CONFLUENCE ENVIRONMENTAL COMPANY

PGG

Groundwater Upwelling and Summer Chum Spawning

PHASE 2: GROUNDWATER MODELING AND OPPORTUNITIES

Prepared for:

Hood Canal Coordinating Council

May 31, 2017

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Groundwater Upwelling and Summer Chum
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1.0 INTRODUCTION

The Hood Canal Coordinating Council (HCCC) commissioned a two-phase study of groundwater resources in the eastern watersheds of Hood Canal north of the Tahuya River to inform summer chum salmon recovery efforts. The first phase focused on compiling available information on the relationship between groundwater and summer chum in selecting spawning habitats and in population success during the egg-to-fry life stage. Phase 2 of this project, reported here, involves research, literature reviews, and interviews specifically on what habitats and groundwater conditions exist 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. The goal of Phase 2 is to identify locations within these watersheds that would be good candidates for protection, enhancement, or creation of habitat to increase the beneficial spawning area for summer chum.

The work for Phase 2 includes the analysis of the United States Geologic Service (USGS) groundwater model for the Kitsap Peninsula to evaluate the simulated spatial distribution of groundwater upwelling and baseflows along the length of the rivers. As part of this effort, simulated baseflows at the stream gaging sites within Dewatto, Anderson, and Tahuya were compared to evaluate how well the model matches the field observed flows. Figure 1 shows the study area for Phase 2 work. This information is presented in Pacific Groundwater Group's (PGG) memo included as Appendix A.

Additional literature reviews were conducted as information was gathered on these watersheds. The annotated bibliography submitted as part of the Phase 1 report has been updated and is included as Appendix B.

The model analysis was supplemented with information gathered during the literature reviews and additional interviews with or information provided by the Hood Canal Salmon Enhancement Group (HCSEG), Washington Department of Fish and Wildlife (WDFW), and USGS. Analysis of the USGS model, along with review of GIS information and WDFW salmon usage information have been used to identify areas for potential protection as well as areas where additional research could be conducted that could be beneficial to summer chum population growth and recovery efforts.

2.0 OVERVIEW OF MODELING RESULTS

The USGS recently developed and calibrated a groundwater flow model for the Kitsap Peninsula to improve the understanding of water resources in that area and for use as a tool to assess future groundwater withdrawal effects on groundwater levels and streamflows during low-flow conditions (Frans and Olsen 2016). The model was utilized to analyze groundwater contribution to the Tahuya, Dewatto, and Anderson watersheds. Their summary of this analysis is provided below and more detailed results are included as Appendix A.

Six scenarios were run for the model based on input from project stakeholders. These scenarios are described as follows:

1. Steady-state condition
2. No pumping and return flows
3. A 15 percent increase in groundwater pumping
4. An 80 percent decrease in outdoor water usage (conservation)
5. A 15 percent decrease in recharge (drought)
6. Particle tracking to evaluate source areas for select wells

The steady-state condition was analyzed for this report to capture typical conditions seen on the Peninsula. For Scenario 5, the model showed that reducing the recharge by 15 percent between 2005 and 2012 had the largest overall effect on the Kitsap Peninsula. Water levels declined throughout the model domain and baseflow amounts decreased by as much as 18 percent compared to baseline conditions in the model. Removing all pumping and resulting return flows increased water levels in many areas and increased baseflows between 1 and 3 percent. This shows that the model domain in general is sensitive to groundwater pumping or drought conditions.

The simulated groundwater discharge to the Tahuya, Dewatto, and Anderson were extracted from both an average steady-state simulation and a monthly transient simulation (2005 to 2012) to evaluate the distribution of groundwater upwelling and baseflows in these watersheds. Each model cell has a horizontal dimension of 500 by 500 feet. Thus, model output is on a scale of every 500 feet in a horizontal direction. When plotted in the figures included in this report, the center of each cell is represented by a dot or node. Areas of focused upwelling simulated in the model can be used together with other criteria to select areas for further investigation of summer chum population recovery success.

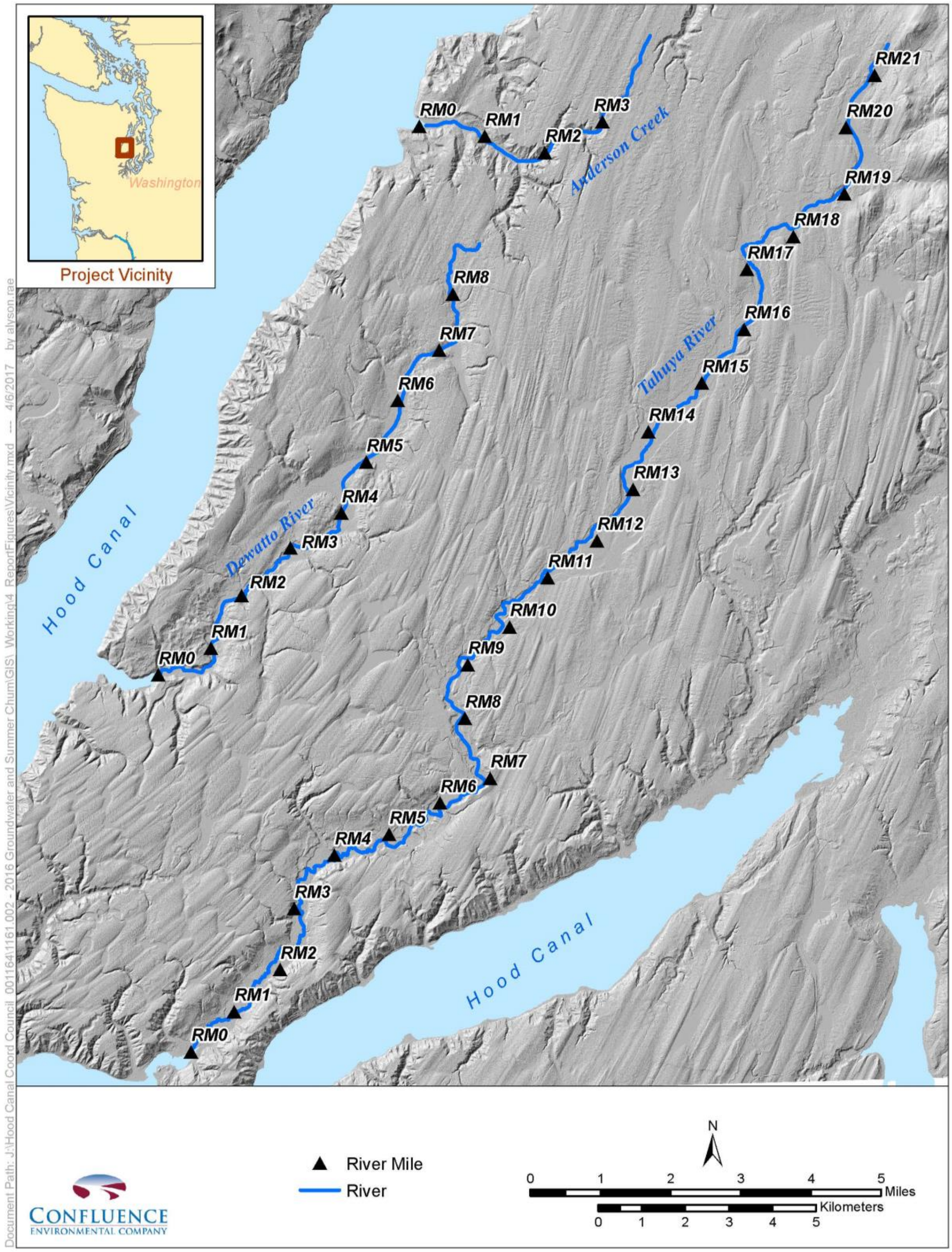

Figure 1. Phase 2 Study Area

Model results were extracted from the model at the location of three gaging stations located on the Tahuya, Dewatto, and Anderson where stream flow was measured by the USGS or Kitsap Public Utilities District (KPUD) during the summer months of 2011 and 2012 in support of model calibration. Table 1 lists the gage stations and locations analyzed.

Table 1. Gage Stations Located within Tahuya, Dewatto, and Anderson Systems

Gage Station	Location
USGS 12067700	Tahuya river mile (RM) 7.0
USGS 12068500	Dewatto RM 2.0
KPUD-AN	Anderson 700 feet from mouth

Based on the comparison to measured data, the simulated numbers for the watersheds are as follows:

- Tahuya measured data was on average approximately half the simulated data,
- Dewatto measured data was on average approximately 40 percent lower than simulated data, and
- Anderson measured data was on average approximately 40 percent higher than simulated data.

Despite the disparity between the simulated and measured baseflows at these locations, the model calibration to baseflows was considered acceptable for the entire model domain (see model calibration discussion in Appendix A). Given the much larger scale of the USGS model relative to the three watersheds, and the inherent uncertainty associated with using a model to represent complex systems, use of the model for smaller systems (e.g., Anderson) and at fine scales within these watersheds should be used with caution.

The model results discussed in Appendix A, and shown in Figure 2 below, show that in general groundwater upwelling is concentrated along the mainstem of each stream with very little exchange between groundwater and surface water occurring in the tributaries, which could indicate that the tributary flows are largely driven by overland flow. However, as explained in Appendix A, shallow perched groundwater may provide some groundwater discharge to these upper tributaries. Model results should be limited to use as a screening tool to identify broad stream reaches composed of several model cells (five or more) where upwelling may be focused and which should ultimately be confirmed with field based investigations (see limitations of model in Appendix A). Actual observations of upwelling and baseflow (where available) are generally more informative than model predictions.

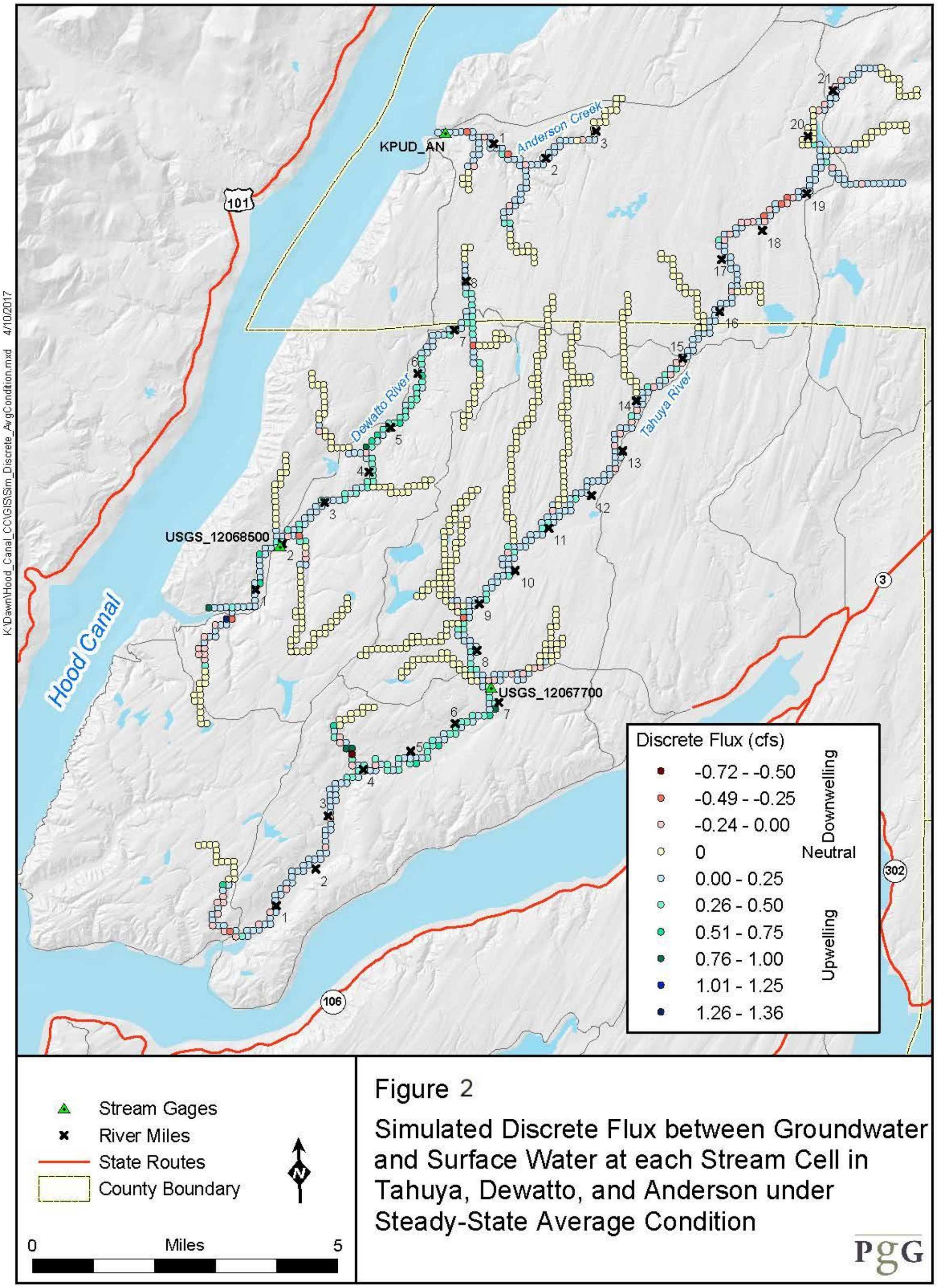

Figure 2. Simulated Discrete Flux Between Groundwater and Surface Water at Each Stream Cell in Tahuya, Dewatto, and Anderson Under Steady-State Average Condition

3.0 OVERVIEW OF INTERVIEWS

Scientists at the HCSEG, WDFW, and USGS were contacted to discuss observations of summer chum in these systems, areas of observed groundwater upwelling, opportunities for conservation or enhancement, and clarifications on the Kitsap Peninsula model. The results of these discussions are summarized below.

3.1 Hood Canal Salmon Enhancement Group

Representatives from the HCSEG were interviewed by telephone on March 28, 2017. HCSEG works with WDFW in these watersheds and collects otolith, scale, and DNA samples. HCSEG has worked throughout all three watersheds. They are very familiar with the conditions in each watershed. They have good relationships with landowners in each watershed and have proposed assessment work that they anticipate will further strengthen their relationships.

HCSEG communicated the importance of the lowermost reaches and estuaries, perhaps more so than groundwater resources higher in the watershed. Although, they also noted the importance of groundwater in maintaining base flows of cool water in the stream systems. HCSEG reports summer chum spawning in the following extents of these rivers:

- Tahuya River: observed up to RM 4.0, highest concentration in first 3 miles
- Dewatto River: observed up to RM 0.75, highest concentration in first 0.5 miles
- Anderson Creek: few if any summer chum returns to the creek

These observations are during existing run sizes. It is reasonable to expect that as the number of returning adults increase, summer chum will move (somewhat) higher in the systems to locate available locations suitable for spawning.

HCSEG has not used groundwater information to inform project siting except to add large woody debris at the mouth of a cool creek or along a bank where upwelling may be contributing to bank instability. HCSEG has been looking at the question of whether some reaches go dry during summer low flows due to changes in groundwater and/or changes in sediment supply. Additional information on groundwater resources as a tool to help focus or inform their restoration and conservation work would be welcomed. Specifically, an assessment project that HCSEG is proposing for Salmon Restoration Fund Board funding in the Tahuya (and Union) River watershed would benefit from additional groundwater data that would help inform this question of what is causing flows to go subsurface.

