Draft Research Proposal to the Washington State Joint Legislative Task Force on Water Supply

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Submitted By
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On behalf of the Joint Legislative Task Force on Water Supply Research Scoping Work Group

Background

In 2020, the Joint Legislative Task Force on Water Supply (Task Force) enlisted the State of Washington Water Research Center (WRC) to develop a synthesis of existing knowledge about water supply and demand in the Skagit Basin, and the Washington State Academy of Sciences to review a study of the Skagit Estuary entitled the "Final Technical Report: Lower Skagit Instream Flow Studies" produced by Duke Engineering & Services (1999; Duke Estuary Study), and to review the WRC Skagit Water Supply and Demand synthesis (Supply and Demand Synthesis). The final products of this process included a WSAS Estuary Study Review, and a WRC Supply and Demand Synthesis.

The Supply and Demand Synthesis includes a Knowledge Gaps component (available under the Knowledge Gaps Tab of the Synthesis) intended to identify knowledge gaps in relation to water supply and demand in the Skagit, and propose brief approaches to filling these gaps. The WSAS Estuary Study Review includes recommendations for further study (Section II in the Estuary Study Review).

After submission of these products in 2021, the Task Force requested the development of a proposal that includes proposed scopes of work for research, using the Knowledge Gaps in the Synthesis and recommendations for further research provided by WSAS in the Estuary Study Review (Task Force charge). To accomplish this task, the WRC coordinated a Work Group that includes several Task Force members who volunteered their time and expertise, a subset of the WRC research team who contributed to the Supply and Demand Synthesis, as well as the Executive Director and staff support of WSAS and the Chair of the WSAS review committee. This Work Group participated in a process that ultimately led to the draft proposal for research projects submitted herein.

This draft proposal focuses on two "Top Tier" projects which garnered the strongest support among Work Group members and for which project leads were identified to lead both proposal and project development were the projects to be funded. Importantly, while the two projects focused on here were chosen by the combination of interest and available research capacity, there are several other “Second-Tier” and “Third-Tier” projects that could be revisited and possibly pursued depending on the interests of the Task Force co-Chairs and the Task Force at large.

The remainder of this document summarizes the process of the Work Group, the two top–tier proposals, a summary of second- and third-tier proposals for possible further review. A summary of draft proposed budgets is provided for discussion. Finally, an appendix with further information about the Work Group participants and supporting information is provided.

Work Group Process

The Work Group was formed via a request by the WRC for participation of Task Force Members, Researchers who contributed to the Water Supply and Demand Synthesis, WSAS, and the Department of Ecology, which is the administrative conduit through which all of the work discussed in this document is being pursued. The list of workgroup members is provided in Appendix A.1. The working group had two meetings and several additional online interactions via email as described in the following process steps below.

Step 1: Preferred proposal submission (9 Dec 2021)

Prior to the first workgroup meeting, the Work Group members were asked to choose and modify as appropriate any high priority research proposals from the supporting materials as charged by the Task Force. This solicitation resulted in 10 submissions, one of which included several individual proposals.

Each of these proposals are available here. Work Group members were asked to read all proposals prior to meeting 1.

Step 2: Meeting 1 (15 Dec 2021; agenda & supporting materials)

Meeting 1 entailed discussing a process proposed by WRC staff, and presentations of a subset of the proposals. During this pre-meeting period, some Work Group members suggested that some of the proposals were closely related enough to be grouped into one integrated proposal. After discussion, this resulted in one group of three initial proposals relating to the estuary being grouped for integration, and two proposals relating to groundwater and ground/surface water interactions being grouped for integration. These two groups of proposals were introduced by the proposers and discussed. Due to time constraints, the remaining proposals were held for presentation during the second meeting.

Also during this meeting, WSAS offered to take the lead in developing the Estuary-related proposal due to the fact that their review was a proximate impetus for the related proposals. Nathan Rossman of HDR agreed to take the lead on coordinating the development of the groundwater proposal. The leads of these two integrated proposals were tasked to begin immediately to further develop scope and budget estimates for these projects.

Between meeting 1 and 2, one of the proposals (Controlled Drainage and Ditch Storage, Lahue and Friebel) was withdrawn in favor of Estuary proposals), and all but one proposal submitted by Kiza Gates on Behalf of WDFW) were withdrawn in favor of an estuary proposal being integrated into the proposal being lead by WSAS.

Step 3: Meeting 2 (18 Feb 2022, agenda & supporting materials)

Meeting 2 began with an update from WSAS on the Estuary proposal development, a presentation of the integrated groundwater proposal, and the remaining proposals. Slides for these presentations are available here.

The total estimated budget for all of these proposals was well over the total funding available to the Task Force to distribute. Therefore a straw poll of Working Group members was proposed to help select from the remaining 5 proposals.

Step 4: Straw Poll and results

A straw poll ranking of the 5 remaining proposals was solicited after Meeting 2. Nine of the Work Group members provided their rankings. A summary of these rankings are provided here. In short, the estuary study and the groundwater study received the strongest support. “Updated Skagit River Habitat and Flow Assessment” received an intermediate level of support.

After the Straw Poll, a solicitation was sent to Work Group members asking if anyone was willing to take the lead in developing two of the remaining proposals: “Resolve uncertainties in the water rights data” and “Analysis of the tradeoffs in hydropower flow regulation”. No interest was forthcoming, so these two proposals were withdrawn. More recently, the proposal entitled “Updated Skagit River Habitat and Flow Assessment” was also withdrawn due to the withdrawal of interest in carrying out the study. More context about the current status and prospects for these proposals is provided in the proposal tier breakdown below.

Proposals

Based on the process discussed above, three tiers of proposals have developed: Tier 1 is the most viable based on the development of a robust leadership and research team and most preferred by the Work Group based on the straw poll. These include (in order of budget size, with no implied ordering of consequence):

- Comprehensive Hydrologic Study of the Skagit Estuary
- Skagit River Basin Groundwater Study
- Skagit River Tributary Instream Flow Habitat Assessment

Tier 2 proposals were identified as of interest, but upon straw polling of the Work Group, received less interest. Further, While lead PI's could undoubtedly be found for these projects if they were to be pursued, no researchers initially offered to take the lead on the Tier 2 projects. Tier 3 projects are defined as all of the remaining project briefs developed as part of the Skagit Water Supply and Demand Synthesis Knowledge Gaps. They are available for review in that document, but are not discussed further in this document.

Tier 1

Comprehensive Hydrologic Study of the Skagit Estuary

WSAS's Committee on the Skagit River has prepared a scope of work for a proposed comprehensive hydrologic study of the Skagit estuary. The scope is designed to show the full range of research that will be needed to fill gaps in the current scientific understanding of the estuary. The scoping document lays out six framing elements, followed by five near-term and three longer-term proposals. It recognizes that conditions in the estuary vary markedly through the annual cycle, and from year to year, and that full understanding can only result from an extended, multi-year period of observation and modeling. Thus, the scope identifies and describes research investments that are applicable immediately, and those that will support research over multiple years. It also acknowledges that our current understanding will change over time as new information becomes available, and it is essential that what we know now continues to be informed by what we learn over time. The specific subproject proposals are:

FY 2023
Subproject 1: Data collection about topographical and seasonal inundation dynamics.
Subproject 2: Understanding temporal variation in aquatic habitat characteristics.
Subproject 3: A synthesis of habitat suitability index development of targeted fish species.
Subproject 4: Conducting hydrodynamic modeling.
Subproject 5: Developing life cycle models that integrate the estuary and the upstream basin.
FY 2024 and Beyond
Subproject 6: Long-term data collection to understand temporal variation in aquatic habitats.
Subproject 7: Expanding and continuing hydrodynamic modeling.
Subproject 8: Continuing integration of the estuary and the upstream basin.

In addition, the committee recommends the development of water supply scenarios due to climate change when better data are available from the research projects.
The six framing elements underpinning these subprojects are:
1. Topographical and seasonal inundation dynamics
2. Temporal variation in aquatic habitat characteristics
3. Synthesis of habitat suitability index development of targeted fish species
4. Hydrodynamic modeling
5. Integration of the estuary and the upstream basin

6. Measurement error, uncertainly, and error propagation

The full “Comprehensive Hydrologic Study of the Skagit Estuary” proposal is presented in Appendix A.2.1 of this document and downloadable here (pdf): Comprehensive Hydrologic Study of the Skagit Estuary - May 2022.pdf

Skagit River Basin Groundwater Study

The proposed study will be focused on the mainstem Skagit River and select tributaries between approximately Sedro-Woolley and Cape Horn (near Concrete), WA, and will produce a more complete understanding of groundwater resources and aquifers at multiple spatial and temporal scales, and the findings are particularly important in the face of climate change as temperatures increase and snow and ice resources dwindle.

This proposed study involves three project parts, including: 1) subsurface geology and aquifer characterization (hydrogeologic framework); 2) groundwater baseflow assessment via hydrograph separation; and 3) groundwater-surface water interactions via seepage run surveys and hydraulic gradients at paired gaging stations. The seepage run surveys will provide measurements of stream discharge and new transects and be analyzed to determine reach gains/losses attributable to groundwater exchanges.

The full “Skagit River Basin Groundwater Study” is presented in Appendix A.2.2 and downloadable here (pdf): Skagit Basin GW Study Proposal - May 2022.pdf

Skagit River Tributary Instream Flow Habitat Assessment

Salmonids in the Skagit River watershed use tributary streams to spawn and rear. Population growth and climate change will alter the amount and timing of streamflow and will impact salmonid spawning and rearing habitat in the Skagit River tributaries. This instream flow study will model the relationship between streamflow and salmonid habitat in Grandy Creek. We will compare the available fish habitat under natural flow conditions to projected fish habitat under a climate change scenario as well as two future growth scenarios.

The full “Skagit River Tributary Instream Flow Habitat Assessment” is presented in Appendix A.2.3 and downloadable here (pdf): Proposal Grandy Creek Instream Flow - May 2022.pdf

Tier 2: Submitted but withdrawn due to capacity constraints

Tier 2 proposals were submitted but withdrawn primarily due to a lack of capacity to lead and complete the proposals and/or the projects themselves. Of these, at least three are still viable and a research lead and team can be pursued more broadly at the request of the Task Force

Co-Chairs, conditional on a discussion of budget viability given other proposals in play. The titles of these two proposals are listed below with links to the brief summary proposals.

1. Water Claims Analysis with Remote Sensing - May 2022.pdf
2. Tradeoffs in flow regulation - May 2022.pdf

These proposals are also listed in Appendix A.3.1 and A.3.2 of this document.

Tier 3 Proposals

Tier Three proposals are all Knowledge Gaps and associated proposal briefs provided in the Water Supply and Demand Synthesis that were not selected or modified for carrying forward further.Several of these form the basis of the larger integrated proposals represented in Tier 2 and Tier 1. As with Tier 2 proposals, if the Co-Chairs request further discussion or consideration of any of these tier three proposals, the WRC will pursue them further, subject to some discussion of viability given the budget constraint and other competing proposals.

Budget Summary

Tier 1

Each proposal is accompanied by a budget estimate. Tier 1 bottom line budget estimates are as follows:

Comprehensive Hydrologic Study of the Skagit Estuary
For the 5 subprojects feasible in FY 2023, total direct costs are estimated to be $510,000. Including overhead at 26%, the total estimated cost is $642,600.

Skagit River Basin Groundwater Study
This proposal comprises three parts. Total direct costs are estimated at $406,738. Including 26% overhead the total estimated cost is $462,646.

Skagit River Tributary Instream Flow Habitat Assessment
The estimated direct costs of this project are $101,773. WSU will charge 13% overhead on this subaward, for a total of $115,003.

These estimates for Tier 1 projects as proposed sum to a total of $1,220,250.

Tier 2

Because the Tier 2 projects are less well-developed, their budget estimates are somewhat less precise, but are as follows:

Water Claims Analysis with Remote Sensing: $150,000 plus 26% overhead, for a total of $189,000.

Tradeoffs in Flow Regulation: $200,000 direct costs, $246,000 with 26% overhead.

