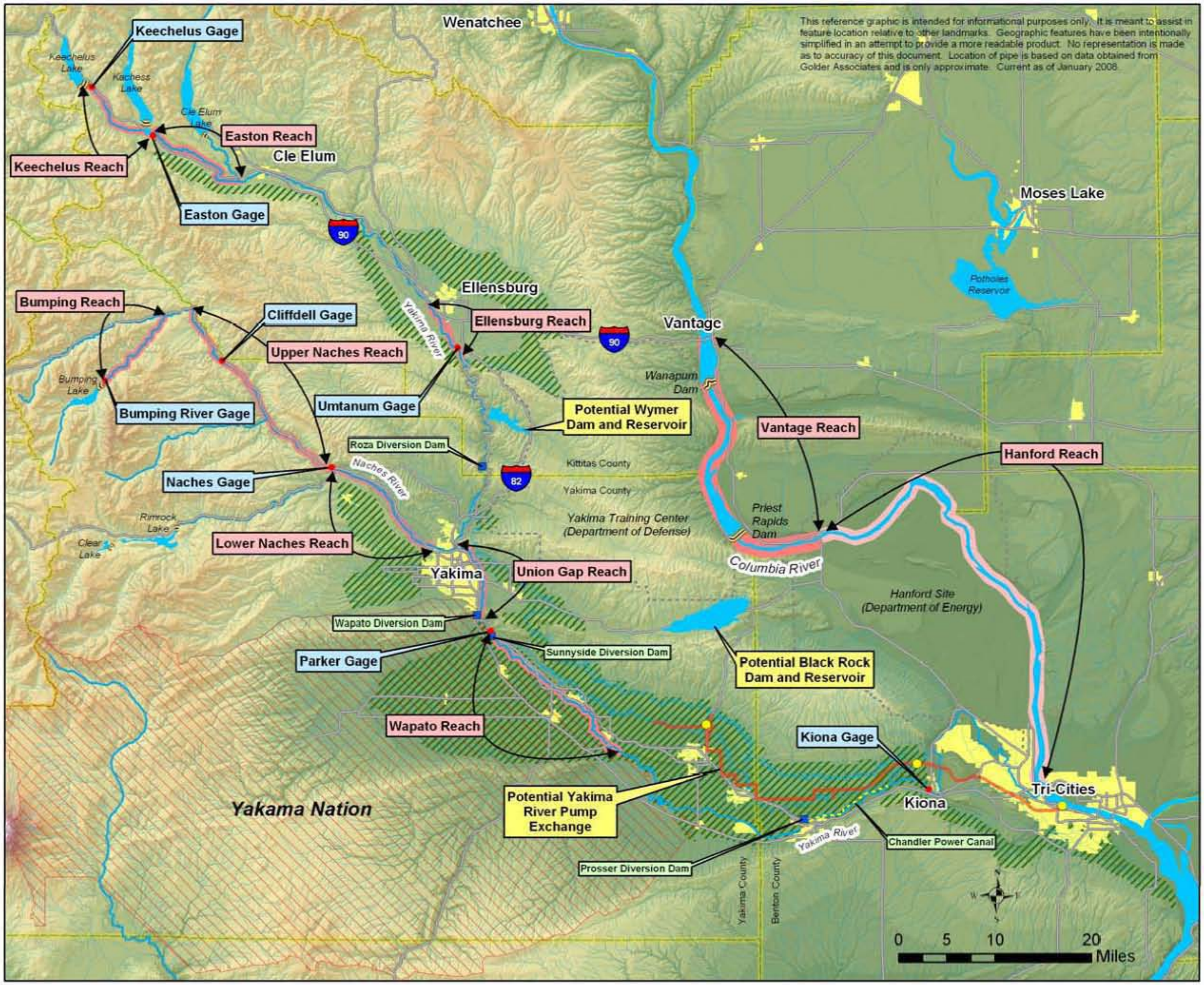

Figure B-1. Map of the Yakima River basin showing the Easton, Ellensburg, Lower Naches, and Wapato floodplain reaches.

Table B-1. Summary of monthly median flow and associated Spring Chinook fry and subyearling habitat for the Easton floodplain reach (based on the 1981-2005 period of record)

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Spring Chinook Fry**	**Spring Chinook Juvenile**
	No Action		
Mar	419	10,372	--
Apr	539	9,247	--
May	220	15,224	--
Jun	220	--	244,573
Jul	220	--	244,573
Aug	434	--	223,298
Sep	240	--	247,077
	Wymer Dam and Reservoir		
Mar	431		--
Apr	525	9,298	--
May	220	15,224	--
Jun	220	--	244,573
Jul	220	--	244,573
Aug	220	--	244,573
Sep	220	--	244,573
	Wymer Plus		
Mar	431	10,227	--
Apr	518	9,323	--
May	220	15,224	--
Jun	220	--	244,573
Jul	220	--	244,573
Aug	220	--	244,573
Sep	220	--	244,573
	Black Rock		
Mar	455		--
Apr	553	9,196	--
May	357	11,142	--
Jun	325	--	248,750
Jul	220	--	244,573
Aug	220	--	244,573
Sep	220	--	244,573
	Unregulated		
Mar	840	8,773	--
Apr	1,358	11,700	--
May	1,630	13,094	--
Jun	917	--	128,327
Jul	335	--	246,415
Aug	183	--	239,941
Sep	156	--	236,561

Table B-2. Summary of monthly median flow and associated Steelhead fry and subyearling habitat for the Easton floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Steelhead Fry**	**Steelhead Juvenile**
		No Action	
Mar	419	15,928	--
Apr	539	14,366	--
May	220	21,408	--
Jun	220	--	259,131
Jul	220	--	259,131
Aug	434	--	259,171
Sep	240	--	264,025
		Wymer Dam and Reservoir	
Mar	431	15,739	--
Apr	525	14,468	--
May	220	21,408	--
Jun	220	--	259,131
Jul	220	--	259,131
Aug	220	--	259,131
Sep	220	--	259,131
		Wymer Plus	
Mar	431	15,739	--
Apr	518	14,519	--
May	220	21,408	--
Jun	220	--	259,131
Jul	220	--	259,131
Aug	220	--	259,131
Sep	220	--	259,131
		Black Rock	
Mar	455	15,360	--
Apr	553	14,264	--
May	357	16,924	--
Jun	325	--	275,065
Jul	220	--	259,131
Aug	220	--	259,131
Sep	220	--	259,131
		Unregulated	
Mar	840	13,289	--
Apr	1,358	16,911	--
May	1,630	19,141	--
Jun	917	--	157,825
Jul	335	--	273,607
Aug	183	--	250,077
Sep	156	--	243,470

Table B-3. Summary of monthly median flow and associated Bull Trout fry and subyearling habitat for the Easton floodplain reach (based on the 1981-2005 period of record).

Month	Median Monthly Flow (cfs)	Habitat (m^2)	
		Bull Trout Fry	Bull Trout Juvenile
No Action			
Mar	419	--	--
Apr	539	17,335	--
May	220	25,708	--
Jun	220	--	294,346
Jul	220	--	294,346
Aug	434	--	284,272
Sep	240	--	296,861
Wymer Dam and Reservoir			
Mar	431	--	--
Apr	525	17,432	--
May	220	25,708	--
Jun	220	--	294,346
Jul	220	--	294,346
Aug	220	--	294,346
Sep	220	--	294,346
Wymer Plus			
Mar	431	--	--
Apr	518	17,480	--
May	220	25,708	--
Jun	220	--	294,346
Jul	220	--	294,346
Aug	220	--	294,346
Sep	220	--	294,346
Black Rock			
Mar	455	--	--
Apr	553	17,480	--
May	357	20,265	--
Jun	325	--	300,651
Jul	220	--	294,346
Aug	220	--	294,346
Sep	220	--	294,346
Unregulated			
Mar	840	--	--
Apr	1,358	21,399	--
May	1,630	24,338	--
Jun	917	--	182,433
Jul	335	--	299,150
Aug	183	--	289,694
Sep	156	--	286,300

Table B-4. Summary of monthly median flow and associated resident Rainbow Trout fry and subyearling habitat for the Easton floodplain reach (based on the 1981-2005 period of record)

Month	Median Monthly Flow (cfs)	Habitat (m^2) Resident Rainbow Trout Fry	Habitat (m^2) Resident Rainbow Trout Juvenile
No Action			
Mar	419	--	--
Apr	539	--	--
May	220	--	--
Jun	220	--	--
Jul	220	26,353	--
Aug	434	20,276	--
Sep	240	--	261,111
Wymer Dam and Reservoir			
Mar	431	--	--
Apr	525	--	--
May	220	--	--
Jun	220	--	--
Jul	220	26,353	--
Aug	220	26,353	--
Sep	220	--	256,325
Wymer Plus			
Mar	431	--	--
Apr	518	--	--
May	220	--	--
Jun	220	--	--
Jul	220	26,353	--
Aug	220	26,353	--
Sep	220	--	256,325
Black Rock			
Mar	455	--	--
Apr	553	--	--
May	357	--	--
Jun	325	--	--
Jul	220	26,353	--
Aug	220	26,353	--
Sep	220	--	256,325
Unregulated			
Mar	840	--	--
Apr	1,358	--	--
May	1,630	--	--
Jun	917	--	--
Jul	335	22,039	--
Aug	183	28,060	--
Sep	156	--	241,009

Table B-5. Summary of monthly median flow and associated spring Chinook fry and subyearling habitat for the Ellensburg floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Spring Chinook Fry**	**Spring Chinook Juvenile**
		No Action	
Mar	1,982	7,185	--
Apr	2,424	7,903	--
May	2,370	7,956	--
Jun	3,061	--	54,590
Jul	3,523	--	57,478
Aug	3,960	--	60,210
Sep	1,673	--	79,921
		Wymer Dam and Reservoir	
Mar	2,161	7,635	--
Apr	2,641	7,693	--
May	2,551	7,780	--
Jun	2,901	--	53,590
Jul	2,978	--	54,071
Aug	3,340	--	56,334
Sep	1,660	--	80,659
		Wymer Plus	
Mar	2,161	7,635	--
Apr	2,641	7,693	--
May	2,552	7,779	--
Jun	2,939	--	53,827
Jul	3,004	--	54,234
Aug	3,335	--	56,303
Sep	1,664	--	80,432
		Black Rock	
Mar	2,178	7,678	--
Apr	2,894	7,609	--
May	3,258	7,728	--
Jun	3,030	--	54,396
Jul	2,735	--	53,302
Aug	2,513	--	56,669
Sep	1,369	--	97,179
		Unregulated	
Mar	2,809	7,581	--
Apr	4,379	8,095	--
May	5,259	8,380	--
Jun	3,675	--	58,296
Jul	1,453	--	92,410
Aug	918	--	127,804
Sep	856	--	132,054

Table B-6. Summary of monthly median flow and associated Steelhead fry and subyearling habitat for the Ellensburg floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Steelhead Fry**	**Steelhead Juvenile**
	No Action		
Mar	1,982	8,530	--
Apr	2,424	9,038	--
May	2,370	9,128	--
Jun	3,061	--	68,011
Jul	3,523	--	70,170
Aug	3,960	--	72,211
Sep	1,673	--	100,513
	Wymer Dam and Reservoir		
Mar	2,161	8,909	--
Apr	2,641	8,674	--
May	2,551	8,825	--
Jun	2,901	--	67,264
Jul	2,978	--	67,624
Aug	3,340	--	69,315
Sep	1,660	--	101,268
	Wymer Plus		
Mar	2,161	8,909	--
Apr	2,641	8,674	--
May	2,552	8,823	--
Jun	2,939	--	67,441
Jul	3,004	--	67,745
Aug	3,335	--	69,291
Sep	1,664	--	101,036
	Black Rock		
Mar	2,178	8,945	--
Apr	2,894	8,527	--
May	3,258	8,731	--
Jun	3,030	--	67,867
Jul	2,735	--	67,374
Aug	2,513	--	71,954
Sep	1,369	--	118,161
	Unregulated		
Mar	2,809	8,480	--
Apr	4,379	9,263	--
May	5,259	9,533	--
Jun	3,675	--	70,879
Jul	1,453	--	113,284
Aug	918	--	145,531
Sep	856	--	149,121

Table B-7. Summary of monthly median flow and associated Bull Trout fry and subyearling habitat for the Ellensburg floodplain reach (based on the 1981-2005 period of record).