In HCSEG's opinion, the creation of spawning channels, similar to what has been done in the Lower Columbia River and British Columbia, are not an appropriate treatment for the Hood Canal rivers.

3.2 WDFW

There was no interview with Mark Downen of WDFW, but via email he provided spawning ground survey data for summer chum from 2009 through 2016 for Anderson, Dewatto, and Tahuya. The numbers of summer chum discussed below are the sum of the live and dead fish observed during the single survey event with the highest count for that year. WDFW does not do any redd surveys in these rivers at this time.

Survey efforts in Anderson Creek have been limited to three or fewer partial or spot surveys over seven out of the eight years since 2009. From 2009 to 2015, all survey data in Anderson Creek were on observations made between RM 0.0 and RM 0.2. In 2016, two surveys were conducted that extended as far up as RM 1.0. Effectively, no summer chum spawning has been documented in the creek. Two live fish were observed in 2012 and one or zero fish observed during all other years.

In Dewatto River, WDFW spawner surveys occur in an index reach from RM 0.3 to RM 1.8. Summer chum were observed in all survey years. The highest number of summer chum were observed in 2015 with a total number of 205. The lowest number of summer chum was 11 fish in 2010.

In Tahuya River, summer chum return counts are presented by reach in Figure 3. WDFW has surveyed up to four reaches in the river. No summer chum were observed in 2010 and 2011, but in ensuing years the number of returns have been increasing. In 2016, more than 1,000 summer chum were documented by WDFW. Since 2012, the highest number of summer chum have been observed in the reach between RM 1.0 and RM 2.6. The numbers between RM 1.0 and RM 2.6 have ranged between 84 and 627 since 2012. The lowermost reach from RM 0.6 to RM 1.0 has had the second highest number of summer chum ranging from 43 to 189 in a single year. The reach between RM 2.6 and RM 5.0 has been surveyed annually since 2013. The number of summer chum ranged between 22 and 31 before spiking to 240 in 2016. In 2016, a reach between RM 5.0 and RM 7.5 was surveyed for the first time and six live fish were observed.

Mark Downen hypothesized three main factors affecting summer chum spawning distributions in the Tahuya River. First, the number of fish returning will affect the distance (and time) over which they spawn. The larger the run, the more protracted the spawning area and spawn timing can be. Second, hatchery summer chum are released into the system in a small tributary near RM 1.1. Returning adult numbers tend to be greatest near and downstream of this tributary. Third, the availability of suitable spawning habitat may result in fish moving higher in the river, particularly with higher run sizes. Mark reports that substrates in the lower Tahuya are unconsolidated and may be too unstable to provide favorable egg incubation conditions. Sediment conditions higher in the watershed appear more stable and conducive to successful egg incubation.

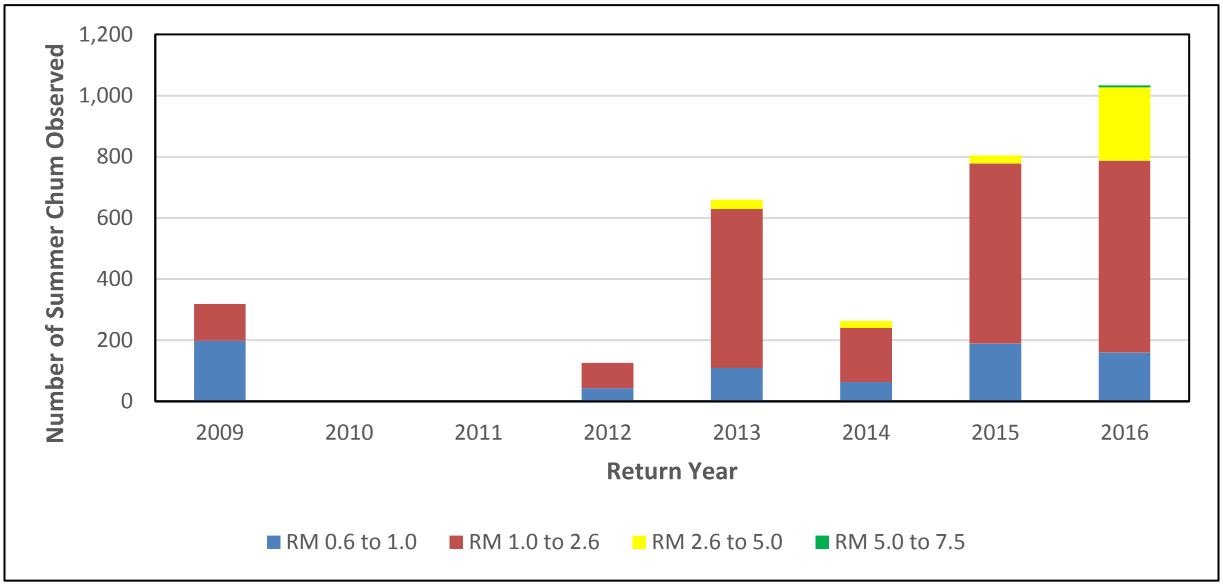

Figure 3. Summer Chum Returns in the Tahuya River

Source: M. Downen, WDFW

In an interview with Todd Hillson (WDFW), he stated that 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. WDFW observations of egg-to-fry survival at restored Hamilton and Duncan sites are 50 percent or higher (e.g., 60 percent in 2003 to 2004, Hillson 2004), which is higher published survival rates in the literature (e.g., Quinn [2005] literature review reported 12.9 percent survival). Mr. Hillson also indicated that 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

The Lower Columbia Fish Enhancement Group has conducted several projects focusing on fall chum salmon recovery in river systems draining into the Columbia River. Pete Barber, formerly with the organization, managed several of these projects. His projects focused on fall chum rather than summer chum, which potentially limits the project applicability due to life history trait differences between the runs. Pete 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. A "chum centric" design approach entails no woody debris or habitat complexity, which is preferred habitat conditions for other juvenile salmon species who may prey on emerging chum salmon. Since chum salmon emerge from the gravel and promptly move downstream, they do not require or necessarily benefit from instream rearing features such as large wood or cover.

3.4 USGS

Lonna Frans, lead developer and author of the Kitsap Peninsula model for USGS, recommended using the Kitsap groundwater model as a rough first-cut in identifying areas of upwelling in streams on the Kitsap Peninsula. She recommended using the model in a broad way for identifying spatial patterns, but not to focus on absolute numerical values. When looking for areas with higher rates of groundwater upwelling, she suggested using a scale of five model cells or more (each model cell is 500 feet by 500 feet). Areas predicted by the model as having higher rates of groundwater upwelling should only be used as a screening tool to be confirmed with field measurements.

Lonna also mentioned that there was less data available for model calibration in Mason County (which covers much of the Dewatto and Tahuya watersheds) than in Kitsap County, and therefore it was difficult to assess how well the model is calibrated in that area. She mentioned that calibration to streams in general was a challenge and that they had difficulty in simulating adequate flux in the headwaters of many streams. She mentioned that the larger flows were better matched and that matching the flows in smaller streams was much trickier, in which case simulating baseflows within the right order of magnitude was generally considered acceptable.

During our conversation, the topic of future field data collection came up and there are methods developed by the USGS for collecting continuous measurements of streambed temperatures during baseflow conditions that can be used to map long reaches of streams and identify areas of cooler water that could indicate focused groundwater upwelling. These areas can then be confirmed with measurements of hydraulic heads between the groundwater and overlying stream (see Section 5.0 below).

4.0 GIS ANALYSIS

GIS was used to overlay information on surficial geology, wetlands, Light Detection and Ranging (LiDAR) data, and parcel information to compare to the average monthly model outputs from August to October. This time period was chosen because Hood Canal Summer Chum Salmon enter the systems to spawn between mid-September and late October (Kuttel 2003). The analysis of these overlays was focused in the regions where WDFW surveys have documented fish presence or where SalmonScape indicates historic runs have occurred (WDFW 2017). Focusing on these areas will allow identification of possible areas to collect further information based on existing fish use or areas where there may be opportunities for restoration or protection in order to increase the number of summer chum within these systems. The monthly model results did not vary more than 5 percent for August through October in the areas of focus, so September data is displayed in Figures 4 to 8.

When analyzed, the surface geology layer obtained from USGS did not provide additional information to help interpret modeled changes in groundwater because the surface geology along the mainstem of these systems is uniform and composed of Quarternary alluvium deposits. The focus was also on the mainstem of the systems since those are the areas where WDFW and HCSEG have noted fish presence and based on results from the Kitsap model, it is where groundwater upwelling is most concentrated (Appendix A).

4.1 Tahuya

Based on a review of the Tahuya steady-state average model results shown in Figure 2, there are areas of potential groundwater upwelling around RM 2.0 and between RM 4.0 and RM 12.0 (see Appendix A, Figure 5). The highest concentration of upwelling is between RM 4.0 and RM 8.0. According to WDFW RM 0.6 to RM 2.6 has the highest concentration of summer chum usage, with the majority of the usage in RM 1.0 to RM 2.6. WDFW spawning surveys have identified fish up to RM 7.5 and SalmonScape identifies historic runs up to RM 8.9 (WDFW 2017). Based on a review of the Mason County Hydrology GIS information, there is a large wetland complex from approximately RM 2.0 to RM 3.5, which is in the area of positive groundwater upwelling. These areas are shown on Figures 4 and 5 below. The hydrology of these wetland complexes cannot be determined based solely on a review of groundwater model output; however, they may be supported by a source of groundwater upwelling in this area.

The areas of the wetland complex between RM 2.0 and RM 3.0 are owned by Neyhart Tahuya Farms (the larger parcels in this reach shown on Figure 4). From RM 1.0 to RM 2.0 parcels are owned by a variety of private land owners. When looking at the predicted summer monthly groundwater flux from the model, there is generally upwelling around RM 1.0 and RM 2.0 (represented by orange [very slight upwelling], green, and blue [stronger upwelling] nodes shown on Figure 4). These two groundwater upwelling locations are indicated by six model cells of upward flux, which is enough to indicate a trend according to USGS. The red nodes on this figure are representing downwelling for that cell based on the model. This figure also shows the parcels for the development around Maggie Lake, which may have groundwater withdraws for drinking water. If drinking water wells are withdrawing from the Vashon Recessional or Vashon Advanced aquifer layers identified in the model, this may mean a reduced capacity for groundwater discharge in this area.

WDFW have observed summer chum in the Tahuya system as far up at RM 7.5. This indicates that the wetland complexes seen between RM 2.0 and RM 4.0 do not present barriers to access. There is an area of simulated groundwater upwelling during the summer months in the area of RM 4.0 as shown on Figure 5 (12 model cells total). This area of upwelling is stronger than that around RM 2.0 as indicated by the green and blue nodes. This area is just downstream of a housing development which may also have groundwater withdraws for drinking water. Property ownership in this area is primarily forestry related (as shown in Figure 5), but there are some private ownerships.