Appendices

A.1. Work Group Members

Work Group Member	Standing/Affiliation
Jones Atterberry	Task Force Member
Jenna Friebel	Task Force Member
Kiza Gates/Timothy Quinn	Task Force Member / Substitute Rep.
Elizabeth Lovelett	Task Force Member
Thomas Mortimer	Task Force Member
Larry Wasserman	Task Force Member
Ria Berns	Task Force Member, ECY
Michael Goodchild	WSAS
Donna Riordan	WSAS
Amanda Koltz	WSAS
Correigh Greene	Research Team
Guillaume Mauger	Research Team
Nathan Rossman	Research Team
Julie Padowski	Research Team / WRC
Chad Wiseman	Research Team
Jonathan Yoder	Research Team / WRC

A.2. Tier 1 Proposals

A.2.1 Comprehensive Hydrologic Study of the Skagit Estuary

WASHINGTON STATE
Academy of Sciences
Science in the Service of Washington State

Proposed Scope for a Comprehensive Hydrologic Study of the Skagit Estuary

Prepared for the Joint Legislative Task Force on Water Supply

April 2022

ABOUT THE WASHINGTON STATE ACADEMY OF SCIENCES

The Washington State Academy of Sciences (WSAS) was requested by Governor Christine Gregoire and authorized by the Washington State Legislature in 2005. WSAS is a not-for-profit organization of Washington State's leading scientists and engineers dedicated to serving the state. Members are elected by their peers for outstanding contributions to research. Dr. Roger M. Myers is President.

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- Jenna Friebel, Executive Director, Skagit Drainage and Irrigation District Consortium.
- Kiza Gates, Water Team Lead, Science Division, Habitat Program, Washington Department of Fish & Wildlife
- Correigh Greene, Research Biologist, NOAA Fisheries, Northwest Fisheries Science Center
- Tom Mortimer, Attorney, Skagit PUD

TABLE OF CONTENTS

BACKGROUND

The estuary of the Skagit River is a complex system bounded on one side by Skagit Bay of the Salish Sea, and at its upstream end by the branching of the Skagit River immediately downstream of the city of Mount Vernon. It is fed by water that accumulates in the upper Skagit Valley, which extends into the Cascade Mountains and the Canadian Province of British Columbia and contains several impoundments. Water that reaches the estuary is especially critical during the low-flow season of late summer, and is also subject to flooding and inundation during the high-flow winter season. The flow of the river is critical to the life cycles of salmonid species, to agriculture in the fertile Skagit Valley, for recreation and domestic use, and for its esthetic value. All of these uses and concerns must compete, especially during the period of water scarcity in late summer. Thus, decisions about these competing concerns need to be based on the best possible scientific understanding of the processes at work in the estuary.

In 1999, Washington State commissioned Duke Engineering to conduct a study of the estuary with a view to understanding its hydrology and ecology ("the Duke Study")[1] as a scientific basis for management decisions about such topics as in-stream flow levels and water withdrawals. However, a 2021 peer review of that study by a committee of the Washington State Academy of Sciences ("the WSAS Review")[2] found many weaknesses in the data that were collected and the methods of analysis that were used, and identified ways in which a new study might take advantage of developments since the 1990s: new data sources, better sampling designs, cheaper sensors, better understanding of fish ecology, and new simulation models. Also in 2021, a parallel analysis was conducted by the State of Washington Water Resources Center that examined supply and demand factors in the entire Skagit Basin ("the WRC Supply and Demand Study").[3]

Following receipt of the WSAS Review, a meeting of the Joint Legislative Task Force for Water Supply in the Skagit ("the JLTF") was held on 4 October 2021 to discuss possible next steps. The following motion was moved by Senator Wagoner and approved:

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[1] Duke Engineering. 1999 Duke Estuary Study, section 3 of the "Final Technical Report: Lower Skagit River Instream Flow Studies."

[2] WSAS (Washington State Academy of Sciences) 2021. Independent Peer Review of the Estuary Portion of the 1999 Duke Engineering "Final Technical Report: Lower Skagit River Instream Flow Studies" Prepared for the Washington State Joint Legislative Task Force on Water Supply. January 2021.

[3] Jonathan Yoder, Siddharth Chaudhary, Brittany Duarte, Correigh Greene, Jordan Jobe, Gabe LaHue, Cindy Maroney, Guillaume Mauger, Harriet Morgan, Julie Padowski, Kirti Rajagopalan, Crystal Raymond, Matthew Rogers, Nathan Rossman, Navdeep Singh, Britta Timpane-Padgham, Chad Wiseman, Jason Won. 2021. Skagit Water Supply and Demand Synthesis. Story Map Series Prepared for the State of Washington Joint Legislative Task Force on Water Supply. https://doi.org/10.7273/4n11-9k73

I [Senator Wagoner] move that WRC and WSAS scope a single proposal on prioritizing and addressing knowledge gaps that were raised by the Skagit Water Supply and Demand Synthesis and the Duke Study peer review. In the scoping process, WRC and WSAS shall utilize an iterative process including interactions with the committee to assist in clearly articulating goals and assisting in the development of the scope.

The JLTF formed a Working Group of stakeholders ("the Working Group"), who were invited to develop outline proposals that might form part of that scope. A total of nine such "Outline Proposals" were submitted, three of which directly addressed the issues of the estuary. These were subsequently discussed by the WSAS committee (now the WSAS Science Committee on the Skagit River, in short "the Committee"), and iterated with the stakeholders. What follows here is the result of that iterative process, in the form of a proposed scope for a Comprehensive Hydrologic Study of the Skagit Estuary (CHSSE).

INTRODUCTION

What follows in this proposed scope is founded on the following principles. First, like the WSAS as a whole, the Committee "provides expert scientific and engineering assessments to inform public policy making" (WSAS Mission at https://washacad.org/aboutus). We recognize that many interests and perspectives inform policy decisions; our focus is entirely on the best available science to inform those decisions. Second, what follows is designed to show the full range of research that will be needed to fill gaps in the current scientific understanding of the estuary, as identified in the WSAS Review and the WRC Supply and Demand Study. Third, we recognize that conditions in the estuary vary markedly through the annual cycle, and from year to year, and that full understanding can only result from an extended, multi-year period of observation and modeling. Thus, we have attempted to identify and describe those research investments that are needed immediately, and those that will allow for and support research over multiple years.

Finally, we suggest that the potential impacts of changing climate on the Skagit watershed provide an overarching issue that will need to be considered as research is conducted. Those impacts range from the timing and amount of the snowpack at the headwaters, to sea-level rise in Skagit Bay, changing salinization in the estuary, and changes in summer water temperature in the river. The uncertainties (what we know and with what level of certainty, what we don't know, and what we need to know) that are inherent in all research will be amplified in a future where change is occurring more rapidly than before. Acknowledging upfront that our current understanding will also change over time as new information becomes available, it is essential that what we know now continues to be informed by what we learn over time.

The next six sections describe key framing elements of the proposed scope of research to understand more fully the Skagit estuary as a whole, rather than as a set of unconnected parts. While we recognize that current funding for research is limited and that not all of this research can be funded now, these framing elements represent a synthesis of ideas that surfaced in the Duke Review, the WRC Supply and

Demand Study, the three Outline Proposals dealing with the estuary, comments received from members of the Working Group, and the discussions of the Committee. The elements are followed by the Committee's outline of proposed research investments that, if worked on over several years, will create a more complete hydrologic picture of the estuary necessary to provide insights needed to guide its management.

I. PROPOSED FRAMING ELEMENTS OF THE CHSSE

The Committee recommends that six elements should together frame the CHSSE. These six elements all recognize weaknesses that were identified in the Duke Review and will need to be addressed if the CHSSE is to be successful in filling scientific knowledge gaps today and in the coming years. Following the identification of these elements, specific proposals are presented for near-term and longer-term research.

1. Topographical and seasonal inundation dynamics

The focus of the CHSSE should be on the Skagit tidal delta, that is, the portion of the lower river that is historically subject to tidal variation in elevation and salinity. At its most extensive, this area might be seen as including: 1) the lower river below the USGS gage in Mt. Vernon, 2) wetlands and channels along and between the North and South Forks of the delta (from the Swinomish channel to wetlands north of Stanwood), 3) wetlands and channels along the Swinomish Channel, and 4) wetlands and mudflats in Skagit Bay and Padilla Bay between mean higher high water and mean lower low water. Forcing factors at extents greater than these areas (e.g., tides, upriver flows) could factor into the topographical and seasonal inundation dynamics element, but these dynamics will not be directly analyzed from the perspective of the combined effects of tidal processes and river flow on fish and their habitat in this framing element.

2. Temporal variation in aquatic habitat characteristics

A variety of fish species use the Skagit delta at different time periods based on their life histories. Flow conditions and water use needs also have seasonal patterns. The temporal variation within the delta requires that research projects evaluate flow conditions suitable for habitat forming processes and fish habitat use over an entire water year. Recognizing that annual variability exists in flow conditions, multiple water years that represent an adequate range in natural conditions should be evaluated. This element addresses the critical need to establish a baseline condition that captures the range of variability be established as a basis for comparison for management and climate change scenarios.

3. Synthesis of habitat suitability index development of targeted fish species

A synthesis of existing fish knowledge would identify the needs of fish that can be incorporated into the data acquisition program and into subsequent analysis and modeling. Substantial advances have been made in species-specific knowledge of fish life history diversity with respect to the use of lower-river/estuary ecotone and estuary habitats in the past two decades. While the Duke report focused on juvenile Chinook salmon, other species/life stages use the estuary. These include nonlisted salmon species with juvenile life stages that use deltas (coho and chum), listed species whose juvenile life stages migrate through the delta (steelhead & bull trout), and adult stages of some of these species that migrate through the delta during low flow periods (e.g., Chinook). This element would encompass efforts to provide a broader, updated synthesis of this knowledge.

4. Hydrodynamic Modeling

Several efforts have been made in the past two decades to model the hydrology of the estuary using software tools such as the Skagit Hydrodynamic Modeling project, or SHDM. Models will need to be updated to accommodate changes in the geometry of the estuary channels and recent advances in our understanding of the interactions between hydrology and fish. The three-dimensional finite elements used in models should be adequate to address the critical periods of low flow and inundation, and the influence of tides. While a comprehensive review of all past modeling efforts may not be possible or necessary due to time and resource constraints, a compendium of them would be useful to inform ongoing research.

5. Integration of the estuary and the upstream basin

While it may be appropriate to consider the estuary in isolation when addressing several key issues, nevertheless there are scientifically important ways in which the tides and upriver flows influence and are influenced by the estuary. Water temperature in the estuary, a key issue for fish habitat during late-summer low flow, is influenced by tides and by upstream factors such as shade, groundwater seepage into streams, and glacier melt. Some fish species need upstream habitat to complete their life cycle. Over time, the CHSSE will need to address these issues, and to find ways to fill gaps in our knowledge. For example, the DHSVM-RBM model may be valuable in modeling unregulated downstream flow and water temperature, and it may be possible to revisit the Duke study and its analysis of upstream fish habitat in the light of new developments in species-specific habitat needs for diverse life history expression. If necessary, these unregulated flows and temperatures can be used as input to a model of the reservoir system to examine regulated flows. This element encompasses work to address how these two systems, the estuary and the upstream basin, impact each other.

6. Measurement error, uncertainty, and error propagation

Every element of the CHSSE will be subject to uncertainty, from the measurement of the geometry of the estuary's channels through to the estimates and predictions from the various models and analyses. It is important that best efforts be made to estimate these uncertainties, and to propagate them through to each study's conclusions using techniques such as simulation. This element is meant to ensure that these uncertainties are recognized and addressed appropriately in each specific research proposal.

Water Supply Scenarios Due to Climate Change to be Examined when better data are available from the research projects described above

Many aspects of the estuary environment are already changing and are expected to continue to change in the coming decades due to changes in hydrology, glaciers, water temperature and/or sea level rise due to projected warmer climate, changing management practices, and sedimentation and channel erosion.

These and other causes of change, including low probability but high impact catastrophic events such as tsunamis and earthquakes, will influence the estuary and its habitat availability across the estuary. They should be enumerated and examined as different water supply scenarios in the CHSSE.

For illustrative purposes, some key scenarios could include

- A number of climate emissions scenarios
- Downscaling of global climate models to regional analyses
- Projections for changes out to several future dates, e.g., 2040 and 2080
- Simulations of a variety of water years
- Simulations of various land use scenarios

In particular, the hydrodynamic modeling system described below would provide a valuable tool to better understand the extent and timing of climate-induced changes and the impact on water supply as well as in-channel and estuary habitat. Given the uncertainly in climate predictions, the use of an ensemble-based approach is suggested.

II. OUTLINE OF PROPOSED RESEARCH INVESTMENTS

This section describes proposed research investments aligned with the six framing elements outlined above. With the available funding, not all projects can be funded or completed in FY 2023 (by June 2023). The Committee recommends a focus on the following near-term investments with current funding. This focus will add to and update the current understanding of the estuary while simultaneously paving the way for longer-term and multi-year research projects within the estuary, consideration of findings from upriver research, and ongoing (or forthcoming) insights about changes in the Skagit watershed that will likely occur due to a changing climate.