		Habitat (meters^2)	
Month	**Median Monthly Flow (cfs)**	**Bull Trout Fry**	**Bull Trout Juvenile**
	No Action		
Mar	1,982	--	--
Apr	2,424	10,696	--
May	2,370	10,767	--
Jun	3,061	--	80,516
Jul	3,523	--	83,511
Aug	3,960	--	86,343
Sep	1,673	--	115,859
	Wymer Dam and Reservoir		
Mar	2,161	--	--
Apr	2,641	10,409	--
May	2,551	10,528	--
Jun	2,901	--	79,479
Jul	2,978	--	79,978
Aug	3,340	--	82,324
Sep	1,660	--	116,657
	Wymer Plus		
Mar	2,161	--	--
Apr	2,641	10,409	--
May	2,552	10,527	--
Jun	2,939	--	79,725
Jul	3,004	--	80,146
Aug	3,335	--	82,292
Sep	1,664	--	116,412
	Black Rock		
Mar	2,178	--	--
Apr	2,894	10,410	--
May	3,258	10,913	--
Jun	3,030	--	80,315
Jul	2,735	--	79,407
Aug	2,513	--	84,339
Sep	1,369	--	134,522
	Unregulated		
Mar	2,809	--	--
Apr	4,379	12,244	--
May	5,259	12,957	--
Jun	3,675	--	84,496
Jul	1,453	--	129,365
Aug	918	--	168,469
Sep	856	--	172,892

Table B-8. Summary of monthly median flow and associated resident Rainbow Trout fry and subyearling habitat for the Ellensburg floodplain reach (based on the 1981-2005 period of record).

		Habitat (meters^2)	
Month	Median Monthly Flow (cfs)	Resident Rainbow Trout Fry	Resident Rainbow Trout Juvenile
No Action			
Mar	1,982	--	--
Apr	2,424	--	--
May	2,370	--	--
Jun	3,061	--	--
Jul	3,523	10,580	--
Aug	3,960	10,563	--
Sep	1,673	--	98,972
Wymer Dam and Reservoir			
Mar	2,161	--	--
Apr	2,641	--	--
May	2,551	--	--
Jun	2,901	--	--
Jul	2,978	10,602	--
Aug	3,340	10,587	--
Sep	1,660	--	99,707
Wymer Plus			
Mar	2,161	--	--
Apr	2,641	--	--
May	2,552	--	--
Jun	2,939	--	--
Jul	3,004	10,601	--
Aug	3,335	10,588	--
Sep	1,664	--	99,481
Black Rock			
Mar	2,178	--	--
Apr	2,894	--	--
May	3,258	--	--
Jun	3,030	--	--
Jul	2,735	9,699	--
Aug	2,513	10,130	--
Sep	1,369	--	116,143
Unregulated			
Mar	2,809	--	--
Apr	4,379	--	--
May	5,259	--	--
Jun	3,675	--	--
Jul	1,453	8,652	--
Aug	918	9,256	--
Sep	856	--	145,724

Table B-9. Summary of monthly median flow and associated spring Chinook fry and subyearling for the Lower Naches floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Spring Chinook Fry**	**Spring Chinook Juvenile**
		No Action	
Mar	1265	10066	--
Apr	1802	12147	--
May	2297	14608	--
Jun	2291	--	170483
Jul	988	--	158941
Aug	559	--	190631
Sep	1540	--	139361
		Wymer Dam and Reservoir	
Mar	1276	10118	--
Apr	1807	12163	--
May	2304	14651	--
Jun	2302	--	171349
Jul	922	--	164178
Aug	482	--	194745
Sep	1594	--	140326
		Wymer Plus	
Mar	1276	10118	--
Apr	1807	12163	--
May	2304	14651	--
Jun	2302	--	171349
Jul	912	--	164972
Aug	484	--	166633
Sep	1576	--	140004
		Black Rock	
Mar	1265	10066	--
Apr	1853	12312	--
May	2453	15565	--
Jun	2320	--	172765
Jul	831	--	171399
Aug	699	--	181567
Sep	1215	--	149671
		Unregulated	
Mar	1,426	10822	--
Apr	2,463	15625	--
May	3,374	16725	--
Jun	2,879	--	214401
Jul	1,067	--	155396
Aug	540	--	191861
Sep	506	--	194062

Table B-10. Summary of monthly median flow and associated Steelhead fry and subyearling for the Lower Naches floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Steelhead Fry**	**Steelhead Juvenile**
		No Action	
Mar	1,265	14487	--
Apr	1,802	18504	--
May	2,297	22153	--
Jun	2,291	--	209519
Jul	988	--	205682
Aug	559	--	227952
Sep	1,540	--	182892
		Wymer Dam and Reservoir	
Mar	1,276	14545	--
Apr	1,807	18550	--
May	2,304	22197	--
Jun	2,302	--	210361
Jul	922	--	209584
Aug	482	--	228777
Sep	1,594	--	183403
		Wymer Plus	
Mar	1,276	14545	--
Apr	1,807	18550	--
May	2,304	22197	--
Jun	2,302	--	210361
Jul	912	--	210175
Aug	484	--	228947
Sep	1,576	--	183233
		Black Rock	
Mar	1,265	14487	--
Apr	1,853	18971	--
May	2,453	23119	--
Jun	2,320	--	211739
Jul	831	--	214963
Aug	699	--	222363
Sep	1,215	--	195315
		Unregulated	
Mar	1,426	15346	--
Apr	2,463	23180	--
May	3,374	25131	--
Jun	2,879	--	253081
Jul	1,067	--	201963
Aug	540	--	228710
Sep	506	--	230067

Table B-11. Summary of monthly median flow and associated Bull Trout fry and subyearling for the Lower Naches floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Bull Trout Fry**	**Bull Trout Juvenile**
		No Action	
Mar	1265	--	--
Apr	1802	26228	--
May	2297	31730	--
Jun	2291	--	295251
Jul	988	--	273217
Aug	559	--	293584
Sep	1540	--	248924
		Wymer Dam and Reservoir	
Mar	1276	--	--
Apr	1807	26300	--
May	2304	31792	--
Jun	2302	--	296457
Jul	922	--	277080
Aug	482	--	292280
Sep	1594	--	250619
		Wymer Plus	
Mar	1276	--	--
Apr	1807	26300	--
May	2304	31792	--
Jun	2302	--	296457
Jul	912	--	277666
Aug	484	--	292615
Sep	1576	--	250054
		Black Rock	
Mar	1265	--	--
Apr	1853	26967	--
May	2453	33114	--
Jun	2320	--	298429
Jul	831	--	282407
Aug	699	--	289515
Sep	1215	--	261830
		Unregulated	
Mar	1,426	--	--
Apr	2,463	33202	--
May	3,374	36622	--
Jun	2,879	--	355815
Jul	1,067	--	269185
Aug	540	--	294136
Sep	506	--	295124

Table B-12. Summary of monthly median flow and associated resident Rainbow Trout fry and subyearling for the Lower Naches floodplain reach (based on the 1981-2005 period of record).

		Habitat (m^2)	
Month	**Median Monthly Flow (cfs)**	**Resident Rainbow Trout Fry**	**Resident Rainbow Juvenile**
No Action			
Mar	1265	--	--
Apr	1802	--	--
May	2297	--	--
Jun	2291	--	--
Jul	988	17652	--
Aug	559	18618	--
Sep	1540	--	248924
Wymer Dam and Reservoir			
Mar	1276	--	--
Apr	1807	--	--
May	2304	--	--
Jun	2302	--	--
Jul	922	17919	--
Aug	482	18808	--
Sep	1594	--	250619
Wymer Plus			
Mar	1276	--	--
Apr	1807	--	--
May	2304	--	--
Jun	2302	--	--
Jul	912	17960	--
Aug	484	18782	--
Sep	1576	--	250054
Black Rock			
Mar	1265	--	--
Apr	1853	--	--
May	2453	--	--
Jun	2320	--	--
Jul	831	18287	--
Aug	699	18721	--
Sep	1215	--	261830
Unregulated			
Mar	1,426	--	--
Apr	2,463	--	--
May	3,374	--	--
Jun	2,879	--	--
Jul	1,067	18173	--
Aug	540	18604	--
Sep	506	--	295124

Table B-13. Summary of monthly median flow and associated Coho fry and subyearling for the Wapato floodplain reach (based on the 1981-2005 period of record).