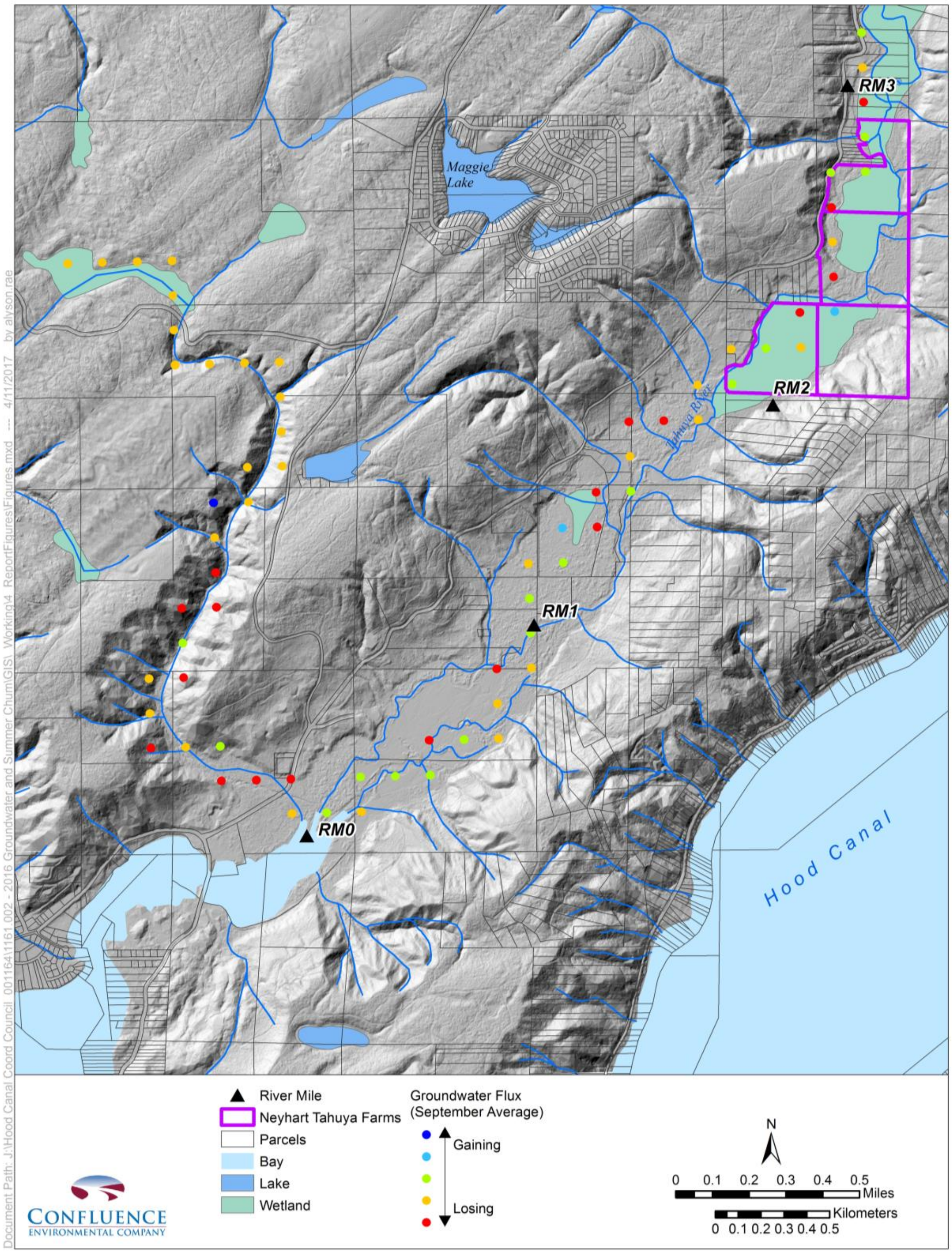

Figure 4. Average September Groundwater Flux: Tahuya RM 0.0 to RM 3.0

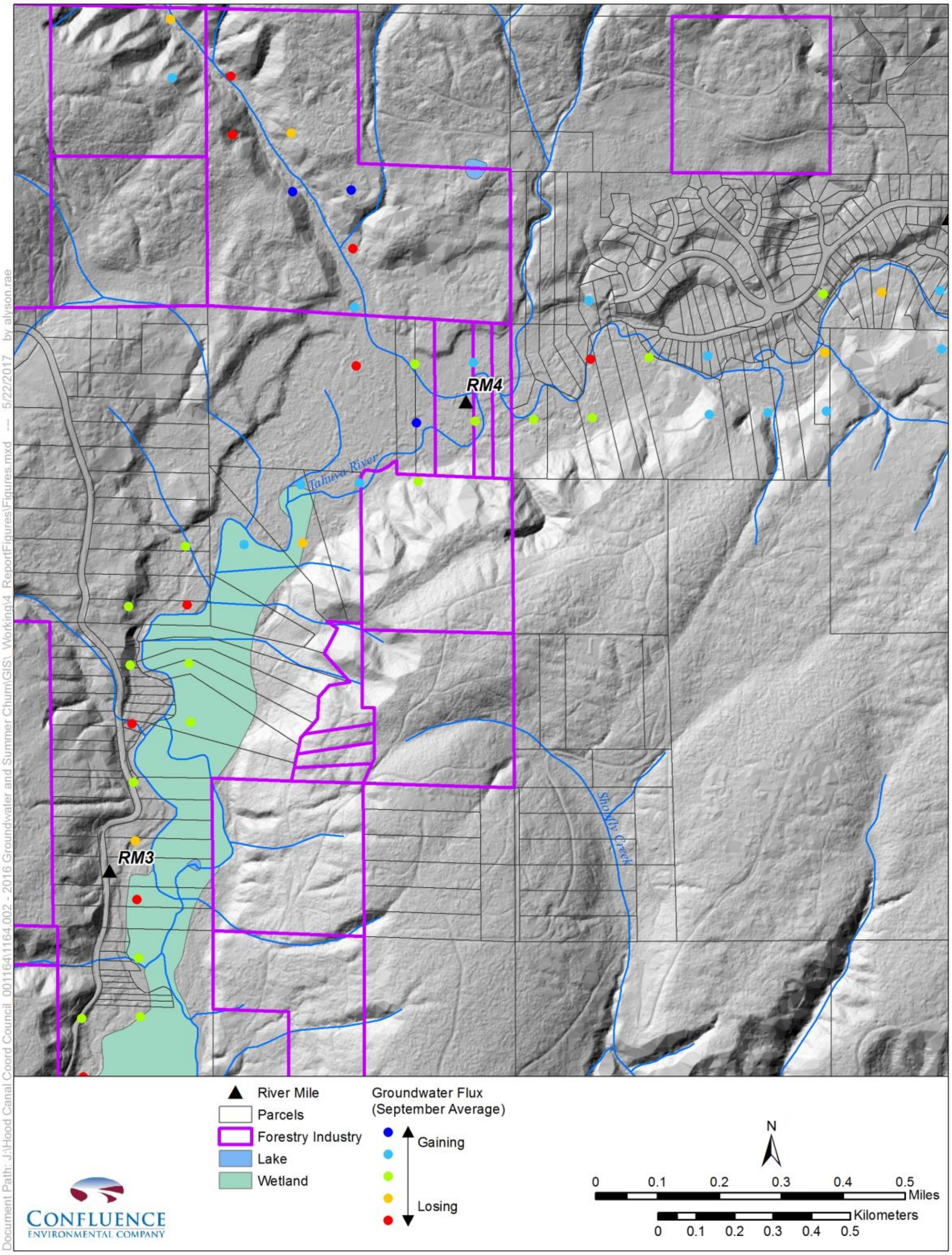

Figure 5. Average September Groundwater Flux: Tahuya RM 3.0 to RM 4.5

4.2 Dewatto

Based on a review of the Dewatto steady-state average conditions shown in Figure 2, there are areas of potential groundwater upwelling throughout the mainstem of the Dewatto (also see Appendix A, Figure 7). As described above, the currently low numbers of summer chum returning to the Dewatto are using the lower 0.75 miles. WDFW SalmonScape shows historic runs as far up as RM 4.9 in this system (WDFW 2017). The GIS analysis focused on the first mile of the river in this watershed when considering groundwater upwelling areas that summer chum may prefer. A general review of upwelling areas higher in the watershed was conducted where groundwater contributes to base flow but is not currently used by summer chum.

When looking at simulated average monthly flux data there is modeled groundwater upwelling occurring August through October in the region of the mouth and between RM 1.0 and RM 2.0 represented by a string of 14 model cells (see Figure 6 below). The LiDAR data for this watershed and WDFW's stream catalog (Washington Department of Fisheries 1975) were reviewed to determine if there would be any large obstructions between the mouth and RM 1.0 to determine if anything may be blocking summer chum access to the upwelling above RM 1.0. No steepening of the channel or large obstructions were observed (see Figure 6).

In analyzing property ownership, there are large tracts of forestry ownership in the region of potential upwelling near the mouth of the river, with the exception of a small parcel that belongs to the Port of Dewatto and is developed as the Dewatto River Campground. The HCSEG owns the parcel just below RM 1.0 and the parcel that surrounds RM 1.0 is privately owned (see Figure 6). All three of these parcels would require landowner permission for access to the river for research, conservation or restoration opportunities.

When considering the historic extent of the summer runs there is a large area of potential upwelling (as simulated with the model by a series of five blue and green nodes) and a wetland complex in the area of RM 4.0 (see Figure 7). There do not appear to be any blocking features between RM 1.0 and RM 4.0 to limit current summer chum access. In looking at LiDAR information above RM 4.0, there appears to be a large area of flat riparian or historic lake bed that extends west to east. This large, low gradient area may be a historic barrier for the summer chum run and upwelling areas above this location would not be good candidates for enhancement.

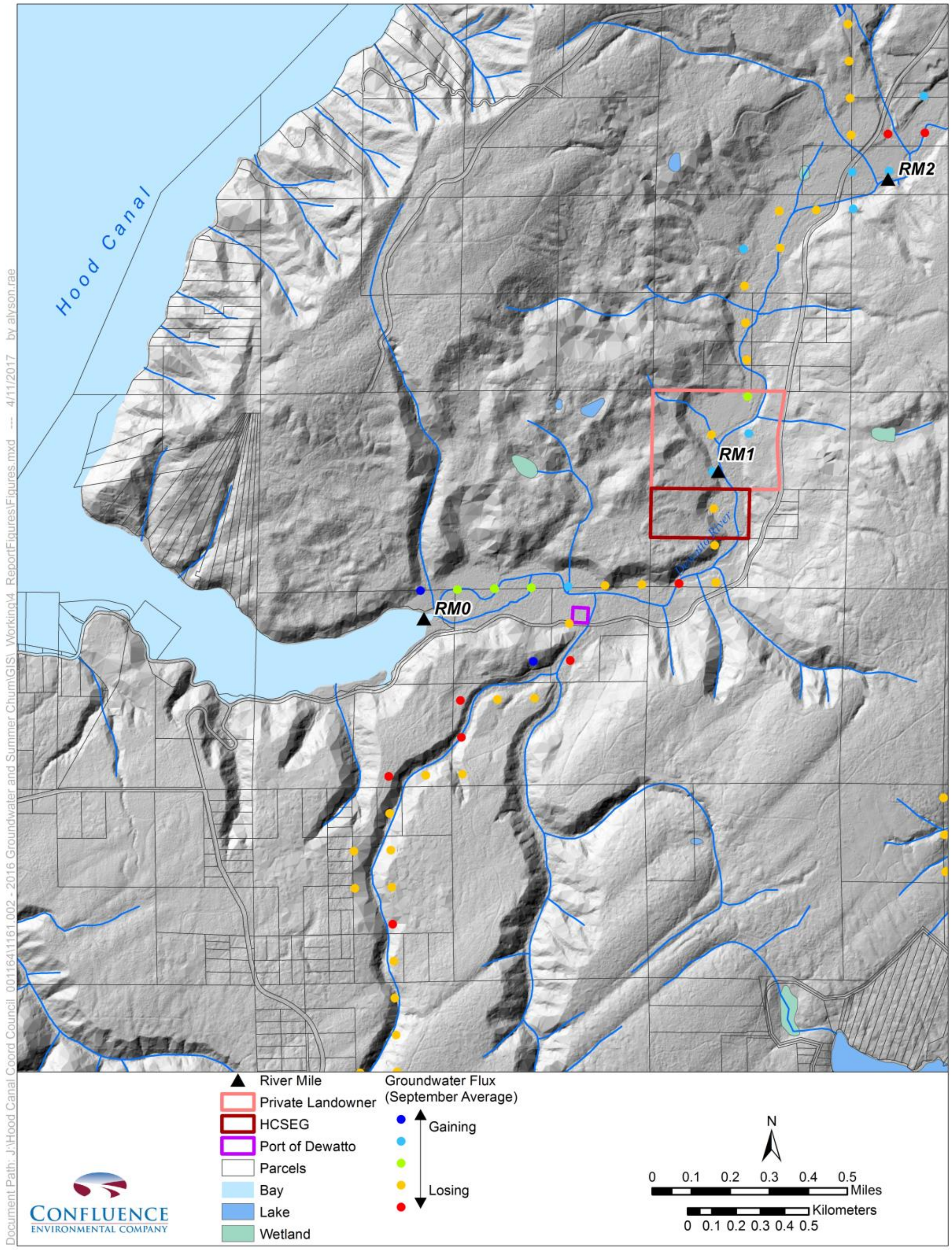

Figure 6. Average September Groundwater Flux: Dewatto System RM 0.0 to RM 2.0

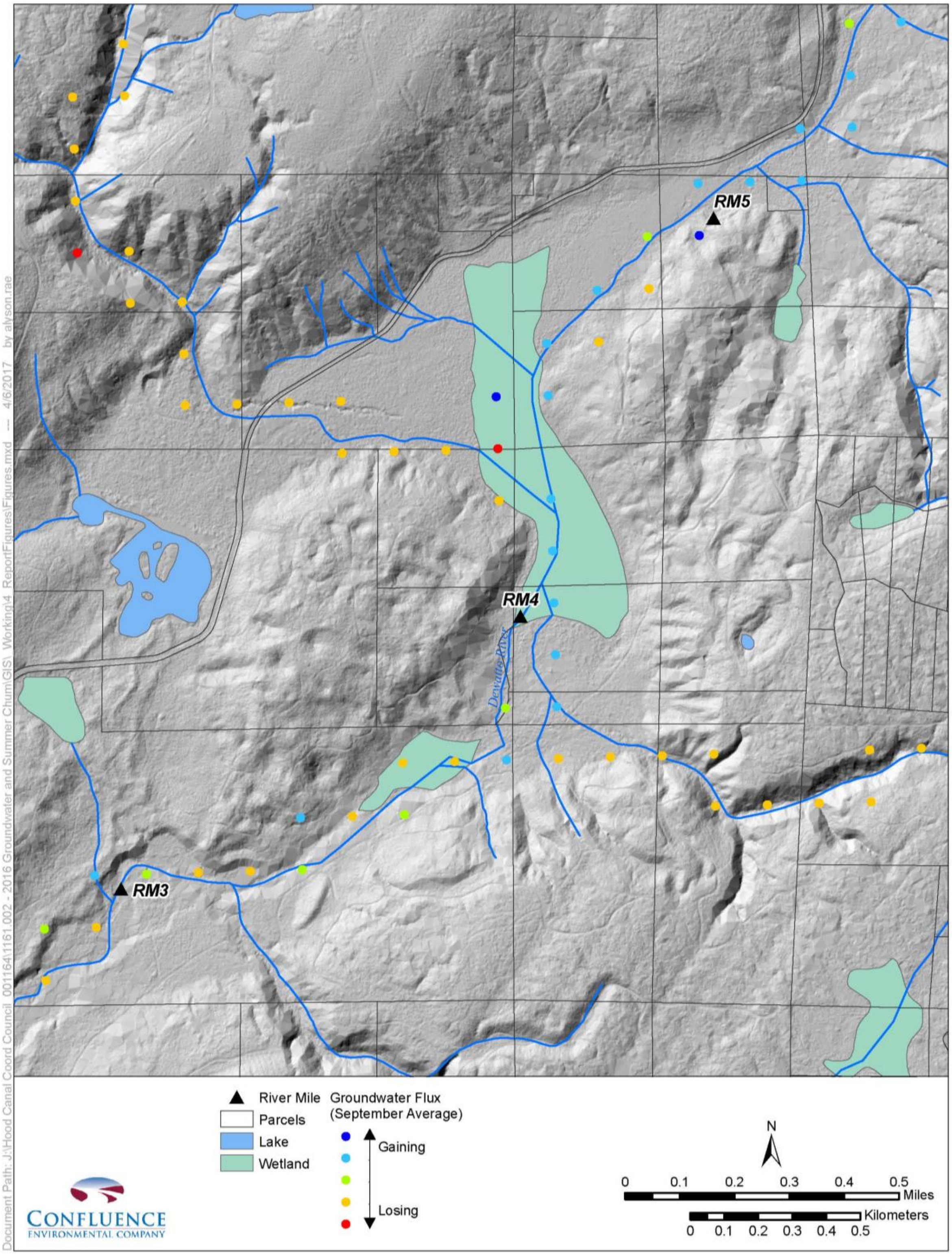

Figure 7. Average September Groundwater Flux: Dewatto System RM 3.0 to RM 5.0

4.3 Anderson

The GIS analysis for Anderson focused on the watershed as a whole since WDFW has not documented summer chum in this system. The SalmonScape reports summer chum being historically distributed in this system up to RM 1.7, so this was the area of focus for this watershed (WDFW 2017). The Washington State Conservation Commission indicates there is a culvert in the upper watershed at the crossing of Nellita-Hintzville Road that is a complete barrier on the upper mainstem (Kuttel 2003). This is above RM 3.0 in the system.

Based on a review of the summer monthly modeling data, there are six model cells that have stronger upwelling in the vicinity of RM 1.0 in this system (see Figure 8).

The parcels around RM 1.0 are forestry industry lands and working with this land owner on river access would be needed to collect additional information.