The total cost estimate of the set of near-term projects to be conducted in FY 2023 (Projects 1 – 5 below) is $510,000, with the caveat that specific project costs are best determined by the research teams that will conduct the work. Approximations of cost are included in Table 1. Three additional projects are recommended as longer-term projects that build on the findings of the near-term work.

Table 1: List of proposed near- and long-term research projects of the CHSSE

FY 2023		
Project 1	Data collection about topographical and seasonal inundation dynamics	$75,000
Project 2	Improve understanding temporal variation in aquatic habitat characteristics	$50,000
Project 3	Conduct a synthesis of habitat suitability index development of targeted fish species	$100,000
Project 4	Conduct Hydrodynamic modeling	$210,000
Project 5	Develop life cycle models that integrate the estuary and the upstream basin	$75,000
Total		**$510,000**
FY 2024 and Beyond		
Project 6	Long-term data collection to understand temporal variation in aquatic habitat characteristics	TBD
Project 7	Expand and continue hydrodynamic modeling	TBD
Project 8	Continue integration of the estuary and the upstream basin	TBD

Near Term Projects – FY 2023

Project 1: Data collection about topographical and seasonal inundation dynamics

The committee considers it important to initiate data collection as early as possible, rather than waiting until hydrodynamic modeling begins. A first step will be to compile existing data that has been collected by various programs since the era of the Duke Study (1999), such as the Skagit HDM[4]. These data could be reviewed, updated, and incorporated as updates to existing reports and analyses where appropriate, with gaps identified where new date need to be collected.

In particular, because of the high cost and other limitations of sensors and measuring devices at the time, the Duke Study was able to build only a limited observational picture of the estuary. The CHSSE will be able to take advantage of the very rapid development of new technologies over the past two decades to build a much more complete picture. Specifically, the following could be investigated and if feasible employed:

- airborne and satellite-borne LiDAR to map elevations at fine resolution across the estuary (since LiDAR does not penetrate water, data might be collected at the lowest possible tide levels to best capture tidal channel and tidal flat topography);
- ground-based sensors that can be used to acquire point observations of water depth, flow rates, water temperature, and salinity; and
- fine-resolution multispectral imagery acquired from satellites, aircraft, and drones.

This work can be conducted by a team of academic and/or private consultants with the charge of 1) compiling and organizing existing topographical and seasonal inundation data, 2) updating existing reports and analyses with more recent data; and 3) gathering new data, e.g., LiDAR and ground-based sensor data, and fine-resolution multi-spectral imagery. The proposed product would be an up-to-date compendium of estuary specific physical data that would contribute to future modeling efforts.

Project 2. Improve understanding temporal variation in aquatic habitat characteristics

As noted above, the temporal variation within the delta requires that research projects evaluate flow conditions suitable for habitat forming processes and fish habitat use over an entire water year. Recognizing that annual variability exists in flow conditions, multiple water years that represent an adequate range in natural conditions should be evaluated.

The committee recommends a research project to define a baseline condition that captures the range of variability of flows be established as a basis for comparison for management and climate change scenarios over time.

A physics-based hydrodynamic model could be validated for a range of flows to ensure that the model accurately characterizes the complex relationships between river/fluvial processes and tidal processes. Some of this work has already been completed by PNNL as part of the refinement of the Skagit HDM[5], but among the issues to be examined in more detail is whether the model would simulate channel/bed-

[4] Skagit HDM, September 2017. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26867.pdf

[5] Ibid.

forming processes (such as erosion and sediment transport) or assume the bed is fixed in time, which while computationally easier to accomplish, may not be as useful for understanding variation.

In addition, water surface elevation data should be acquired at multiple locations within the study area in the estuary to ensure a high degree of validation. Once the physical model is validated, it can be used to evaluate a range of water years with known tidal and river flow information from existing data and weather stations. The model can be used for an analysis of scenarios at a variety of temporal scales ranging over the full water year, to the full chinook smolt outmigration period, and to shorter time periods of extreme high or low flow events. The model could also be used to evaluate a variety of scenarios including management and climate change scenarios.

This work can be conducted by a team of researchers familiar with the data and methodologies of the current models (e.g., the Skagit HDM). The proposed product would be an up-to-date understanding of flow conditions over several years that identify areas suitable for habitat forming processes and fish habitat use over an entire water year.

Project 3. Conduct a synthesis of habitat suitability index development of targeted fish species.

An extensive review of fish knowledge in the Skagit should be conducted and include available published literature and other ongoing (and therefore incomplete) research efforts within the basin to avoid duplication. These studies will likely have different conditions compared to published studies in other systems. It also will be useful to summarize and leverage other data from the estuary, to understand how the variety of fish utilize the estuary (including their presence and density related to seasonal stream flows), and to develop a method to establish habitat suitability indices (HSIs) of targeted fish species.

Each of the projects are described briefly below could provide critical information in the near term:

3A. Utilize the Skagit River System Cooperative's (SRSC) fish monitoring dataset (1995-present) to examine responses of multiple fish species to flow and associated habitat conditions.

SRSC has focused on juvenile chinook salmon, and a current goal of SRSC is to use these data to develop models addressing fish-habitat relationships in the delta.

3B. Conduct a multivariate analysis of water metrics to determine the attributes tied tovarious flow conditions.

River flow is often considered a master variable for determining habitat conditions in rivers, with extreme flows as one parameter affecting fish measured in Skagit streams. In addition to stream flow, water quality measurements such as temperature and invertebrates are measured in lowland tributaries. This project would conduct a multivariate data analysis of habitat attributes (e.g., velocity, temperature, invertebrates, and estuary/lower main channel salinity) integrating landscape drivers (e.g., land use, shade, water availability). Data would be collected from fish habitat, with evaluation of multiple dimensions of habitat characteristics and potential impacts (andtheir spatial variation). Integrating these metrics could help determine best management practices, such as flow management versus other management interventions (e.g., improved shade).

3C. Develop species, life-stage specific, and seasonal HSIs for fish species occupying the estuary.

Using available methodologies[6], developing estuary specific HSIs would improve understanding of how changes in water level, flow, and substrate affect species and life stage specific habitat use. Skagit River specific HSIs for the estuary could be calculated to establish a baseline condition of the habitat needs of fish. These HSIs could then be calculated for the study area under a variety of management and climate scenarios to determine if there are any significant positive or negative changes.

3D. Conduct a hydrodynamic evaluation of the influence of freshwater flows upon estuarine habitat forming processes and habitat use by salmon, addressing current and future climate scenarios for the Skagit delta and associated Skagit Bay nearshore.

River flow can affect many habitat features in estuaries, the extent of wetland marshes, and migratory connectivity for salmon populations. Many research-based improvements such as hydrodynamic models of tidal inundation and river flow, incorporation of climate impacts, use of lidar and other remotely sensed information, and improved understanding of the fish habitat use have been developed for the Skagit Basin, but have not yet been used to update conclusions about contributions of river flow to tidal delta habitats used by fish.

This project would construct an integrated model of fish habitat opportunity in the delta and nearshore as functions of existing and potential future delta footprint, tidal inundation, temperature, and most importantly, the Skagit River hydrograph. It also would integrate existing datasets and model products, such as:

- The Salish Sea Model (Khangaonkar et al. 2018, 2021) and Skagit Delta Hydrodynamic Model (Yang and Khangaonkar 2006, 2009), which examine circulation, tidal inundation, river flow, and other water properties in the delta and nearshore.
- Analyses linking salinity variation, vegetation change, and sediment accretion,
- Modeled climate impacts including downscaled air temperature and Skagit river flow (see Skagit Story Map), and tidal delta impacts of sea level rise and changes in circulation (Northwest Science, 2016, Volume 90 (1)).
- lidar-based maps of tidal elevation and channel structure (Beechie et al. 2018)
- 20+ years of fish monitoring data (Greene et al. 2021) coupled with physical observations, enabling evaluation of site-specific fish-habitat relationships.

[6] https://www.google.com/books/edition/Development_and_Evaluation_of_Habitat_Su/88pBfPKB-cAC?hl=en&gbpv=0

Over time, this project will help improve the understanding of:

- Fish habitat: The integrated model will evaluate what levels of seasonal flow optimize residency of salmonids across the tidal delta and nearshore for the full rearing season, taking into account changes to the delta wetland footprint.
- Future climate: Climate impacts impose both seasonal constraints (e.g., increased temperatures) as well as potential opportunities (increased inundation from sea level rise) for fishes in the tidal delta, so incorporating scenarios of these cumulative effects isnecessary to address the influence of seasonal flow.
- Surface water: The new study will better quantify how much water is needed to support fish habitat in the delta and nearshore, in turn providing new and improved information on the potential for water use by people.

Project 4. Conduct hydrodynamic modeling

Data to be used in modeling should be acquired from the estuary over an extended period of time—at least five years—in order to gain knowledge of annual variations, especially during the critical periods of late-summer low flow and winter inundation. If the period of active research in the CHSSE is limited by practical issues such as budget resources, plans should be made in the near term to identify available data and then to identify key data needed to collect to fill gaps, as well as to sustain the acquisition of critical data beyond this period of active research. To accomplish that goal, we recommend the following projects.

4A. Create a working group of researchers to identify models and data domains.

A short-term planning effort could be organized to bring together researchers to identify data that can be gathered now, as well as their sources and limitations, that ultimately can be used in future modeling, as suggested in Table 1. Similarly, a working group could also identify which models to prioritize, exclude or add in order to address questions of interest, as suggested in Tables 2 and 3, and thus bring to light the strengths and limitations of various models.

Table 2: Examples of data inputs for hydrodynamic model

Data element	**Existing data**	**Data source**	**Limitations**
Wetland surface elevations	Lidar (years)	USGS NOAA lidar consortium	Higher uncertainty in wetted channels, highly vegetated areas
Delta water surface elevations	Water level gages (2010-2020)	Skagit River System Cooperative	Spatial coverage limited to fish sampling sites in NF, SF, bayfront.

Delta temperatures and salinities	Water level gages (2010-2020)	Skagit River System Cooperative	Spatial coverage limited to fish sampling sites in NF, SF, bayfront.
Other	TBD	TBD	TBD

Table 3: Preliminary examples of models to be examined to address questions of interest

Model domain	**Key SOW requirements**	**Key outputs**	**Possible model**	**Key model assumptions**
Delta hydrodynamics	Model entire delta subject to inundation	Water surface elevations Area inundated Velocity Water depth Duration of inundation Duration of specific water depth ranges Shear stress Temperature	Salish Sea Model/Skagit River HDM	Model solutions are exact (no error)
Freshwater flows	Physics-based flow inputs below Mt. Vernon gage	Spatiotemporal snowpack, snowmelt, streamflow, and water temperature	Skagit DHSVM-RBM	Model extent currently stops at Mt. Vernon Models natural flows (i.e. no reservoir operation)
Freshwater flows after reservoir operations	Reservoir operations	Regulated streamflow at key locations (i.e dam operation is included)	SkagitSim Reservoir Operations Model	
Other	TBD	TBD	TBD	TBD

4B. Perform additional modeling to simulate future water temperatures to determine the flow levels needed to maintain water temperatures at levels that are consistent with salmon recovery goals.

A key factor affecting fish – in particular the flow levels needed to maintain healthy habitat conditions for salmon – is water temperatures. Warmer air in the future could lead to in hospitable water temperatures even if instream flow targets are met.

For surface water, water temperature will likely be a dominant constraint on low flows, given the implications for salmon viability. For groundwater, baseflow rates, and the proportion of streamflow composed of baseflow from groundwater, could play a significant role in moderating temperatures. More data and modeling could also provide information related to water quality for municipal and agricultural uses.

Future water temperatures can be estimated with the River Basin Model (RBM), which was designed to work with DHSVM flows and provides physically-based water temperature estimates. The model can also be used to simulate the relationship between flow levels and water temperatures at specific times in the future. Modeling results could be confirmed, in part with eDNA monitoring for upstream fish presence.

Project 5. Develop life cycle models that integrate the estuary and the upstream basin

This project would develop life cycle models that incorporate spatial variation to account for movements of fish within the watershed. Because fish are capable of moving and migrating, understanding the quantitative impacts of flow management to fish populations requires a spatially informed model.

Many fishes are highly mobile and move both upstream and downstream to find high quality habitat (e.g., food, refuge, optimal temperatures, or dissolved oxygen). This is especially true for Pacific salmon, which must eventually migrate to the ocean at some point in their life cycle. Movements within a watershed complicate assessment of the effects of flow-related impacts to habitats in portions of the watershed upon the entire population because patchy high-quality habitats may "buffer" impacts of poor-quality habitats, even as they reduce the total amount of habitat in the basin. In addition, evaluating flow-related impacts should account for multiple limiting factors or cumulative impacts to habitat at different life stages.