		Habitat (m²)	
Month	Median Monthly Flow (cfs)	Coho Fry	Coho Juvenile
No Action			
Mar	3,109	113291	--
Apr	2,475	115060	--
May	1,167	97711	--
Jun	744	--	244035
Jul	652	--	256605
Aug	649	--	257015
Sep	640	--	258245
Wymer Dam and Reservoir			
Mar	3,026	113603	--
Apr	2,447	114480	--
May	1,126	96862	--
Jun	702	--	249774
Jul	652	--	256605
Aug	651	--	256742
Sep	641	--	258108
Wymer Plus			
Mar	3,357	112360	--
Apr	3,220	112874	--
May	1,966	105177	--
Jun	1,540	--	270516
Jul	1,507	--	268860
Aug	1,506	--	268810
Sep	1,496	--	268374
Black Rock			
Mar	3,410	112161	--
Apr	4,208	109164	--
May	4,023	109859	--
Jun	3,176	--	399787
Jul	1,332	--	262853
Aug	1,301	--	261809
Sep	1,300	--	261775
Unregulated			
Mar	4,581	107763	--
Apr	7,262	99196	--
May	9,096	89780	--
Jun	6,900	--	577910
Jul	2,732	--	361141
Aug	1,651	--	276086
Sep	1,610	--	274029

Appendix C - Assessment of Wymer Reservoir Release Temperature to the Yakima River – TSC Technical Memorandum No. 86-68220-08-01

United States Department of the Interior

BUREAU OF RECLAMATION
PO Box 25007
Denver, Colorado 80225-0007

IN REPLY REFER TO:

86-68220
RES-3.10

Date: January 11, 2008

To: Gwendolyn Christensen, UCA-1122
Kim McCartney, UCA-1120

From: Merlynn D. Bender
Reclamation, TSC, 86-68220

Subject: Assessment of Wymer Reservoir release temperature to the Yakima River - Technical Service Center Technical Memorandum No. 86-68220-08-01

Summary

Wymer Dam and reservoir have not been built. Projected Wymer Reservoir seasonal stratification and subsequent release temperatures were modeled with the two-dimensional CE-QUAL-W2 (W2) model (Cole and Wells, 2002). If cold water is conserved during average and wet years, Wymer Reservoir releases could cool Yakima River temperatures during late summer and autumn. During low storage years in which the warm surface water would be released, Wymer Reservoir releases could warm Yakima River temperatures.

Though not modeled, Wymer Reservoir water quality could be problematic. Nutrients and organics flushed from the Yakima River watershed would be pumped into Wymer Reservoir. Wymer Reservoir, a relatively deep and large reservoir, is expected to strongly stratify, and water resident time of lower layers is expected to be several months. Stagnant conditions of cool bottom layers and warm surface temperatures may allow significant algal growth and detrital matter (dead algae) to settle into lower layers where it will decay. Algae, detritus, and other dark particles in the water column could warm Wymer Reservoir more than clear water conditions. Poor water quality or partially decayed organics released from Wymer Reservoir could also adversely impact Yakima River biotic resources or create taste and odor problems for downstream users.

Mitigation for warm temperatures and poor water quality during dry years might include both structural and operational strategies. Wymer Reservoir water quality might be improved by introducing cleaner water, by implementing strategies to selectively flush lower layers, or by maximizing cold water storage.

The following sections describe model development, inputs, and results and focus on water temperature. Conclusions and suggestions for further modeling and data collection are also presented.

Selection of years for simulation

The Upper Columbia Area Office selected years 1991 as an average year, 1994 as a dry year, and 1997 as a wet year (Sonnichsen, October 25, 2007). This appears to be an appropriate choice of years to demonstrate the effects of Wymer Reservoir on Yakima River temperatures. The wet and average years each followed a year with projected carryover storage of 88,000 acre-ft (108.55 million cubic meters (Mm^3)) in Wymer Reservoir. The average year is a year in which Wymer Reservoir should provide cool water and additional flow to reduce Yakima River temperatures for cold water fish. The dry year followed a year without carryover storage or 8000 acre-ft (9.87 Mm^3) in Wymer Reservoir. The dry year represents a near worst-case scenario in which warm Wymer Reservoir surface waters are discharged to the Yakima River during autumn. The wet year and average year storage patterns in Wymer Reservoir were similar. During average and wet years, the Yakima River is expected to have ample water, quicker travel times, and lower water temperatures. During average and wet years, modeled releases from Wymer Dam cooled Yakima River temperatures. Therefore, the model results and discussion will focus on the dry year.

Model construct

A three branch model with one tributary was assembled to allow for future modifications and potential advanced studies (Figure 1). Five structures (outlets) at the dam were included to investigate selective withdrawal. However, only two outlets, the upper and lower river outlets located in the lower portion of Wymer Reservoir were used for this study. One meter thick (3.28 ft) water layers and 32 active longitudinal segments provided sufficient spatial detail to model a larger Wymer Dam scenario than the current design. A larger modeled container also facilitates potential water mass balance calculations at high pool elevations. Model geometry was developed using contour data developed for the Yakima River Basin Storage Study Wymer Dam and Reservoir Appraisal Report (Reclamation, September 2007). All vertical elevations in the Wymer W2 model and results are referenced to North American Vertical Datum 1988 (NAVD88).

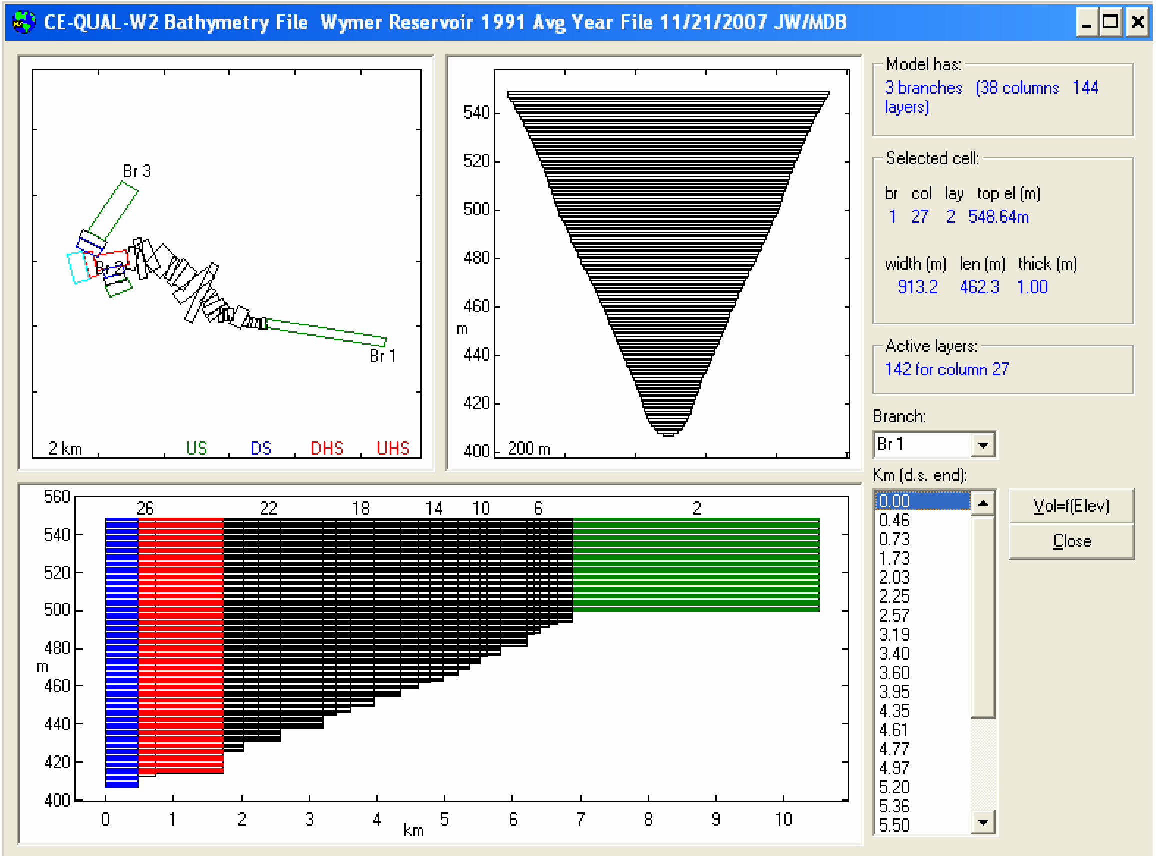

Figure 1. Modeled Wymer Reservoir longitudinal segments, the cross section at Wymer Dam, and one meter (3.28 ft) layers of the main branch segments.

Inflow, outflow, and storage input data

The Upper Columbia Area Office provided inflow, outflow, and storage data for the proposed Wymer Reservoir from November 1, 1980 through October 31, 2005. These data were generated using the Yakima Project RiverWare (Yak-RW) model, a daily time-step reservoir and river simulation model used for system operational planning (Reclamation and State of Washington, October 2007). The Yak-RW model uses a 25 year hydrologic period of historical water years of 1981-2005 (November 1, 1980-October 31, 2005). The Wymer Reservoir elevation capacity information in the Yak-RW model was a previous version of the elevation versus storage curve and may be different than that used in the Wymer Reservoir W2 model.

Wymer Reservoir pumped inflow was modeled as a tributary to the forebay segment distributed evenly between specified elevations 1614.57 ft (492.12 m) and 1621.13 ft (494.12 m) NAVD88. Inflows were provided by the Upper Columbia Area Office RiverWare model of the Yakima River System. Wymer Reservoir inflows were initially added to the surface layer of the Wymer Reservoir W2 model until the modeled elevation of the discharge pipe to Wymer Reservoir was submerged.

Total reservoir outflow data were generated using the Yak-RW model of the Yakima River system and provided by the Upper Columbia Area Office. To conserve the cold water pool during a dry year, modeled releases were initially made from the upper (elevation 1460.56 ft (445.18 m) NAVD88) of the two river outlets until releases became too warm (greater than 15 °C (59 °F)).

At that time, half of the outflow was distributed to the upper river outlet (elevation 1460.56 ft (445.18 m) NAVD88) and half to the lower river outlet (elevation 1379.57 ft (420.49 m) NAVD88) as a mixed release. This release scheme allowed for some flushing of the lower reservoir layers and allowed for releasing a cooler mixed temperature until late August. For the average and wet year simulations when ample cold water would be available, half of the outflow was distributed to the upper river outlet and half to the lower outlet as a mixed release for the entire period to provide flushing of lower layers of Wymer Reservoir. No leakage or spillway flows were included in the outflows.

An area capacity curve from the "Yakima River Basin Storage Study Wymer Dam and Reservoir Appraisal Report," (Reclamation, September 2007), was used for developing water surface elevation versus time from daily modeled storage volume. The reservoir bathymetry (x, y, z) data points for this study were imported to the Watershed Modeling Software (WMS) Package (EMS, Inc., 2007) to create the geometry input data for the Wymer Reservoir W2 model. The resulting Wymer Reservoir W2 model geometry data were imported to Animation Graphics Portfolio Manager (AGPM) software (Loginetics, Inc., 2007) and the elevation-capacity curve values in NAVD88 were exported to a spreadsheet to check against the area capacity curve used in the appraisal report (Reclamation, September 2007). Modeled volumes are comparable and slightly larger than the values shown in the appraisal report. Water surface elevation data for Wymer Reservoir in NAVD88 were then calculated by interpolation from the Wymer Reservoir storage volumes output from the Yak-RW model. The interpolated elevations were used in the W2 water mass balance computer program to estimate daily local inflows required to balance flows in and out of Wymer Reservoir.