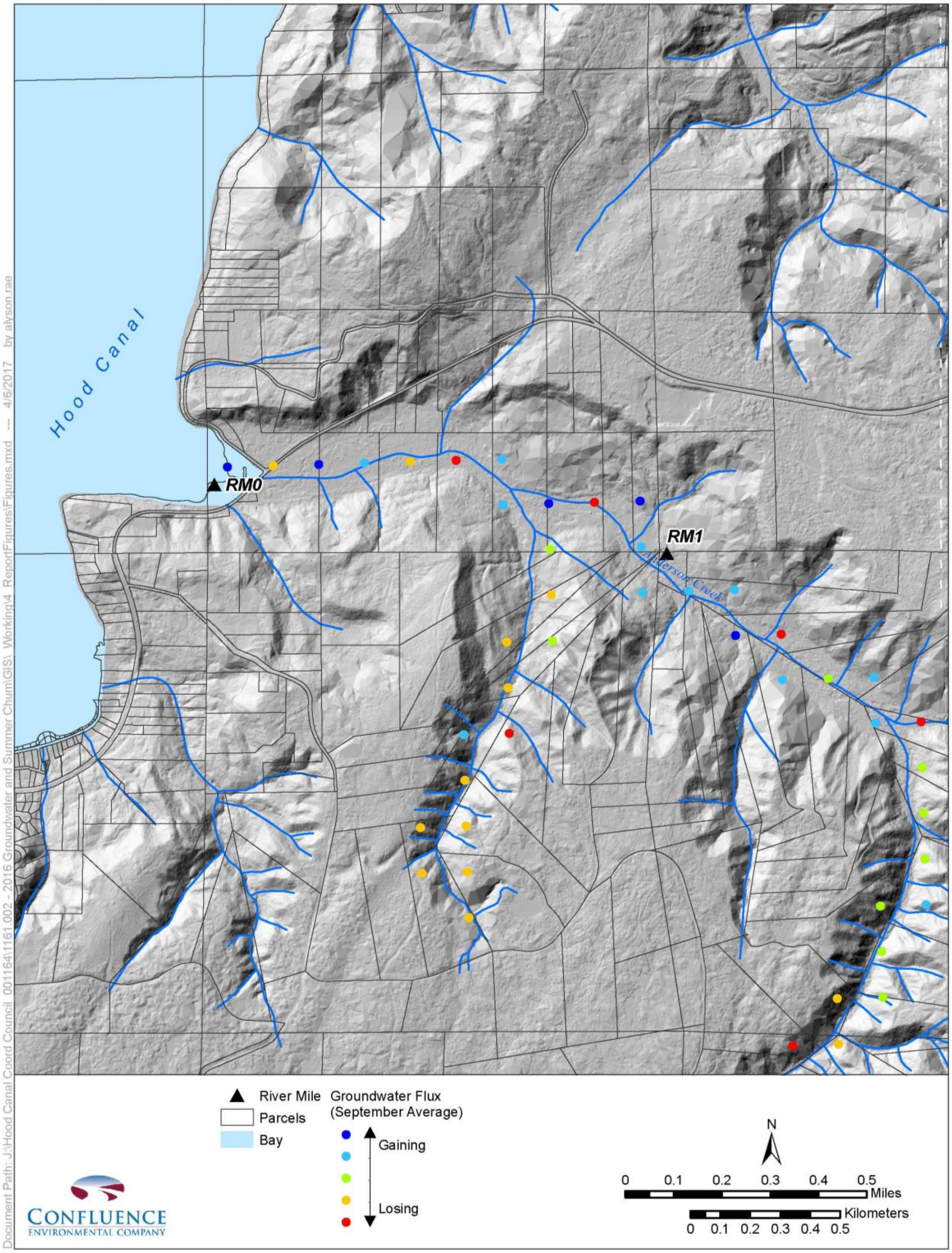

Figure 8. Average September Groundwater Flux: Anderson Creek RM 0.0 to RM 1.5

5.0 DISCUSSION

The average steady-state simulation and the monthly stress periods for the model calibration involved data from 2005 to 2012 which partially overlaps the WDFW data available on summer chum spawning. So, the use of the monthly stress periods paired with WDFW spawning surveys would indicate that there is a good relationship between simulated upwelling and currently observed summer chum usage. Data are lacking on where redd locations are in these rivers. Even if there were redd location data, the model does not provide high enough resolution to screen for correlations between spawning or other habitat feature locations. Additionally, site specific data would need to be collected to make these correlations.

When looking at the headwaters for these systems they all originate in the same general upland area without a clear divide to direct flow. This is different than in streams in more mountainous areas where there is a clear hydrologic divide for headwaters. Beaver activity and wetlands in the headwaters and upper portions of these systems can therefore affect the relative flows of water into each watershed and even whether the water flows west to Hood Canal or east to Puget Sound. The groundwater model does not provide information on surface flows that may change due to beaver activity, so this information is provided as potential future consideration when looking at base flows for these watersheds.

There are several types of site-specific studies that could be conducted to confirm whether groundwater upwelling is indeed occurring in a particular location. Some of these studies are:

- Synoptic seepage surveys conducted during baseflow conditions. This is a study of groundwater seepage over a short period of time to provide a "snapshot" of the hydraulic gradient.
- Installation and monitoring of instream mini-piezometers with pressure transducers and temperature monitoring. This type of study would provide continuous measurements on groundwater vertical gradients beneath the streambed at the location of the mini-piezometers (indicating upwelling vs. downwelling conditions) and temperatures.
- Streambed temperature surveys. These surveys are conducted during baseflow conditions and warmer summer months when differences in groundwater and surface water temperatures are greatest. The surveys involve collecting continuous streambed temperatures coupled with a GPS along reaches of streams to identify areas of cooler water that may be supplied by groundwater. The method could involve collection of data while rafting down the stream. More elaborate methods of temperature sensing have been developed by the USGS using fiber optic distributed temperature sensing (FO-DTS) technology which involves running a fiber optic temperature cables along stream reaches up to a kilometer long (https://water.usgs.gov/ogw/bgas/fiber-optics/).
- Locations of upwelling identified with temperature surveys can then be confirmed by measuring the difference in hydraulic head between the groundwater and overlying stream.

Based on the analysis of model results and additional information, there are areas of opportunity in each of the reviewed watersheds. A discussion of these opportunities on a system-by-system basis is included below.

5.1 Tahuya

The Tahuya is the largest watershed that was reviewed for this project and based on model results, receives the largest groundwater flux between the three systems. The watershed drains approximately 45 square miles of land (Kuttel 2003). As shown in Appendix A, Figure 11, the measured baseflows at the USGS station recorded summer flows between 5 and 12 cubic feet per second (cfs) between 2011 and 2012. According to the instream flow rule, the instream flows for the Tahuya at RM 2.5 from August 15 to September 15 is 5.5 cfs (WAC 173-515-030).

The 2003 Washington State Conservation Commission Limiting Factors report stated that the middle reaches of the Tahuya lose surface flow to the groundwater (Kuttel 2003). This report stated that the possible recipient of that water is the Dewatto based on a paper from 1965. The USGS 1965 paper hypothesized that the Dewatto watershed may be receiving groundwater that is sourced from the Tahuya River (Garling and Molenaar 1965). Looking at the results portrayed in Figure 2, there are losing reaches between RM 12.5 and RM 15.0, as well as a losing reach between RM 17.0 and RM 19.0. However, in looking at the general pattern of groundwater flow predicted by the USGS model, it doesn't appear that this is the source of groundwater in the Dewatto within any of the upper hydrostratigraphic layers of the model.

There are areas within the Tahuya River where the model predicts more distinct areas of upwelling that could be compared to each of the other areas, and, if redd data were also collected within these reaches along with other water quality aspects (e.g., dissolved oxygen, temperature, electrical conductivity, etc.), there may be some correlations found between groundwater upwelling and specific Hood Canal Summer Chum preferences. Collection of continuous measurements of streambed temperatures during baseflow conditions between RM 0.0 and RM 4.5 to map areas of cooler water could be used to locate areas of focused groundwater upwelling within this reach. This collection could be done at a smaller scale by hand or by teaming with USGS for a more elaborate fiber optic collection method (see descriptions above). Areas mapped as having cooler temperatures could then be investigated for upwelling gradients using piezometers or seepage surveys. If redd surveys were also conducted this information could be used to determine if the area around RM 1.0 and RM 4.0 are indeed weak and strong areas of upwelling and whether Hood Canal Summer Chum are indeed attracted to these areas for spawning.

The area of slight upwelling simulated around RM 1.0 is well below the wetland complexes that are seen above RM 2.0, so additional data collection here focusing on whether the summer chum are attracted to this area because of upwelling conditions or other factors could be compared to the area of stronger upwelling surrounding RM 4.0 where there may be different factors at play. If more site-specific groundwater data was wanted, nested piezometers could be installed within the stream reaches of interest to collect measurements of hydraulic heads between the groundwater and overlying stream. Pairing this information with redd locations would allow for a more positive correlation between Hood Canal Summer Chum and groundwater site selection. However, property ownership in these reaches is varied and the effort to gain approval for installation of monitoring equipment may be challenging.

In contrast, the areas of the wetland complex between RM 2.0 and RM 3.0 are owned by Neyhart Tahuya Farms and if agreements could be reached with this single land owner there could be opportunities for both additional site-specific data collection and some conservation in order to ensure continued access to the larger upwelling areas seen around RM 4.0.

5.2 Dewatto

The Dewatto is a smaller watershed than the Tahuya, draining approximately 23 square miles (Kuttel 2003). However, the summer baseflows for this watershed are larger than the Tahuya. As shown in Appendix A, Figure 12 the measured baseflows at the USGS station recorded low flows between 14 and 23 cfs between 2011 and 2012. According to the instream flow rule the instream flows for the Dewatto at RM 1.5 from August 15 to October 1 is 13.5 cfs (WAC 173-515-030).

There are areas of upwelling identified in the Dewatto system from the model simulations between RM 2.0 and RM 4.0 where the historic upper extent of access stops. It appears that based on the data presented in Figure 2, the Dewatto generally has stronger upwelling overall than the Tahuya in the lower reaches. However, there are areas of stronger upwelling simulated above the Dewatto RM 3.0 and summer chum are extending well beyond this range in the Tahuya.

The Dewatto watershed is a smaller watershed than the Tahuya and some comparisons of overall base flows between the watersheds could also indicate whether certain timing thresholds are not being met for the Dewatto above RM 1.0. This would involve either installing a stream gage lower in the Dewatto system (around RM 0.75) and comparing that to the Tahuya USGS gage data at Station 12067700 over time or conducting some targeted low-flow measurements using hand held instrumentation while conducting the habitat surveys discussed above.

There is opportunity to collect temperature measurements similar to what is discussed above for the Tahuya system. There are also possibilities for teaming with the Port of Dewatto and HCSEG for long term monitoring and river access in the area just above and below RM 0.75. The Port of Dewatto property is on a tributary to the Dewatto and may present some opportunities for analyzing whether upwelling is occurring in the area of confluence and if this location may be prime for enhancement of habitat.

Any information collected on site-specific groundwater upwelling would benefit from pairing with redd surveys in order to correlate actual Hood Canal Summer Chum spawning preferences with groundwater upwelling. This information could also be compared with information collected in the Tahuya to compare whether there are differences in preference based on scale or other factors that may be dictating why the Tahuya returns are so much higher than in the Dewatto River.

5.3 Anderson

The Anderson watershed is the smallest analyzed and has no reports of active runs. Anderson drains only 5 square miles and as shown in Appendix A, Figure 13, the measured summer baseflows from 2011 to 2012 varied from 6 to 7.5 cfs. According to the instream flow rule the instream flows for the Anderson at RM 0.1 from August 1 to September 15 is 6.0 cfs (WAC 173-515-030).

This watershed has summer groundwater upwelling conditions within the mainstem and summer chum runs historically extended up to RM 1.7. The watershed as a whole may be small enough that minor impacts to upwelling or habitats that would go unnoticed in Tahuya or Dewatto have a larger impact here. A habitat survey for the first mile of the system could provide insight on whether there are other habitat conditions that are hampering or limiting access.

Land ownership is primarily forestry industry for the lower reaches, so if studies or restoration efforts are desired below RM 1.0, agreements would need to be reached with the land owners. Another option is that information gathered in the Tahuya and Dewatto watersheds could be applied to Anderson once a better understanding of the specific preferences of Hood Canal Summer Chum is reached.

6.0 RECOMMENDATIONS

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.

In general, the Kitsap Peninsula is hydrologically rain dominated. When looking into the future at effects of climate change, studies do not predict that the annual total precipitation would change, but the timing of the precipitation might. Storms are predicted to become more intense, and shorter in duration. This could decrease overall infiltration of precipitation into the groundwater and increase surface runoff into streams (Climate Impacts Group 2009). The USGS model did not look specifically at the effects of climate change, but did analyze a scenario where there was overall 15 percent less groundwater recharge to simulate a drought scenario. This drought scenario showed that some systems in the model domain saw a baseflow decrease of up to 18 percent. There is a possibility that with stronger and shorter duration storms there would be less water infiltrating into groundwater and the effects on groundwater discharge to the streams may be similar to the drought condition simulated by USGS. If there is a concern with the potential reduction of groundwater contributions to these systems due to climate change, additional literature review relating to this topic and possible data collection or modeling would be needed. Information gained from a literature review relating to climate change effects on the Kitsap Peninsula could potentially be used to develop additional runs with the USGS model to simulate scenarios that would mimic future climate change conditions. Output from the model could be evaluated spatially to quantify and understand which systems (and reaches within individual systems) are predicted by the model to be most susceptible to climate change impacts.

Based on the model results for the steady-state conditions in the Tahuya, Dewatto, and Anderson watersheds, groundwater influence exists almost exclusively in the mainstem. The model did not look at contributions of very shallow groundwater in the upper reaches of the system as discussed in Appendix A. Recommendations for additional work are summarized below based on three different categories:

- Locations for additional research
- Locations for potential protection
- Locations for potential creation or enhancement

6.1 Locations for Additional Research

Additional research for all of these systems would be needed to pin-point more accurately where groundwater upwelling is occurring and to what degree Hood Canal Summer Chum have a preference to this condition. Overall, it would be beneficial to continue to collect continuous flow measurements at the USGS and Kitsap PUD stations. Collecting and analyzing this data would provide information on whether there is enough flow in the various systems during late summer for chum to access rivers. Additional monitoring stations may be needed at higher locations if it is possible that low flow issues are preventing access higher in the system.

In order to further understand what is driving the Hood Canal Summer Chum to select particular areas for spawning on the east side of the Hood Canal, it is recommended to focus on the Tahuya and Dewatto watersheds. Both of these systems have existing populations that are returning in measurable numbers.

An opportunity that is readily achievable and does not require an extensive effort for these watersheds would be to conduct a temperature study within the following targeted reaches:

- Tahuya: RM 1.0 to RM 4.0
- Dewatto: RM 0.5 to RM 1.0 and RM 3.0 to RM 4.0

Additionally, temperature surveys could be conducted along these reaches. These surveys could be very simplistic (walking or floating a reach with a temperature probe or using a drone) or more complex depending on costs and precision requirements[1]. Confluence has licensed drone operators and would be able to capture relative heat on the surface of the streams at low flow conditions. In order to utilize a drone with an infrared camera there would need to be clear canopy above the stream on the reach being analyzed. Results of the temperature surveys could be combined with seepage surveys. Together, these data could be used to identify focused groundwater upwelling areas. These areas could then be instrumented with mini-piezometers to monitoring groundwater vertical gradients over time.

It would also be beneficial to collect geo-referenced redd survey data to map where Hood Canal Summer Chum are utilizing spawning beds to determine if groundwater upwelling areas are driving their site selection or if it is other factors. This should be done in the lower reaches of the systems where more spawning is occurring.

There is certainly an opportunity to also team with the HCSEG to conduct some research on their Dewatto property. Temperature surveys could be conducted at this location. If the survey shows cooler areas, then nested mini-piezometers could be installed to measure vertical hydraulic gradients and compare that to redd survey data. This data could then be used to potentially correlate groundwater upwelling with spawning preferences. As stated in the Phase 1 report, 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 at this HCSEG-owned property if groundwater upwelling is found to determine whether this preference for groundwater-fed habitats leads to greater population success for Hood Canal Summer Chum specifically.

At this time, no contacts have been made with Mason County Public Works personnel. The Tahuya and Dewatto are both in Mason County. Mason County Public Works may have plans for monitoring these systems in the future (currently each system has only one USGS gaging station). If additional information is desired in the future on these two systems, it may be worthwhile contacting Mason County Public Works to determine what monitoring they are currently doing of these systems and if there is any information that may be useful to determine suitable spawning habitat.

There is very limited current discharge data available for the Dewatto and Tahuya. A few recent synoptic measurements of discharge were collected at USGS gaging stations on the mainstem of the Tahuya just above RM 7.0 (2004 to 2012 USGS 12067700), as well as a nearby tributary (2011

1 The USGS has developed fiber-optic distributing temperature sensing (FO-DTS) technology that is capable of continuous monitoring of streambed temperatures on scales of kilometers (https://water.usgs.gov/ogw/bgas/fiber-optics/). This technology has been applied in other states, but not for systems on the Kitsap Peninsula.

to 2012 USGS 12067680), and on the mainstem of the Dewatto at approximately RM 2.0 (2011 to 2012 USGS 12068500). Historic continuous discharge data from 1947 to 1974 is also available for the Dewatto USGS station. To our knowledge discharge is not currently being collected on the Dewatto and Tahuya. Continuous monitoring of discharge of these two systems would provide valuable information on current flooding and summertime baseflows and potential long-term impacts from climate change.

