Groundwater Upwelling and Summer Chum Spawning

PHASE 1: LITERATURE REVIEW AND INTERVIEWS

Prepared for:

Hood Canal Coordinating Council

February 27, 2017

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PHASE 1: LITERATURE REVIEW AND INTERVIEWS

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TABLE OF CONTENTS

TABLES

APPENDICES

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1.0 INTRODUCTION

The Hood Canal Summer Chum evolutionary significant unit (ESU) was listed as threatened under the U.S. Endangered Species Act in 1999. The ESU has of two independent populations: Hood Canal and Strait of Juan de Fuca. The Hood Canal Coordinating Council (HCCC) is the Regional Recovery Organization for Hood Canal and Eastern Strait of Juan de Fuca Summer chum salmon recovery, responsible for the implementation of the Hood Canal and Eastern Strait of Juan de Fuca Summer Chum Salmon Recovery Plan (Plan) The Plan that was prepared by the HCCC in 2005 and adopted by NOAA Fisheries in 2007 identifies a comprehensive approach to ensure the long-term survival of summer chum in this ESU. Habitat restoration plays a vital role in this recovery plan. Confluence Environmental Company (Confluence) and its subcontractor, Pacific Groundwater Group, were hired by HCCC to compile the scientific documentation relating summer chum productivity to groundwater upwelling and inform how groundwater resources data should be used to guide future restoration work.

This work is divided into two phases; this report focuses on Phase 1. Phase 1 entailed conducting a literature review and interviewing scientists and fisheries managers familiar with the work conducted to date on chum salmon biology and habitat restoration. Phase 1 focused on answering the following questions:

1. Is there a correlation between groundwater and population success of summer chum and, if so, is this a model to follow for additional summer chum restoration efforts?

2. Can this model be replicated in other areas, specifically in the watersheds of the east coast of the Hood Canal north of Tahuya River?

This report is divided into the main tasks of Phase 1 — the literature review and the interviews. The report then provides discussion and recommendations for moving forward with Phase 2 work.

2.0 OVERVIEW OF LITERATURE REVIEW

The search for literature to review began with a request of documents from HCCC's library, followed by a search for on-line references. Finally, documents that were not available from on-line resources were found at the University of Washington library. While at the university library, an additional search was conducted based on references contained in previously reviewed documents.

The goal of the literature review was to answer the two following questions:

1. Are there productivity success estimates for chum in naturally occurring groundwater-fed spawning areas?

2. What actions have been taken by Washington Department of Fish and Wildlife and the Lower Columbia Fish Enhancement Group to investigate the influence of groundwater on chum spawning and early rearing success?

An annotated bibliography of all literature reviewed for this effort is included in Appendix A. References cited herein are also found in Appendix A. The annotated bibliography lists a brief description of the material covered and whether the document answers the literature review questions.

Most studies looked at either (1) groundwater and other habitat variables in spawning site selection, or (2) for the improved success of spawning (i.e., egg-to-fry survival) through demonstrated production increases. Overall, preference of groundwater-fed areas by chum salmon is generally presented as an established fact, although there are limited data documenting quantifiable measurements of a preference by or survival benefits to summer chum salmon specifically. There are limited data on how much this preference actually contributes to overall production increases for fall chum, and no peer reviewed data was found on summer chum.

The literature review identified several habitat and water quality characteristics that are preferentially used for spawning by chum salmon. In most reports, groundwater upwelling is stated as a favorable habitat type, although other conditions such as substrate type, water depth, velocity, and turbidity influenced likelihood of use. In general, groundwater upwelling sites are understood to enhance spawning habitat and egg survival by providing stable temperatures, low turbidity, oxygenated water, and a mechanism for carrying waste products away.

A large majority of the research that was found on this topic focused on projects in Alaska and British Columbia, which have abundant fall chum runs. The following sections focus on the review of these regions first, since they had the most information. The Alaska literature reviewed focuses on the likelihood for spawning site selection based on critical habitat variables including groundwater upwelling. The British Columbia literature focuses on the improved success of spawning through demonstrated production increases in fall chum.

2.1 Alaska and Russia Research

In Alaska, presence of groundwater keeps streams from freezing, increasing egg incubation success and increasing availability of overwintering habitat (Woody and Higman 2011). In this 2011 study, Woody and Higman documented salmon–groundwater links in the headwaters of two Alaskan rivers, the Nushagak and Kvichak. The study looked at sockeye, Chinook, and chum spawning. Salmon presence and spawning were documented at numerous upwelling sites throughout these areas. The report did not designate specific differences in preference between the different salmon species analyzed.

The research currently being conducted for the Susitna-Watana Hydroelectric Project in Alaska has not been able to successfully quantify upwelling as a habitat suitability factor, though its importance for spawning site selection is apparent. Fall chum salmon are the most abundant anadromous salmon returning to the Susitna River, with minimum returns around 400,000 adults. The Susitna studies have quantified fall chum spawning site preference based on channel type (i.e., main channel, side channel, side slough, etc.), which showed a strong preference for side-channels and sloughs along the middle segment of the Susitna. At several of these sites semi-quantitative measurements of vertical gradients show water rising, indicating upwelling conditions. Aerial flyovers and thermal imaging also indicate most of these sites provide thermal refuge from freezing during the winter time for chum redds. Spawning success in side channels and sloughs was also shown to be positively correlated to other habitat criteria (e.g., substrate, water depth, velocity, etc.).

A study conducted on the Kwethluk River in Alaska found that summer chum salmon redd site selection was associated with the exchange of river water and groundwater and did not depend on surface-water velocity and substratum size, when analyzing main channel and two different types of off-channel habitats (Mouw et al. 2014). Flood off-channel habitats were those connected only during times of high flows where flood flows scoured the off-channel thalweg deep enough to encounter the alluvial aquifer and therefore provide upwelling both during flood and normal flow conditions. Spring off-channels were habitats that flow year-round due to alluvial aquifer upwelling conditions rather than being engaged only during flood flows. In the main channel, spawning was concentrated in regions of local downwelling, relying more on bed topography in this higher-flow habitat. In contrast, spawning in flood off-channel habitats was concentrated in localized upwelling areas. In spring, off-channel habitats, spawning occurred throughout the channels regardless of upwelling or bed topography conditions. The paper did not discuss the occurrence of freezing conditions in the mainstem versus the side-channel habitats; however, it was noted that the main channel and flood off-channels had water temperatures as low as 0°C, while spring channels did not go below 1°C. Compared to the main channel conditions, the off-channel areas had up to 8°C cooler temperatures in the summer and up to 5°C warmer temperatures in the winter.

Leman (1993) conducted a study assessing spawning conditions and survival of summer chum in the Kamchatka River, Russia, which freezes in the winter. The research looked at spawning in both groundwater-fed sites and those influenced by subsurface stream flow from 1982 to 1988. Leman defined the zone which included subsurface flow versus groundwater flow as the streambed surface to between 10 to 30 meters deep for this system. The study characterized spawning grounds at 120 sites and observed that approximately 60 to 70 percent of the summer chum spawning sites were in groundwater-fed channels with the remainder located in areas influenced by upwelling river flow. The groundwater-fed channels had cooler and more stable temperatures throughout egg incubation, while upwelling river flow sites had warmer temperatures but more seasonal fluctuation of temperatures. Groundwater sites allowed eggs to mature 1 to 1.5 months faster than the subsurface stream flow sites. The paper did not indicate whether this timing led to increased egg-to-fry survival through documented increased production.

Burrill et al. (2010) measured inter-gravel and surface-water temperatures and vertical hydraulic gradient at sites on the mainstem Tanana River in interior Alaska. Study sites were identified by an aerial helicopter survey of winter-time open-water habitat that exhibited signs of spawning fall chum. For all sites included in study, the vertical hydraulic gradient below the streambed was found to be positive (i.e., upward), suggesting that all of the sites experienced upwelling. Three commonalities among these spawning areas were inter-gravel water temperatures warmer than surface waters, upwelling present, and gravel substrate mostly free of sand. The study showed a positive correlation between vertical hydraulic gradient and accumulated thermal units (ATUs). This positive correlation means that areas with stronger upwelling would provide enough ATUs to allow fry to emerge sooner post-fertilization. However, the study did not look at overall survival to indicate whether this earlier emergence was beneficial.

2.2 British Columbia Research

British Columbia is another area of extensive research with respect to importance of groundwater upwelling for salmonid spawning habitat. In this region of the world, groundwater upwelling also serves to provide protection from freezing temperatures in stream systems. A more detailed summary of these studies and their relevant conclusions are included in this section.

An extensive study has been conducted on fall chum salmon within the Cheakamus River in British Columbia since 2001 (Fell et al. 2015). Groundwater influence on spawning site selection and productivity has been studied since 2007 and will continue at least through 2017 for river kilometers 0.5 to 8.0. The study is being conducted by Instream Fisheries Research for BC Hydro partially to test the effectiveness of the approved Water Use Plan for the Cheakamus River. The spawning benefit from groundwater upwelling in this system is similar to that in Alaska, where the groundwater provides warming of the surrounding water during the winter (1.5 to 2.0°C higher than in the river). This study, therefore, focused on temperature variances as the indicator for presence of upwelling within redds.

Fell et al. (2015) document that groundwater upwelling has a positive influence on both spawning site selection and productivity for chum in this system. Higher densities of pre-spawning adult chum salmon have been documented in the groundwater-fed side channels. The study compared peak spawning times to peak fry outmigration times over seven years in the upper section of the study area and determined that, over time, the majority of out-migrating fry appear to be emerging from redds with groundwater influence based on the temperatures measured in the productive redds. In 2014, side-channel habitats that were groundwater fed produced 92 percent of the total yield of chum fry within the upper section of the study area.

Ongoing studies from the Cheakamus River will provide additional information on these topics in the coming years. The study will continue to analyze chum salmon selection preference for groundwater in the mainstem and its effects on productivity through 2017. The study is also analyzing areas that are classified as effective spawning sites, but that are not being consistently utilized by chum. The study will focus on looking at temperature regimes in these areas.

British Columbia has placed a priority on the construction of groundwater-fed spawning channels for salmon habitat restoration. Between 1977 and 1991 more than 40 side channels were constructed on 17 different river systems (Bonnell 1991).