Water mass balance

The W2 output was first checked on the more critical dry year using the calculated water surface elevation and the water mass balance computer program. For the dry year, the average amount of flow required to balance flows during April through October 1994 was about -10.6 ft^3/sec (-0.30 m^3/sec). For the average and wet years, the average amount of flow required to balance flows during the April through October period were both about -20.8 ft^3/sec (-0.59 m^3/sec) because of the similarity in the modeled operational scenario which fills and empties Wymer Reservoir to similar elevations. The patterns and total average amount of flow to correct the water mass balance were similar between the average and wet year periods simulated, however the individual daily correction flows were not similar because of the different filling and discharge rates. During winter and spring, flow would typically need to be added to Wymer Reservoir to balance flows. During the summer and autumn, flows would need to be removed. This corresponds to the Yak-RW operational modeling which did not include rain and local inflow to the surface of Wymer Reservoir and did not include evaporation or potential other water losses. Error in the water mass balance could be distributed to the dynamically modeled side branches of the Wymer W2 model separately for each year modeled. However, because of time constraints, inconsistency with the operational modeling, and the relatively small amount of flow needed to correct the water mass balances for each year type, the water mass balance was not corrected for this cursory modeling sensitivity analysis. If Wymer Reservoir becomes a preferred alternative, future Yak-RW operational modeling and W2 modeling should include local inflows and evaporation to derive a more accurate water mass balance.

Meteorological data

Agriculture meteorological (AGRIMET) stations close to the proposed Wymer Reservoir site do not exist. Most of the meteorological information for the Wymer Reservoir temperature modeling was developed from the Harrah Washington AGRIMET station which includes solar radiation data. The Harrah AGRIMET station is about 50 miles (80 km) south of Wymer Dam at elevation 850 feet (259.1 m) and will likely be less windy and warmer. Missing data were filled in or estimated from National Oceanic and Atmospheric Administration (NOAA) local climatological data (LCD) collected at the Yakima Washington Municipal Airport meteorological station located about 25 miles (40 km) south of Wymer Dam (46° 34' N, 120° 32' W). Unfortunately, LCD solar radiation data is not available at this station. The Yakima Municipal Airport data has most of the wind out of the northwest and the wind data is collected at 32.8 feet (10 m) above the ground at elevation 1085 feet (330.7 m) above mean sea level. Wymer Reservoir would be several hundred feet higher and is oriented in an east to west direction. Using Yakima Municipal Airport data in future modeling could induce more wind mixing than may be expected at Wymer Reservoir. A snowy October and windy December occurred during 1991; however, in general 1991 is an average meteorological year. A large wind storm occurred in the first week of April 1997 and would likely have destratified Wymer Reservoir. This wind event may require the W2 model to start after the wind storm in 1997 under some conditions. The 1991 daily Harrah Washington meteorological data was complete. However, there were three days in 1994 that were missing and one day in 1997 was missing. Yakima Municipal Airport LCD data were used to fill in these missing days. Wind speeds collected at 32.8 feet (10 m) were adjusted to 6.56 feet (2 m) heights. Wind speed values were calculated at 6.56 feet (2 m) height using the $1/7^{th}$ power law. No solar radiation data were available from the Yakima Municipal Airport, so the average of the day before and after was used. Some cloud cover (0 to 10 miles (0 to 16 km) horizontal visibility) data in conjunction with other meteorological data indicating clear and cloudy conditions were available to check the average. The daily average meteorological data for 1991, 1994, and 1997 were nearly complete. However, the average daily values will have a tendency to minimize mixing dynamics caused by wind storms occurring over a few hours. Overall, expect the modeled meteorology to conservatively produce strong stratification in Wymer Reservoir.

Assessment of water temperature

Water temperatures above 20 °C (68 °F) may stress cold water fish. Water temperature data from the Yakima River at Umtanum Gage (Hydromet identifier UMTW) were used to model inflow temperature to Wymer Reservoir. The maximum temperature reported for the seven year period between January 1, 1991 and January 1, 1998 was 19.6 °C (67.25 °F). However, just downstream of the Umtanum Gage, Roza Reservoir (Hydromet identifier RDR) temperatures during the summer of 1998 reached 21.1 °C (70 °F). Average year round water temperature of the Yakima River in this reach is typically about or less than 10 °C (50 °F) allowing for cold water fishery habitat much of the time. Cold winter and spring water from the Yakima River will be pumped to Wymer Reservoir. Later in the year, Wymer releases could help cool Yakima River temperatures if the reservoir is not drawn down to the point where warm surface water is withdrawn and discharged to the Yakima River. Selective withdrawal of mid-depth (not cold) water during early summer could conserve cold water for autumn releases. Currently, the two Wymer Dam river outlets are to be located relatively close to the reservoir bottom and would, in a couple of weeks, drain the cold water pool.

Daily average Yakima River temperatures at Umtanum were used as inputs to Wymer Reservoir and were input as a tributary, as discussed previously. The Middle Fork Boise River data at the Twin Springs Gage (Hydromet identifier BTSI) were used to determine a seasonal estimation of low-flow tributary-branch inflow temperatures. Only small flows of 0.35 ft^3/s (0.01 m^3/s) were input to each tributary-branch. Those small flows are minimally-contributing heat sources and were included to serve as place holders for future modeling.

Calculation of mixed Yakima River temperatures

Yakima River water temperature comparison data sets were developed from the available hourly temperature data at Umtanum Gage for the years 1991, 1994, and 1997. The resulting comparison data sets represent “after sunset” warm riverbed conditions rather than a maximum water temperature condition. The data indicated that the warmest temperatures for this relatively large river at the Umtanum Gage could occur near sunset because of upstream warming. Below where Wymer Reservoir releases flow into the Yakima River, it was assumed that thermal mixing occurred quickly and that a complete mixed assumption was valid. Unfortunately, the hourly temperature data collected at Umtanum contain many missing, erroneous, or double data points. Many of the missing hourly values occurred during the afternoon. Therefore, midnight data sets were developed and supplemented with daily average temperatures. Midnight data tended to be recorded more often and provided a more complete daily data set for comparison than other hours of the day. Midnight Yakima River temperatures tend to reflect some of the daytime upstream heating of the water and riverbed. If the temperature in the last hour of the day was missing, the previous hour (11 p.m.) was used. If 11 p.m. data were missing, 10 p.m. data were used. If the previous hour data were missing, the daily average value was used after comparing it to the daily maximum temperature and previous day’s data.

If no data existed for a day, the previous day's daily average was used, or a day before that day, if two consecutive days were missing. The resulting data set reflects water temperature above the daily average and less than the daily maximum while minimizing erroneous data points such as when the sun was shining directly on an exposed thermistor. Maximum daily water temperatures were not used to avoid focusing on data which may be unrealistically warm due to missing or erroneous data. Also, it is assumed that fish and other mobile aquatic biota might take refuge in cool water refugia during the warm portion of the day.

The maximum hourly water temperature for the Yakima River at Umtanum recorded during 1991, 1994, and 1997 was 18.81 °C (65.85 °F) on July 3, 1991 at 8 p.m. The highest water temperature in the comparison data set using primarily "after sunset" data was 18.53 °C (65.35 °F) recorded on July 22, 1994 at midnight. The average of all the available hourly 1991, 1994, and 1997 data was 9.12 °C (48.42 °F). The minimum of all the available hourly 1991, 1994, and 1997 was -0.81 °C (30.55 °F) potentially suggesting supercooled moving water at temperatures less than freezing or potential ice formation during cold winter days. As shown in Table 1, the dry year (1994) data contained the largest daily average, the largest maximum, and lowest minimum water temperatures of the 1991, 1994, and 1997 comparison "after sunset" data sets which is expected for a low flow year. The comparison "after sunset" data is typically less than 1 °C (1.8 °F) cooler than the maximum temperatures and avoids the criticism associated with selecting a maximum data set that may have erroneously warm temperatures due to data collection errors or daily average temperatures that are too cool for comparison. Furthermore, manually processing the data provided a visual check to assure that the data for each day is within expected ranges when compared to previous or later days of data. This process improved the confidence in the comparison data sets.

Table 1. Yakima River at Umtanum water temperature statistics (°C) for selected average, dry, and wet years (n=365) derived from estimated "after sunset" hourly data.

Year	Type	Minimum	Average*	Maximum
1991	avg	0.78	9.13	18.14
1994	dry	-0.14	9.96	18.53
1997	wet	0.22	9.00	17.78

* this statistic is the average of the daily "after sunset" data for a 365 day sample (n=365) and is not the average of all the hourly data

This water temperature data analysis indicated that Yakima River temperatures at Umtanum were occasionally greater than 20 °C (68 °F) and could stress cold water fish. Additional cold water released from Wymer Dam to the Yakima River could potentially improve the cold water fishery if other water quality conditions were not compromised.

Initial conditions

Wymer Dam has not been built, thus no reservoir temperature profile data exist. Therefore, an initial reservoir temperature profile was assumed at the beginning of spring stratification. Stratification of the proposed off-stream Wymer Reservoir depends on the weather, the inflowing temperature of the Yakima River water filling the reservoir, and inflow mixing during filling. The location of the discharge pipe filling Wymer Reservoir is currently near the dam and may mix the forebay. Therefore, professional judgment was used to estimate a Wymer Dam forebay profile that was used throughout Wymer Reservoir as initial conditions for simulations beginning in April. The after winter bottom temperature will be near 4 °C (39.2 °F) which is the maximum density of water (Wetzel, 1983). Mid-depth temperatures will be slightly warmer, due to mixing, than the average March Yakima River temperatures at Umtanum which are typically around 5 °C (41 °F). The surface temperature will reflect the weather during the last week of March which causes surface water temperature to typically be around 7 to 8 °C (44.6 to 46.4 °F) and is influenced by mixing and other variables. The resulting initial condition temperature profile used for modeling all years is shown in figure 2 for a deep Wymer Reservoir condition. Shallower Wymer Reservoir initial conditions will use the top of figure 2.