Because they incorporate multiple life stages, all life cycle models address multiple possible limiting factors. Many life cycle models have been developed to account for spatial variation and some can accommodate for movements of individuals within basins, and these can readily be adapted for the Skagit River basin.

Long Term Projects -- FY 2024 and beyond

All of the following research projects would also contribute to a deeper understanding of the Skagit estuary, and build on the work completed in the first set of projects described above. They would be conducted beyond the next fiscal year, so no cost estimates are included at this time.

Project 6. Long-term data collection to understand temporal variation in aquatic habitat characteristics

A commitment to data collection over an extended period of time—at least five years—will be needed in order to gain knowledge of annual variations in other parameters such as sediment, salinity and temperature. The complex relationship between these parameters and flow is less understood in the estuary and would be much more difficult to model on a shorter time scale.

As first priority, the CHSSE should be closely aligned with Duke 1999's and IFIM methods in the use of water surface elevation and duration of inundation as a first step toward understanding the relationship between flow/tide and habitat as defined through habitat suitability indices (HSIs). If there is a finding that water withdrawal or climate scenarios could significantly affect water surface elevations, the WSAS could re-engage in scoping of future work to better understand how the changes in flow due to the evaluated scenarios may or may not affect sediment processes, temperature, salinity, or invertebrates.

In addition, other issues to research over the next several years include:

<u>Sediment processes:</u> Evidence suggests that sediment processes are somewhat episodic. Sediment transport also has thresholds for initiation of movement and transport related to flow rate/depth and sediment characteristics. Sediment transport processes (suspended load and scour/bedload) tend to occur at higher freshwater flows rates, rather than the lower flow rates (below 10,000 cfs) where the greatest stresses may currently exist, but more research is needed.

<u>Water temperature:</u> Water temperature may be impacted by a variety of water supply scenarios. A conservation of mass analysis could be conducted to refine the importance of water withdrawals on temperature.. It is important to be able to differentiate potential changes in water temperature due to natural conditions, water withdrawals scenarios, and other issues like shade in riparian zones. Under existing conditions most of the estuary does not have shade, including extensive mudflats, marshes and tidal channels.

Project 7. Expand and continue hydrodynamic modeling

Glaciers in the upper Skagit basin contribute substantial water to streamflow in late summer, the time of lowest flows and greatest likelihood of scarcity. These glaciers are sensitive to climate change and changes in glacier melt water will affect surface water availability in the basin in the future.

The DHSVM hydrologic model used to simulate streamflow includes aglacier model that simulates melting glaciers and the contributions of glacier melt water to streamflow. However, the glacier model has not been thoroughly validated to ensure it adequately represents glaciers, glacier melt water, and the response of glaciers to warming. Additional model refinement could improve on the glacier simulations, thereby ensuring thatfuture streamflow estimates accurately reflect changes in glacier contributions to flows. This refinement would hopefully help to reduce the bias in the streamflow, particularly for summerlow flow times when water scarcity is of greatest concern, and would improve also flow simulations for the tributaries. In addition, model refinement would enable better understanding of effects of glaciers on summer flows and will improve understanding of low flow and summer temperature constraints on cold-water fishes.

Project 8. Continue integration of the estuary and the upstream basin

Conduct a habitat and flow assessment that includes habitat beyond the lower reaches of the Skagit River basin that could provide more current understanding of the system and food web.

The Skagit River is a dynamic hydrologic system, and habitat has likely changed at the sites examined in the Duke report in 1999. While it may be appropriate to consider the estuary in isolation when addressing several key issues, nevertheless there are scientifically important ways in which the tides and upriver flows influence and are influenced by the estuary. Over time, the CHSSE will need to address these issues, and to find ways to fill gaps in our knowledge and improve our understanding of flow-based constraints on fish populations.

For example, water temperature in the estuary, a key issue for fish habitat during late-summer low flow, is influenced by tides and by upstream factors such as shade, groundwater seepage into streams, and glacier melt. Some fish species need upstream habitat to complete their life cycle.

In addition, the DHSVM-RBM model may be valuable in modeling unregulated downstream flow and water temperature, and it may be possible to revisit the Duke study and its analysis of upstream fish habitat in the light of new developments in species-specific habitat needs for diverse life history expression. If necessary, data about these unregulated flows and temperatures can be used as inputs to a model of the reservoir system to examine regulated flows.

An update of understanding of the watershed would provide current data, as recent analyses assume depths and velocity profiles have remained similar. Conditions likely vary across the watershed, so a better understanding of how flow conditions influence spawning and rearing habitat will depend upon better studies of fish, their habitats, and patterns of flow that incorporate spatial variation. Such a study could be done by applying the IFIM modeling approach used by Duke Engineering (1999) to other reaches with different cross-sectional areas and associated substrate types with updated HSIs for updated portions of the watershed. This modeling should be done for both reference reaches (little impacts to the hydrograph, riparian conditions, and aquatic substrates) as well as places associated with various impacts to flow, temperature, and riparian conditions.

This study could fill a critical gap in knowledge about surface water if it expands the IFIM analysis to tributaries that are critical for fish habitat, rather than only the mainstem. With information about flow levels that are optimum for fish habitat, the DHSVM surface flow modeling and projections could be used to understand the frequency with which these flows are met now and how that would change with climate change. While current DHSVM modeling includes all the tributaries, it is difficult to use this information when it is not known what the optimum flows are for fish in the same locations.

Finally, and as noted above, we recognize that many interests and perspectives inform policy decisions. Our focus in preparing this scope for a Comprehensive Hydrologic Study of the Skagit Estuary has been on research that can provide the best available science to inform future decisions. We consider the projects described here as representing the range of research that will be needed to fill gaps in the current scientific understanding of the estuary, as identified in the WSAS Review and the WRC Supply and Demand Study. We recognize that conditions in the estuary vary markedly through the annual cycle, and from year to year, and that full understanding can only result from an extended, multi-year period of observation and modeling. Thus, we have attempted to identify and describe those research investments that are needed immediately, and those that will allow for and support research over multiple years.

APPENDIX A: COMMITTEE ROSTER

For questions related to this project, contact:
Donna Gerardi Riordan, Executive Director – donna.riordan@washacad.org

WSAS Committee on the Skagit Water Supply

Michael Goodchild (Chair) – good@geog.ucsb.edu

Dr. Michael Goodchild is an Emeritus Professor of Geography at the University of California, Santa Barbara. Until his retirement, Dr. Goodchild was Jack and Laura Dangermond Professor of Geography, and Director of UCSB's Center for Spatial Studies. His research interests center on geographic information science, spatial analysis, and uncertainty in geographic data. Dr. Goodchild was elected member of the National Academy of Sciences and Foreign Member of the Royal Society of Canada, member of the American Academy of Arts and Sciences, and Foreign Member of the Royal Society and Corresponding Fellow of the British Academy. He was Chair of the National Research Council's Mapping Science Committee, and of the Advisory Committee on Social, Behavioral, and Economic Sciences of the National Science Foundation. Dr. Goodchild has a PhD in geography from McMaster University, and has received five honorary doctorates.

Rebecca Flitcroft – rebecca.flitcroft@usda.gov

Dr. Rebecca Flitcroft is a Research Fish Biologist and Team Leader in Landscape and Ecosystem Management at the US Forest Service. Her research on watershed analysis and management is focused on statistical and physical representations of stream networks in analysis and monitoring that more realistically represent stream complexity and connectivity for aquatic species along four primary lines of research: multiscale salmonid ecology; stream network analysis; climate change and salmonid life history; and integrated watershed management. Dr. Flitcroft conducts studies to expand the existing knowledge base about the interaction between complex life-history phenology of Pacific salmonids and their environment, particularly in the context of climate change as it relates to available habitats in coastal draining systems. Dr. Flitcroft is involved with local, regional, and state-wide efforts in Oregon to develop coordinated management techniques focused on watersheds. Dr. Flitcroft holds a PhD in Fisheries Science from Oregon State University.

Eric Grossman – egrossman@usgs.gov

Dr. Eric Grossman is a Research Geologist at the Pacific Coastal and Marine Science Center of the United States Geological Survey and a Research Associate at Western Washington University. His expertise includes coastal geology and marine geophysics, coastal ecosystems and restoration, estuaries, hydrodynamics, local and indigenous knowledge, and fluvial and littoral sediment transport. Dr. Grossman is a founding member of the Skagit Climate Science Consortium. He has received the USGS Western States Diversity Award, Washington State

Governor's Smart Communities Award, Coastal America Award, USGS Western Region Science Strategy Success Award, and Department of Interior Partners in Cooperation Award. Dr. Grossman has a PhD in marine geology and geophysics from the University of Hawaii.

Se-Yeun Lee – lees@seattleu.edu

Dr. Se-Yeun Lee is an Instructor in Civil and Environmental Engineering at Seattle University, and was previously a Research Scientist with the Climate Impacts Group at the University of Washington. Dr. Lee has been involved in interdisciplinary research focusing on understanding and modeling the complex interactions between climate, hydrology and natural resource management, and particularly climate change impacts on hydrology in the Skagit Basin. She has authored peer-reviewed research papers, book chapters, and reports, and has worked with and advised managers and decision-makers. Dr. Lee has a PhD in civil and environmental engineering from the University of Washington.

Mark Wigmosta – mark.wigmosta@pnnl.gov

Dr. Mark Wigmosta is a Chief Scientist and Technical Lead for the Computational Watershed Hydrology Team at the Pacific Northwest National Laboratory. Mark is also a Distinguished Faculty Fellow in the University of Washington Department of Civil & Environmental Engineering. He has over 30 years of experience in distributed watershed hydrology, including the potential impacts of land-use and climate change on water resources and renewable energy. Dr. Wigmosta was the principal developer of the Distributed Hydrology-Soil-Vegetation Model (DHSVM), which has been widely used in forest management applications. Mark has authored more than 55 peer-reviewed research papers and book chapters, and his research on renewable energy received an American Geophysical Union Editor’s Choice Award. Dr. Wigmosta has a PhD in environmental engineering and science from the University of Washington.

A.2.2 Skagit River Basin Groundwater Study

Proposed Scope of Work

Skagit River Basin Groundwater Study

Submitted to the Washington State Joint Legislative Task Force on Water Supply

April 28, 2022

Western Washington University
Skagit Quaternary Consulting
HDR

Background

The State of Washington Joint Legislative Task Force on Water Supply identified development of information on groundwater (GW) as a major gap limiting management of water resources in the Skagit River basin (Basin). Subsequently, the Washington State Water Research Center (WRC) conducted a synthesis study covering water resources availability and use in the Basin and developed specific knowledge gaps associated with various disciplines, including groundwater (Yoder et al. 2021). This proposal was developed with the goal of partially filling knowledge gaps identified as a result of that synthesis study.

Western Washington University and HDR Engineering, Inc. (HDR)[1] propose a three-part study seeking to unravel some of the complexity of GW resources with a focus on the lower Skagit River valley, between Sedro-Woolley and Cape Horn, in Skagit County. The proposed study is designed to characterize subsurface hydrogeologic units and GW resources, including investigation of groundwater/surface water (GW-SW) interactions. The reach between Sedro-Woolley and Cape Horn likely has significant GW resources and faces development pressure. This proposed study will also evaluate basin-wide GW baseflow (GW discharge flowing to streams) throughout the Basin.

The motivation for this proposal is to help water resource managers and decision makers better understand GW-SW interactions and degree of connections between GW and surface water in an area with complex, unevenly distributed, GW resources. Much of the west end of Skagit County is underlain by dense glaciomarine till and lodgment till

[1] Western Washington University will lead Project Part 1; primary lead and contact: Bob Mitchell, Professor, Geology Department; rjmitch@wwu.edu, cse.wwu.edu/geology/rjmitch. HDR will lead Project Parts 2 and 3; primary lead and contact: Nathan Rossman, Hydrogeologist; nathan.rossman@hdrinc.com, HDR (hdrinc.com).

(a.k.a. hardpan; Pessel et al. 1989; Dragovich et al. 1999), which do not hold significant GW resources (Savoca et al. 2009). Glacial outwash terraces known to contain abundant GW (aquifers) are common in the Skagit River valley between Sedro-Woolley and Cape Horn, but the largest accumulations of sand and gravel are located on the north side of the Valley (Riedel 2017). Despite this variability only, a few GW studies have been undertaken in Skagit County upstream of Sedro-Woolley. A study by the U.S. Geological Survey (USGS) (Hidaka 1973) identified Day Creek and Alder Creek as having significant GW input from large glacial outwash terrace aquifers during low-flow periods in late summer. We suspect that other tributary streams are also fed by these aquifers, including Muddy Creek, Red Cabin Creek, Jones Creek, and Grandy Creek.