In a one-year study of improved groundwater-fed spawning areas in Southern British Columbia, Lister et al. (1980) observed high survival in these improved areas when compared to natural spawning areas elsewhere in the province. The study looked at formerly active flood channels that were cut off from the main river, but are fed by groundwater. Improvement techniques included removal of obstructions, excavation to increase groundwater flow and depth, increase in flow depth with structures, and addition of spawning gravel within these systems. The study assessed fall chum salmon spawning, egg-to-fry survival, and fry production at seven side-channel improvement projects. At these sites, egg-to-fry survival averaged 16.3 percent, approximately twice that of the six natural spawning areas documented in other studies. Maximum fry production in developed channels was estimated to be 517 fry/m^2, which is comparable to documented fry production in natural spawning areas from other studies.

Bonnell (1991) collected data from 24 channel improvement projects from 1978 to 1987 for analysis of production of emergent chum salmon in these systems. Bonnell (1991) expanded on the Lister et al. (1980) study by looking at a larger span of time. The review of data produced similar observations, including increased spawning in constructed groundwater-fed side channels in British Columbia. The paper reviewed did not designate whether summer or fall chum were analyzed; however, because Bonnell identified Lister et al. as a source for much of his comparisons, it is assumed that fall chum were analyzed. Bonnell (1991) calculated the annual production of emergent chum salmon was over 290 fry/m^2 in the constructed channels and the associated egg-to-fry mean survival over 16 percent. The study also showed that production and survival continued to be high for more than four years following construction.

2.3 Washington State Research

The Washington State studies that were found as part of this literature search covered areas in the Puget Sound region as well as the Columbia River, and focused on other salmonid species in addition to chum. A few studies were found that did answer the previously stated literature review questions. In addition, the literature search involved reviewing groundwater reports for the Chimacum Creek and Quilcene River systems, with a focus on groundwater–surface water interactions supporting upwelling conditions that were shown to be favorable for summer chum spawning based on the overall literature search.

2.3.1 Washington Research on Spawning Site Selection and Critical Habitat Variables

A frequently cited reference in the Washington studies regarding summer chum preference of groundwater upwelling areas is from the Life History of Chum Salmon chapter of *Pacific Salmon Life Histories* by E.O. Salo (1991). This chapter stated *"chum salmon prefer to spawn immediately above turbulent areas or where there is upwelling,"* but did not provide any data or references to support the statement.

A study conducted by Cowan (1991) evaluated three artificially developed and two natural groundwater-fed side channels on the East Fork Satsop River in Washington State. The study demonstrated a positive correlation between recruitment of chum salmon spawners and streamflow discharge in the channels. The range of egg-to-fry survival in all groundwater-fed channels in the study was 21 to 55 percent, which is improved over the ranges reported in other coastal streams. Cowan (1991) hypothesized that well-protected groundwater-fed channels likely moderate adverse effects on fry production by floods and other events that influence production in the main river channel.

In the Columbia River, Geist (2000) and Geist et al. (2001) examined hyporheic discharge in the Hanford Reach and Ives Island areas. These papers considered hyporheic discharge as a mix of phreatic groundwater and river water discharging into the river. Geist (2000) documented fall Chinook salmon spawning at Locke Island and Wooded Island hyporheic upwelling areas. The study found that fall Chinook salmon spawned predominantly in areas where hyporheic water discharged into the river channel. This upwelling water had a dissolved solids content indicative of river water and was presumed to have entered highly permeable riverbed substrate at locations upstream of the spawning areas. Rates of upwelling into spawning areas averaged 1,200 $l/m^2/day$ as compared with approximately 500 $l/m^2/day$ in non-spawning areas. Geist (2000) surmised that physical and chemical gradients between the hyporheic zone and the river may provide cues for adult salmon to locate suitable spawning areas. The study also showed that spawning locations were highly correlated with hyporheic discharge that was composed of mostly river water and not phreatic groundwater. The water that discharged into the fall Chinook salmon spawning locations had greater volume, higher dissolved oxygen, and lower specific conductance than water that discharged into non-spawning locations.

Geist et al. (2001) observed that chum and Chinook salmon spawned at different locations at Ives Island on the Columbia River based on characteristics of the hyporheic zone. Chum salmon redds were observed in areas where bed temperatures were 7 to 11°C warmer than the Columbia River and the vertical gradient between bed and river were positive (upwelling). The paper reviewed did not specifically state that fall chum were analyzed, but did state that the Ives Island chum are part of the Columbia River ESU.

2.3.2 Groundwater Report Review for Chimacum and Quilcene Systems

A 2004 USGS study focused on the ground-water system in the unconsolidated glacial deposits in the Chimacum and Tarboo Creek and the Big and Little Quilcene River basins (Simonds et al 2004). Geologic maps for the area were updated using LIDAR and drillers' logs from 110 inventoried wells. Each of the creeks examined had a unique pattern of gaining and losing reaches, owing to the hydraulic conductivity of the streambed material and the relative altitude of the surrounding water table. In general, the study found that groundwater parallels the surface topography.

As reported from the 2004 study, the mainstem of Chimacum Creek generally gains water from shallow groundwater system, except near the town of Chimacum, where it is losing water. The report provides data collected from piezometer sites stationed along the system (see Figures 12 and 13 from the report reproduced herein on pages 8 and 9). Figure 13 from the report provides a table showing piezometer river mile location. The reaches just above the confluence of the East Fork Chimacum and Mainstem Chimacum are losing reaches (upper reach 2, lower reach 3, and reach 8). In the portions of the creek, gaining conditions dominate in the summer, when the outlet from Delaney Lake (river mile 13) is dry, creek stages are low, and groundwater levels are high relative to the creek stages. This is a seasonally fluctuating condition. On the East Fork of Chimacum Creek, the reaches above Reach 8 also have extensive groundwater contribution in the summer. In an area below the confluence, between locations C4 and C3, there is an inflow of groundwater that pushed the system into a strong gaining condition. The stream returns to a generally gaining condition below site C2. Overall, the study found that Chimacum Creek receives a net gain of about 5 ft^3/s of groundwater over its entire length in the summer and about 7 ft^3/s in the fall.

Simonds et al. (2004) showed that the Big Quilcene River generally gains water from the shallow groundwater system after it emerges from a bedrock canyon (approximately river mile 4) and loses water from the town of Quilcene to the mouth. The losing condition in the lower reaches may be due to sediment deposition, which causes the channel bed to become disconnected from the water table. This system had a high amount of seasonal variation, which may be due to errors in measuring such a high-volume system. Generally, the data show that gains exceed losses during winter and spring high flow. Conversely during the low flow season, losses exceed gains.

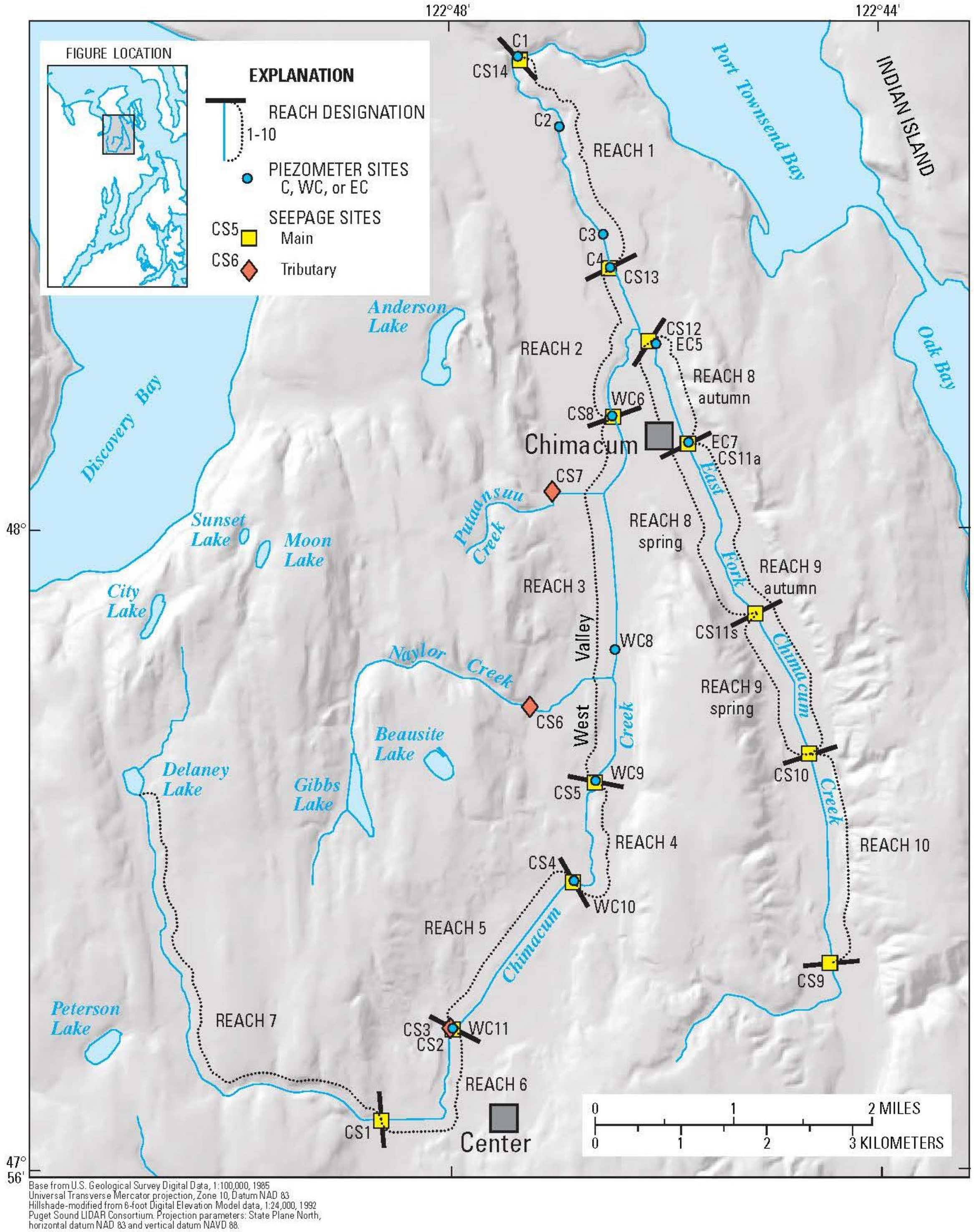


Figure 12. Locations of mini-piezometers and seepage-run measurement sites in the study reaches of the Chimacum Creek drainage basin, eastern Jefferson County, Washington.