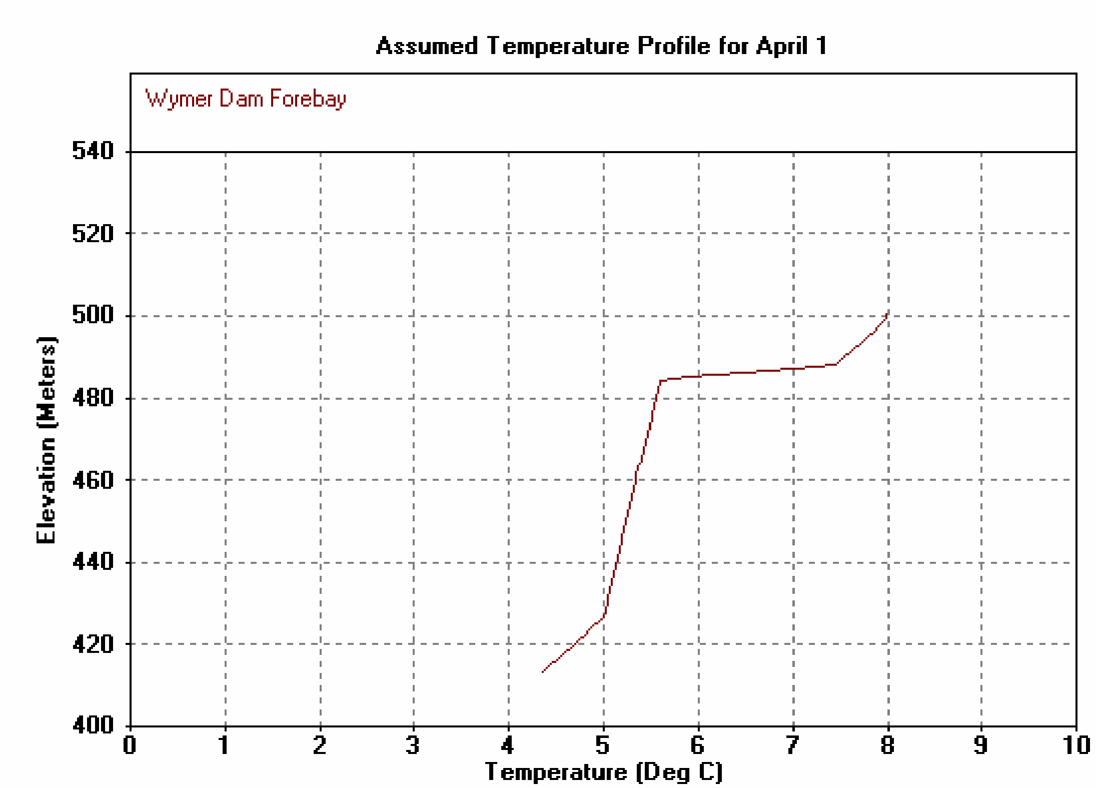

Figure 2. Assumed Wymer Reservoir initial condition temperature profile for April 1.

Selective withdrawal

A sensitivity analysis of selective withdrawal releases from upper (elevation 1460.56 ft (445.18 m) NAVD88), lower (elevation 1379.57 ft (420.49 m) NAVD88), and mixing releases from the two river outlets was done. Sensitivity analysis using a dry year indicated that first releasing from the upper outlet to save cold water and then releasing from both outlets was a desirable release scenario. This mixed release scenario allowed for flushing poor quality water from bottom layers and produced a cooler overall release temperature. Major shifts from warm upper outlet releases to cold bottom water releases tend to be problematic in dry years with low reservoir elevations which increases the chance of releasing warm surface water.

During dry years in which Wymer Reservoir only fills about half way, releases made only from the upper (elevation 1460.56 ft (445.18 m) NAVD88) river outlet to conserve cold water for late summer and early autumn will become too warm by late July. Changing over to the lower river outlet (elevation 1379.57 ft (420.49 m) NAVD88) initially releases cold water. Within a few days the cold water pool is drained and warm surface water is released which may exceed the Yakima River temperature standard. Once the reservoir storage reaches 60,000 acre-ft (74.01 Mm^3) or late July, the upper outlet (elevation 1460.56 ft (445.18 m) NAVD88) should be closed and mixed releases should be made by combining 50 percent from the lower river outlet and 50 percent from the upper river outlet. The modeled Wymer Dam release temperatures for the period April 1 through October 31 for the dry year (1994) is shown in Figure 3. No releases occurred during spring filling.

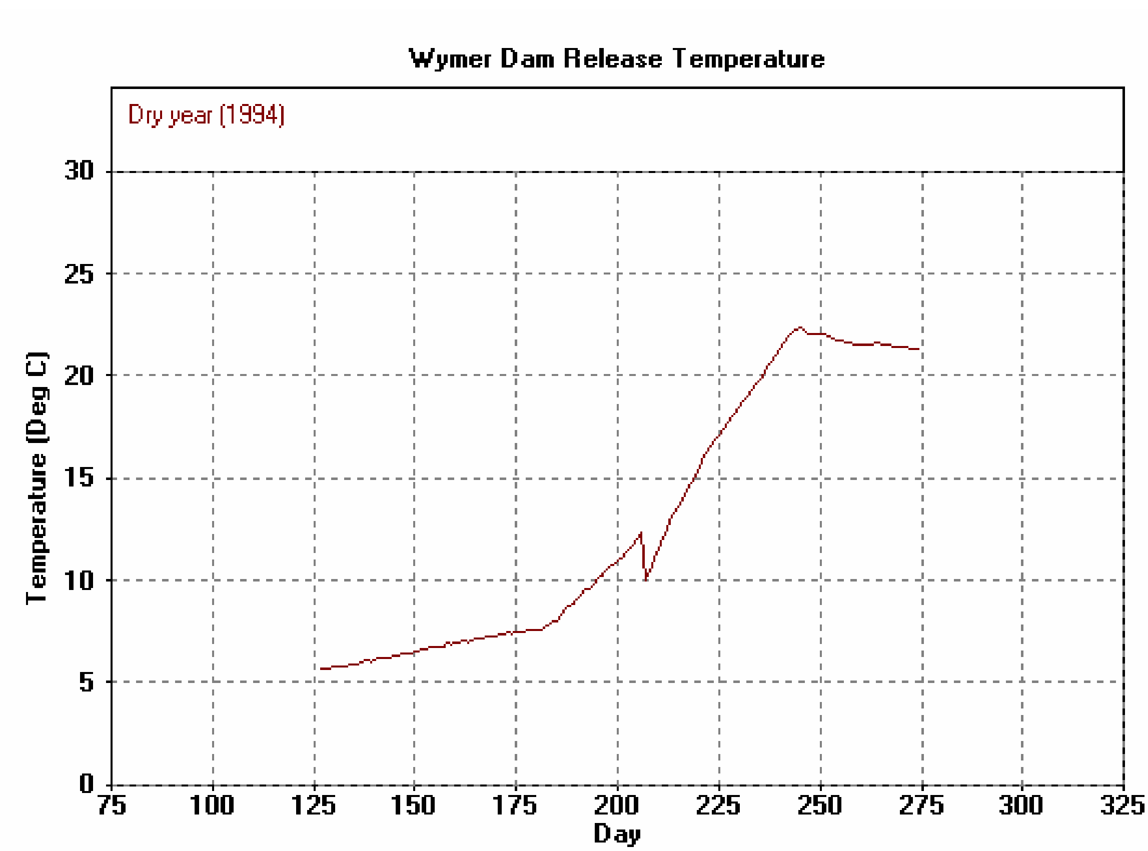

Figure 3. Wymer Dam release temperatures by first releasing only from the upper river outlet through July 24 (day 205) and then mixing 50 percent from the upper river outlet and 50 percent from the lower river outlet for a dry year (1994)

Discussion

As currently planned, allowing Wymer Reservoir to be drawn down to a minimum pool of 8000 acre-ft (9.87 Mm^3) could be problematic. Doing so would allow warm surface water to be released to the Yakima River. Preliminary W2 temperature modeling in conjunction with flow-weighted temperature calculations showed that, during dry years the Yakima River downstream of Wymer inflows, the mixed Yakima River water temperatures could increase by 1.1 °C (2 °F) during late August. This increase in Yakima River temperatures may exceed standards. While not modeled, other water quality impacts related to Wymer releases are possible.

Runoff containing nutrients and organics could get pumped into Wymer Reservoir. As a result, algae could be plentiful and the resulting detrital matter could settle and decay in bottom layers resulting in low dissolved oxygen concentrations (DO) in stagnant bottom layers of the reservoir. When this water is released it could cause poor quality water to be released from the lower river outlet if an effective selective withdrawal strategy is not employed.

Organics caught in the dead storage pool would decay quicker at warmer temperatures and reduce DO. If the DO and consequently oxidation reduction (redox) potential dropped to low levels, nutrients and other compounds may be released from the sediments which might be released into the Yakima River. The rate of release increases if the sediments are disturbed by agitation from sediments (Wetzel, 1983). In addition, head cutting of upstream delta deposits during storms may also suspend sediments. Downstream water users could be affected by poor water quality released from Wymer Reservoir.

Either structural mitigation at Wymer Dam, such as selective withdrawal or aeration, or operational mitigation, such as releasing more and colder water from upstream reservoirs, could be used to alleviate potential environmental impacts. Maintaining higher reservoir elevations could also be used to mitigate temperature and other water quality concerns.

Maintaining higher Wymer Reservoir elevations would allow the warm surface waters to float above withdrawal levels and would allow bottom sediments to remain cool under bottom water layers. Figure 4 shows modeled temperature conditions for Wymer Reservoir in branch 1 during August 9, 1994 and the strong thermal stratification. Note that the upper outlet is at elevation 1460.56 ft (445.18 m) NAVD88 centerline elevation and the lower outlet is at 1379.57 ft (420.49 m) NAVD88 centerline elevation. Considering the proposed filling and release scenario and resulting strong stratification and lengthy water residence times, metalimnetic DO depletion and adequate surface and bottom DO are anticipated though not modeled with W2. The cool bottom waters allow high DO and minimal decay of organics. However, at low pool elevations in which Wymer Reservoir heats up, warming of the sediments by dropping warm surface waters onto the sediments would accelerate decay of organics and deplete DO in lower layers.

The dashed outline on figure 4 is the modeled cold water volume less than the zone criteria of 0 to 18 °C (32 to 64.4 °F) on August 9, 1994 under the modeled conditions; and that modeled cold water volume is 12,378 acre-ft (15.27 Mm^{3}) or about 31 percent of the modeled storage volume in Wymer Reservoir on that day. Therefore, over two-thirds of the water in Wymer Reservoir would be either warmer than 18 °C (64.4 °F) or would be dead storage and not available for release on that randomly selected day of August 9, 1994. That cold water volume is a relatively small volume that is rapidly depleted under the modeled release conditions. Except for the cold water in dead storage, by the last week in August no cool water is available for release during a dry year (1994). Furthermore, it may be beneficial to stop releasing from Wymer Dam to prevent raising Yakima River mixed temperatures under such warm conditions. However, as will be described in the following section on modeled flow-weighted temperatures, the Yakima River may have the capacity to absorb warm Wymer Dam releases without exceeding the water temperature standards.