Overall, the study will produce a more complete understanding of GW resources and aquifers at multiple spatial and temporal scales, and the findings from this proposed study are particularly important in the face of climate change as temperatures increase and snow and ice resources dwindle (Riedel and Larrabee 2016). The information gleaned from this study would fill an important information gap in our understanding of the water resources in Skagit County and the Skagit River basin as a whole. Specifically, we anticipate several useful outcomes from this study for water resource managers, decision makers, and citizens:

- This study will help reveal how, and to what magnitude, GW helps the streams listed above maintain flows and therefore their ability to offer thermal refuge for aquatic species, such as endangered and threatened salmon and trout, during summer drought.

- Groundwater baseflow to streams will be compared against recent assessments of spatially-explicit long-term average GW recharge rates to provide a check between two distinctly different methods characterizing different but related components of the water budget of the GW system. This provides improved understanding of important water budget components overall in the Basin.

- Water managers may wish to consider managed GW recharge or injection to replenish aquifers during the rainy season, within the large mostly undeveloped glacial terraces north of Hamilton, with the intent of increasing streamflow returns through the GW system in tributaries during low-flow periods or droughts. This would be a form of developing a specific climate change adaptation strategy. In addition, deeper aquifers may be able to provide a source for “emergency” GW withdrawals to directly sustain minimum instream flows. Findings from this proposed study will provide the necessary information to conduct additional (separate) specific detailed studies for such purposes.

- Results would provide useful information for improving the GW component of existing or new surface hydrology models that are used to project future changes in water resources and streamflow due to climate change, as well as during both low-flow and flooding events (in the focus study area and elsewhere in the Basin). The study results will also provide a starting point (i.e. conceptual model stage) for future GW studies aimed at developing numerical modeling tools (i.e. GW flow models), such as those developed for the lower Skagit River basin and its tributaries below Sedro-Woolley by the USGS (Johnson and Savoca 2010), thereby adding baseline information helpful to possible future studies addressing how GW uses or management strategies may be expected to influence stream baseflow.

- The information from the proposed project would help municipal and residential well owners better understand how the use of GW is related to streamflow (and streamflow depletion), and thus how they have the potential to influence streamflow and aquatic habitat in their watershed.

Project Scope

This proposed study involves three project parts (or primary tasks), including: 1) subsurface geology and aquifer characterization (hydrogeologic framework); 2) groundwater baseflow assessment via hydrograph separation; and 3) GW-SW interactions via seepage run surveys and hydraulic gradients at paired gaging stations. The scope of work of each project part is described in more detail in the sections following Project Management Services.

Project Management Services

The purpose of this task is to monitor, control and adjust scope, schedule, and budget as well as provide monthly status reporting, accounting, and invoicing.

HDR Services

1) prepare a Project Management Plan (Project Guide) outlining the project scope, team organization, schedule, and communications information (not to include WWU portion of Project Part 1).
2) Coordinate and manage the project team.
3) Subcontract with and manage project subconsultants.
4) Prepare monthly status reports describing the following:

a. Services completed during the month
b. Services planned for the next month
c. Needs for additional information
d. Scope/schedule/budget issues
e. Schedule update and financial status summary

5) Prepare monthly invoices formatted in accordance with contract terms.
6) Project Manager will attend monthly project management meetings with the client Project Manager to review project scope, schedule, and budget issues.

Client Responsibilities

1) Attend project management meetings.
2) Timely processing and payment of invoices.
3) Review and process contract change requests and amendments, if needed.

Assumptions

1) Notice to proceed will occur before June 15, 2022.
2) The project duration will be 10 months.
3) One project management meeting will be held per month with 3 hours of project manager time will be required for each meeting preparation, attendance, follow-up, and notes.
4) Invoices will be HDR standard invoice format.
5) Expense backup will not be provided with invoices but will be available for review at HDR.

Deliverables

1) Scope of services, schedule (Gantt chart or project milestones), and budget (PDF file and two copies).
2) Project Management Plan (Project Guide) (PDF file).
3) Subconsultant subcontracts.
4) Monthly reports and invoices (one copy with invoice can be mailed or e-mailed PDF file)
5) Monthly project schedule and budget updates.
6) Project management meeting agenda and notes (e-mailed PDF files).

Project Part 1- Hydrogeologic Framework

Western Washington University (WWU) will bear primary responsibility for this task under separate contract with the WSU WRC. HDR will support this task with field support and oversight to WWU, including informing this task with the results from Part 2 and Part 3 of this proposed study. Skagit Quaternary Consulting will provide field work, access to the 1:6,000 scale surficial mapping, and oversight support to WWU under subcontract to HDR.

The primary objective is to build upon and enhance the Middle Skagit Valley Hydrogeologic Assessment produced by HDR Inc. (2017) through development of a three-dimensional (3D) hydrogeologic framework in a Geographic Information System (GIS) environment. The HDR (2017) study was restricted to the Skagit River valley floor (i.e. modern floodplain), relied on 1:100,000 scale geologic map products, and had limited constraints on well locations and water levels. For this proposal the study area covers an extensive several hundred foot-thick sequence of glacial outwash deposits north and west of the HDR (2017) study area between Sedro-Woolley and Cape Horn (Figure 1). We plan to determine if these glacial deposits have hydraulic connection with the unconfined aquifer in the valley floor, and if they are viable as an aquifer system with the potential for substantial GW storage (Figure 1).

The Project Part 1 scope of work will include:

1) Characterizing the upland glacial outwash deposits north of the Middle Skagit valley floor and examining connectivity to floodplain aquifers. A conceptual model will be developed using a synthesis of several data sources, including 2017 Light Detection and Ranging (LiDAR) digital mapping, updated field mapping, available borehole data from municipalities, gravel mines and state agencies, available driller well logs from Washington State Department of Ecology (WSDOE) well report viewer database, and previous hydrogeological reports covering the focus study area (e.g. HDR 2017; 2019; Yoder 2021).

   Due to the variable geology within the glacial terrace, a lack of existing wells, and unknown connections between deeper aquifers and surface streams, we propose to drill two new deep wells. The well logs will help us develop a better 3-D model of the hydrogeology and will be used to seasonally monitor fluctuations in groundwater levels for deeper aquifers along three transects. This will, in turn, allow the identification of the degree of connection between deeper aquifers and shallow aquifers and streams.

   The Valley floor geomorphology is being mapped at 1:6,000 scale based on LiDAR digital elevation models, and the area from Cape Horn down to Hamilton has been mapped, while the area downstream to Sedro-Woolley is being mapped in 2022 (Riedel 2020). This effort includes a preliminary assessment of the hydrogeology in the proposed study area and provides data to improve upon the HDR (2017) study that relied on geology mapped at 1:100,000 scale. A series of springs along the Skagit River near Hamilton has been recently identified but not published, and this proposed study would also map these and other springs along the streams that cut through the glacial outwash terraces. This helps in the identification of the degree of hydraulic connection between upper aquifers and deeper confined aquifers due to the presence of thick silt and clay deposits.

We propose establishing three well transects from the upland glacial outwash deposits north of the Skagit River to the south along the Skagit River (Figure 1). The transects will be based on existing groundwater wells perpendicular to hypothesized GW elevation contours produced by HDR (2017), other sources of subsurface geology data, and the two new deep wells. The transects would include any monitoring wells installed by HDR along streams to assess GW-SW interactions as Part 3 of this proposal.

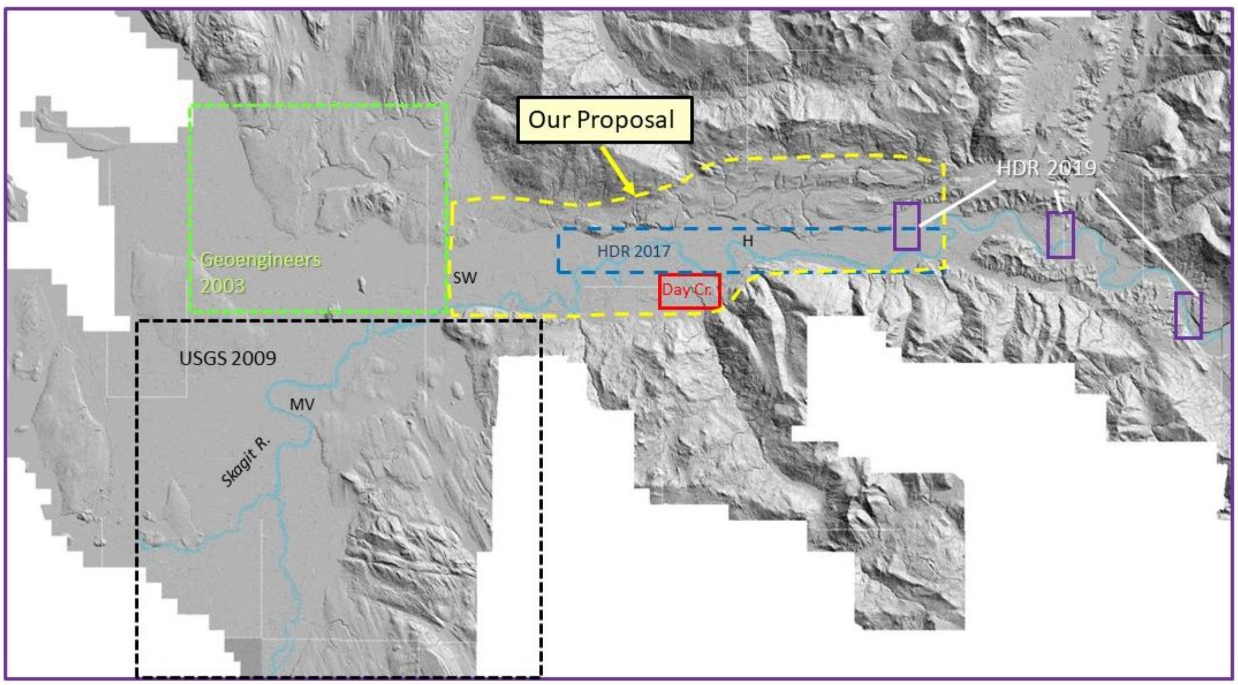

Figure 1. Approximate study area boundaries. Yellow dashed line covers our proposed study area, black USGS (Savoca et al. 2009; Johnson and Savoca 2010), blue HDR (2017), purple HDR (2019), green GeoEngineers (2003), and red a study associated with the Day Creek Mine (Robinson et al. 2005).

2) Developing a 3D hydrogeology framework model of the study area in the ArcGIS environment. The model extents would cover the existing model domain of HDR (2017) and be expanded to include the upland glacial outwash system (Figure 1).

The 3D model will be developed using new well log information and wells logs from the HDR (2017) study. HDR will provide Excel files of wells logs (and locations) and stratigraphy used to develop cross sections.

HDR Services

1) Skagit Quaternary Consulting will provide field work and oversight support to WWU under subcontract to HDR.
2) Drilling services will be performed by a qualified drilling company subcontracted under HDR, and HDR will provide field oversight of drilling activities and geological logging in support of WWU/Skagit Quaternary Consulting.
3) Inform Task with results from Part 2 (Task 300) and Part 3 (Task 400) of this study and vice-versa.

Client Responsibilities

1) Provide HDR with drilling operations access and right of entry for private land access.

Assumptions

1) Consultation among tasks by HDR will not exceed 20 hours (in Skagit Quaternary Consulting subcontract).
2) Drilling oversight and geological logging will not exceed 88 hours (by HDR).
3) WWU and Skagit Quaternary Consulting will develop a study plan and communicate with the drilling company to locate new wells and collect coordinates of well locations.
4) The drilling company will obtain any permits required to install wells.
5) A drilling company will be able to install the two deep monitoring wells with the sonic drilling method. Assumes all drilling equipment expenses are covered by subconsultant. It is assumed that the drilling company will perform well development after installation.
6) There will be site access to install monitoring wells in the targeted areas identified by WWU/Skagit Quaternary Consulting in the glacial outwash terraces north of the Skagit River.
7) HDR staff will oversee drilling to ensure wells are drilled to desired depth and completed appropriately; drilling will be accomplished in no more than 11 days.
8) Groundwater levels will be measured by WWU or Skagit Quaternary Consulting.