Credit: U.S. Geological Survey, Department of the Interior/USGS
From Simonds, F.W., C.I. Longpré, and G.B. Justin. 2004. Ground-water system in the Chimacum Creek basin and surface water/ground water interaction in Chimacum and Tarboo creeks and the Big and Little Quilcene rivers, Eastern Jefferson County, Washington. U.S. Geological Survey Scientific Investigations Report 2004–5058, Reston, Virginia.

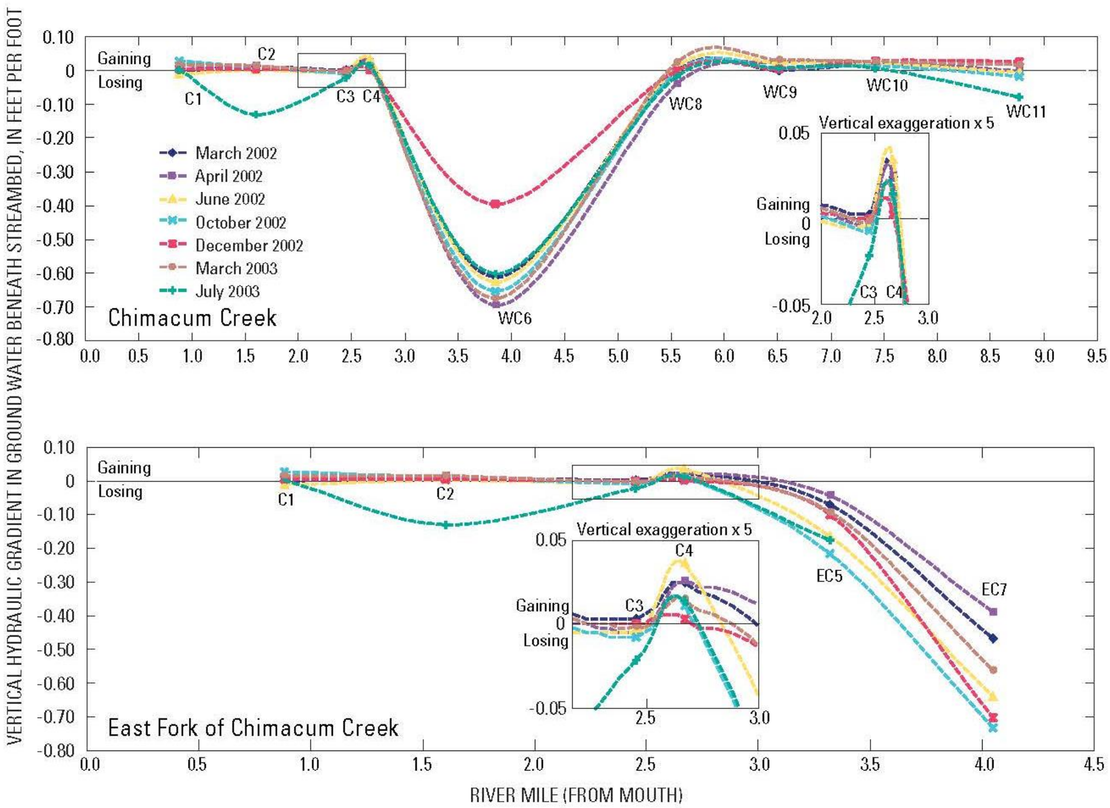


Figure 13. Vertical hydraulic gradient in ground water beneath the streambed measured at mini-piezometers in Chimacum Creek and East Fork Chimacum Creek, eastern Jefferson County, Washington, March 2002-July 2003.
Locations of mini-piezometers and seepage-run measurement sites are shown in figure 12.

Credit: U.S. Geological Survey, Department of the Interior/USGS
From Simonds, F.W., C.I. Longpré, and G.B. Justin. 2004. Ground-water system in the Chimacum Creek basin and surface water/ground water interaction in Chimacum and Tarboo creeks and the Big and Little Quilcene rivers, Eastern Jefferson County, Washington. U.S. Geological Survey Scientific Investigations Report 2004–5058, Reston, Virginia.

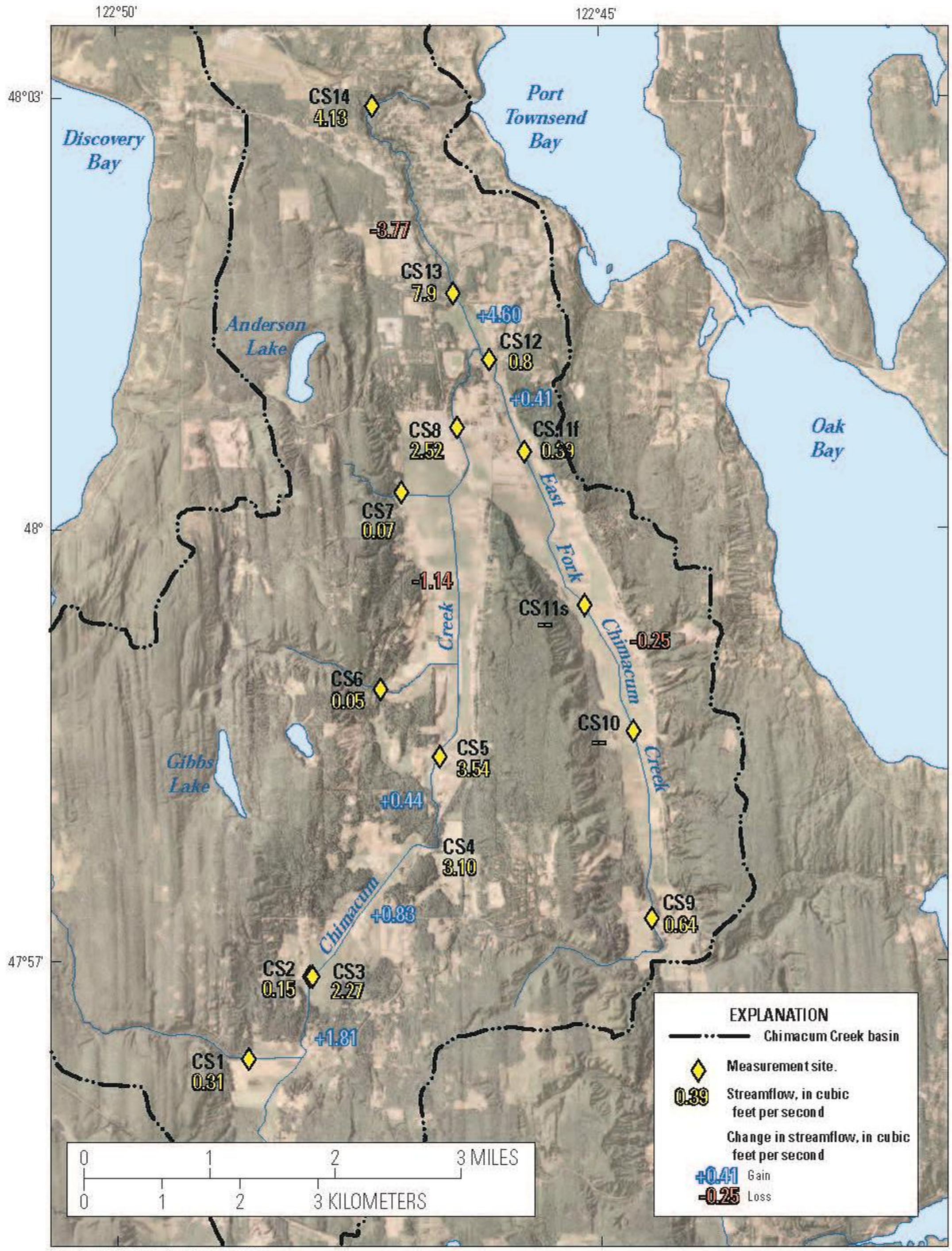
For the Little Quilcene River, Simonds et al. (2004) shows that the river generally loses water. This water loss starts where the river exits the bedrock streambed around river mile 3 and enters an alluvial streambed. The loss continues until river mile 1.1, where there is a slight gain that may be due to the proximity of Leland Creek. The river again enters a losing reach as it approaches the mouth. For this system, the seasonal variations are small.

A USGS study from 2011 of the Chimacum Creek system provide an updated overview of groundwater analysis conducted for the Chimacum Creek basin (Jones et al. 2011). Analysis of 187 drillers' logs provided data to construct four hydrogeologic sections and maps showing extent and thickness of hydrogeologic units within the study area. Based on the mapping, Chimacum Creek surficial geology from the Port Townsend Bay to Delaney Lake consists of the following:

- Vashon Recessional Outwash
- Quarternary Alluvium
- Older Glacial deposits
- Vashon Recessional Outwash
- Vashon Lodgement Till
- Vashon Advance Outwash
- Eocene marine sedimentary bedrock

The Upper Aquifer identified by the study lies predominantly in the Vashon recessional outwash and coarse-grained Vashon Till units. Within these units, the coarse-grained sediments can be water bearing and may form an unconfined water table when not overlain by the Upper Confining hydrogeologic units (primarily Quarternary Alluvium). The Upper Aquifer was found to have an average thickness of 18 feet.

Jones et al. (2011) shows that the upper reaches of the mainstem of Chimacum Creek are generally gaining and the lower reaches are losing, which is correlated to the surficial geology. The overall gains and losses measured are shown in Figure 12 from the report, reproduced herein on page 11. The study was conducted to analyze groundwater flow to inform water management decisions for the water resources within the study area. Spring flow as groundwater discharge was not measured directly for this study. The study primarily focused the analysis of discharge from groundwater due to withdraws for various human uses and where recharge is occurring to supplement these withdraws. Due to the focus and scale of the study the losing conditions reported in the lower reach may not be at a scale that would be informative for chum spawning location preferences.



Base from U.S. Geological Survey and/or
Washington Division of Geology and Earth Resources
digital data, 1983, 1:100,000
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)

Figure 12. Synoptic streamflow measurements and gain/loss amounts, Chimacum Creek basin and vicinity, Washington, July 10, 2007.

Credit: U.S. Geological Survey, Department of the Interior/USGS
From Jones, J.L., W.B. Welch, L.M. Frans, and T.D. Olsen. 2011. Hydrogeologic framework, groundwater movement, and water budget in the Chimacum Creek basin and vicinity, Jefferson County, Washington. U.S. Geological Survey Scientific Investigations Report 2011–5129, Reston, Virginia.

3.0 OVERVIEW OF INTERVIEWS

Scientists from the National Marine Fisheries (NMFS), Washington Department of Fish and Wildlife (WDFW), and Lower Columbia Fish Enhancement Group were contacted regarding their knowledge of summer chum salmon and research being conducted within Washington regarding the influence of groundwater on site selection and productivity. Table 1 lists the personnel interviewed. A summary of these interviews, by agency, is provided below the table.