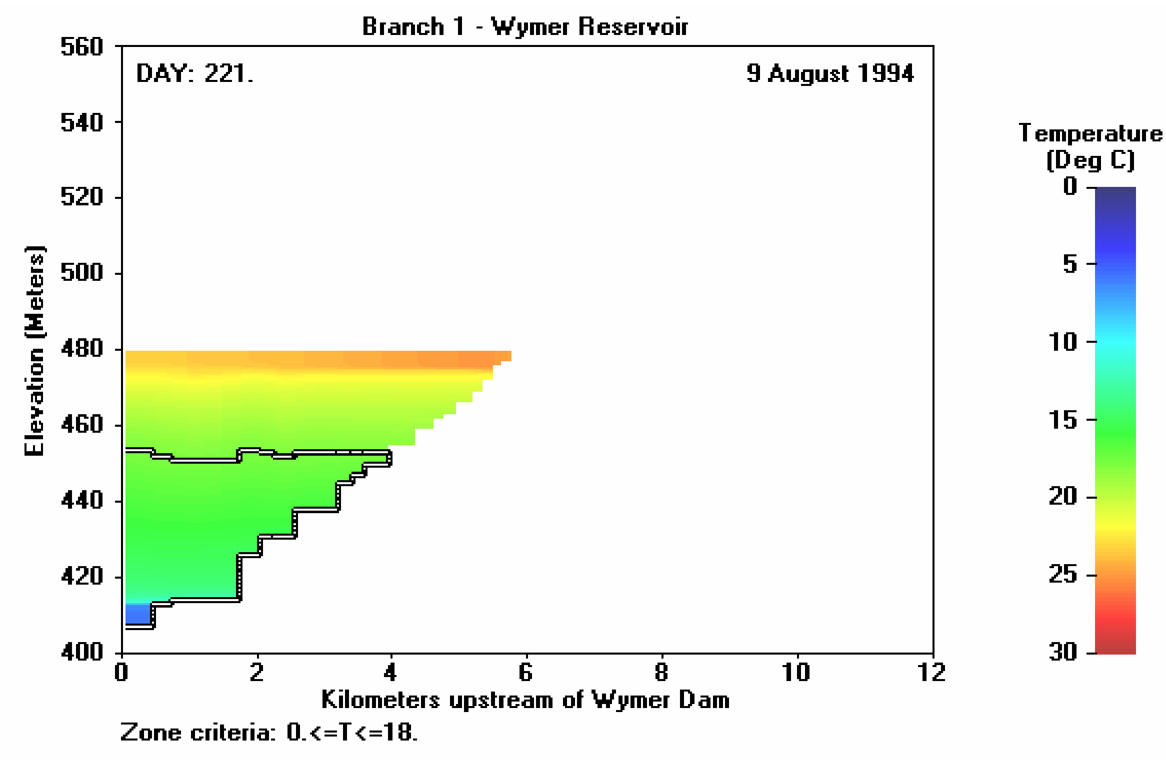

Figure 4. Modeled Wymer Reservoir temperatures during proposed operating conditions in 1994

Modeled flow-weighted temperatures

The modeled flow-weighted Yakima River temperatures downstream of Wymer Dam releases can occasionally be greater than 18 °C (64.4 °F) in dry, average, and wet years. Even without Wymer Dam releases, historical Yakima River temperatures were occasionally higher than 18 °C (64.4 °F) as shown in Table 1. In average and wet years, Wymer Dam releases tend to cool Yakima River temperatures. In dry years with low pool elevations, Wymer Dam releases tend to warm the Yakima River during the months of August and September.

Figure 5 shows modeled flow-weighted mixed Yakima River temperatures downstream from Wymer Dam releases. Some of the time, the data on figure 5 reflects zero release from Wymer Dam and therefore historical warm Yakima River temperatures at Umtanum gage, not caused by Wymer Dam releases. Many of the warmest Yakima River temperatures occur when Wymer Dam is not releasing water to the Yakima River and therefore default to the historical value. Therefore, the title of figure 5 can be misleading since it is not always a mixed river temperature and is simply the historical Yakima River temperature under zero Wymer Dam releases. For instance, during the average year of 1991 (blue line on Figure 5), Yakima River temperatures were warmest before cool releases from Wymer Dam began on July 7 (day 188) which reduced the mixed Yakima River temperature. Similar cooling patterns are seen in the wet year 1997 (yellow line). Whereas, during the dry year 1994 (purple line), mixed Yakima River temperatures initially drop and then warm quickly during late summer.

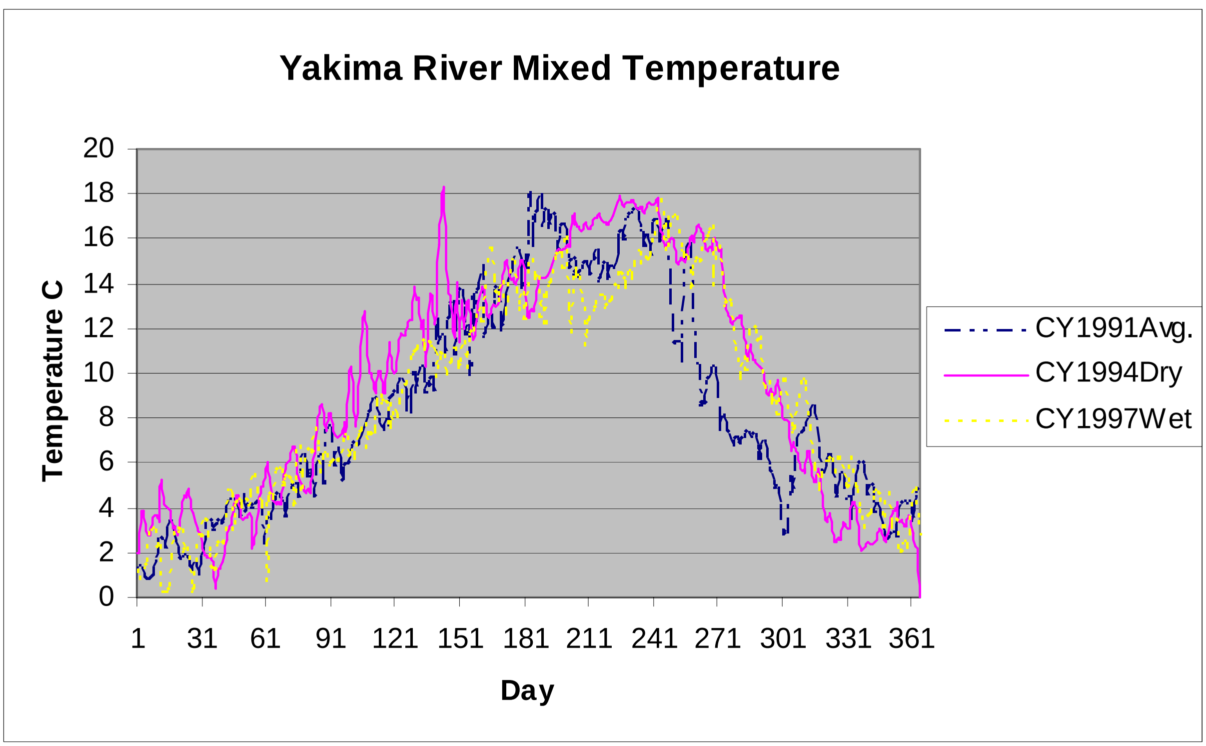

Figure 5. Modeled flow-weighted mixed water temperature just downstream of Wymer Dam discharge for dry, average, and wet calendar years.

Conclusions

1) W2 output for average and wet years showed that Wymer Reservoir releases should cool Yakima River temperatures during autumn and provide additional flow velocity thereby decreasing the water travel time, increasing depths, and decreasing the heating of the riverine water.
2) During multiple dry years and excessive drawdown of Wymer Reservoir, warmer water may be discharged into the Yakima River during autumn with the current outlet configuration which includes minimal selective withdrawal capabilities.
3) During dry years, the two proposed river outlets from Wymer Reservoir allow only minimal selective withdrawal options to conserve the cold water pool for autumn releases. A discharge pipe to top-of-weir elevation 1613.566 ft (491.8 m) NAVD88 is proposed for filling Wymer Reservoir. This discharge structure might also be designed to allow selective withdrawal of warmer water to save more cold water under high pool conditions. With properly designed selective withdrawal and operations to match, it may be possible to conserve more cold water for release to the Yakima River for maintenance and improvement of cold water species. If selective withdrawal is considered feasible, additional temperature modeling may be required to further assess additional selective withdrawal capability.
4) Filling Wymer Reservoir through a discharge pipe near Wymer Dam has the potential to mix warm surface waters or cool bottom waters with inflowing Yakima River water. This could potentially reduce the cold water pool available for autumn releases or disturb stagnant water in the dead storage pool during filling operations. This potential for mixing in the forebay may require more study.
5) Wymer Reservoir will have a period of strong thermal stratification with cold bottom water and warm surface water. Though not modeled, algal biomass is expected to grow in the warm surface layers of Wymer Reservoir. DO depletion in metalimnetic or bottom layers due to the settling detrital organic matter and minimal flushing of lower layers is also expected. Further investigation of water quality may be warranted.
6) Due to the cold bottom temperatures and stagnant conditions during filling of Wymer Reservoir in spring, the summer and autumn bottom releases from Wymer Dam may contain partially decayed organics that may decay in the Yakima River. Wymer releases may contain contaminants that may be detrimental to fish. These potential impacts on Yakima River water quality may warrant more study.
7) Structural or operational mitigation might alleviate temperature and other water quality concerns in the Yakima River caused by Wymer Reservoir releases. More modeling would be required to quantify benefits of mitigation.
8) To conserve cold water during dry years in which pool elevations are less than 80,000 acre-ft (98.68 Mm^3) (which is half or the irrigation portion stored), the upper river outlet should be used until pool elevation reaches 60,000 acre-ft (74.01 Mm^3) or August 1. After August 1, both the upper and lower river outlets should be used to mix releases to a desirable release temperature.
9) Future RiverWare operational modeling might include local inflow to Wymer Reservoir and evaporation to potentially improve the water mass balance.
10) Future RiverWare operational modeling should include recently updated elevation versus capacity data that were used in the W2 model.
11) The coarse bathymetry data used for this study are adequate for appraisal level and feasibility level studies. However, if there is an opportunity to collect flown topography with modern LIDAR or EDM survey equipment, it may be beneficial to collect high resolution bathymetric data before designing Wymer Dam or flooding the bottoms of Lmuma Creek canyon and Scorpion Coulee Creek canyon by coffer dam construction.

12) If Wymer Reservoir is selected as a preferred alternative, additional water quality data assessment and modeling might be necessary to investigate maximizing water quality released to the Yakima River. Additional nutrient, organic, and other water quality data would need to be collected at least monthly from the Yakima River at Umtanum to model DO in Wymer Reservoir and releases. The water quality data collection would likely focus on developing dry year water quality input data sets for further Wymer Reservoir water quality modeling under stagnant or a low pool conditions.