It is recommended that research results be analyzed from Tahuya and Dewatto prior to conducting studies regarding groundwater upwelling on the Anderson. By gathering more information on the Tahuya and Dewatto populations a better understanding of what is specifically attracting Hood Canal Summer Chum could inform protection and restoration efforts on Anderson.

6.2 Locations for Potential Protection

Based on a review of aerial photographs and parcel information some areas upstream of upwelling zones within the Tahuya and the Dewatto are either currently developed or appear to be preparing for development. The existing developments are likely withdrawing groundwater for drinking water. Review of well logs from the drinking water wells installed in this area could reveal whether the wells are pulling water from the shallow aquifers that feed the Tahuya or Dewatto. Based on the summer baseflows reported in 2011 and 2012 the Tahuya and Dewatto are around their low flow requirements already; therefore, additional withdraws from groundwater resources that feed these systems may be limited.

If the recent Hirst decision (*Whatcom County v. W Wash. Growth Mgmt. Hr'gs Bd. No* 91475-3) holds, it may limit the installation of new domestic private drinking water wells that would be relying on the shallow aquifers that feed the Tahuya and Dewatto. Watershed planning and research was being conducted by the WRIA 15 Planning Unit until 2005. A Watershed Management Plan was published in 2005 and the plan was never adopted. There are no current watershed planning efforts being supported by Ecology within WRIA 15. Specific protection measures for watersheds were not addressed in the plan and additional work on a watershed management plan is currently not being supported by Ecology.

Prior to recommending specific parcels along the Tahuya or Dewatto for preservation of groundwater upwelling habitats it is recommended that additional research be conducted to find specific upwelling locations because the USGS model is not refined enough to provide this information on a parcel-by-parcel level.

6.3 Locations for Potential Creation or Enhancement

A number of design techniques could be applied to create or enhance the groundwater to surface water connections. The literature search and interviews conducted as part of Phase 1 and 2 of this project have shown that side channels and spawning channels created in areas with connections to groundwater and/or surface water have been successful based on use and egg-to-fry survival rates to restore habitat for chum salmon in the Lower Columbia River and British Columbia. Large woody debris and engineered log jams can also scour holes to enhance groundwater to surface water connections. These techniques can be effective when properly sited based on groundwater resources at a site.

There are areas within the mainstem of the Tahuya and Dewatto that have upwelling conditions. According to the mapped steady state average annual results from the model, the stronger and larger of these areas are included on the following reaches:

- Tahuya: RM 4.0 through RM 7.0
- Dewatto: RM 4.0 through RM 6.0

For the Tahuya watershed summer chum have been observed above RM 4.0. If enhancement opportunities arise in the reach of RM 4.0 to RM 7.0, this could be prime area to increase the length of summer chum spawning activity without needing site specific information. Conducting additional research to target specific parcels for enhancement opportunities or agreements with land owners would be recommended if there are no readily available opportunities at this time.

For the Dewatto watershed, it is recommended that there be additional studies to determine why summer chum are not extending into the system past RM 1.0 prior to focusing enhancement efforts in the more concentrated upwelling areas of RM 4.0 through RM 6.0.

The groundwater model does not provide output fine enough to determine whether a side-channel system within a stretch of potential upwelling would provide increased upwelling compared to the primary watercourse. Additional research into summer chum use of areas with upwelling in side-channels (with summer chum access during spawning periods) would provide information on whether creation of side channels would be preferred over the mainstem upwelling locations is recommended before creation projects are considered.

7.0 REFERENCES

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Appendix A
PGG Model Summary Memo

PACIFIC groundwater GROUP

Technical Memorandum

To: Patty Michak – Hood Canal Coordinating Council

From: Dawn Chapel, Hydrogeologist – Pacific Groundwater Group

Re: Kitsap Peninsula Groundwater Model Results for the Tahuya, Dewatto and Anderson Watersheds

Date: April 10, 2017

This memo summarizes Pacific Groundwater Group's (PGG) review of the Kitsap Peninsula Groundwater Flow Model. Specifically, PGG extracted the simulated flux between groundwater and surface water in the Tahuya River, Dewatto River, and Anderson Creek to identify potential locations of focused groundwater upwelling in these streams. Areas of focused upwelling simulated by the model can be used together with other criteria to select areas for further investigation of summer chum population recovery success.

A list of the tables and figures attached to this memo is presented below. The following sections provide a summary of the groundwater model, simulated aquifers and confining units, how streams are simulated in the model, and overall model calibration success. Subsequent sections describe model predictions of groundwater flux to the Tahuya River, Dewatto River, and Anderson Creek. The last section describes the limitations of using the model results to identify specific areas of focused groundwater upwelling.

LIST OF TABLES AND FIGURES

1.0 SUMMARY OF GROUNDWATER MODEL

The USGS recently developed a groundwater flow model for the Kitsap Peninsula to improve understanding of water resources, and as a tool to assess future groundwater withdrawal effects on groundwater levels and stream flows during low-flow conditions (Frans and Olsen, 2016).

The model uses the MODFLOW-NWT computer program (Niswonger et al 2011) to solve the three-dimensional mathematical equations for groundwater flow within a model domain. The model domain is defined with a finite difference grid comprised of 536 rows, 362 columns, and 14 layers representing various layers of aquifers and aquitards at depth. Each model cell in the grid has a horizontal dimension of 500 x 500 feet. Thus, model output is on a scale of every 500 feet in a horizontal direction. A map view of the model domain is shown in Figure 1.

The model simulates three-dimensional groundwater flow through the hydrogeologic framework from areas of recharge (model inflows) to areas of discharge (model outflows). The model does not simulate overland surface water flow. Precipitation that infiltrates to groundwater is the main source of recharge to the model; and the model discharges to streams, the Puget Sound, and (to a lesser extent) springs and wells. Groundwater discharge to streams sustains late-summer and early-autumn streamflow (baseflow) in the model area.

The model was calibrated to transient conditions, which means that groundwater levels, inflows, and outflows vary with time. Each time period is represented in the model using stress periods, each of which is represented with constant hydrologic stresses (i.e. pumping and recharge). The calibration simulated the period between January 1985 and December 2012 using annual stress periods between 1985 and 2004 and monthly stress periods between 2005 and 2012. The model was calibrated to both field measured groundwater levels and field measured baseflows (these parameters are referred to as "calibration targets"). Calibration targets included 18,835 groundwater level measurements from 618 different wells between January 2007 and December 2012 and 321 stream baseflow measurements at 43 locations collected during the summer of 2011 and 2012.

Once calibrated, the model was used to simulate six predictive scenarios assuming different configurations of future pumping and recharge. One scenario simulated with the calibrated model was a steady-state simulation using an average of 2005-2012 pumping rates and the 30-year annual average groundwater recharge. The steady-state model simulation results in one single solution of groundwater flow that is allowed to come into equilibrium with applied stresses. It represents a long-term "average" condition in groundwater flow and flux under those conditions, and the solution does not change with time.

2.0 SIMULATED AQUIFERS AND CONFINING UNITS

The Kitsap Peninsula is underlain by a thick and complex sequence of glacial and nonglacial sediments (various combinations of gravel, sand, silt, clay and "hardpan") overlying Tertiary bedrock (claystone, siltstone, sandstone, and volcanic rocks) at depth. The simulated groundwater system occurs in the glacial and nonglacial sediments with aquifers composed of glacial outwash and other coarse-grained interglacial deposits and confining units composed of fine-grained interglacial, glacial till and glaciolacustrine deposits (Frans and Olsen, 2016)[1]. Four glaciations and three interglaciations are recognized in the Puget Sound lowland. Glacial deposits of the last major glacial advance (Vashon Stade) are exposed at the surface on the Kitsap Peninsula. Table 1 summarizes the hydrogeologic units (i.e. aquifers and confining units) represented in each layer in the model. In some cases, the deposits that comprise these units can be highly heterogeneous with variable compositions and thicknesses. The ability of the model to represent all the lithologic complexities in the deposits is limited and can only represent a simplification of actual conditions.

Review of the model output shows that most of the simulated streams (see below) receive groundwater baseflow predominantly from the top three layers of the model. Groundwater in deeper layers of the model discharges primarily towards the Puget Sound.

3.0 REPRESENTATION OF STREAMS

Figure 1 shows the location so simulated streams in the model domain and Figure 2 shows the location of simulated streams in the southwest portion of the model in the vicinity of the Tahuya River, Dewatto River, and Anderson Creek. Streams are modeled as a boundary condition to the groundwater system using the Stream Flow Routing (SFR) Package in MODFLOW. The SFR package simulates the exchange of groundwater with streams based on the difference between the simulated groundwater level and stream stage for each model cell represented in the SFR Package. Groundwater can flow from the aquifer to the stream (upwelling) or from the stream to the aquifer (downwelling) depending on whether stream stage or groundwater level is higher. The rate of exchange is also controlled by the conductance of the assigned streambed sediments, which is a measure of the ease with which water can flow through the streambed sediments (a combined function of streambed permeability, thickness, and cross sectional area). The SFR Package also simulates the routing of surface water from one stream cell to the next as it exchanges with groundwater in the downstream direction. Gains and loses can be evaluated for individual sections of the stream or cumulatively for the entire stream. Sections of streams can also go dry if seepage to the aquifer is greater than the amount of flow in the stream.

[1] Aquifers are layers of rock or sediment that are relatively permeable and easily transmit groundwater. Confining units are layers of rock or sediment that have low permeability and do not easily transmit groundwater.

Output from the model can be used to assess the rate of exchange between groundwater and surface water at each discrete model cell or the cumulative stream flow derived from exchanges with groundwater (i.e. baseflow).

Overland surface water flow to streams is not simulated in the groundwater flow model; however, springs that discharge along the marine bluffs and stream valley walls were represented in the model using the Drain Package, which removes groundwater from the model domain at those locations. The rate of discharge to the simulated spring is controlled by the difference between the assigned drain elevation and the simulated groundwater level in the aquifer adjacent to the drain. While spring discharge could eventually enter a stream via overland flow, this mechanism is not supported in the USGS model, and drain discharge is instead removed from the model domain at the location of the drain. Drain locations were specified in areas of the Kitsap model where the full thickness of an aquifer truncates along valley walls. This was most prominent for the Vashon Advanced Outwash Aquifer (model layer 3 in Table 1). Figure 2 shows the location of simulated drains in the southwest area of the model domain in relation to the simulated streams. A number of drains were simulated along the valley walls of the lower Tahuya River (up to about RM 4) and lower Dewatto River (up to about RM 1), and along much of Anderson Creek (Figure 2). The amount of groundwater discharge to these drains relative to groundwater discharge to the simulated streams was evaluated with the steady-state results in Section 5.1 below.

4.0 MODEL CALIBRATION

Model calibration requires adjusting model input parameters within reasonable limits to try and match calibration targets. The objective of model calibration is to minimize the difference (residual) between the measured and simulated target values. Calibration targets included measured groundwater levels and stream baseflows. Model parameters adjusted during calibration included aquifer properties (hydraulic conductivity and storage coefficient), recharge, and properties controlling the hydraulic connection between groundwater and both streams and the Puget Sound.

The results of the calibration are typically evaluated using statistical measures on the residual data. For example, the mean residual of all groundwater level targets was 3.70 feet with a standard deviation of 47.01 feet and the mean residual of all baseflow targets was 0.1 cubic feet per second (cfs) with a standard deviation of 2.46 cfs. One measure commonly used to evaluate overall model calibration success is the root mean square error (RMSE) of the residuals divided by the total range of observations, with the goal of achieving a value less than 10%. For the Kitsap model, this value was 7% for groundwater level targets and 6% for stream baseflow targets, indicating an overall good model fit (Frans and Olsen, 2016).

While the model was fairly well calibrated for its application at the regional scale, it is not suitably calibrated to smaller scales such as short reaches of individual streams (see Limitations of Model Section below). There were also limited calibration targets available in Mason County (which covers much of the Dewatto and Tahuya watersheds) relative to Kitsap County, making it difficult to assess how well the model is calibrated in that area.

5.0 MODEL RESULTS

Simulated groundwater discharge to the Tahuya River, Dewatto River, and Anderson Creek was extracted from both the (average) steady-state simulation and the monthly stress periods from the transient calibration simulation (2005 to 2012) to evaluate the distribution of groundwater upwelling and baseflows in these watersheds. Results are discussed below.

5.1 STEADY-STATE AVERAGE RESULTS

The average steady-state groundwater discharge (cfs) to simulated stream cells in the model is presented in Figures 3 and 4. Each stream cell is shown with a circle centered on the 500 x 500 ft model cell. Figure 3 shows the discrete groundwater discharge to each stream cell and Figure 4 shows the cumulative baseflow at each stream cell (i.e. flow derived from groundwater discharge that is routed down the stream).

The discrete groundwater flux to stream cells in Figure 3 is the simulated flux between the stream and groundwater at that location. Positive values (color coded in blue tones) indicates groundwater discharging to surface water at that location (upwelling), while negative values (color coded in red tones) indicates surface water discharging to groundwater at that location (downwelling). Areas where there is no exchange between groundwater and surface water are color coded yellow.

The cumulative groundwater discharge to streams presented in Figure 4 represents surface water baseflow calculated as the discrete groundwater discharge at each cell plus groundwater discharge from all upgradient cells that get routed downstream in the SFR Package.

These model results show that in general groundwater upwelling is concentrated along the mainstem of each stream with very little exchange between groundwater and surface water occurring in the tributaries, which could indicate that tributary flows are largely driven by overland flow. The lack of exchange between groundwater and surface water in the model is mainly due to upper model layers in the uplands being simulated as dry and therefore not able to provide groundwater discharge (i.e. the simulated groundwater levels are below the bottom of the layer). However, there could be areas of shallow groundwater perched on low permeable layers in the uplands (i.e. not connected with the main groundwater system) that can supply some groundwater discharge to these upper tributaries. The presence of shallow perched groundwater may explain why the USGS had difficulty in simulating adequate stream flux in the headwaters of many streams (see summary of USGS interview in main text of Phase 2 report).

5.1.1 Steady-State Average Groundwater Flux to Tahuya River

The Tahuya River is the largest watershed of the three. The results of the steady-state simulation show discrete groundwater upwelling (positive flux) occurring in most of the model cells along the mainstem with values generally ranging from less than 0.1 cfs to 1 cfs in each 500 x 500 ft model cell. Several model cells with upwelling rates in the higher range are concentrated between RM 4.0 and 8.0 (Figure 5). Rates of upwelling are generally less in model cells below RM 4.0.

Above RM 12, there are some model cells with neutral or negative values (i.e. downwelling) along the mainstem suggesting overall less upwelling in these upper reaches (see Figure 3 for these upper reaches).

The model results show the cumulative steady-state groundwater discharge in the Tahuya River (i.e. baseflow) gradually increases from zero in its headwaters to a total of 41.6 cfs at its mouth with the estuary leading to the Hood Canal (Figure 6). Springs simulated along the valley walls of the Tahuya River using the MODFLOW Drain Package (see Section 3.0 above) provides about 4 cfs of additional discharge that could contribute to the baseflow.

5.1.2 Steady-State Average Groundwater Flux to Dewatto River

The results of the steady-state simulation show discrete groundwater upwelling (positive flux) occurring in almost all model cells along the mainstem of the Dewatto River with values generally ranging from less than 0.1 cfs to 1 cfs in each 500 x 500 ft model cell. Several model cells with upwelling rates in the higher range are concentrated between River Miles (RM) 3.5 and 6.0 (Figure 7). This is depicted by the darker blue tones of the points in Figure 7.