Table 1. Confluence Interviews and Phone Conversations Conducted in Phase 1

Interviewee	Association	In-person or via phone	Date of interview
Mark Downen	WDFW fish biologist	Phone	January 6, 2017
Pat Powers	Former WDFW engineer	Phone	January 9, 2017
Matt Longenbaugh	NMFS	In-person	January 11, 2017
Tim Tynan	NMFS	In-person	January 11, 2017
Todd Hillson	WDFW	Phone	January 24, 2017
Pete Barber	Formerly with Lower Columbia Fish Enhancement Group	Phone	January 24, 2017

3.1 NMFS

NMFS personnel (Tim Tynan and Matt Longenbaugh) were not aware of data documenting changes in productivity associated with groundwater upwelling areas. In considering the success of salmon recovery efforts in the Big Quilcene, Matt indicated the City of Port Townsend may have some relevant data through studies associated with their water right for withdrawing flow from the river. They thought some data may also be available from WDFW to understand recent historic chum extents in the eastern Hood Canal river systems between the Tahuya River and Big Beef Creek. Of the watersheds along the east side of Hood Canal, Big Beef Creek will have the most data due to the WDFW monitoring.

In looking ahead to restoration, Matt recommended approaching restoration by identifying wetlands potentially beneficial to summer chum restoration and protecting those wetlands. He recommended working with Kitsap and Mason counties on those protections. Given Tim's previous work in Hood Canal, including contributing to ranking of restoration projects for funding, he could be a good source of site-specific information during Phase 2 work.

3.2 WDFW

WDFW has fish count data in Hood Canal rivers and some habitat data. They do not have hydrology or groundwater data to link fish use to groundwater. The City of Port Townsend and Jamestown S'Klallam Tribe were identified as potential sources of chum and groundwater data.

All WDFW personnel consider upwelling groundwater as a key indicator of preferred chum spawning locations. In the Lower Columbia River region, groundwater monitoring is an important first step in identifying restoration locations and developing a site design. Egg-to-fry survival at restored Hamilton and Duncan sites are nearly 50 percent, which is higher than in natural sites. In British Columbia, large spawning channels have been created using ground- and surface-water sources. The surface-water-fed systems work well also, but require more maintenance to keep the gravels clean and with low percent fines.

3.3 Lower Columbia Fish Enhancement Group

Pete Barber is currently with the Cowlitz Tribe and was formerly with the Lower Columbia Fish Enhancement Group. His experience is largely with fall chum in the Lower Columbia region. He considers identifying suitable sites for fall chum to be straightforward by looking for groundwater upwelling and good gravel substrate. This approach has worked very well for the Hamilton Springs and Duncan Creek restoration sites that have been constructed. He indicated that WDFW and British Columbia both recommend making created channels for chum to be "chum centric" to discourage juvenile predators, notably juvenile coho salmon, from moving into the area. This design approach entails no woody debris and no rearing habitat.

4.0 DISCUSSION

4.1 Literature Findings

Numerous studies reviewed document that summer and fall chum selectively spawn in areas of groundwater upwelling or groundwater-fed systems. Productivity analysis of fall chum spawning shows increased productivity in areas where spawning occurs in localized upwelling within side-channel habitats (e.g., Fell et al. 2015). No literature reporting quantitative analysis of summer chum productivity in relation to groundwater spawning was identified.

Groundwater provides numerous benefits to a variety of salmonid species which vary based on species and geographic location characteristics. Overall, groundwater upwelling provides reliable temperatures, low turbidity, and oxygenation. Groundwater upwelling is found to provide more stable temperatures than hyporheic discharge of river water, which continues to have seasonal fluctuation in temperature; although it is dampened slightly due to the hyporheic flow process. The functional importance of selecting groundwater upwelling areas that commonly freeze, such as in Alaska and British Columbia, is to provide warmer water at the riverbed level than surface water and therefore provides ice-free habitat and egg incubation conditions during the winter.

Studies were found that analyzed the benefit of whether the source of upwelling was phreatic groundwater or river water that was moving through inter-gravel flow paths within the substrate. Phreatic groundwater upwelling is sourced from an underlying aquifer compared to river water that moves through a relatively short flow path within the shallow substrate of a river. These studies focused on chum or other salmonid species in general and did not specify whether results applied to summer or fall chum or whether it was due to localized differences in the water being supplied between different stream systems (i.e., was the difference based on the other water quality benefits and what that benefit provided to salmon species in that particular system).

Some studies focused on localized upwelling that occurred in the locations of established redds, while others looked at spawning within groundwater-fed systems in general. The Mouw (2014) study conducted in Alaska for summer chum did look at a comparison of systems that had localized upwelling versus those that were groundwater fed. The study found that chum spawning occurred throughout the spring-fed systems and in localized groundwater locations for the other off-channel systems. This study also found that within main channels, where flow was higher, the summer chum preferred downwelling locations driven by favorable bed topography. This study was conducted in Alaska where the drivers for selecting sites is presumed to be different than the summer chum in Hood Canal.

The study on the Cheakamus River in British Columbia appears to be the most extensive study in the literature review that analyzed both site selection as well as productivity; however, again, the study was focused on fall chum on a system where warmer water is a benefit to egg survival due to potential for freezing in the river system. This study investigated but did not find a positive correlation between groundwater upwelling areas and increased chum salmon production. The study will be continuing into the future and may provide additional information with regard to specific habitat constituents that are drawing the salmon to groundwater upwelling locations specifically.

Studies in Washington were limited to other salmon species and fall chum. Studies conducted on the East Fork of the Satsop River in Washington State show that egg-to-fry survival in groundwater-fed channels is improved over the ranges reported in other coastal streams; however, the study did not quantify how this affected production in this system. The research that was reviewed on chum spawning in the Quilcene River system (Beecher 2000) was done in an area of water loss according to the USGS groundwater studies and focused on water flow level and the effects on spawning area versus groundwater upwelling. The other literature that was reviewed concerning studies in the Quilcene focused on general water supply management in the system rather than preference for summer chum spawning in groundwater upwelling locations.

4.2 Interview Findings

Based on these interviews, groundwater-fed channels are recognized as a key consideration in where chum choose to spawn. Efforts in the Lower Columbia River and in British Columbia to create spawning habitat that provides clean water and good gravel have been well used by chum. Surface-water or groundwater sources have both been successful; however, groundwater is preferable, in part due to apparent chum preference in natural settings and in part due to lesser maintenance needs to keep the gravels free of fine sediment.

The interviewees had additional recommendations for contacts to discuss further work and research being conducted. Contacting these sources was outside of the scope for this phase of work.

5.0 RECOMMENDATIONS

Recommendations are summarized below based on answering the two primary Phase 1 questions.

5.1 Correlations between groundwater and population success of summer chum and model information to follow for additional summer chum restoration efforts.

Based on the Phase 1 literature review and interviews, it is clear that summer chum, along with other salmonid species, prefer groundwater fed habitats for spawning. In planning for watershed restoration to support summer chum recovery, groundwater models and/or site specific information relating to groundwater upwelling can help inform where to focus efforts. The identification and enhancement of these areas within tributaries of the eastern shore of Hood Canal would appear to have a beneficial effect on the health and survival of this ESU. The USGS groundwater model for the Kitsap Peninsula is anticipated to be a good source of information in tributaries along the eastern shore of Hood Canal. The analysis of the model that is included in the Phase 2 scope of work can help identify potentially favorable locations for salmon recovery efforts (see discussion below in Section 5.2).

There is a challenge in directly linking these spawning preferences to increased productivity and overall population success. Anecdotally, there are high egg-to-fry survival rates in the groundwater-fed off-channels constructed in the Lower Columbia River region which suggests a positive contribution related to the groundwater inputs. Based on the interviews conducted to date, it is not likely that there are sufficient data to support a definitive correlation analysis between summer chum production increases and groundwater-fed systems. If specific documentation of groundwater upwelling's positive influence on egg-to-fry survival is desired by HCCC, there are several models and methods described in the papers found concerning how to measure and track this increase in egg-to-fry survival by summer and fall chum. These studies could be replicated in other areas of the east coast of Hood Canal between the Tahuya River and Big Beef Creek and expanded to determine whether this preference for groundwater-fed habitats leads to greater population success for summer chum specifically.

5.2 Groundwater upwelling site selection models that may be replicated in other areas, specifically in the watersheds of the eastern shoreline of the Hood Canal north of Tahuya River.

The Frans and Olsen (2016) USGS report on groundwater-flow systems for the Kitsap Peninsula was briefly reviewed with the expectation of a more detailed review in Phase 2. The report documented development and calibration of the MODFLOW model and provided data concerning the geology and hydrogeology of the eastern shoreline of Hood Canal. The Welch et al. (2014) USGS report on the hydrogeologic framework and groundwater of the Kitsap Peninsula provided additional data on geology, hydrogeology, stream flow, and water budgets. Stream flow gaging was conducted on the Dewatto, Anderson and Tahuya during summer low flow periods as part of the USGS study. These rivers appear to be receiving base flow primarily through the Vashon Advance and Vashon Recessional Aquifer Units. The simulated water levels in the Vashon Advance Aquifer Unit from the USGS model shows water levels converging towards Dewatto and Anderson and the lower reaches of Tahuya, suggesting groundwater discharge in those areas.

As scoped, Phase 2 of this project involves research and literature reviews specifically on what habitats and groundwater conditions exists within the Dewatto River and Anderson Creek watersheds, with a broader look at the other watersheds on the eastern shoreline of the Hood Canal north of Tahuya River. Analysis of the USGS groundwater model for the Kitsap Peninsula is included in our scope. The model can be used to evaluate the simulated spatial distribution of baseflows along the length of the rivers, which may show certain reaches receiving higher rates of flow than others. As part of this effort, simulated baseflows at the stream gaging sites within Dewatto, Anderson and Tahuya will be compared to evaluate how well the model matches the field observed flows.

Analysis of the USGS model, along with review of the local geology and hydrogeology documents found as part of the Phase 1 research, and other landscape characteristics, could help to identify favorable groundwater-fed restoration sites that could be beneficial to summer chum population growth.

It is recommended that there be the addition of some specific interviews with hatchery or fishery managers to determine the extent of historic summer chum access additional information on recommended restoration site selection criteria and the monitoring techniques to inform the future selection of habitat restoration sites.