This technical memorandum should be referenced as follows:
U.S. Bureau of Reclamation, January 11, 2008, "Assessment of Wymer Reservoir release temperature on Yakima River temperature," Technical Service Center Technical Memorandum No. 86-68220-08-01 from Merlynn D. Bender, Environmental Applications and Research Group (86-68220) to Gwendolyn Christensen, UCA-1122 and Kim McCartney, UCA-1120

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Appendix D - Aquatic Macroinvertebrates

Introduction

Reclamation's Yakima Project extends along both sides of the Yakima River in south-central Washington and provides irrigation water for approximately 465,000 acres of irrigable lands. The Yakima Project has succeeded in making this part of Washington one of the most productive agricultural areas in the United States (Pfaff, 2002). Reclamation operates the dam and reservoir system to meet specific authorized project purposes such as irrigation water supply, instream flows for fish, and flood control. Hydroelectric power is produced incidentally.

The Project consists of storage reservoir dams, diversion dams, canals, powerplants, and fish protection facilities. Storage dams include Keechelus, Kachess, Cle Elum, Bumping Lake, and Rimrock Lake. Diversion dams include Easton, Roza, Sunnyside, Tieton, and Prosser. Through the presence and use of the many facilities in the Project, flows in the Yakima River watershed are heavily regulated; however, large floods still occur which maintain some alluvial complexity (Snyder and Stanford, 2001).

Reservoirs are typically operated to store water from the end of irrigation season in October until releases for irrigation are required the following spring or summer. Through August, September, and October, when reservoirs are drawn down to meet irrigation needs, releases are coordinated to maintain system storage flexibility for winter and the next operating season.

Until early September, most irrigation water requirements are met from reservoirs on the Yakima River (Keechelus, Kachess, and Cle Elum reservoirs) with minimal releases from Naches River reservoirs (Rimrock and Bumping). Around September 1, major releases are transferred from the reservoirs on the Yakima River to Rimrock Reservoir on the Naches River. This regulation scheme in which the upper basin experiences elevated flows during the summer, while the Naches experiences abnormally high flows during the first part of September, is termed "flip-flop." These releases during late-summer represent a significant alteration from the natural flow regime in this area. Diversions further down-river at Sunnyside and Wapato along the Yakima River also alter flows and divert half of the entire river flow during May to October crop irrigation (Stanford et al., 2002).

Responses of biota to regulated river systems are often complex and variable. While organisms inhabiting running waters are adapted to extremes in flow (Lytle and Poff, 2004) these adaptations are to natural or normative flows. Flow-regime modifications that alter flow events in different seasons may have large impacts on biota. Some biota may be more sensitive in detecting hydrological changes than others. Camargo and Jalon (1990) found that aquatic macroinvertebrates were better than fish communities for detecting changes and for reflecting recovery from alterations caused by dams. Changes in macroinvertebrate distributions caused by river regulation may occur because of altered habitat, changes in sediment input, water quality, thermal regimes, and flow patterns (Ward, 1976; Riveritage, 1984; Riveritage et al., 1987). Considerable evidence exists that hydraulic conditions are driving forces affecting distribution and abundance patterns of benthic invertebrates (Statzner et al., 1988) and methods have been proposed for linking flow regimes and aquatic invertebrate communities (Extence et al., 1999). Poff et al. (1997) suggest that flow can be defined in terms of discharge magnitude, frequency of a given flow occurrence, duration of a specific flow, flow timing, and the rate of change or flow flashiness. Human alterations from the natural pattern of the flow regime of a river may be defined with these flow criteria. Lateral connectivity between river channels and the floodplain are also often affected by river regulation with reduced connectivity occurring because of dampened flood peaks (Bunn and Arthington, 2002). Benthic invertebrates are also a major part of the food resource for fishes, and changes in invertebrate communities may result in changes in condition of fish communities (e.g., Waters, 1982; Bowlby and Roff, 1986; Wilzbach et al., 1986). Differences in the ability of streams to produce salmonids are often related to food availability rather than physical habitat (Bisson and Bilby, 1998).

Presently, the Storage Study is examining options to augment storage to benefit water users, along with fish, in the Yakima basin. Alternative plans include basin water exchanges with the Columbia River and creating additional storage by development of new reservoirs or enlarging present reservoirs. Potential water storage facilities include a reservoir at Wymer and the Black Rock reservoir proposal. At least some of these alternatives could result in more normative flows within the basin. The purpose of this paper was to collect information on aquatic invertebrate assemblages associated with the Yakima Project and present data relevant to potential flow effects.

Macroinvertebrate Literature for the Yakima Project Area

Reclamation staff conducted surveys throughout the basin to identify factors related to benthic macroinvertebrate distribution. The Storage Study is one of the few studies that collected macroinvertebrates in the mainstem Yakima River. Both quantitative (Slack sampler) and qualitative (D-frame net) methods were used for sample collection. Elevation was a significant variable important in describing benthic invertebrate communities and is often observed and caused by upstream-to-downstream changes in temperature, sediment, and quality and quantity of invertebrate food resources. Agricultural influences were also observed in the data with midges being especially common at lower elevation sites associated with higher levels of agriculture. Typical of the river continuum concept, or RCC (Vannote et al., 1980), higher elevation communities contained invertebrates such as shredders that utilize coarse particulate organic matter while lower elevation sites contained invertebrates that feed on periphyton algae (scrapers). Reclamation determined that most of the large river sites were either unimpaired or moderately impaired by using a multimetric condition index. Lower condition indexes were observed in the Yakima River between Umtanum and Parker, perhaps caused by water diversions, wastewater discharges, and irrigation return flows (Cuffney et al., 1997).

Small first- to third-order streams (ca. 1-9 m in width) were sampled (D-frame net) in the Yakima River basin using Environmental Monitoring and Assessment Program criteria. Streams appeared to be unaffected by chemical pollution, but poor physical conditions were often noted. Timber management appeared to impact biological communities (25% of the stream kilometers were deemed biologically impaired) from excessive fine sediment and deficient large woody debris (Merritt et al., 1999).

Reclamation determined that flip-flop affects the insect community in an upper Yakima River riffle near the town of Ellensburg. Some insects were stranded as flows were decreased, especially those that were in the pupal stage. It appeared that many invertebrates, however, were capable of migrating to the channel or entering the drift as the stream bottom was exposed. There was also the suggestion that some taxa were entering the shallow hyporheic zone to avoid drying. Standing crop density in river substrates more than doubled after flip-flop, indicating that a large portion of the insect community was successfully moving down the drying bank. The increase in drift density during flip-flop was mainly attributed to Simuliidae and Chironomidae (Arango, 2001).

Samples were collected at several points along the Yakima and Naches Rivers. Floodplains were anthropogenically impacted in lower reaches of the Yakima as evidenced by lack of hyporheic stoneflies in monitoring wells. These organisms were negatively correlated with increased nitrate suggesting a response to water quality. ??

Distribution of benthic macroinvertebrates (Surber samples) along the floodplain demonstrated the importance of off-channels habitats for food access by salmonids and suggested invertebrate taxonomic differences between off-channels and mainstem samples. Both invertebrate habitats had similar abundance values and averaged around 10,000 individuals/m2.

The importance of flow for maintaining off-channels environments was emphasized and it was suggested that these areas were often dewatered because of reduced base flows. Productivity decreases in benthic invertebrates caused by flow alterations likely impact the quality of salmonid habitat (Stanford et al., 2002).

Comparisons were made between benthic macroinvertebrate assemblages associated with unregulated tributaries and those below storage and diversion reservoirs. Heptageniid mayflies were identified as being sensitive and declined with river regulation in the Yakima Project area. Taxa richness below diversion dams was similar to that at unregulated tributaries, while richness associated with storage reservoirs was lower. Sampling at various distance downstream of Cle Elum and Bumping Reservoirs suggested recovery of heptageniid mayflies at distances ranging from 1500-9700 m downstream of the dam. It also appeared that there was recovery from high abnormal flows over time, with heptageniid mayfly abundance increasing with time post flip-flop. Macroinvertebrate communities below Cle Elum and Bumping Reservoirs appeared to recover relatively quickly from dam-induced impacts with distance and time (season) (Nelson, S.M., 2004).

Aquatic macroinvertebrates associated with salmon redds in the shallow hyporheic zone of the Cle Elum and Yakima Rivers were examined. Macroinvertebrate communities below the Cle Elum Dam contained Hydra at densities that theoretically could affect alevin survival. However, there was no significant relationship between alevin survival at hatching and Hydra abundance. Macroinvertebrate samples from the less-regulated Yakima River had the highest taxa richness and contained a relatively balanced community containing Ephemeroptera, Plecoptera, Trichoptera, and Diptera. The community at Cle Elum was numerically dominated by non-insect taxa (Nelson, S.M. and M. Bowen, 2004).

Samples from this study were all collected above the Cle Elum and Bumping reservoirs and might contain reference sites suitable for comparison to macroinvertebrate communities below the reservoirs. Macroinvertebrate biomass (standing crop) appeared to be low (<0.5g/m2) relative to values important to salmonid production (0.6 to 0.8 g/m2) (Weng et al. 2001). Mean drift values of 0.28 individuals/m3 were also on the low end of the scale of 0.5 to 5.0 individuals/m3 summarized in Riveritage (1977); O'Hop and Wallace (1983); and Cellot (1989) (Nelson, S.M., 2005).

Aquatic benthic invertebrates were compared below a diversion dam (treatment reach, Wapatox) and further downstream where water was returned (reference reach) to the Naches River, Washington. Invertebrates were collected from three habitat types during December 2002 and December 2003. Flows differed between the years and were relatively low (ca. 7 m3/S) in 2002 and much higher during 2003 (ca. 18 m3/cm) for a flow increase of about 2.5X. Analysis of invertebrate and environmental variables indicated that distance below the dam was an important variable in structuring invertebrate assemblages in all habitats and also that shallow-fast and deep-slow invertebrate structure changed between sampling years. Changes in environmental variables that were likely associated with flow at shallow-fast sites included increased channel width and increased sand in 2003.

Invertebrate drift biomass in backwater habitats declined during the high flow year, as did the abundance of benthic fish-food items. Decreased hydraulic residence times may have resulted in flushing of drift invertebrates out of backwaters. The change in aquatic invertebrates in this important juvenile salmonid habitat may decrease habitat suitability for juvenile rearing.

Benthic invertebrate biomass ranged from 0.43 to 4.62 g/m2 over the 2-year study suggesting a fair-good potential for supporting a fishery according to Mangum's criteria (Mangum, 1989) (Nelson and Bowen, 2003).

Flow Impacts to Aquatic Invertebrates

Flow magnitude and timing

In a study to determine how much deviation and change from unregulated flow conditions can be permitted without negatively affecting downstream biota, Morgan et al. (1991) found that invertebrate density doubled if flows were generally held between a range of about 1 to 3X the base flow. Moog (1993) found severe damage to the invertebrate and fish communities with daily flow alterations from an Austrian hydropower facility. A reduction of between 75- to 95-percent of benthic biomass was evident in the first few kilometers and a reduction of between 40- to 60-percent of biomass compared with undisturbed areas could be detected within the following 20 to 40 km. These releases were extreme with increases of 28 to 60X base flow. Quinn and Hickey (1990) state that generally, flood flows need to exceed about 20X the median flow to have significant effects on invertebrate abundance and taxonomic richness 3 to 4 weeks after a flood event. Irvine (1985), however, observed that a 5X increase in flow resulted in a 72- to 90-percent reduction in density of invertebrates that were probably resident in periphyton that was sloughed off. Of primary importance is the scour and dislodging of organisms due to high flows. Bogatov (1978) found that invertebrate populations normally associated with sand bars were reduced in biomass about 10X during floods, while those in more stable stony reaches were only reduced by a factor of 2 or 3X.