Deliverables

1) A final report summarizing the above scope of work
2) An ArcGIS 3D hydrogeology framework model of the Skagit River valley aquifer systems with appropriate cross sections, in the study area.

WWU and Skagit Quaternary Consulting Bios

Bob Mitchell, Ph.D., currently serves as the Digges Distinguished Professor of Engineering Geology in the Geology Department at Western Washington University where he has been a faculty member since 1996. Bob has supervised over 30 MS students on hydrogeology and watershed hydrology modeling projects in the Puget Sound region. He has degrees in Geology (BS), Geophysics (MS), Physics (MS), and a Ph.D. in Environmental Engineering. Bob teaches courses in engineering geology, surface-water hydrology, hydrogeology, ground-water contamination, and GIS.

Jon L. Riedel, Ph.D., is a Licensed Geologist in Washington State since 2001. He holds a M.S. degree in Geography from the University of Wisconsin and a Ph.D. in Earth Science from Simon Fraser University in 2007. His academic and professional career have focused on understanding the glacial and fluvial history of Skagit Valley, and he has published more than a dozen peer-reviewed studies on these topics during the past 25 years. Jon is currently leading a multi-year effort to map the surficial geology of the Skagit Valley floor from Gorge Dam to Puget Sound at 1:6,000 scale. He serves on the board of directors for the Northwest Scientific Association and the Skagit Climate Science Consortium, where he is a founding member and president.

Henry Williams is a MS graduate student in Geology at WWU. Henry was recently admitted and will start in the fall of 2022. He has a BS in Geosciences from Pacific Lutheran University in Tacoma, WA (3.9 GPA) and a GIS Certificate from the University of Washington. He completed a senior thesis at PLU related to supraglacial debris on Emmons Glacier on Mt. Rainier at PLU and presented his research results at the GSA annual meeting in October 2021. His senior thesis was supported by a NASA grant. Henry came highly regarded by the Geoscience faculty at PLU.

Project Part 2- Hydrograph Separation (Baseflow)

HDR will bear primary responsibility for this task under contract with the WSU WRC.

The primary objective is to quantify GW baseflow over time at a variety of scales and sites with existing streamflow gage records across various parts of the Skagit River basin, including the basin up-gradient from Mount Vernon. A second objective will be to determine the baseflow index (ratio of baseflow to total streamflow) at each evaluated site. A third objective will be to compare baseflow against recently obtained GW recharge estimates generated as a part of the WRC synthesis study (Yoder et al. 2021) in addition to precipitation and glacial melt records, providing an improved assessment and comparison of Basin water budget components

The Project Part 2 scope of work will include:

1) Determine GW discharge (baseflow) time series and temporal averages across the Basin at different spatial scales including basin-wide and sub-basin scales using publically-available existing streamflow gage records and hydrograph separation techniques. The ratio of baseflow to total streamflow will be calculated to determine the baseflow index of the various sites analyzed. Two different techniques (equations) will be selected for hydrograph separation, selected after a period of review to determine appropriate and efficient calculation methods. The methods will be described, and results compared and contrasted.

2) Assess how the derived GW baseflow estimates compare to recently developed GW recharge estimates as well as precipitation and glacial melt records for the historic period (see Yoder et al. 2021, Groundwater tab). The possible causes for differences, including methodological and temporal differences, along with potential accuracy concerns, will be discussed. The underlying datasets will be obtained from the Yoder et al. (2021) study and extracted to overlap as near as possible with the watersheds associated with the sites evaluated for GW baseflow.

Client Responsibilities

1) Facilitate data or study transfer from other study partners (UW, NOAA, WSU), upon request

Assumptions

1) Evaluation will be limited to public data or otherwise data that is readily available via request.

Deliverables

1) Draft and final technical memorandum describing the utilized data, methodology, and discussion of findings.

Project Part 3- Seepage Runs and Hydraulic Gradients

HDR will bear primary responsibility for this task under separate contract with the WSU WRC.

The primary objective is to evaluate GW-SW interactions on select tributary streams within the area of focus between Sedro-Woolley and Cape Horn (near Concrete). These GW-SW interactions will be evaluated by measuring the hydraulic gradient from paired groundwater (monitoring well with level logger) and surface water (stream gage with level logger) elevations over the course of several months, covering a period of low tributary stream flow. These GW-SW interactions will also be evaluated with seepage run surveys of select Skagit River tributaries during a period of low tributary stream flow.

The Project Part 3 scope of work includes the following:

1) A study plan will be developed that defines specific methods and locations to meet the stated objectives and the associated services listed herein. Site reconnaissance and logistics will be conducted, and these findings will be included in the study plan.

2) The first method used to perform this part of the study involves establishing paired GW-level and stream-stage monitoring stations to collect time series of hydraulic gradients between GW and SW. This will rely on installation of monitoring wells and stream stage gaging sites and recording of water levels via pressure transducers and continuous data loggers. Up to twelve new pairs of monitoring wells and stream gaging stations will be installed. Level loggers will be placed in the monitoring wells and at the river gaging locations. At each paired location, a level logger will be placed locally to record local barometric pressure (to post-process the groundwater and river surface water elevations). The relative elevations between the monitoring well and river level elevations will be surveyed. The groundwater and river level elevation data will be continuously recorded for up to four months spanning the typical low flow period (i.e., August and/or September). Data will be downloaded up to four times.

3) The second method used to perform this part of the study involves performing synoptic streamflow (or stream discharge) surveys along transects (or seepage runs) during low-flow periods without precipitation inputs, accounting for tributary flows. The measurements will be made on sites along up to six select tributaries in the Sedro-Woolley to Cape Horn reach on the north side of the Skagit River. The seepage run survey results will provide stream discharge rates and then will be used to determine GW-SW interactions as stream gains/losses between measurement transects locations. Flows will be measured during one synoptic survey at up to six of the following tributaries:

    - Grandy Creek
    - Alder Creek
    - Muddy Creek
    - Red Cabin Creek
    - Mannser Creek
    - Jones Creek
    - Childs Creek
    - Wiseman Creek
    - Coal Creek
    - Hansen Creek

4) Perform comparisons between new information and previous findings from the HDR (2017) study, and the USGS (Hidaka 1973; Savoca et al. 2009). Evaluate spatial variability among the GW-SW interactions from seepage run discharge

surveys, and temporal dynamics of GW-SW interactions at paired gages (with monitoring wells and surface water stage recorders).

Client Responsibilities

1) Provide HDR with stream access and right of entry for private land access, monitoring equipment installation and drilling operations.

Assumptions

1) There will be no more than 12 monitoring wells and 12 surface water gages. Assume 24 transducers/data loggers for water level measurements, and 6 barometric pressure loggers (30 total loggers).
2) A drilling company will be able to install the 12 monitoring wells with the sonic drilling method. Assumes all drilling equipment expenses are covered by subconsultant.
3) The drilling company will obtain any permits required to install wells.
4) There will be access to install monitoring wells near the Skagit River tributary streams/creeks in proximity to paired river gages.
5) HDR staff will oversee drilling; drilling will be accomplished in 4 days doing oversight and logging sediments in the well and the substrate.
6) Stream gages will have level loggers that can be installed with angle iron or slant pipes. HDR has no warranty against equipment theft or vandalism, damages or losses from flooding and debris impacts.
7) HDR staff will install transducers and the stream gage equipment. Assume 4 days to install stream gage equipment.
8) There will be no more than 12 tributary flow measurements during the seepage run survey. Assume 5 days to conduct seepage run survey (discharge measurements). The seepage run surveys will be performed with wadable equipment and methods. Up to six of the tributaries will have multiple (at least two) flow measurements at locations pursuant to understanding groundwater gain or loss in those tributaries, site access, and site reconnaissance.

Deliverables

1) A draft and final technical memorandum describing the utilized data, methodology, and discussion of findings.

Project Schedule

The project schedule is expected to take ten months from notice to proceed. This schedule assumes that there will be a notice to proceed by June 15, 2022. A notice to proceed is at a later date, the schedule will need to be re-negotiated and could result in pushing field work to 2023.

Milestones	**Date**
Notice to proceed	June 15, 2022
Hydrogeologic framework	June 15, 2022 – April 15, 2023
Draft hydrograph separation technical memorandum	January 31, 2023
Final hydrograph separation technical memorandum	March 31, 2023
Seepage run and hydraulic gradient study plan	July 31, 2022
Seepage run and hydraulic gradient study–data collection complete	December 31, 2022
Draft seepage run and hydraulic gradient technical memorandum	January 31, 2023
Final seepage run and hydraulic gradient technical memorandum	April 15, 2023

Project Budget

Two separate budgets are provided below, including one for Western Washington University (WWU) and one for HDR, Inc. (HDR). **The combined proposal fees are estimated to be $541,813, including $79,167 for WWU, and $462,646 for HDR.** All subcontractors are included under the HDR budget estimate.

WWU Budget Estimate

The will be conducted primarily by a Geology MS graduate student at WWU and will serve as a basis a MS thesis. The project will be supervised by Dr. Robert Mitchell a professor in the Geology Department and Dr. Jon Riedel a regional consultant. Note that Jon Riedel will be contracted under HDR (see Skagit Quaternary Consulting in the HDR budget).

Item	**Fee**
MS Graduate student RA stipend 9-month:	$17,600
MS Graduate student summer salary year one:	$7,200
MS Graduate student summer salary year two:	$7,200
MS Graduate student benefits:	$7,776
Bob Mitchell one month summer salary:	$13,590
Bob Mitchell benefits:	$2,854
MS Graduate student tuition (12 thesis credits):	$4,611
Travel costs:	$2,000
Sub-total direct costs:	$62,831
WWU overhead 26% of total direct costs:	$16,336
Totals	**$79,167**

HDR Budget Estimate

Total proposed fees are estimated to be $462,646. Fees are subject to change as a result of: 1) findings of the study plan development, to be performed under Part 3 of this proposal; 2) site access/permission constraints; and 3) limited duration of validity of driller's quotes. Subconsultants include Skagit Quaternary Consulting (Task 2, $15,000), Holt Services (Task 2, $106,455), Cascade Drilling (Task 4, $46,091), and PLSA Survey (Task 4, $20,400). Expenses include travel expenses for site reconnaissance and field work, and field equipment rental and purchased equipment (e.g. level loggers, gaging equipment, level logger housing).

Task #	Task Description	Labor	Total Expenses	Total Subconsultants	Subtotal	F&A (26%)	Total
1	Project Management	$26,773	$0	$0	$26,773	$6,961	$33,734
2	Part 1 - Hydrogeologic Framework	$10,886	$3,344	$123,884	$138,114	$3,700	$141,814
3	Part 2- Hydrograph Separation	$58,469	$0	$0	$58,469	$15,202	$73,671
4	Part 3- Seepage Run and Hydraulic Gradient	$85,315	$30,246	$67,821	$183,382	$30,046	$213,428
	Totals				$406,738	$55,909	**$462,646**

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A.2.3 Skagit River Tributary Instream Flow Habitat Assessment

Proposal # and Date: 20220425SBWTFWG, 04/25/2022

Project: Skagit River Tributary Instream Flow Habitat Assessment

Client: Skagit Basin Water Task Force Work Group

Submitted by: Thomas Gast & Associates Environmental Consultants
P.O. Box 1137
Arcata, CA 95518

Contact Person: Thomas Gast, Principal Scientist
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Summary

Salmonids in the Skagit River watershed use tributary streams to spawn and rear. Population growth and climate change will alter the amount and timing of streamflow and will impact salmonid spawning and rearing habitat in the Skagit River tributaries. This instream flow study will model the relationship between streamflow and salmonid habitat in Grandy Creek. We will compare the available fish habitat under natural flow conditions to projected fish habitat under a climate change scenario as well as two future growth scenarios.

Introduction

Larry Wasserman, on behalf of the Swinomish Indian Tribe, submitted the proposal, "Updated Skagit River Habitat and Flow Assessment" for the Skagit Basin Water Task Force Work Group. This is a detailed proposal, cost estimate, and schedule for completing the Instream Flow Study on Grandy Creek.