Appendix A
Annotated Bibliography

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ANNOTATED BIBLIOGRAPHY

This annotated bibliography provides brief summaries of the literature sources identified and reviewed as part of Phase 1 of the evaluation of using groundwater data to inform summer chum salmon restoration in eastern Hood Canal. The two literature review focus questions for Phase 1 were:

1. Are there productivity success estimates for chum in naturally occurring groundwater-fed spawning areas?
2. What actions have been taken by Washington Department of Fish and Wildlife and the Lower Columbia Fish Enhancement Group to investigate the influence of groundwater on chum spawning and early rearing success?

Ando, D., Y. Shinriki, Y. Miyakoshi, H. Urabe, R. Yasutomi, T. Aoyama, Y. Sasaki, and M. Nakajima. 2011. Seasonal variations in and effect of incubation water temperature on vertebral number in naturally spawning chum salmon. Fisheries Science 77:779-807.

Article did not address either of the focus questions for this phase. Study addressed vertebral number response of spawning chum salmon at various incubation water temperatures. Results suggest that vertebral number response is influenced by genetic components of chum salmon. The authors hypothesize that a later spawning population of chum salmon utilizes groundwater, resulting in a low and stable vertebral number response.

Bakkala, R.G. 1970. Synopsis of biological data on the chum salmon, *Oncorhynchus keta* (Walbaum) 1792. U.S. Fish and Wildlife Service Circular 315, Washington, D.C.

Article did not address either of the focus questions for this phase. Article provides background for chum life history. Included is a general overview of areas preferential for chum spawning. No discussion of groundwater in relation to spawning habitat.

Beecher, H. 2000. Sensitivity of summer chum salmon spawning habitat to flow change in the Quilcene River memo. Washington Department of Fish and Wildlife, Olympia, Washington.

Article did not address either of the focus questions for this phase. Flow changes in the Quilcene River impact summer chum spawning by creating scour and desiccation risks. Based on review of groundwater data from other literature, the area studied as part of this article was in a losing reach of the Big Quilcene system.

Bernthal, C., and B. Rot. 2001. Habitat conditions and water quality for selected watersheds of Hood Canal and the Eastern Strait of Juan de Fuca. PNPTC Technical Report TR 01-1. Point No Point Treaty Council, Kingston, Washington.

Report did not address either of the focus questions for this phase. The report summarizes current habitat conditions for Pacific salmon in nine streams in Hood Canal and the Strait of Juan de Fuca. Parameters studied include instream habitat, riparian characteristics, large woody debris, temperature, and spawning gravel. Also included are recommendations for restoration and future monitoring needs for these streams. Information presented in this report may apply to Phase 2.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83--138 *in* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication, Bethesda, Maryland.

Article did not address either of the focus questions for this phase with respect to chum salmon specifically. Discusses the selection of upwelling areas as spawning by salmonids in general based on older research. Use of areas with groundwater flow may have survival advantages if the water quality (suitable temperatures and dissolved gases, and lack of damaging heavy metals and sediments) in such areas is more suitable than in areas without groundwater.

Bonnell, R.G. 1991. Construction, operation, and evaluation of groundwater-fed side channels for chum salmon in British Columbia. American Fisheries Society, Symposium 10:109-124, Bethesda, Maryland.

Study did not directly address the focus questions because it looked at restored channels in British Columbia. The information presented may be useful in future phases when looking at restoration benefits. Study collected data from 24 channel improvement projects from 1978 to 1987 for analysis of production of emergent chum salmon in these systems. The review of data showed increased spawning in constructed groundwater-fed side channels in British Columbia. The paper reviewed did not designate whether summer or fall chum were analyzed; however, because Bonnell identified Lister et al. as a source for much of his comparisons, it is assumed that fall chum were analyzed. Bonnell (1991) calculated the annual production of emergent chum salmon was over 290 fry/m2 in the constructed channels and the associated egg-to-fry mean survival over 16 percent. The study also showed that production and survival continued to be high for more than four years following construction.

Burrill, S.E., C.E. Zimmerman, and J.E. Finn. 2010. Characteristics of fall chum salmon spawning habitat on a mainstem river in interior Alaska. U.S. Geological Survey Open-File Report 2010-1164, Reston, Virginia. Prepared for Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative.

Paper did provide egg-to-fry success estimates for chum in naturally occurring groundwater-fed spawning areas. Study measured inter-gravel and surface-water temperatures and vertical hydraulic gradient at sites on the mainstem Tanana River in interior Alaska. Study sites were identified by an aerial helicopter survey of winter-time open-water habitat that exhibited signs of spawning fall chum. For all sites included in study, the vertical hydraulic gradient below the streambed was found to be positive (i.e., upward), suggesting that all of the sites experienced upwelling. Three commonalities among these spawning areas were inter-gravel water temperatures warmer than surface waters, upwelling present, and gravel substrate mostly free of sand. The study showed a positive correlation between vertical hydraulic gradient and accumulated thermal units (ATUs). This positive correlation means that areas with stronger upwelling would provide enough ATUs to allow fry to emerge sooner post-fertilization. However, the study did not look at overall survival to indicate whether this earlier emergence was beneficial.

Cascadia Consulting Group. 2003. Watershed management plan for the Quilcene-Snow Water Resource Inventory Area (WRIA 17). Prepared for WRIA 17 Planning Unit, Jefferson County, Washington.

Report did not address either of the focus questions for this phase. The Watershed Management Plan purpose is to recommend actions to ensure clean water for fish and human uses through water quality protection and enhancement, water conservation, and habitat protection/restoration. The Plan includes an assessment of both surface- and groundwater quality, quantity, and uses in the various water bodies of WRIA 17. Information presented in this report may be applicable to Phase 2.

Correa, G. 2002. Salmon and steelhead habitat limiting factors, Water Resource Inventory Area 17 Quilcene-Snow Basin, final report. Washington State Conservation Commission, Olympia, Washington.

Report did not address either of the focus questions for this phase. The purpose of the report is to summarize salmonid habitat data including riverine and nearshore processes and human-induced impacts to salmon productivity in WRIA 17. The report compiles various assessments, studies, analyses, and professional knowledge on these topics to assess the current level of knowledge and recommendations for additional research needed. Report has stock assessments for chum, but does not designate a specific species. Chum population status and distribution information presented in this report may be applicable to Phase 2.

Cowan, L. 1991. Physical characteristics and intragravel survival of chum salmon in developed and natural groundwater channels in Washington. American Fisheries Society Symposium 10:125-131, Bethesda, Maryland.

Paper did provide egg-to-fry survival estimates for groundwater upwelling influenced areas. The study evaluated three artificially developed and two natural groundwater-fed side channels on the East Fork Satsop River in Washington State. The study demonstrated a positive correlation between recruitment of chum salmon spawners and streamflow discharge in the channels. The range of egg-to-fry survival in all groundwater-fed channels in the study was 21 to 55 percent, which is improved over the ranges reported in other coastal streams. Report hypothesized that well-protected groundwater-fed channels likely moderate adverse effects on fry production by floods and other events that influence production in the main river channel.

Douglas, T. 2006. Review of groundwater-salmon interactions in British Columbia. Prepared for Watershed Watch Salmon Society and Walter & Duncan Gordon Foundation, Vancouver, British Columbia, November 2006.

This report does not cite specific productivity success estimates for chum in naturally groundwater-fed spawning areas, but it does provide a good summary of the importance of groundwater's role in supporting favorable salmon habitat in general. The report also discusses potential impacts to groundwater-fed streams from land use activities (such as well pumping and de-vegetation) that can decrease groundwater supplies and thereby impact important upwelling areas. Report cites numerous studies linking upwelling and favorable fish habitat in general, but has limited discussion specific to chum spawning sites. Report does discuss a study for sockeye in the Taku River that showed 60% of the spawning habitats were characterized by upwelling water. Another study that was cited demonstrated that young-of-the-year (age-0) brook trout prefer cooler water in summer when flow rate of cold groundwater accounted for 87% of the variance in trout density.

Locally, groundwater entering a stream can be predominantly phreatic, predominantly hyporheic, or a mixture of both. Spatial variability in groundwater upwelling can be related to surficial geology, topography, and stream geomorphology. Thermal patchiness in streams can provide habitat for species existing at the margin of their environmental tolerances and these "thermal refugia" may be responsible for persistence in rivers with high temperatures. Authors cite use of GIS approaches linking site-specific upwelling areas and watershed geomorphology and topography for management and conservation of fish habitat. Author also cites climate change may broadly affect fish habitat by increasing temperatures, altering flows, and causing potential impacts on groundwater.

Durst, J.D. 2000. Fish use of upwellings (annotated bibliography). Alaska Department of Fish and Game, Juneau, Alaska. Compiled for Region III Forest Practices Riparian Management Committee.

This report documents fish use of upwelling areas from a compiled bibliography of 15 studies. All but two studies were conducted in Alaska. The other two were in Canada and Idaho. The literature review was conducted to better understand fish use of upwelling areas and assist with evaluating potential risk to such areas by land-use activities in the Tanana River basin. Several cited studies found linkage/interaction between chum spawning and upwelling areas; most of the studies specifically mention fall chum. Although specific productivity success rates for chum in natural groundwater-fed areas were not quantified, one study of the Chena River in Alaska is cited as demonstrating chum spawning in sites that were directly or indirectly affected by groundwater seepage with an 84.2% average egg survival rate.

The literature review found that key attributes for fish habitat in upwelling areas are warmer winter temperatures and increased or consistent inter-gravel flows. Warmer water provides thermal units needed for hatching and prevents freezing of eggs. Note that winter-time freezing of eggs may not be as critical for chum spawning sites in Hood Canal streams. Upwelling flows oxygenate the water, carry away waste products, and prevent freezing. Fish survival may also benefit from the stability of these environments – stable temperatures, water levels, and inter-gravel flows.

Fell, C., D.J.F. McCubbing, L.J. Wilson, and C.C. Melville. 2015. Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Surveys from 2007-2014, and Chum Fry Production from 2001-2015. Cheakamus River Monitoring Program #1B, Technical Report for BC Hydro – Coastal Generation. InStream Fisheries Research, Inc., Vancouver, British Columbia.