In the Yakima system, Nelson and Bowen compared invertebrate communities under two different flow magnitudes. A flow increase of 2.5X on the Naches River in December was associated with an increase in invertebrate benthic biomass in shallow, fast habitat, but a decrease in food items that salmonids utilize. The decline in drift biomass and food item abundance suggested negative consequences for salmonids related to this flow increase. It also appeared that there were changes in backwater habitats that may have made them less desirable for juvenile salmonids. It was suggested that the decreased hydraulic residence times in backwaters may have resulted in flushing of drift invertebrates out of the backwaters, thus decreasing the amount of food available for young fish.

Artificially high flows at unseasonable times have been documented as having a major effect on benthic composition. Increased summer flows from an impoundment in South Africa (Snaddon and Davies, 1998) resulted in decreased taxa richness and impacts to sensitive families such as heptageniid Ephemeroptera (similar to regulation impacts in the

Yakima Project) (Nelson, 2004). The length of time that biota are exposed to high flows also likely plays a role in the amount of community resiliency that is exhibited, with short-term (pulse) alterations less damaging than long-term (press) alterations. This may explain some of the variance in invertebrate assemblages below Yakima Project reservoirs and may play a role in the low richness values relative to other Reclamation reservoirs (Nelson, 2004). Macroinvertebrate communities below Cle Elum and Bumping Reservoirs appeared, however, to recover relatively quickly from dam-induced impacts with distance and time (season) (Nelson, 2004). Temporal changes in flows may affect even collector-filtering genera that need flow to feed. Winget (1984) found that increased summer flows negatively impacted early instars of collector-filterers such as Brachycentrus.

Regulated water systems which result in low flows and water velocities have also been reported to increase drift when the need of the organism cannot be met for items such as food, oxygen, and temperature (Minshall and Winger, 1968; Vinikour, 1981). Maintaining minimum flow levels to avoid desiccation of aquatic invertebrates was recommended by Weisberg et al. (1990). The density of organisms increased 100X when at least minimum flows were maintained from the Conowingo hydroelectric dam on the Susquehanna River, Maryland. Water abstraction from lowland rivers may have large impacts on aquatic communities relative to those associated with upland rivers (Castella et al., 1995) and enrichment may increase impacts from low flows (Suren et al., 2003).

Arango (2001) determined that flip-flop affected the insect community in an upper Yakima River riffle near the town of Ellensburg. It appeared that some insects were stranded as the water level was lowered in the Yakima River, while other insects entered the drift. Standing crop, however, doubled in samples collected in the river. Dewson et al. (2007) saw a similar pattern of increased drift, but an increased accumulation of invertebrates in the available wetted area in New Zealand streams that experienced decreased flows on a short-term basis. Both of these papers suggest that a major portion of the invertebrate community is successful in moving down the drying bank and back into the wetted area.

Macroinvertebrate community preferred velocities/flows

Literature suggests that aquatic macroinvertebrates found in high-gradient streams and rivers are highly adapted to variable and high discharges within normative flow limits. These organisms have generally evolved morphologies and life history patterns that make them well suited to withstanding flows and velocities associated with heavy spring runoff, torrential rains, and summer spates. Lotic systems are noted for short recovery time from disturbance, especially short-lived disturbance (Yount and Niemi, 1990). The maintenance and/or reestablishment of macroinvertebrate populations following high flows is done through initial resistance to flow, recolonization from the hyporheic (subsurface) zone (Griffith and Perry, 1993), refugia within the substrate (Lancaster and

Hildrew, 1993), or reestablishment of populations through drifting organisms from tributaries and/or upstream locations (Brittain and Eikeland, 1988). Growns and Davis (1994) offer a good discussion of classifying macroinvertebrate fauna into flow exposure groups; obligate, facultative, and avoiders. A similar strategy was used by Extence, et al. (1999) to link benthic invertebrate communities with the prevailing flow regimes of British rivers.

Stark (1993) found, through studies using the macroinvertebrate community index (MCI) in sampling stony riffle habitats, that water depths (10 to 40 cm), current velocities (20 to 120 cm/S), and substrate (6 to 14 cm rock diameter) had little influence on index value. Gore (1978) found the conditions of highest faunal diversity in the Tongue River, Montana, were at a current velocity of 75 to 125 cm/S at a depth of 20 to 40 cm. The mayfly, Rithrogena hageni, was chosen as the indicator species which most closely represented the macroinvertebrate community with the highest diversity. Of the 19 species of macroinvertebrates studied in relation to flow preference, Gore and Judy (1981) found the 85- to 100-percent preference range for velocity was from about 26 to 107 cm/S. Degani et al. (1993) also found that most taxa were found at depths of 5 to 60 cm and at flow velocities between 80 and 100 cm/S with velocities of 60 to 80 cm/S containing the greatest overlap of faunal preference.

Recovery from regulation

The benthic communities below Cle Elum and Bumping Reservoirs appeared to recover from dam-induced impacts with distance and time (season), and improved relatively quickly suggesting that the magnitude of assemblage alteration is relatively minor as a function of distance along the river (Nelson, 2004). Evidence from multivariate analysis, functional feeding studies, and heptageniid indicator organisms all suggested recovery within a relatively short distance (2500-9700 m) below dams. While recovery distance can be very high below large dams such as Glen Canyon (no recovery at 387 km) (Stevens et al., 1997) and Flaming Gorge (69-125 km), (Vinson, 2001), most literature (Camargo and Jalon, 1990; Imbert and Stanford, 1996; Pozo et al., 1997; Voelz and Ward, 1990; Voelz and Ward, 1991; Ward, 1974) suggests recovery below dams as occurring between 4,000 and 10,000 m. These distances are similar to those found with Cle Elum and Bumping Dams in the Yakima Project Area.

The hyporheic invertebrate community may be more impacted by river regulation than macroinvertebrates associated with surface substrates. Nelson and Bowen (2004) show a greater separation along Axis I between hyporheic samples in a comparison of salmon redd habitats in the Cle Elum (regulated) and Yakima (less regulated) Rivers than in invertebrate assemblages collected with a surface Surber sampler. There was, however, no attempt to examine hyporheic communities at sequential distances downstream of the Cle Elum, so no information was available to determine downstream recovery of the shallow hyporheic.

Lateral connectivity/backwater effects

Backwaters in natural systems often function as macroinvertebrate refugia from extreme flows. Negishi et al. (2002) found that backwater habitats accumulated macroinvertebrates during spates and considered lateral heterogeneity of stream channels to be an important element of stream restoration. Nelson and Bowen (2003), however, in a study of the Naches River, found that invertebrate drift biomass and the abundance of benthos preferred by salmonids decreased in a season with higher flows and suggested that invertebrates were flushed out of backwaters. These two studies may demonstrate the differences between a pulse and press sort of disturbance (e.g., Bender et al., 1984) related to differences in flow duration.

Stanford et al. (2002) emphasized he importance of flow for maintaining off-channel environments in the Yakima system and it was suggested that these areas are often dewatered because of reduced base flows. Productivity decreases in benthic invertebrates caused by flow alterations likely impact the quality of salmonid habitat.

Conclusions

Although limited, data indicates a resilience of aquatic invertebrates in the upper part of the Yakima Project area despite the large changes in hydrology associated with flip-flop. Reports suggest that high-quality benthic invertebrate communities exist in this portion of the Project area (Cuffney et al., 1997; Nelson, 2004; Nelson and Bowen, 2003). Likewise, Stanford et al. (2002) report the presence of amphibitic stoneflies in floodplain monitoring wells as an indication of the lack of anthropogenic impact in the Yakima River around the confluence with the Teanaway River and the Yakima River above the Yakima Canyon. There appears to be a dearth of information on macroinvertebrates associated with the large river sites in the downstream portion of the Yakima River. Only Cuffney et al. (1997) reported finalized data on benthic macroinvertebrates in the lower part of the Yakima River [Stanford et al. (2002) collected samples, but these were largely unprocessed]. Cuffney et al. (1997) describe sites along the mainstem Yakima River between Umtanum and Parker as containing moderately impaired communities. Conditions that may have influenced the macroinvertebrate communities included municipal wastewater discharges, irrigation return flows, and hydrological alterations caused by water diversions (Cuffney et al., 1997). Water abstraction in conjunction with enrichment from wastewater discharges may result in major alterations of invertebrate communities (Suren et al., 2003). It is possible that, in the lower portion of the Yakima Project area, water abstraction has more easily detected consequences on the community than the alterations in flow timing that presently occur in the upper part of the project under flip-flop. Castella et al. (1995) suggested that water abstraction may impact lowland rivers more than upland rivers. They suggested these differences in response were related to three environmental factors:

1. Upland rivers typically possess a high level of flow variability within and between years to which resident macroinvertebrates may be adapted,

2. It may be easier to maintain flow velocities for lotic fauna in higher gradient upland rivers, and

3. Drainage density of upland rivers is high with a large number of tributaries that may serve as macroinvertebrate refugia and allow for recolonization of impacted areas (Castella et al., 1995).

Stanford et al. (2002) pointed out the importance of restoring downstream flows in the Yakima River for restoring ecological integrity to the system.

It is likely that benthos distribution in the Yakima Project area is related to discharge, and therefore, the potential for community changes resulting from altered flows is high. Alternatives that shift flows from what were the historic normative flows should have the greatest impact on macroinvertebrate communities. However, despite some of the extreme alterations already present in the system, there is a great diversity and abundance of macroinvertebrates at some sites below dams in the Yakima Project area.

The impact of flow alterations in the Yakima Project area differ depending on the scope and magnitude of seasonal flow operation. Impacts to biota caused by changes in flows are associated with a high degree of uncertainty (Castleberry et al., 1996). Uncertainty is incorporated with possible changes in flow requirements associated with temporal, spatial, life-history, variations in food sources, water quality, diurnal vs. nocturnal differences in flow use (La Voi and Hubert, 1996), and gender-specific velocity preferences (Gore, 1989) by lotic organisms. Different channel morphologies throughout the system will also result in variable changes in velocity with a given discharge. It has been suggested that, because of a lack of effective predictive ecological models, adaptive management or “learning by doing” is a necessary approach to determining whether ecosystem responses to changing flow regimes are having the desired effect (e.g., Acreman and Dunbar, 2004; Bednarek and Hart, 2005).

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