The model results also show the cumulative steady-state groundwater discharge in the Dewatto (i.e. baseflow) gradually increases from zero in its headwaters to a total of 33 cfs at its mouth with the Dewatto Bay (Figure 8). Springs simulated along the valley walls of the Dewatto River using the MODFLOW Drain Package (see Section 3.0 above) provides about 1 cfs of additional discharge that could contribute to the baseflow.

5.1.3 Steady-State Average Groundwater Flux to Anderson Creek

Anderson Creek is a much smaller watershed compared to the Dewatto and Tahuya watersheds. The results of the steady-state simulation show discrete groundwater upwelling (positive flux) occurring along the mainstem and a short distance up its two main tributary headwaters (Figure 9). Discrete upwelling rates generally range from less than 0.1 cfs to 0.4 cfs in each 500 x 500 ft model cell.

The model results show the cumulative steady-state groundwater discharge in the Anderson (i.e. baseflow) gradually increases from zero in its tributary headwaters to a total of 4.5 cfs at its mouth with the Hood Canal (Figure 10). Springs simulated along the valley walls of Anderson Creek using the MODFLOW Drain Package (see Section 3.0 above) provides less than 0.1 cfs of additional discharge that could contribute to the baseflow.

5.2 TRANSIENT GROUNDWATER FLUX TO STREAMS AT GAGING STATION LOCATIONS

Results were extracted from the transient calibration model at the location of three gaging stations located on the Dewatto, Anderson, and Tahuya where stream flow was measured by the USGS or Kitsap Public Utilities District (KPUD) during the summer months of 2011 and 2012 in support of model calibration. Table 2 lists the gage stations and locations analyzed and locations are shown on Figure 3.

Figures 11-13 plot simulated hydrographs of monthly baseflow at each gaging station between 2005 and 2012. Also plotted are the measured baseflows that occurred at each gaging station.

The results show baseflows are generally at their peak during late winter and early spring and at their lowest in October. Results at each gaging station are discussed below.

Despite some disparity between the simulated and measured baseflows at these locations, the model calibration to baseflows was considered good for the entire model domain (see model calibration discussion above). As discussed in the model limitations section below, given the much larger scale of the MODFLOW model relative to the three watersheds, use of the model at fine scales within these watersheds should be used with caution.

5.2.1 Tahuya Baseflow Hydrograph

The simulated baseflows at the Tahuya station varies from about 10 to 30 cfs from year to year (with some variability). Comparison with measured flows at the USGS gaging station shows the measured values to be on average about 100% lower (i.e. half the value) of the simulated baseflows (Figure 11).

5.2.2 Dewatto Baseflow Hydrograph

The simulated monthly baseflows at the Dewatto station varies from about 20 to 32 cfs from year to year (with some variability). Comparison with measured flows at the USGS gaging station shows the measured values to be on average about 40% lower than the simulated baseflows (Figure 12).

5.2.3 Anderson Baseflow Hydrograph

The simulated baseflows at the Anderson station varies from about 3.5 to 6 cfs from year to year (with some variability). Comparison with measured flows at the KPUD gaging station shows the measured values to be on average about 40% higher than the simulated baseflows (Figure 13).

5.3 TRANSIENT GROUNDWATER FLUX TO STREAMS AT END OF OCTOBER 2009

The baseflow hydrographs presented above show the lowest baseflows occurring at the end of October in all three watersheds, with 2009 being the lowest year (Figures 11-13).

The simulated groundwater flux to discrete stream cells at the end of October 2009 is shown in Figure 14. The October 2009 flux rates are less than the steady-state average condition (Figure 3), as would be expected, but the overall pattern of areas of focused upwelling is similar.

6.0 LIMITATIONS OF MODEL

Application of the USGS Kitsap groundwater model for identifying discrete areas of focused groundwater upwelling in the three watersheds should be performed with caution. The model was developed on a regional scale and calibrated to broad-based patterns of stream baseflow rather than localized baseflow variations. Areas of upwelling and downwelling will be controlled by the hydrogeologic framework, which is not always well defined in portions of the model domain. All groundwater models include degrees of intrinsic error and uncertainty associated with necessary simplifications, approximations and assumptions; which are more prominent when the scale of desired prediction does not match the scale of model design and calibration. For these reason, actual observations of upwelling and baseflow (where available) are generally more informative than model predictions.

Given these limitations, model results at individual model cells should not be interpreted as factual. As summarized in the USGS report (Frans and Olsen, 2016) and discussed with one of the authors of the model (Lonna Frans) during project interviews (see main text in Phase 2 Report), interpretations of simulation results should be limited to scales several times greater than the model spatial and temporal resolution of 500 ft and 1 month. It is suggested that model results be limited for use as a screening tool to identify broad reaches composed of several model cells (5 or more) where groundwater upwelling may be focused and which should ultimately be confirmed with field based investigations. Similarly, simulated averaged and time-series baseflow quantities should not be interpreted as actual values, but instead used as a screening tool for identifying likely periods of low flow, seasonal changes, and "order of magnitude" flows that could be used to guide further field based investigations.

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Table 1. Kitsap Peninsula Model Layers and Hydrogeologic Units

Model layer	Hydrogeologic Unit
1	Vashon Recessional Aquifer (Qvr)
2	Vashon Till confining unit (Qvt)
3	Vashon Advanced aquifer (Qva)
4	Upper Confining Unit (QC1)
5	Permeable Interbeds (QC1pi) , included locally with QC1
6	Confining Unit (QC1)
7	Sea Level Aquifer (QA1)
8	Middle Confining Unit (QC2)
9	Glaciomarine Aquifer (QA2)
10	Lower Confining Unit (QC3)
11	Deep Aquifer (QA3)
12	Basal Confining Unit (QC4)
13&14	Bedrock (BR)

Table 2. Gage Stations Used for Model Calibration in the Tahuya, Dewatto, and Anderon Systems

Gage Station	Approximate Location
USGS 12067700	Tahuya River RM 7.0
USGS 12068500	Dewatto River RM 2.0
KPUD-AN	Anderson Creek 700 feet from mouth

RM = River Mile

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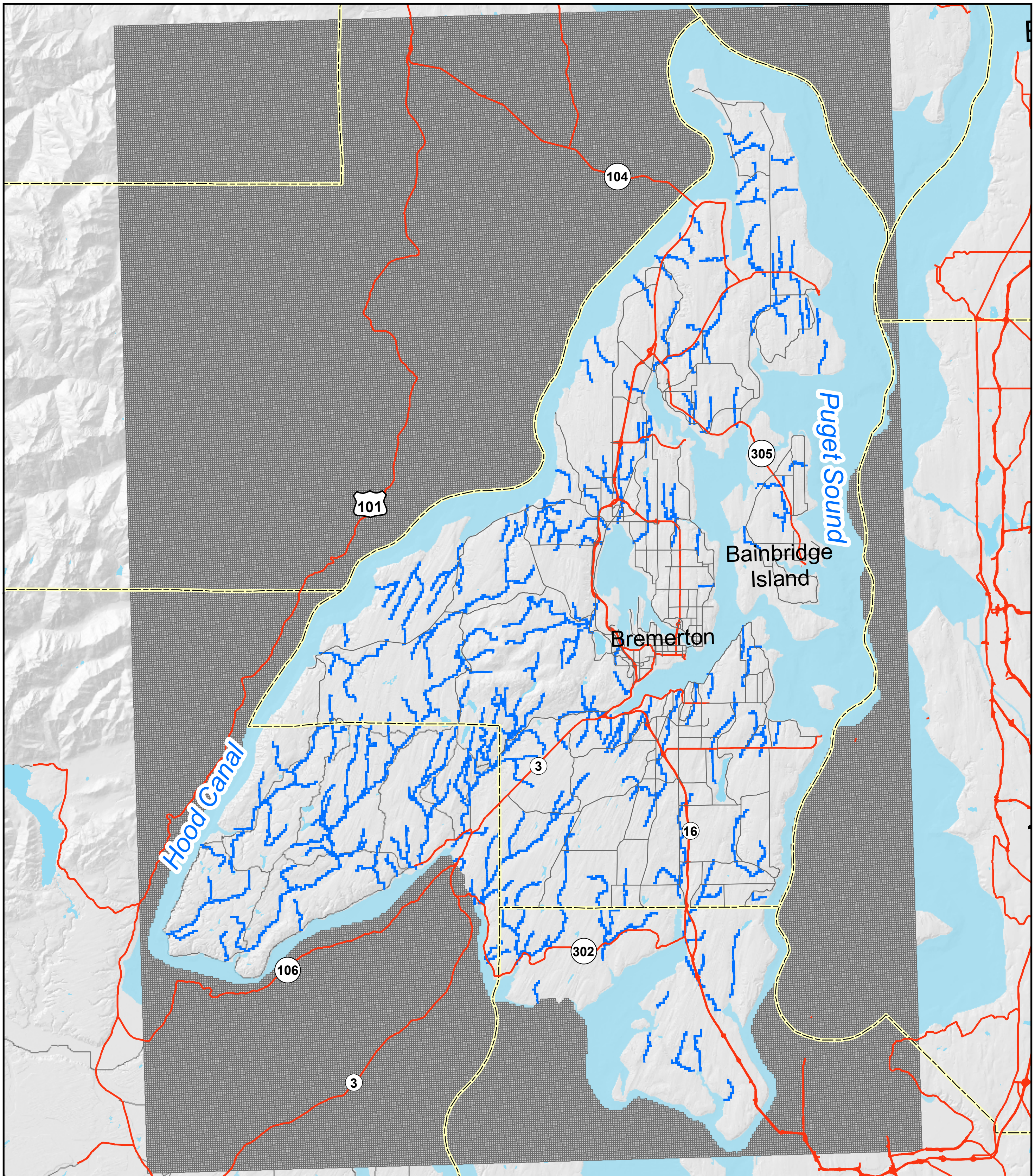


Simulated Streams

No Flow Cells (Inactive Area of Model)

State Routes

County Boundary

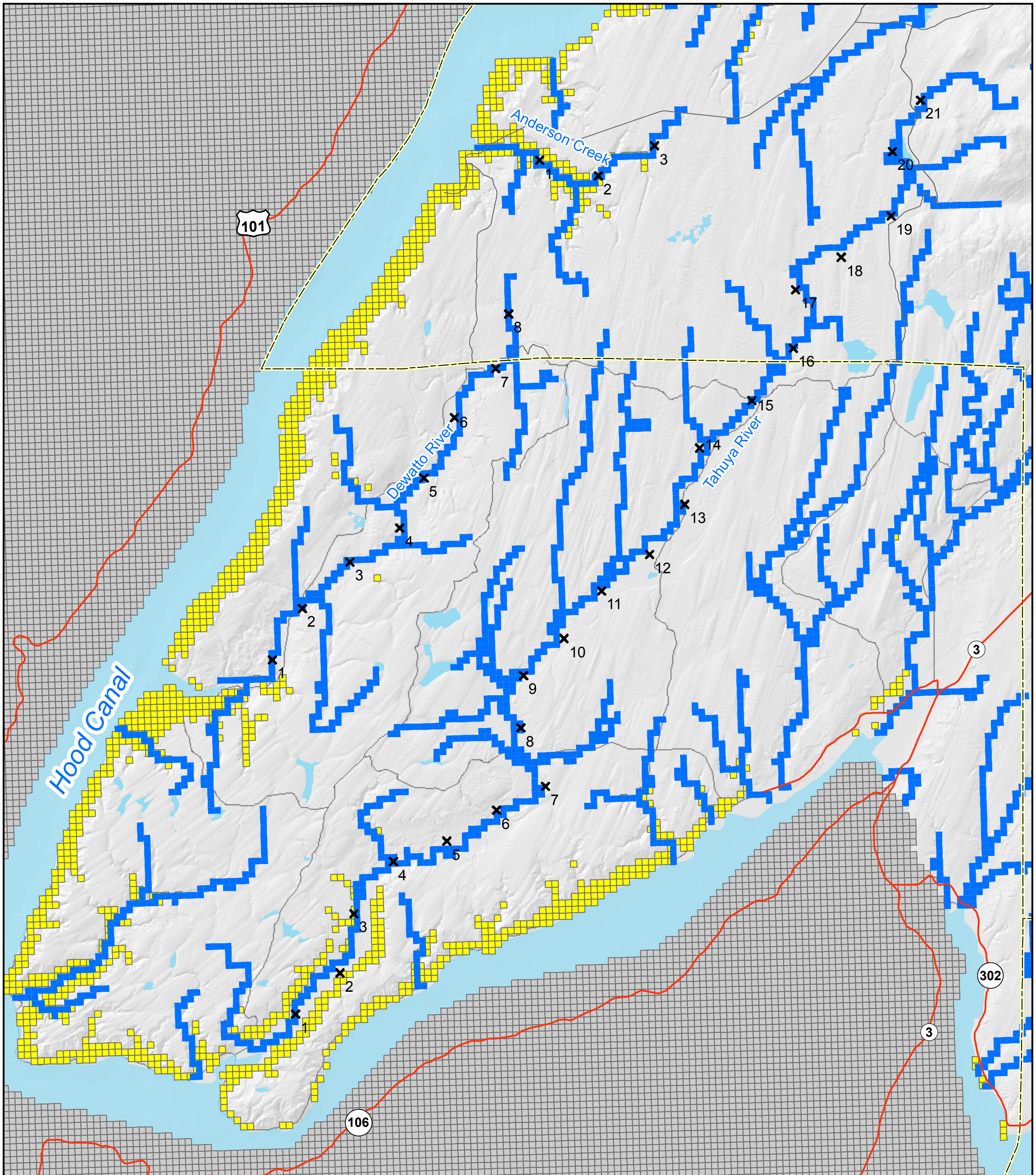
N

0 Miles 10

Figure 1

Kitsap Peninsula Model Domain and Simulated Streams

PGG



× River Miles
Simulated Streams
Simulated Drains
No Flow Cells (Inactive Area of Model)
County Boundary
State Routes

0 Miles 2

N

Figure 2
Southwest Area of Kitsap Peninsula Model Domain and Simulated Streams and Drains