Paper did provide productivity success estimates for chum in naturally occurring groundwater-fed spawning areas. Groundwater influence on spawning site selection and productivity has been studied since 2007 and will continue at least through 2017 for river kilometers 0.5 to 8.0. The spawning benefit from groundwater upwelling in this system provides warming of the surrounding water during the winter (1.5 to 2.0°C higher than in the river). Report documents that groundwater upwelling has a positive influence on both spawning site selection and productivity for chum in this system. Higher densities of pre-spawning adult chum salmon have been documented in the groundwater-fed side channels. The study compared peak spawning times to peak fry outmigration times over seven years in the upper section of the study area and determined that, over time, the majority of out-migrating fry appear to be emerging from redds with groundwater influence based on the temperatures measured in the productive redds. In 2014, side-channel habitats that were groundwater fed produced 92 percent of the total yield of chum fry within the upper section of the study area.

Frans, L.M., and T.D. Olsen. 2016. Numerical simulation of the groundwater-flow system of the Kitsap Peninsula, west-central Washington. U.S. Geological Survey Scientific Investigations Report 2016–5052, Reston, Virginia.

Report did not address either of the focus questions for this phase. Study area is underlain by a thick sequence of unconsolidated glacial and interglacial deposits that overlie sedimentary and volcanic bedrock units that crop out in the central part of the study area. Groundwater flow was simulated using the groundwater-flow model, MODFLOW-NWT, to analyze drinking water availability. Used the well information from 2,116 drillers logs to construct 6 hydrogeologic sections and unit extent and thickness maps. 2014 Kitsap Peninsula plates 1 and 2 referenced in report. Dewatto and Anderson Creek are within the Vashon recessional aquifer for the surficial Hydrogeologic Unit. Plate 2 contains cross sections, but none of the cross sections cross Dewatto or Anderson Creek. Information presented in this report will be applicable in Phase 2.

Geist, D. 2000. Hyporheic discharge of river water into fall chinook salmon (*Oncorhynchus tchawytscha*) spawning areas in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57:1647-1656.

The paper did not provide productivity improvement estimates for chum in groundwater systems. It focuses on research being conducted in the Columbia River on Chinook spawning preference for groundwater upwelling conditions. The study considered hyporheic discharge as a mix of phreatic groundwater and river water discharging into the river. Documentation was for fall Chinook salmon spawning at Locke Island and Wooded Island hyporheic upwelling areas. The study found that fall Chinook salmon spawned predominantly in areas where hyporheic water discharged into the river channel. This upwelling water had a dissolved solids content indicative of river water and was presumed to have entered highly permeable riverbed substrate at locations upstream of the spawning areas. Rates of upwelling into spawning areas averaged 1,200 $l/m^2/day$ as compared with approximately 500 $l/m^2/day$ in non-spawning areas. Author surmised that physical and chemical gradients between the hyporheic zone and the river may provide cues for adult salmon to locate suitable spawning areas. The study also showed that spawning locations were highly correlated with hyporheic discharge that was composed of mostly river water and not phreatic groundwater. The water that discharged into the fall Chinook salmon spawning locations had greater volume, higher dissolved oxygen, and lower specific conductance than water that discharged into non-spawning locations.

Geist, D.R., T.P. Hanrahan, E.V. Arntzen, G.A. McMichael, C.J. Murray, and Y. Chien. 2001. Physicochemical characteristics of the hyporheic zone affect redd site selection of chum and fall chinook salmon, Columbia River. Prepared under Contract No. 00000652, Project No. 199900304, by Pacific Northwest National Laboratory, Richland, Washington, for Bonneville Power Administration.

Study observed that chum and Chinook salmon spawned at different locations at Ives Island on the Columbia River based on characteristics of the hyporheic zone. Chum salmon redds were observed in areas where bed temperatures were 7 to 11°C warmer than the Columbia River and the vertical gradient between bed and river were positive (upwelling). The paper reviewed did not specifically state that fall chum were analyzed, but did state that the Ives Island chum are part of the Columbia River ESU.

Johnson, T., K. Adicks, C. Weller, and T. Tynan. 2008. ESA-listed Hood Canal summer chum salmon: A brief update on supplementation programs, natural-origin vs. supplementation-origin returns, and recovery. Washington State Department of Fish and Wildlife, Olympia, Washington.

Report did not address either of the focus questions for this phase. The report provides an overall update on summer chum recovery efforts in Hood Canal. Supplementation programs and restoration programs appear to have been successful in reducing extinction risk of several stocks. As of the writing of the report (2008), Hood Canal summer chum are not yet meeting recovery goals set by Washington Department of Fish and Wildlife or Point No Point Treaty Council, but populations are on an upward trend and show positive signs of meeting these goals.

Jones, J.L., W.B. Welch, L.M. Frans, and T.D. Olsen. 2011. Hydrogeologic framework, groundwater movement, and water budget in the Chimacum Creek basin and vicinity, Jefferson County, Washington. U.S. Geological Survey Scientific Investigations Report 2011–5129, Reston, Virginia.

Report did not address either of the focus questions for this phase; however, it does provide a review of groundwater analysis for the Chimacum Creek basin, which is part of the overall Phase 1 literature review. The study was conducted to analyze groundwater flow to inform water management decisions for the water resources within the study area. Spring flow as groundwater discharge was not measured directly for this study. The study primarily focused the analysis of discharge due to withdraws for various human uses and where recharge is occurring to supplement these withdraws. Analysis of 187 drillers' logs provided data to construct four hydrogeologic sections and maps showing extent and thickness of hydrogeologic units within the study area. Based on the mapping, Chimacum Creek units from lower to upper are: Vashon Recessional Outwash, Quarternary Alluvium, Older Glacial deposits, Vashon Recessional Outwash, Vashon Lodgement Till, Vashon

Advance Outwash, and Eocene marine sedimentary bedrock. The Upper Aquifer identified lies predominantly in the Vashon Recessional Outwash and coarse-grained Vashon till units. Within these units, the coarse-grained sediments can be water bearing and may form an unconfined water table when not overlain by the Upper Confining hydrogeologic units (primarily Quarternary Alluvium). The Upper Aquifer was found to have an average thickness of 18 feet. The report does contain a figure showing areas of gains and losses along the Chimacum Creek system.

Kuttel, Michael, Jr. 2002. Salmonid habitat limiting factors Water Resource Inventory Area 14, Kennedy-Goldsborough Basin. Washington State Conservation Commission, Olympia, Washington, November 2002. P. 134.

Report does not provide quantitative productivity success estimates for chum in natural groundwater-fed areas, but does provide summary of existing information (literature, data, and technical interviews) on the limiting factors related to salmonid habitat in WRIA 14. WRIA 14 is located mostly in Mason County, immediately south of Kitsap County WRIA 15. Like WRIA 15, the streams in WRIA 14 are rainfall-dominated and subject to low summer flows because of the lack of snowpack. Groundwater and storage in wetlands and beaver ponds all contribute to maintain summer stream flows. Report indicates South Puget Sound chum typically spawn between September and March and prefer to spawn immediately above turbulent areas or in areas of groundwater upwelling. Author notes that late chum stocks often select spawning sites near springs above 4°C, which protects the eggs from freezing and results in relatively consistent emergence timing from year to year. Intertidal spawning by chum also provide similar benefit (waters warmed by marine during each tide). Fry emerge generally from March through May and immediately head to estuary where they linger as they transition from fresh to salt water. Habitat limiting factors identified were: fish passage, riparian condition, bank stability, floodplain connectivity, width/depth ratio, substrate embeddedness, large woody debris, pool density and frequency, off-channel habitat, temperature, dissolved oxygen, adequate stream flow, and nutrients.

Landino, S. 2009. Comments on proposed water instream flow rule for WRIA 17 streams. Letter to Washington State Department of Ecology from National Marine Fisheries Service Washington State Habitat Office, Lacey, Washington, June 1, 2009.

Letter did not address either of the focus questions for this phase. This comment letter addresses a proposal from Ecology to adopt a water resource management rule aimed at conserving salmon and steelhead. NMFS identifies a few recommended changes to the proposed rule relating to instream flow management and metering new wells in WRIA 17.

Leman, V.N. 1993. Spawning sites of chum salmon, *Oncorhynchus keta*: Microhydrological regime and viability of progeny in redds, Kamchatka River Basin. Journal of Ichthyology 33(2):104-117.

Paper summarized a study assessing spawning conditions, groundwater upwelling and survival of summer chum in the Kamchatka River, Russia. This system freezes in the winter. The research looked at spawning in both groundwater-fed sites and those influenced by subsurface stream flow from 1982 to 1988. The study characterized spawning grounds at 120 sites and observed that approximately 60 to 70 percent of the summer chum spawning sites were in groundwater-fed channels with the remainder located in areas influenced by upwelling river flow. The groundwater-fed channels had cooler and more stable temperatures throughout egg incubation, while upwelling river flow sites had warmer temperatures but more seasonal fluctuation of temperatures. Groundwater sites allowed eggs to mature 1 to 1.5 months faster than the subsurface stream flow sites. The paper did not indicate whether this timing led to increased egg-to-fry survival through documented increased production.

Lestelle, L., L. Mobrand, and W. McConnaha. 2004. Information structure of Ecosystem Diagnosis and Treatment (EDT) and habitat rating rules for Chinook salmon, coho salmon, and steelhead trout. Mobrand Biometrics, Inc., Vashon Island, Washington.

Article did not address either of the focus questions for this phase. Assesses all life stages of Chinook, coho, and steelhead, including habitat factors to estimate productivity. Study aims to address how the quality and quantity of different habitats affect performance of salmonid populations in the Pacific Northwest utilizing EDT.

Lestelle, L., R. Brocksmith, T. Johnson, and N. Sands. 2014. Guidance for updating recovery goals for the Hood Canal and Strait of Juan de Fuca summer chum salmon populations. Prepared for Hood Canal Coordinating Council, pages 1-123.

Report did not address either of the focus questions for this phase. The report addresses the status of existing recovery goals that were identified in a formal recovery plan for Hood Canal summer chum, which provided background for literature reviews. Report recommends updates to these goals as well as "prioritizing future habitat restoration and protection actions, addressing harvest goals, continuing reintroduction efforts, and maintaining monitoring and evaluation efforts." Information presented in this report will likely be applicable in Phase 2.

Lister, D.B., and R.J. Finnigan. 1997. Rehabilitating off-channel habitat. Chapter 7 *in* P.A. Slaney and D. Zaldokas, editors. Fish Habitat Rehabilitation Procedures, Watershed Restoration Technical Circular No. 9, Watershed Restoration Program, Vancouver, British Columbia.

Article did not address either of the focus questions for this phase. Lister outlines the process for restoration of both groundwater and surface-water-fed off-channel salmon habitat including planning, design, and construction of these channels specifically for chum salmon habitat restoration. The article did not specify which species of chum the channel design was focused on. Information may be useful in Phase 2.