Firm Profile

Thomas Gast & Associates Environmental Consultants

Thomas Gast & Associates Environmental Consultants (TGAEC) is a federally registered Small Business specializing in fisheries investigations, particularly instream flow studies. Additional services include fish population assessment and monitoring, fish tagging studies, hydraulic habitat modeling, impact analysis, flow measurements including acoustic Doppler current profiler (ADCP) measurements, water quality monitoring, geomorphology, hydrogeology, Endangered Species Act consultation, bathymetry mapping, and boat support. Mr. Gast has provided training in IFIM implementation and PHABSIM analysis, and has been involved with all aspects of instream flow studies including study design, stakeholder meetings, field data collection, data modeling and analysis, habitat time series calculation and presentation, impact analysis, and report writing. TGAEC staff have worked with acoustic tag, radio tag, and PIT tag study design, implementation, data analysis, and reporting. Activities have included planning, equipment construction, calibration, installation and maintenance, fish surgeries, tracking, data collection, analysis, reporting, and presentation. Staff also have extensive experience monitoring fish populations with rigorous quantitative direct observation protocols and multiple pass electrofishing. Staff have been involved in a multitude of additional studies including deep water Chinook redd mapping, eelgrass monitoring, literature review, flow measurements, and boat support.

TGAEC is including Mr. Gast's former colleague at Normandeau, Mark Allen, an expert in developing Habitat Suitability Criteria (HSC). Also included is Mr. Gast's long-time collaborator, Dr. Richard Koehler, a professional hydrologist (American Institute of Hydrology credential 13-H-5008) and expert in time-series data presentation and analysis.

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Study Area

The study area consists of Grandy Creek from the confluence with the Skagit River to Grandy Lake. The Grandy Creek Watershed is approximately 18 square miles and the stream channel is approximately six miles long. The elevation increases from approximately 100 feet at the confluence to 800 feet at Grandy Lake.

Methodology

Development of a relationship between suitable aquatic habitat and river flow for selected species and life stages within the IFIM/PHABSIM framework depends on the measurement or estimation of physical habitat parameters (e.g., depth, velocity, substrate/cover) within the study reach. Generally, the distribution of these parameters at given river flows are determined at points along transect lines across the stream channel, positioned to account for spatial and flow-related variability. A variety of hydraulic modeling techniques can be used to simulate water depth and velocity as a function of river flow; substrate and cover values are generally fixed at a given point. With physical habitat thus characterized for a range of river flows, the suitability of the habitat (for a particular species and life stage) at each point is scaled from zero to one, usually by multiplying together the corresponding suitability values for depth, velocity, and substrate from the appropriate habitat suitability criteria (HSC) curves. These point estimates of suitability are then used to weight the physical area of the study represented by each point, and the weighted areas are accumulated for the entire study reach to produce an index of useable habitat as a function of river flow for each species and life stage.

The physical area represented by each transect point depends on the design of the PHABSIM study. This study uses the mesohabitat typing, or habitat mapping, approach originally described by Morhardt et al. (1983) and summarized by Bovee et al. (1998). In this design, mesohabitats (broadly defined habitat generalizations) are mapped over the entire study reach, such that each area of the waterway is characterized by a general habitat type, and the total length and proportion of the study reach assigned to each mesohabitat type is determined.

Physical habitat parameters (e.g., river flow dependent depth and velocity, substrate, and cover) representative of each mesohabitat type are measured or modeled at one or more transects placed within the mesohabitat area. The exact number and placement of transects within a mesohabitat type depends on the proportion of the study reach represented by each mesohabitat type, as well as practical issues such as accessibility. Generally, the total number of transects are distributed among mesohabitat types in proportion to the length of the study reach represented by each mesohabitat. The physical area represented by each transect point is then determined by both the lateral distribution of points on a transect, and the length or proportion of the study reach that each transect represents.

Stakeholder Involvement

Agencies, Stakeholders, and Tribes will have the opportunity to provide input into the selection of study reaches, transect locations, species and life-stages of interest, HSC, and calibration flows, as well as reviewing the AWS curves. The study plan will be provided to the WDFW, WA Dept. of Ecology, and interested parties as determined by the Skagit Basin Water Task Force Work Group for review.

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Habitat Mapping

Habitat mapping consists of identifying the type (e.g. pools, runs, and riffles) and measuring the length of individual macrohabitat units over the total distance of stream courses within a project area (Morhardt et al. 1983). The method allows each transect where hydraulic data is collected to be given a weight proportional to the quantity of habitat represented by that transect. Mapping will be conducted by walking the stream channel while deploying biodegradable cotton thread from a surveyor's hip chain to measure total distance. The location and length of each individual macrohabitat type will be calculated by noting the distance from a downstream base reference point to upstream boundaries. Reference points will be marked using surveyor's flagging every 500 feet (generally at the nearest hydraulic control) as well as with GPS waypoints. These marks serve as temporary and fixed, known reference points from which to relocate specific habitat units or other features of interest during the stream studies. Other information noted during the mapping process include estimating the maximum depth for each pool habitat, and determining whether a unit could be hydraulically modeled.

The mapping information will be used to determine the percentages of various macrohabitats, assist with selection of study sites, and the placement of transects for the hydraulic data collection. Each habitat unit will be also evaluated for appropriateness for PHABSIM modeling. Conditions that prohibit satisfactory hydraulic simulation include complex hydraulic conditions associated with strongly transverse flow, plunge pools, or unique split channel configurations. Potentially dangerous and unsafe habitat units, such as those near dangerous falls or cascades, will also identified for subsequent elimination as candidates for hydraulic modeling.

The individual macrohabitat identifications and distances will be entered into a database program to create a sequential map of habitat units along the entire length of stream that was surveyed. The database allows for the computation of the percent abundance of any macrohabitat type within the entire study area or within designated reaches. The mapping data and location markers aid in the relocation of individual habitat units for subsequent inspection and transect selection.

PHABSIM: Transect Selection and Installation

Habitat mapping forms the basis for transect selection. TGAEC expects to install 20 transects. The percent contribution of individual habitat types to total habitat is derived from the total length of a given reach. The PHABSIM habitat analysis relies upon hydraulic conditions measured along stream cross sections, or transects, placed in varying macrohabitats. Habitat unit selection and transect placement will be conducted by the study leads in conjunction with WDFG and Ecology. Actual habitat unit selection and transect placement will be accomplished by a combination of random selection and professional judgment.

Calibration Flows

Calibration flows are the flows at which water surface elevations and velocities are measured and from which the model simulations are built. A total of three sets of calibration flow measurements (high, middle and low) will be made at each transect. Generally, the simulations will be valid for a range of flows from 40 percent of the low calibration flow to 250 percent of the high calibration flow. Velocities at each transect station will be measured at each safe

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calibration flow. In the case of unregulated rivers such as Grandy Creek, calibration flow targets will be identified, but the measurements will be opportunistic depending on the weather during the sampling period. We expect the target flows to be 50 cfs, 25 cfs, and 12.5 cfs. These target flows could change with agency input, more detailed hydrologic analysis, or safety concerns.

Field Data Collection

Water Surface Elevation and Velocity Measurements

Depths and velocity measurements will be collected at each transect at each flow level that can be effectively and safely measured. Data will be collected using wading/velocity measurement techniques at shallow habitats, and an acoustic Doppler current profiler (ADCP) mounted on a rigid trimaran in deep pool habitats. The TRDI RiverPro 1200kHz ADCP sends and receives acoustic pulses in order to measure the Doppler shift and phase change of the echoes to calculate depth and velocity patterns. Additional measurements of water surface elevation for each transect and a single discharge measurement (per transect cluster) will be made at the middle and low flow levels.

The amount and type of data collected will be suitable for use in a hydraulic simulation with the PHABSIM computer model using System for Environmental Flow Analysis (SEFA) software. WDFG and Ecology recommend the three flow IFG4 regression model (Kohr et.al., 2022).

Field data collection and the form of data recording will follow the guidelines established in the IFG field techniques manuals (Trihey and Wegner 1981; Milhous et al. 1984; Bovee 1997). Additional quality control checks that have been found valuable during previous applications of the simulation models will be employed. The techniques for measuring discharge generally followed the guidelines outlined by Rantz (1982). A minimum of 20 wetted stations per stream transect will be established, with a goal of no less than 15 wetted stations at the lowest measured flow.

Substrate and Cover Characterization

Substrate and cover attributes and codes will be determined after the HSC are chosen.

Quality Assurance/Quality Control

To assure quality control in the collection of field data, the following data collection procedures and protocols will be utilized:

Staff gauges will be established and continually monitored throughout the course of data collection. If significant changes occur, water surface elevations will be re-measured following collection of transect water velocity data.

Independent benchmarks will be established for each set of transects. The benchmark will be an immovable tree, boulder, or other naturally occurring object not subject to tampering. Upon establishment of headpin and tailpin elevations, a level loop will be shot to check the auto-level measurements for accuracy. Acceptable error tolerances on level loop measurements are set at 0.02 feet. This tolerance is also applicable to both headpin and tailpin measurements, unless extenuating circumstances (e.g., pins under sloped banks, shots through dense foliage) account for the discrepancies, and the accompanying headpin or tailpin meet the tolerance criteria.

Water surface elevations will be measured on both banks on each transect. If possible, on more complex and uneven transects, such as riffles, water surface elevations will be measured at multiple locations across a transect. An attempt will be made to measure water surface elevations at the same location (i.e., station or distance from pin) across each transect at each calibration flow. Water surface elevation measurements will be obtained by placing the bottom of the stadia rod at the water surface until a meniscus forms at the base or selecting a stable area next to the water's edge.

Pin and water surface elevations will be calculated on-site during field measurements and compared to previous measurements. Changes in stage since the previous flow measurement are also calculated. Patterns of stage change will be compared between transects and determined if reasonable. If any discrepancies are discovered, potential sources of error will be explored, corrected where possible, and noted.

The ADCP will be used to collect water velocity data from stations along each transect where wading is not possible. High-quality and well-maintained current velocity meters were used to collect velocities of shallower, edge cell velocity data.

Prior to deployment, the ADCP will be system checked, compass calibrated, moving bed test performed, and user configured for each individual transect with appropriate commands for the existing environmental conditions. Oftentimes, several transect measurements are necessary to obtain the optimum configuration. Each transect measurement length and discharge calculation will be compared to the actual values or to repetitive measurements in order to ensure accurate bottom tracking and velocity measurements. Real time graphic depictions of depth and velocity are examined during data collection for inconsistencies and obvious errors. As a precaution against data loss, all electronic data files will be copied onto a separate USB drive at the end of each field day.

All calculations will be completed in the field, given adequate time and daylight. Pin elevations and changes in water surface elevations will be compared between flows on the same transect. Discharges will be calculated on-site and will be compared between transects during the same flow conditions (high, mid, and low). If an excessive amount of discharge (greater than 10% of the stream flow) is noted within an individual transect cell, additional stations will be established to more precisely define the velocity distribution patterns at that portion of the transect.

Photographs will be taken at all transects: downstream, across, and upstream at the three calibration flows. Photographs will be taken from the same location at each of the flows, if possible. Photographs provide a valuable record of physical conditions and water surface levels that will be utilized during hydraulic model calibration.

All data (e.g., stationing, depth profiles, velocities, substrate/cover codes) will be entered into the SEFA computer files. Internal data graphing routines will then be used to review the bottom and velocity profiles for each transect separately and in context with others for quality control purposes. All data gaps (e.g., missing velocities) or discrepancies (e.g., conflicting records) will be identified and corrected using available sources such as field notes, photographs, or adjacent data points.

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Transect Weighting

The number of transects selected for each habitat type will be determined by the percentage of the study reach represented by each habitat type. Using this approach, each habitat type will be represented approximately in proportion to that which was mapped. Each transect will be weighted so that each habitat type is represented in the exact proportion to that existent in the study area.

Hydraulic Simulation

The purpose of hydraulic simulation under the PHABSIM framework is to simulate depths and velocities in streams under varying stream flow conditions. Simulated depth and velocity data is used to calculate the physical habitat, either with or without substrate and/or cover information. All data will be entered into the SEFA software used for this analysis.

Water Surface Prediction

The water surface elevations, in conjunction with the transect profiles, will be used to determine water depths at each flow. Water depth is an important parameter for determining the physical habitat suitability. Either an empirical log/log regression formula of stage and flow based on measured data, or a channel conveyance method (MANSQ) that relies on the Manning's N roughness equation, will be used to create rating curves.

The log/log regression method uses a stage-discharge relationship to determine water surface elevations. Each cross section is treated independently of all others in the data set. A minimum of three stage-discharge measurement pairs will be used to calibrate the stage-discharge relationship. The quality of the rating curves is evaluated by examination of mean error and slope output from the model. Mean errors of less than 10% are considered acceptable and less than 5% as very good. In general, the slope between groups of transects should be similar.

MANSQ only requires a single stage-discharge pair and utilizes Manning's equation and channel shape to determine a rating curve; however, it is generally validated by additional stage-discharge measurements. This modeling method involves an iterative process where a beta coefficient is adjusted until a satisfactory result is obtained. In situations where irregular channel features occur on a cross section, for instance bars or terraces, MANSQ is often better at predicting higher stages than log/log. MANSQ is most often used on riffle or run transects and is generally not considered as effective in establishing a rating curves for transects that have backwater effects from downstream controls, such as pools. It can also be useful as a test and verification of log/log relationships.