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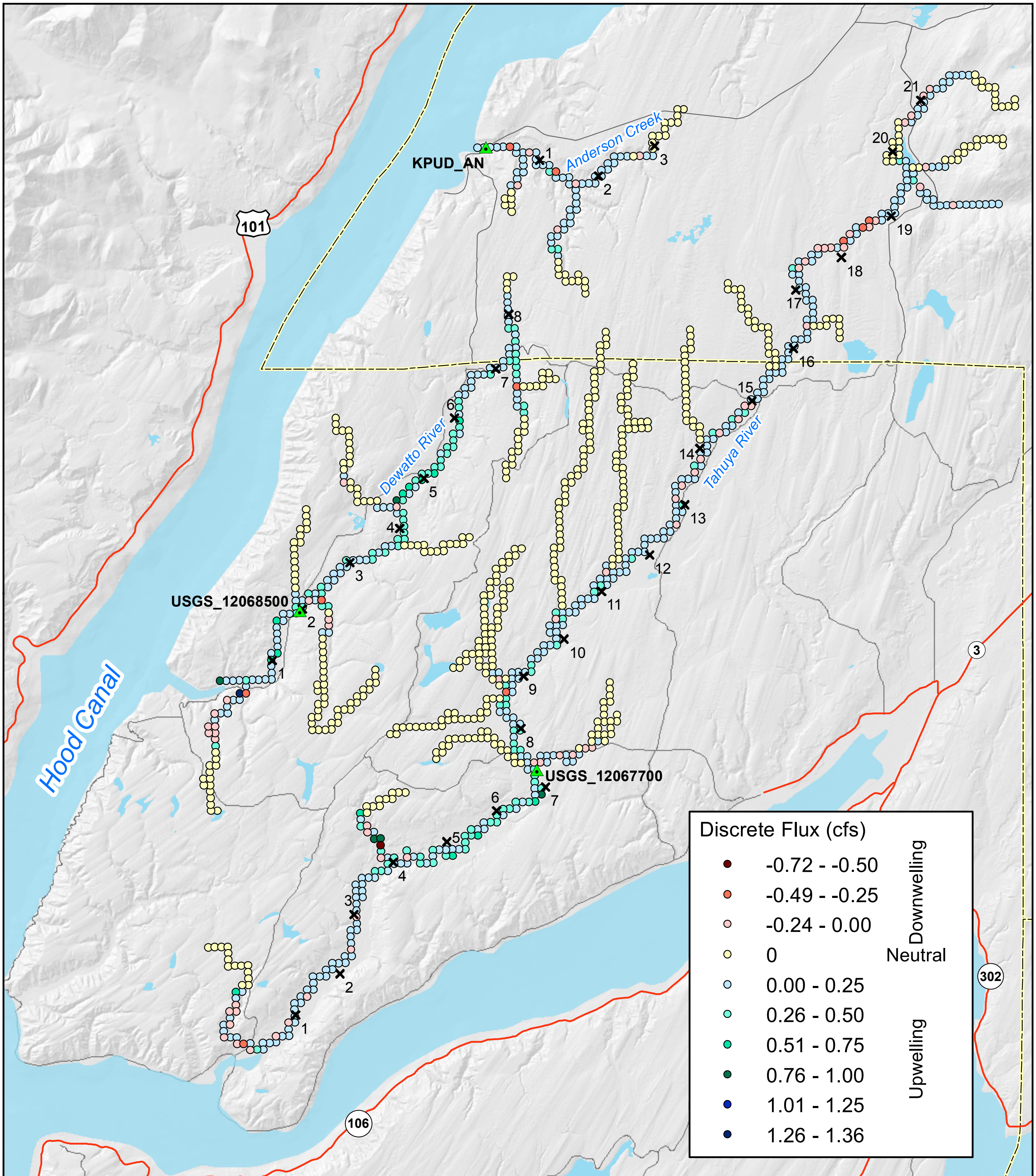

Stream Gages
River Miles
State Routes
County Boundary

0 Miles 5

Figure 3

Simulated Discrete Flux between Groundwater and Surface Water at each Stream Cell in Tahuya, Dewatto, and Anderson under Steady-State Average Condition

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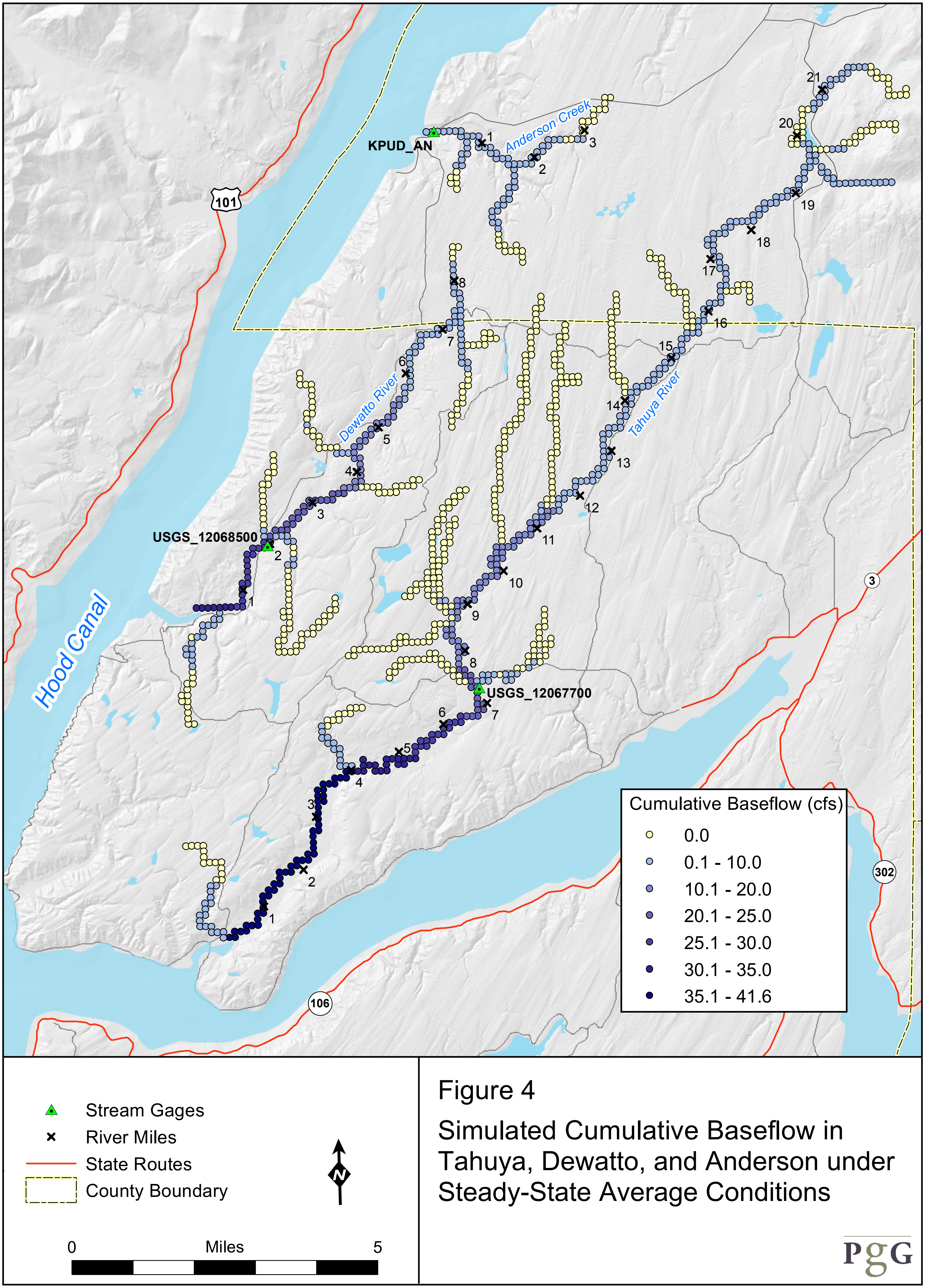
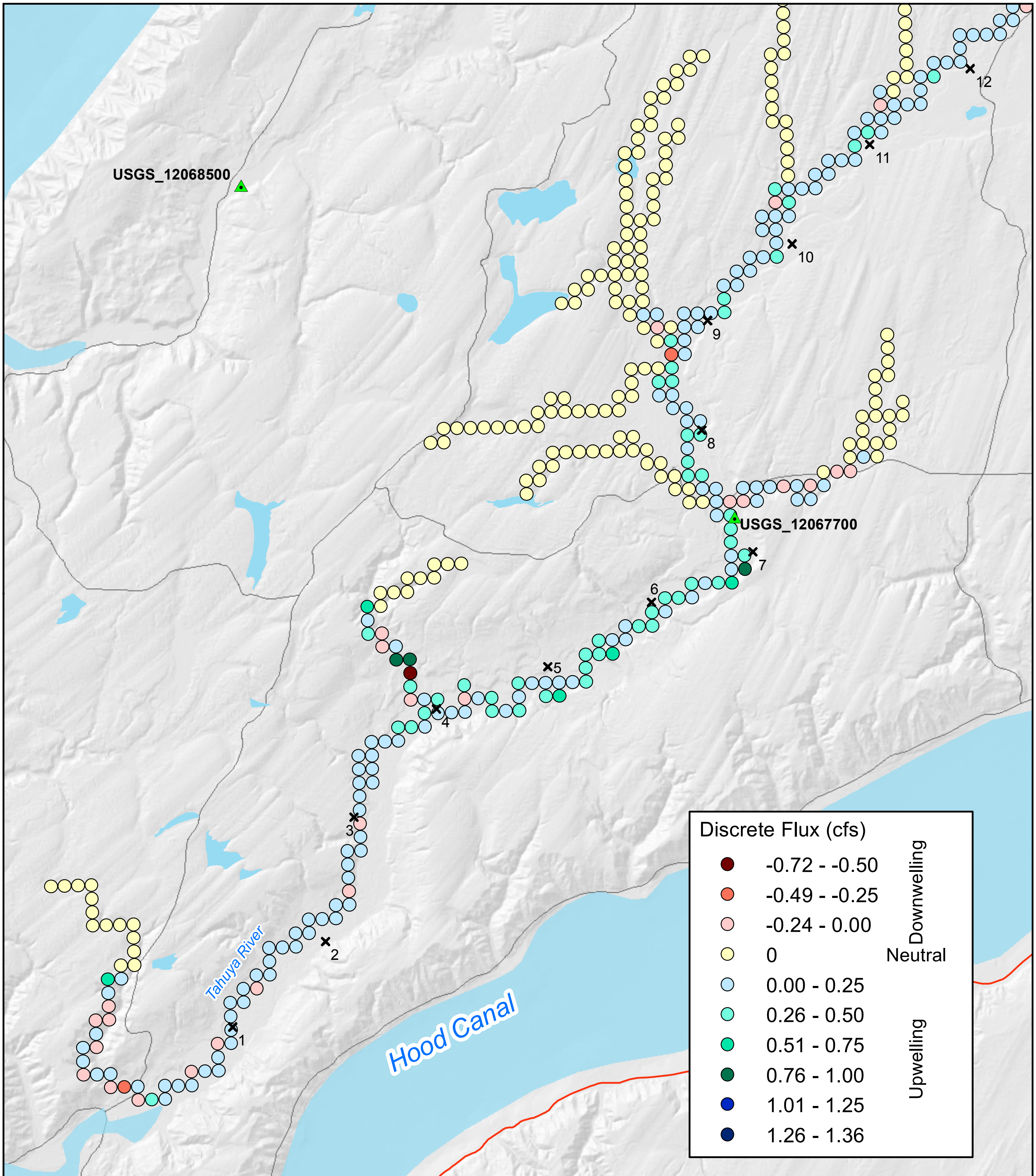


Figure 4

Simulated Cumulative Baseflow in Tahuya, Dewatto, and Anderson under Steady-State Average Conditions



Stream Gages
River Miles
State Routes
County Boundary

0 Miles 1

Figure 5

Tahuya – Simulated Discrete Flux between Groundwater and Surface Water at each Stream Cell under Steady-State Average Conditions