Lister, D.B., D.E. Marshall, D.G. Hickey. 1980. Chum salmon survival and production at seven improved groundwater-fed spawning areas. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1595, Department of Fisheries and Oceans Canada, Vancouver, British Columbia.

Paper summarizes a one-year study of improved groundwater-fed spawning areas in Southern British Columbia and survival of fall chum. Study observed high survival in these improved areas when compared to natural spawning areas elsewhere in the province. The study looked at formerly active flood channels that were cut off from the main river, but are fed by groundwater. Improvement techniques included removal of obstructions, excavation to increase groundwater flow and depth, increase in flow depth with structures, and addition of spawning gravel within these systems. The study assessed fall chum salmon spawning, egg-to-fry survival, and fry production at seven side-channel improvement projects. At these sites, egg-to-fry survival averaged 16.3 percent, approximately twice that of the six natural spawning areas documented in other studies. Maximum fry production in developed channels was estimated to be 517 fry/m^2, which is comparable to documented fry production in natural spawning areas from other studies.

Lohn, D. R. 2005. Endangered Species Act Section 7 Formal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Port Townsend Special Use Permits, HUC 1711001806 (Big Quilcene) and 1711001807 (Little Quilcene): Jefferson County, Washington. National Marine Fisheries Service.

Decision document did not address either of the focus questions for this phase. Decision issued in response to request from Olympic National Forest to re-issue special use permits to the City of Port Townsend for water diversions and uses. Base flow requirements are set for various sub-systems within the Quilcene River watershed as part of this decision. An analysis of summer chum evolutionarily significant unit (ESU) recovery status and designated critical habitat is included. The Big Quilcene River is identified as the center of abundance for the Hood Canal ESU. The document identifies loss of estuary and lower floodplain habitat as the major risk factor for the ESU. The document finds that for the Big Quilcene groundwater discharge in the lower reaches slightly offset the flow diversions that are occurring in the upper river. The document states that it is unknown to what extent upwelling or subsurface flows contribute to Big Quilcene summer chum incubation success.

Maclean, S. 2003. Influence of hydrological processes on the spatial and temporal variation in spawning habitat quality for two chum salmon stocks in interior Alaska. Master's Thesis. University of Alaska, Fairbanks.

Thesis measured habitat spawning conditions for summer and fall chum, including groundwater, dissolved oxygen, temperature, and water velocity in the Chena and Tanana Rivers in Alaska. The study reports that survival of summer chum eggs was highest in river water upwelling zones from hydraulic gradients between the river and the slough. For summer chum, egg survival was positively correlated with the intragravel dissolved oxygen concentration but no statistical significance was identified between egg survival and intragravel water velocity. Alternatively, fall chum salmon were shown to favor spawning in groundwater upwelling areas. The study did note that egg-to-fry survival was low despite high dissolved oxygen and favorable temperature conditions. This may have been due to errors in the study methods, so conclusions may not be supported.

Malcolm, I.A., C. Soulsby, A.F. Youngson, and D.M. Hannah. 2005. Catchment-scale controls on groundwater-surface water interactions in the hyporheic zone: implications for salmon embryo survival. River Research and Applications 21:977-989.

Article did not address either of the focus questions for this phase. In a study conducted in northeast Scotland, Malcolm et al. measured 16 salmon spawning sites with three typologies: groundwater dominated, surface-water dominated, and sites exhibiting transient water table features. The groundwater sites typically were long residence groundwater which resulted in low dissolved oxygen content. These sites were observed to be detrimental to salmon embryo survival.

McGrath, E., and M. Walsh. 2012. The use of groundwater upwelling areas by interior Fraser coho. Prepared for Fraser Watersheds and Salmon Program, Vancouver, British Columbia.

Study did not address either of the focus questions for this phase. Study investigated effects of groundwater upwelling on juvenile coho salmon in the Southern Interior of British Columbia. Results of the study show preference by juvenile coho for groundwater upwelling habitat. Using a Linear Mixed Model, summer coho density at groundwater sites was significantly higher than at control sites. For winter coho, presence of spawning sites was tied to temperature. At the groundwater sites, summer water temperatures were consistently lower and winter water temperatures higher than control sites. Temperature was preferable at the groundwater sites versus the control sites and was the only consistent significant predictor of salmon abundance in this study. McGrath and Walsh recommend that additional studies be conducted in order to further quantify the importance of groundwater in redd site selection by coho.

Michaud, J., and E. Britton. 2005. Preliminary assessment of Lower Hood Canal streams: 2004 study. Prepared by EnviroVision Corp., Olympia, Washington, for WRIA 16 Planning Unit.

Report did not address either of the focus questions for this phase. The purpose of the 2004 study was to provide baseline data for 14 streams in Lower Hood Canal by characterizing runoff, assessing potential land use impacts, and make recommendations for additional intensive investigative studies. The assessment provided insight into potential problem areas relating to flow conditions, surface-water runoff, and nutrient concentrations for future watershed management of Hood Canal. Through the study, no problems were identified that indicated a need for additional investigation. Information presented in this report could be applicable to Phase 2.

Morley, S., P. Garcia, T. Bennett, and P. Roni. 2005. Juvenile salmonid (*Oncorhynchus* spp.) use of constructed and natural side channels in Pacific Northwest rivers. Canadian Journal of Fisheries and Aquatic Sciences 62:2811-2821.

Paper did not address either of the focus questions for this phase. The study was conducted on natural versus constructed side channels designed to benefit both chum and coho salmon. The study assessed the overall effectiveness of stream restoration including habitat, water chemistry, temperature, invertebrate presence, and fish use on channels off the Skagit River, Hoh River, and Quillayute River basin. The research did not assess groundwater impacts on salmon spawning preference and/or abundance.

Mouw, J.E.B., T.H. Tappenbeck, and J.A. Stanford. 2014. Spawning tactics of summer chum salmon *Oncorhynchus keta* in relation to channel complexity and hyporheic exchange. Environmental Biology of Fishes 97(10) 1095-1107.

Report did not address either of the focus questions for this phase. Study looked at natural versus constructed side channels designed to benefit both chum and coho salmon. The study assessed the overall effectiveness of stream restoration including habitat, water chemistry, temperature, invertebrate presence, and fish use on channels off the Skagit River, Hoh River, and Quillayute River basin. The research did not assess groundwater impacts on salmon spawning preference and/or abundance.

Point No Point Treaty Tribes and Washington Department of Fish and Wildlife. 2014. Five-year review of the Summer Chum Salmon Conservation Initiative for the period 2005 through 2013: Supplemental Report No. 8, Summer Chum Salmon Conservation Initiative – an implementation plan to recover summer chum in the Hood Canal and Strait of Juan de Fuca region, September 2014. Washington Department of Fish and Wildlife, Olympia, Washington. 237 pp.

Report did not address either of the focus questions for this phase. Report is a five-year update on the Summer Chum Salmon Recovery Plan. No discussion of groundwater effects on summer chum.

R2 Resource Consultants, Inc. 2013. 2012 Instream flow planning study - summary review of Susitna River aquatic and instream flow studies conducted in the 1980s with relevance to proposed Susitna - Watana Dam Project - 2012: A Compendium of Technical Memoranda. Alaska Energy Authority, Anchorage, Alaska.

This report summarizes aquatic and instream flow studies conducted along the Susitna River during the 1980s. Specific productivity success estimates of chum in natural groundwater-fed spawning areas is not quantified; however, the report does demonstrate a link between fall chum success and groundwater upwelling sites. The report states that chum are the most abundant anadromous salmon returning to Susitna River with minimum returns in the 400,000-plus range. Chum salmon begin their returns in mid-July and peak during September. They spawn primarily in clearwater tributaries and side sloughs of the Middle Segment of the Susitna and "key" in on groundwater upwelling areas with large gravel/small cobble substrates. Silt and finer-grained substrates are not utilized. During the earlier 1980s studies, less than 10% of observed chum in the Susitna spawned in the mainstem. Chum spawn between August and September and incubate through winter, with emergence occurring generally between March and April. Susitna studies show that side sloughs have relatively stable water temperatures where groundwater upwelling is present. Groundwater upwelling in side sloughs provides stable inter-gravel conditions for redds, including warmer temperatures during winter incubation, with protection from dewatering or freezing and favorable water quality conditions (temperature and dissolved oxygen). Eggs laid in non-upwelling areas are prone to freeze during the winter time. Spawning in upwelling areas is mainly limited by available substrate. Excessive fines (defined by the authors as particles less than 0.08 inch in diameter) can reduce amount of inter-gravel flow so eggs don't receive enough oxygen and waste products are not removed. Also, influx of fines can entomb a redd.

R2 Resource Consultants. 2014. Habitat suitability curve development. Susitna-Watana Hydroelectric Project, FERC No. P-14141. Initial Study Report, Study 8.5, Part C, Appendix M. Prepared for Alaska Energy Authority by R2 Resource Consultants, Anchorage, Alaska, June 2014.

Report does not provide quantitative productivity success estimates for chum in natural groundwater-fed spawning areas. The report describes preliminary development of Habitat Suitability Criteria (HSC) curves and Habitat Suitability Indices (HSI) models for the Susitna-Watana Hydro Project. HSC/HSI models are being developed for the Susitna-Watana Hydro Project to predict the functional relationship between fish abundance and independent hydraulic and channel characteristic variables (depth, velocity, substrate, upwelling/downwelling, turbidity, etc.). The report presents details of methodology and preliminary findings for assessing fall chum salmon spawning in the Susitna River using site-specific 2013 HSC sampling data. At the Susitna site, groundwater upwelling was mapped in focus study areas using micro-piezometers to measure vertical hydraulic gradient (VHG). VHG data only indicate the presence of upwelling, downwelling, or neutral, but not actual fluxes. VHG data were only collected at discrete locations with shallow water depths (less than about 2 feet). Thus, the VHG data were not evenly distributed throughout project study areas and the upwelling parameter could only be used categorically in the statistical models. Nevertheless, preliminary univariate statistical modeling indicated that presence of upwelling could be predictive of chum salmon spawning.

R2 Resource Consultants, Inc. 2014. Fish and aquatics instream flow study - evaluation of relationships between fish abundance and specific microhabitat variables. Technical Memorandum. Prepared for Alaska Energy Authority by R2 Resource Consultants, Anchorage, Alaska.