Velocity Simulation

Simulated velocities are based on measured data and a relationship between a fixed roughness coefficient (Manning's n) and depth. In some cases, roughness is modified for individual cells if substantial velocity errors are noted at simulation flows. Velocity Adjustment Factors (VAF's), the degree to which measured velocity and discharge are adjusted to simulated velocity and simulated discharge, are an indication of the quality of hydraulic simulations. These are examined to detect any significant deviations and determine if velocities remained consistent with stage and total discharge. VAF's in the range of 0.8 to 1.2 at the calibration (measured) flow are considered acceptable, and 0.95 to 1.05 are considered excellent.

Habitat Suitability Criteria

Habitat suitability criteria (HSC) are a critical and highly influential component of instream flow modeling. HSC represent the biological component of habitat modeling by assigning the relative suitability of habitat variables to a specific species and life-stages on a scale of 0 (unsuitable habitat) to 1 (optimal habitat). HSC will be selected for use in this project to develop the flow/habitat relationships. Existing information on HSC for target species and life-stages (e.g., spawning, fry, juvenile, and adult rearing) will be collated and reviewed for possible use in flow modeling. The WDFW's database of state-recommended HSC will be the initial source of candidate HSC. However, additional HSC from other sources may be used for comparison with the WDFW HSC for further evaluation; such evaluation will be conducted in collaboration with participating agencies. Likewise, the list of target species and life-stages used for flow modeling will also be determined through a collaborative process. However, for the purposes of this proposal and its estimated costs, it is assumed that HSC will be selected and utilized to represent the spawning, fry rearing, and juvenile rearing life-stages for three species of anadromous fish.

Habitat Simulation

Combining the hydraulic and HSC components generates the habitat suitability (AWS/WUA) index. Unlike hydraulic modeling and calibration, there are a limited number of decisions to make prior to production runs. Transects are weighted according to the percentage of habitat types present in the reach. The range of flows to model, and specific flows within that range, are determined largely by the suitability of the hydraulic data for extrapolation and general flows of interest. Generally, the range of flows of interest are those deemed mandatory either as minimum standards or seasonal requirements, but can also be based on natural flows. The habitat simulation produces the relationship between flow and fish habitat for each species and life-stage of interest.

Hydrology

As part of the Instream Flow Study of Grandy Creek, a complete hydrologic analysis will be performed including, but not limited to:

- Describing the magnitude, frequency, duration, and timing of streamflow
- Developing a historic synthetic hydrograph for Grandy Creek using nearby stream gages

Time Series Analysis

Utilization and interpretation of habitat modeling output, namely habitat index curves, presents a challenge from both a technical and functional perspective. The habitat versus flow relationships derived from PHABSIM represent a conceptual association between flow and habitat. Although some basic inference can be made from this relationship, evaluation without incorporating flow regimes can lead to erroneous interpretations. This analysis is particularly valuable when considering a suite of species and life stages with varying habitat versus flow relationships, and instances when known life history needs may not be directly exhibited in the habitat versus flow relationship output from PHABSIM.

The tendency to look at the maximum, or "peak", of a habitat index curve greatly oversimplifies the results. For example, maximum spawning habitat may occur at a flow that rarely exists in a

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given reach. Additionally, the amount of habitat can be the same at two flows: one lower and one higher than the maximum. Because the amount of habitat available at any given time of year is a function of hydrology, incorporating a time-series analysis provides a more realistic view of available habitat. Such an analysis is important when determining effects of different flow regimes that may result from changes in water usage or climate change. Time series analysis involves matching the habitat index for a given species or life stage to flow.

The major basis for habitat time series analysis is that habitat is a function of stream flow and that stream flow varies over time. Habitat time series displays the temporal habitat change for a particular species and life stage during selected seasons or critical time periods under various flow scenarios. Typically results are represented by habitat duration curves indicating the quantity of habitat that is equaled or exceeded over the selected time period.

Climate Change and Future Development Scenarios

Changes in hydrologic conditions and regime will be evaluated in Grandy Creek with the considerations of climate change, land use, and projected consumptive demand. The long-term influence of climate change in the region will be assessed using the Palmer Hydrologic Drought Index (PHDI), which considers the hydrologic impacts of drought (NOAA, 2022).

In addition to using the PHDI to predict the vulnerability of Grandy Creek watershed to drought, the results of the Skagit Climate Consortium streamflow analyses will be used to model changes in Grandy Creek hydrology, and will predict changes expected in the next 30-years using climate change scenarios of varying severity.

Both climate change and changes in consumptive water demand can influence future hydrologic conditions in Grandy Creek. Following successful modeling of climate change impacts, TGAEC will implement two scenarios to simulate consumptive water demand using projected growth in the region. Using both climate change and water demand scenarios, this model can offer a range of predicted hydrologic conditions in Grandy Creek watershed for the following 30 years.

TGAEC will compare the climate change and future development time series fish habitat scenarios to the natural historic flow time series fish habitat and evaluate the potential impacts of each scenario.

Budget

The cost for Grandy Creek Instream Flow Study will be $101,773. Several assumptions are included in this cost estimate:

- 20 transects will adequately characterize the fish habitat
- HSC for three salmonid species and three life-stages (Total of nine HSC) will be use in the analysis
- Three agency/stakeholder online meetings including one meeting to present the results

- TGAEC staff will be able to arrange stream access at sufficient locations
- The instream flow study is not contentious and will not require facilitation

Schedule

The schedule assumes that contracting will occur, or other arrangements will be made, in order for the study planning to commence in June. The schedule is entirely dependent on the hydrology and field data collection will opportunistically target the appropriate flows. There is always some risk that an early storm and continued early season precipitation will disrupt the schedule entirely.

Schedule of activities and deliverables (WSEL= Water Surface Elevation).

Activity	*Start*	*End*	*Deliverable*
Study Plan	1-Jun-22	1-Jul-22	Draft Study Plan
Agency/stakeholder meeting	1-Jul-22	15-Jul-22	Meeting and Study Plan finalized
Habitat Typing	1-Aug-22	1-Sep-22	Habitat Stratification and Field Memo
Transect installation and low calibration flow	1-Sep-22	1-Oct-22	Depths, Velocities, WSEL, Profile, Attributes
Mid calibration flow	1-Sep-22	1-Oct-22	Depths, Velocities, WSEL
High calibration flow	1-Oct-22	1-Nov-22	Depths, Velocities, WSEL
Habitat modeling	1-Nov-22	1-Jan-23	Habitat Modeling Results
Time series analysis	1-Jan-23	1-Feb-23	Time Series Results
Results Presentation	1-Feb-23	1-Mar-23	Draft Report and Presentation
Final Draft	1-Mar-23	1-Apr-23	Final Report

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A.3 Tier 2 Proposals

Note: Tier 2 proposals were not developed further after the initial round of Working Group prioritization. They are therefore much more brief than Tier 1 proposals. They nonetheless remain available for further consideration at the discretion of the Task Force.

A.3.1. Water Claims Analysis with Remote Sensing

Note: Tier 2 proposals were not developed further after the initial round of Working Group prioritization. They are therefore much more brief than Tier 1 proposals. They nonetheless remain available for further consideration at the discretion of the Task Force.

Resolve uncertainties in the water rights data

Submitted by Yoder

What: Out of the 6,055 total water right documents pertaining to WRIAs 3 and 4, claims represent 4,489 entries, many of which are missing water rights quantity and priority date information in the Department of Ecology Water Rights Tracking System (WRTS) database. Given some water rights have multiple purposes of use, there are 6,852 water right-purpose of use combinations, of which 57% (3,875) have a domestic purpose and 1,308 (19%) have an irrigation purpose. Most entries do not have water right quantity information (97% do not include annual quantity values) or priority dates (99% of entries). Moreover, about 7% of the water rights (about 14% of non-claim water rights) are missing in the spatial Geographic Water Information System (GWIS) database, and there are some duplicate entries as well.

Why: The data gaps prevent an accurate analysis of water rights and how they compare to supply and water use. Pre-1917 surface water claims, pre-1945 groundwater claims, and some post-1917 and pre-1932 surface water claims for riparian rights can be considered "valid". These claims may correspond to water demands in the basin that need to be accounted for, and the extent of "claims" related to basin water demands is unknown. A better understanding of this large proportion of water rights will help understand water security for other water users in all sectors, as well as water security for streamflows, and provides a method for projecting the consequences general adjudications in basins with significant claims with unknown status.

How**:** This knowledge gap could be addressed by combining information from the Ecology WRTS database, manually extracting annual quantity values and priority dates from each claim record individually, and using remote sensing to estimate location and extent of consumptive water use in the basin (especially agricultural use). This Skagit S&D team has already worked to clean the existing Ecology WRTS database for permits and certificates, and could continue this work. The State of Washington Water Research Center is leading several projects that focus on the development and use of remote sensing of consumptive use.

Data Uses and Impacts: *Surface Water:* This would help understand water use in relation to surface flow water use. *Groundwater:* This would help define groundwater use. It is a starting point for refining estimates of future groundwater demands, and both current and future groundwater use estimates (in addition to other water sources).*Fish Habitat*: A better understanding of the spatial variation of water rights will improve understanding of which sub-basins are subject to greater water scarcity for fish. *Ag Demand:* A better understanding of water rights data would provide clearer information about potential current and future demand and usage of water in the basin. *Residential Demand:* This information would help better identify when and where water demand is higher for residential use, and more certainty about where mitigation options, and conservation options (e.g. changes to water user behavior) would be useful. *Potential Socio-Economic impacts:* A better understanding of this large proportion of water rights will help understand water security for other water users in all sectors, as well as water security for streamflows, and provides a method for projecting the consequences general adjudications in basins with significant claims with unknown status.

A.3.2 tradeoffs in Flow Regulation

Note: Tier 2 proposals were not developed further after the initial round of Working Group prioritization. They are therefore much more brief than Tier 1 proposals. They nonetheless remain available for further consideration at the discretion of the Task Force.

Analysis of the tradeoffs in hydropower flow regulation

Submitted by Yoder

What: Examine the physical and economic effects of hydropower flow regulation on downstream uses and demand relative to hydropower electricity generation.

Why: The timing of reservoir releases from Skagit hydropower projects represent physical and economic tradeoffs among potentially competing and/or complementary downstream uses. The downstream effects of hydropower flow regulation are the result of complex flow management for multiple objectives (hydropower generation, reservoir levels for recreation, instream flows for fish habitat and flood regulation), and are combined with the influence of unregulated flows from major tributaries. A better understanding of the tradeoffs inherent in reservoir releases may provide opportunities to optimize flow management and timing for multiple objectives.

How: Historical data on naturalized flows at the dams, reservoir modeling including operating constraints and flexibility for multiple objectives, data on in-stream flow needs for fish, and off-stream demands for water use could be combined using existing models and data (some of which are used in this present synthesis) for a synthesized model of the system. This would likely need to be done in partnership with the hydro-utilities to effectively capture operations and constraints. If it is to be used to affect policy or management, itwould need to be coordinated with the relicensing process.

Data Uses and Impacts*: Groundwater:* It is possible that surface water operations allow for water supplies to be met by surface water sources such that the availability of the stored surface waters offset potential increases in groundwater demands or groundwater use that would otherwise occur. This could be in the form of reduced groundwater pumping from existing wells or reduction in installation of new wells (if surface water can otherwise be accessed). However, it might be more likely that the opposite effect occurs, such that surface water rights are swapped out for groundwater rights to cause a net flow increase locally (at the expense of groundwater).*Fish Habitat:* Hydropower regulation has a big effect on current flows for fish, and could have an important influence on mitigation of climate impacts (that would be expected to occur without flow-regulating operations).This analysis would provide a good historical perspective on flow variation pre- and post-dam building to put hydropower based flow changes in perspective of natural flow-based constraints for fish populations in the Skagit watershed. *Flow Regulation:* Hydropower regulation has a big effect on flow volume at Mt. Vernon, and thus the frequency of instream flow shortfalls.*Ag Demand:* A better understanding of the costs associated with storing water in reservoirs for release for agricultural withdrawals during low flow periods may help determine the feasibility of this option. *Potential Socio-Economic impacts:* Analysis could inform optimization in flow regulation in a socio-economic constraints/tradeoff framework to maximize the potentially achievable benefits that are defined. Requires inputs to define realistic scenarios and operating constraints and environmental conditions (spatio-temporal distribution of supplies and demands).