Report does not provide quantitative productivity success estimates for chum in natural groundwater-fed spawning areas, but summarizes specific microhabitat variables for potential use in developing HSC/HSI models to predict fish (including fall chum) abundance. Microhabitat variables considered for modeling are those that are flow dependent, since future dam operations are likely to impact flows: water depth, velocity, presence of upwelling/downwelling, substrate type, cover, woody debris, turbidity, dissolved oxygen (inter-gravel and surface water). The report states that the exchange between groundwater and surface water (upwelling/downwelling) is expected to alter both the thermal and chemical regimes in aquatic habitats. Groundwater is buffered from surficial influences whereas surface water can be heavily influenced by annual and daily climate changes. Thermal regimes in upwelling areas therefore tend to display less variability in temperatures. The presence of upwelling provides cool or warm (depending on season) water refuge, influencing fish habitat use and distribution and egg/embryo survival. However, the authors reference another study that suggests groundwater chemistry can vary over fine spatial scales within the hyporheic zone, and that the presence of upwelling by itself may not always be an indicator of favorable incubation sites. At the Susitna site, presence of groundwater upwelling has been mapped in focus areas using micro-piezometers to measure VHG. The VHG data are useful for characterizing categorical presence of upwelling/downwelling, but cannot be used to estimate quantitative exchange of flux. Groundwater-surface-water exchanges are being studied in the Susitna River (Groundwater Study 7.5), but are not at a scale that can be currently used in HSC/HSI models.

R2 Resource Consultants, Inc. 2015. Fish and aquatics instream flow study - 2014-2015 study implementation report, Appendix D: Habitat suitability criteria development. Prepared for the Alaska Energy Authority by R2 Resource Consultants, Anchorage, Alaska.

Report does not provide quantitative productivity success estimates for chum in natural groundwater-fed spawning areas, but summarized latest development of HSC/HSI model for simulating probability of fall chum presence at different life stages. Model uses correlations between different hydraulic, physical, and water quality parameters. Latest development of model based on site-specific field data collected between 2012 and 2014 (summer and winter studies). Data collection included spawning surveys, fish surveys/counts, measurements of water depth and velocity, channel structure/cover, substrate type, water quality (temperature, dissolved oxygen, turbidity, electrical conductivity), and presence of upwelling/downwelling (VHG data). Results of the spawning survey indicate most fall chum spawning sites occurred in side-channel and slough habitats (79%) with median water depths of 1.2 feet and preferred substrates of small or large gravel. Currently, because of groundwater upwelling data limitations, the HSC/HSI model is not able to define a clear predictor between groundwater upwelling and chum spawning sites. However, the authors acknowledge that numerous other studies have identified a strong relationship between groundwater upwelling and spawning sites by chum, and that they would continue to evaluate specific influences of upwelling/downwelling in habitat selection for spawning.

Salo, E.O. 1991. Life history of chum salmon. Pages 232-309 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, Canada.

Chapter did not address either of the focus questions for this phase. Chapter reviewed stated *"chum salmon prefer to spawn immediately above turbulent areas or where there is upwelling,"* but did not provide any data or references to support the statement..

Simonds, F.W., C.I. Longpré, and G.B. Justin. 2004. Ground-water system in the Chimacum Creek basin and surface water/ground water interaction in Chimacum and Tarboo creeks and the Big and Little Quilcene rivers, Eastern Jefferson County, Washington. U.S. Geological Survey Scientific Investigations Report 2004–5058, Reston, Virginia.

Report did not address either of the focus questions for this phase; however, it does provide a review of groundwater analysis for the Chimacum Creek basin, which is part of the overall Phase 1 literature review. Report is a detailed study of the groundwater system in the unconsolidated glacial deposits in the Chimacum Creek Basin. Geologic maps were updated using LIDAR and drillers' logs from 110 inventoried wells. Groundwater parallels the surface topography. Chimacum Creek generally gains water from shallow groundwater system, except near Chimacum. In lower portions, gaining conditions dominate in the summer, when creek stages are low and groundwater levels are high. The upper reaches of Tarboo Creek generally gain water from the shallow groundwater system throughout most of the year and the lower reaches have little or no gains. The Big Quilcene River generally gains water from the shallow groundwater system after it emerges from a bedrock canyon and loses water from Quilcene to the mouth. The Little Quilcene River generally loses water. Each of the creeks examined had a unique pattern of gaining and losing reaches, owing to the hydraulic conductivity of the streambed material and the relative altitude of the surrounding water table.

Simonds, F.W., C.I. Longpré, and G.B. Justin. 2004. Map showing surficial geology and locations of inventoried wells and hydrogeologic sections in the Chimacum Creek basin, Eastern Jefferson County, Washington. U.S. Geological Survey, Reston, Virginia.

Maps referenced in document above.

Steward and Associates. 2006. Same-day flow analysis between Ecology gage (17A060) and USGS gage (12052210). Memo to Matt Longenbaugh (NOAA Fisheries) and Bob Metzger (USDA Forest Service), from Steward and Associates, Snohomish, Washington, August 15, 2006.

Memo did not address either of the focus questions for this phase; it does provide a review of groundwater analysis for the Quilcene River basin, which is part of the overall Phase 1 literature review. Steward and Associates performed a cursory analysis of records for two flow gages on the Big Quilcene River from 2002-2005 to identify relationship between flow at two locations on the river. The analysis showed that flow typically increases downstream throughout the summer chum spawning season, which is likely due to a higher inflow from areas downstream of a diversion.

Tynan, T. 1997. Life history characterization of summer chum salmon populations in the Hood Canal and Eastern Strait of Juan de Fuca regions. Washington State Department of Fish and Wildlife, Technical Report H97-06, Olympia, Washington.

Report did not address either of the focus questions for this phase. The purpose of the report is to characterize summer chum life history for Hood Canal and provide information on populations, habitat, spatial and temporal occurrence timing, and other characteristics. Summer chum spawning is addressed but not in relation to particular spawning site selection or productivity success estimates.

Waters, T. 1995. Effects on Fish. Pages 104 – 109 of Sediment in streams: Sources, Biological Effects, and Control. American Fisheries Society, Bethesda, Maryland.

Book did not address either of the focus questions for this phase. Groundwater upwelling and salmon habitat links have been observed throughout the United States. Use of groundwater upwelling areas by brook trout and brown trout for habitat and spawning is common in the Midwest and eastern United States. In comparison, in the Pacific Northwest, it is common for salmonid redds to be located in areas of downwelling stream water that carries suspended sediment.

Washington Department of Fish and Wildlife and Point No Point Treaty Tribes.. 2000. Summer Chum Salmon Conservation Initiative – an implementation plan to recover summer chum in the Hood Canal and Strait of Juan de Fuca region. WDFW, Olympia, Washington, April 2000.

Report did not address either of the focus questions for this phase. Provides good general update on summer chum recovery efforts and identifies potential restoration and protection efforts relating to groundwater upwelling areas. In Hood Canal, groundwater augments summer stream flows. Loss of critical areas and aquifers from development is an issue impacting natural groundwater sources. Report identifies potential restoration and protection efforts relating to groundwater as well as a need for additional research on relationship between groundwater and summer chum.

Washington State Department of Natural Resources. 1995. Big Quilcene Watershed Analysis (excerpt). Washington State Department of Natural Resources, Olympia, Washington.

Report did not address either of the focus questions for this phase. In this excerpt on hydrology from the Big Quilcene Watershed Analysis, a hydrologic assessment of the Big Quilcene Watershed Analysis Unit is presented with the goals of describing the hydrologic function of the watershed and land management influences on the hydrologic processes. Information presented in this report may be applicable for Phase 2.

Webster, D.A., and G. Eiriksdottir. 1976. Upwelling water as a factor influencing choice of spawning sites by brook trout (*Salvelinus fontinalis*). Transactions of the American Fisheries Society 105(3):416-421.

Report did not address either of the focus questions for this phase. Study analyzed the spawning tactics of brook trout in controlled lab environment. Trout selected spawning sites that were near upwelling locations in 21 of 22 controlled trials.

Welch, W.B., L.M. Frans, and T.D. Olsen. 2014. Hydrogeologic framework, groundwater movement, and water budget of the Kitsap Peninsula, west-central Washington. U.S. Geological Survey Scientific Investigations Report 2014-5106, Reston, Virginia.

Report did not address either of the focus questions for this phase. Document does not discuss stream systems specifically, but does have cross sections that will be useful for Phase 2 study.

Welch, W.B., L.M. Frans, and T.D. Olsen. 2014. Surficial hydrogeology, cross section traces and well locations, Kitsap Peninsula, west-central Washington. U.S. Geological Survey, Reston, Virginia.

Plates referenced by 2014 report above.

Welch, W.B., L.M. Frans, and T.D. Olsen. 2014. Hydrogeologic sections, Kitsap Peninsula, west-central Washington. U.S. Geological Survey, Reston, Virginia.

Plates referenced by 2014 report above.

Wilson, J. 2006. Preliminary investigation of chum salmon spawning in Kluane Lake. J. Wilson & Associates, Whitehorse, Yukon. Prepared for The Yukon River Panel Restoration and Enhancement Fund.

This study did not address either of the focus questions for this phase. The study analyzed habitat characteristics within identified fall chum salmon spawning locations associated with groundwater upwelling in Kluane Lake, Alaska. The study did not analyze non-groundwater upwelling habitats. The study area within Kluane Lake was located at the toe of the Silver and Outpost Creek alluvial fans. Wilson collected field measurements on site habitat characteristics including water temperature, water depth, dissolved oxygen, conductivity, and substrate composition. The study area did experience freezing conditions during the study period. In this upwelling habitat, water temperatures varied from 3.6 to 5.7°C, conductivity ranged from 280 us/cm to 940 us/cm and dissolved oxygen from 9.2 ppm to 12.0 ppm. While this study was conducted in a lake environment, it still provides additional support of utilization of groundwater upwelling areas by spawning chum.

Woody, C., and B. Higman. 2011. Groundwater as essential salmon habitat in Nushagak and Kvichak river headwaters: Issues Relative to Mining. Fisheries Research Consulting and Ground Truth Trekking.

This study did not address either of the focus questions for this phase. Report documents salmon–groundwater links in the headwaters of two Alaskan rivers, the Nushagak and Kvichak. Presence of groundwater keeps streams from freezing, increasing egg incubation success and increasing availability of overwintering habitat. The study looked at sockeye, Chinook, and chum spawning. Salmon presence and spawning were documented at numerous upwelling sites throughout these areas. The report did not designate specific differences in preference between the different salmon species analyzed.

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