PGG

K:\Dawn\Hood_Canal_CC\GIS\Sim_Discrete_AvgCondition_Tahuya.mxd 4/10/2017

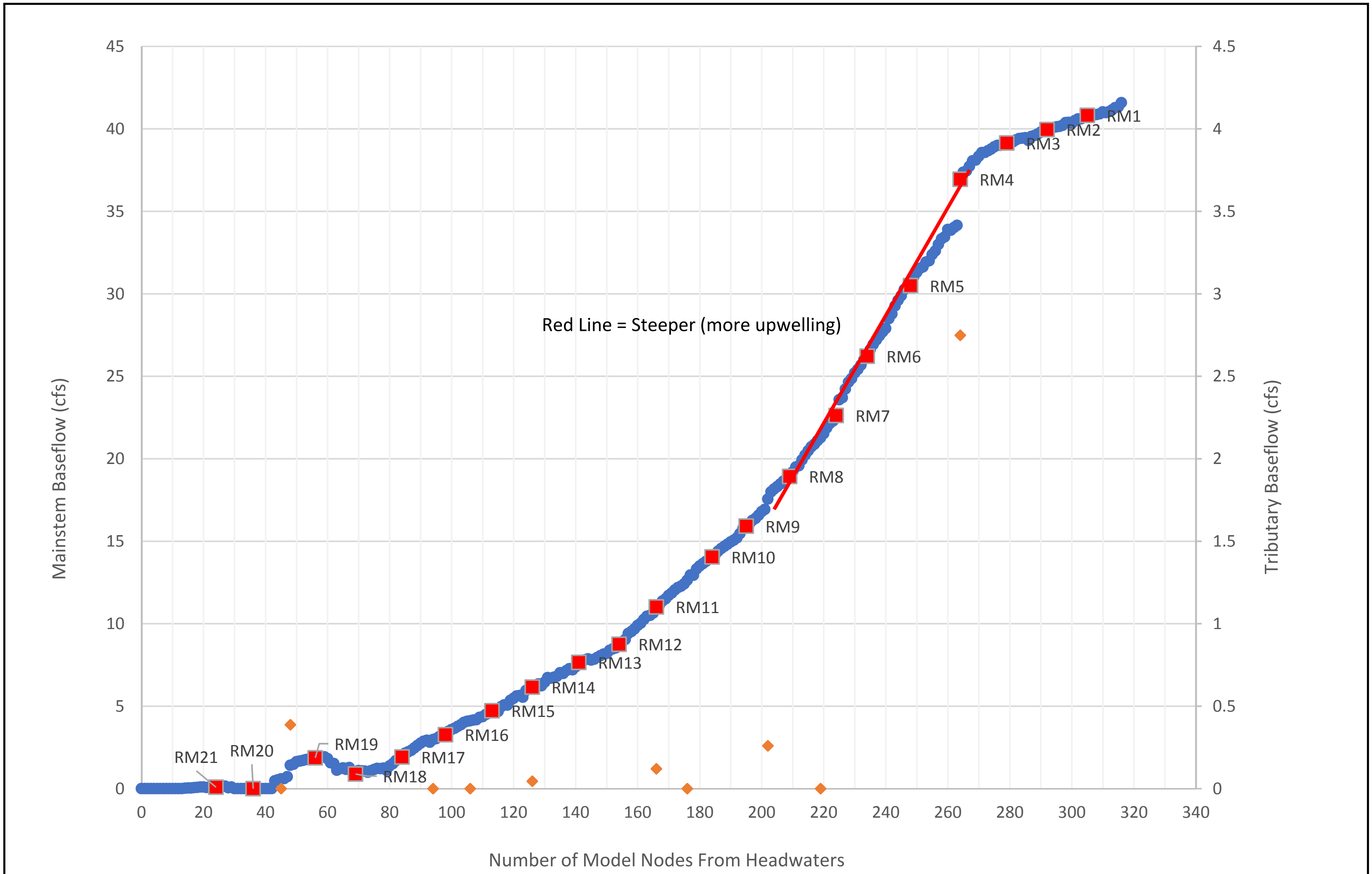


Figure 6. Tahuya - Simulated Steady-State Average Baseflow

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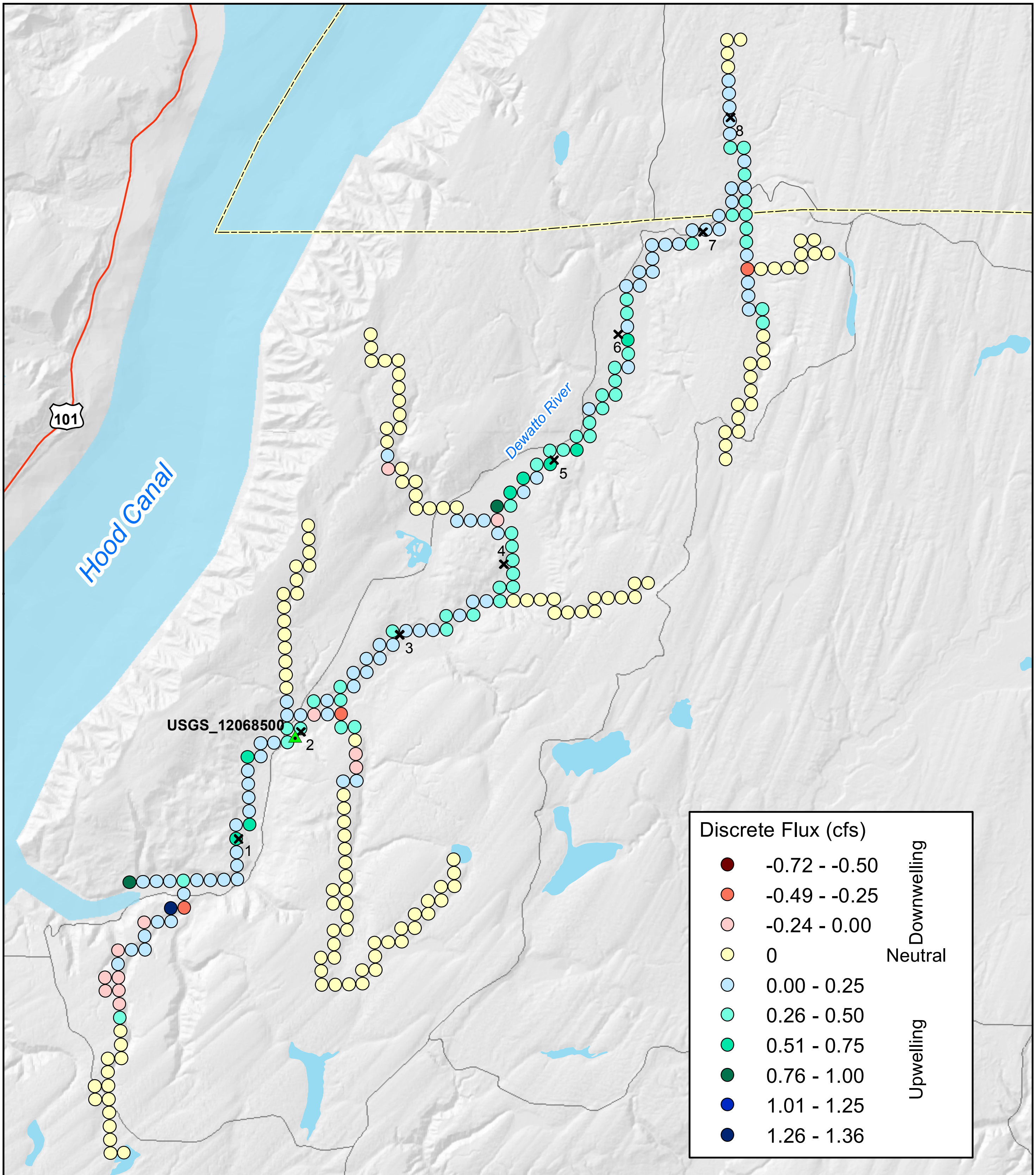
PgG

K:\Dawn\Hood_Canal_CC\GIS\Sim_Discrete_AvgCondition_Dewatto.mxd 4/10/2017



Stream Gages
River Miles
State Routes
County Boundary

0 Miles 1

Figure 7

Dewatto – Simulated Discrete Flux between Groundwater and Surface Water at each Stream Cell under Steady-State Average Conditions

PGG

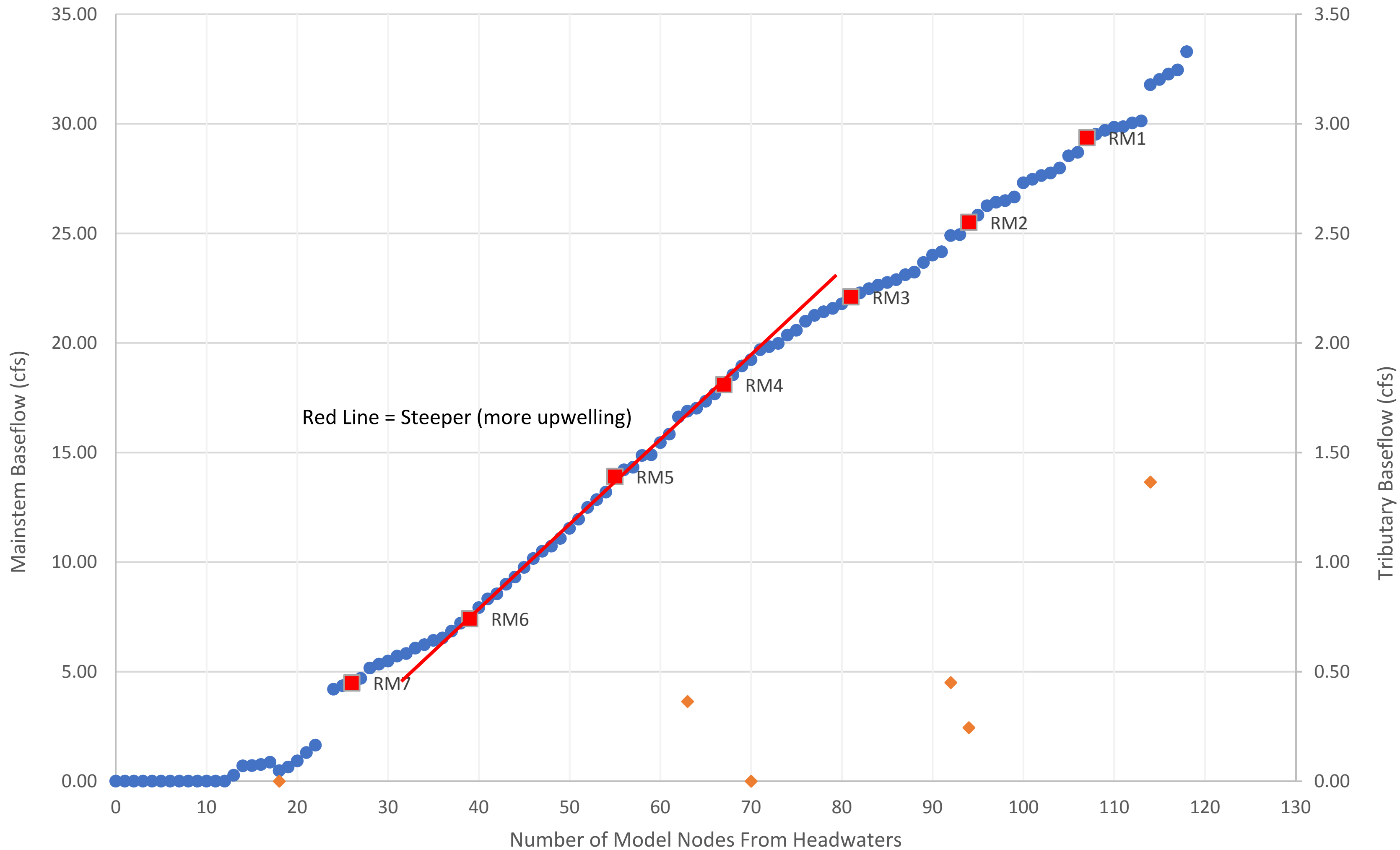


Figure 8. Dewatto - Simulated Steady-State Average Baseflow

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JD1602

PgG

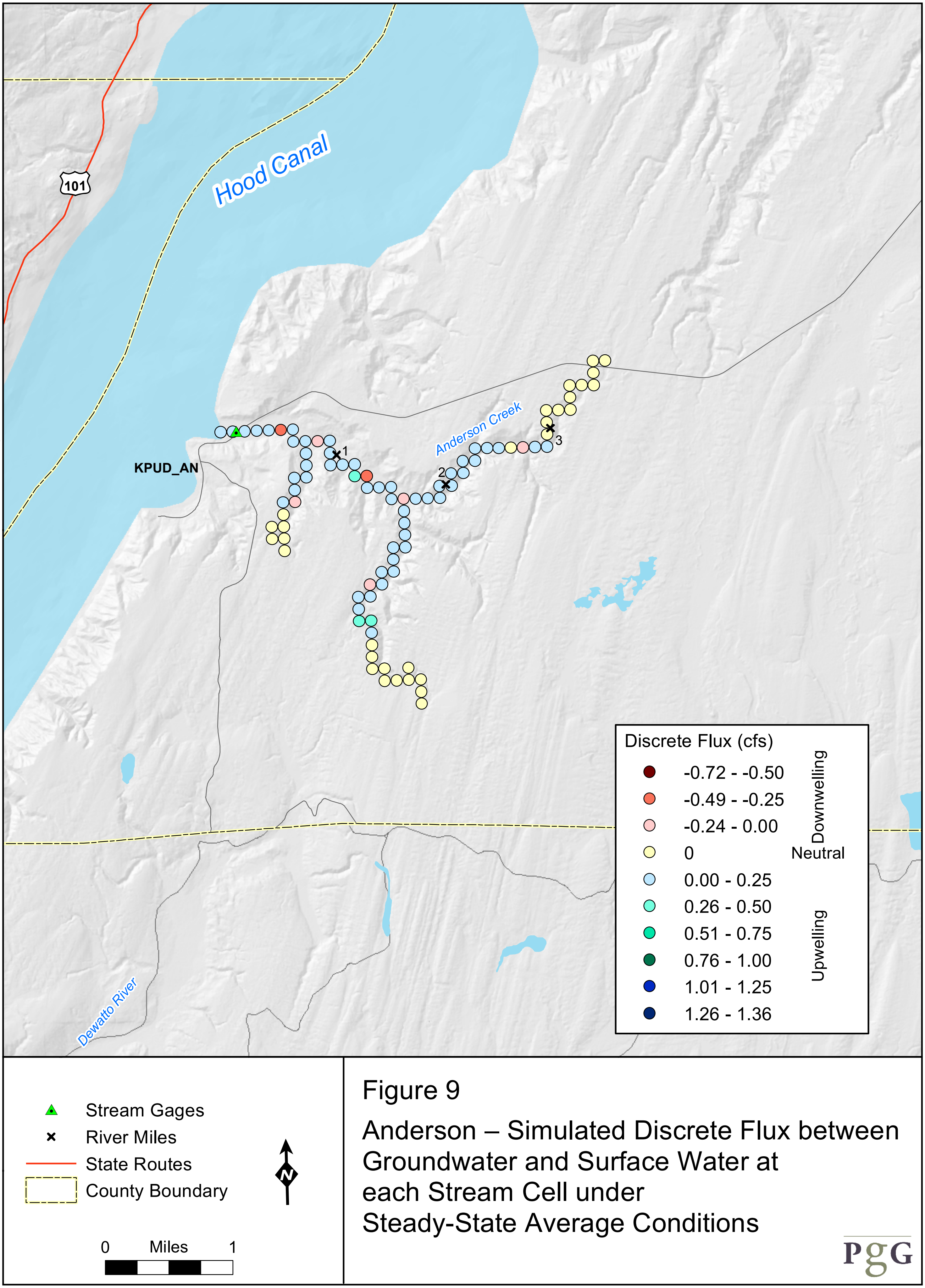

Figure 9

Anderson – Simulated Discrete Flux between Groundwater and Surface Water at each Stream Cell under Steady-State Average Conditions

PgG

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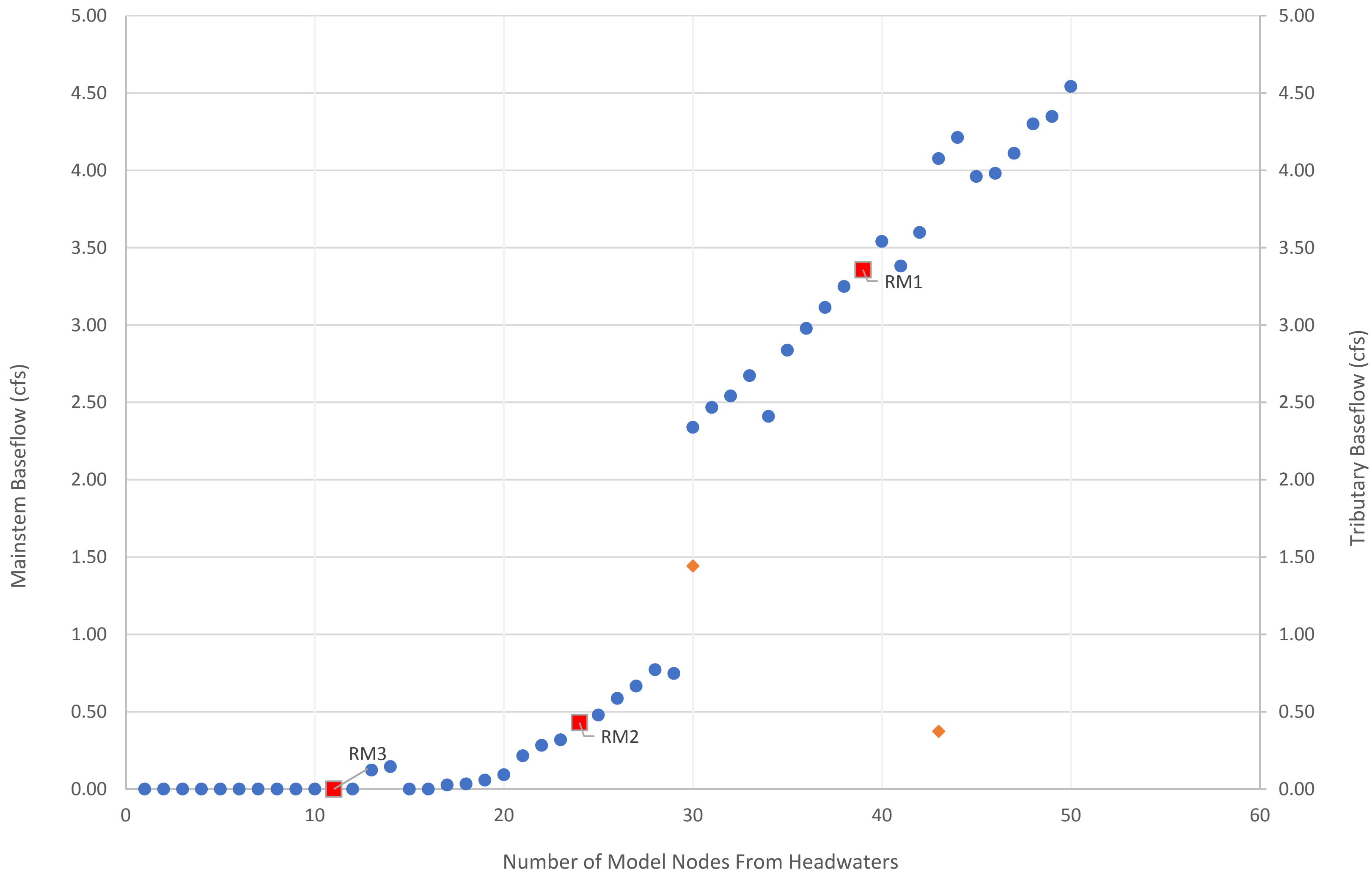

Main Stem Baseflow
Trib Baseflow (Segment)
River Miles

Figure 10. Anderson - Simulated Steady-State Average Baseflow

HCCC
JD1602

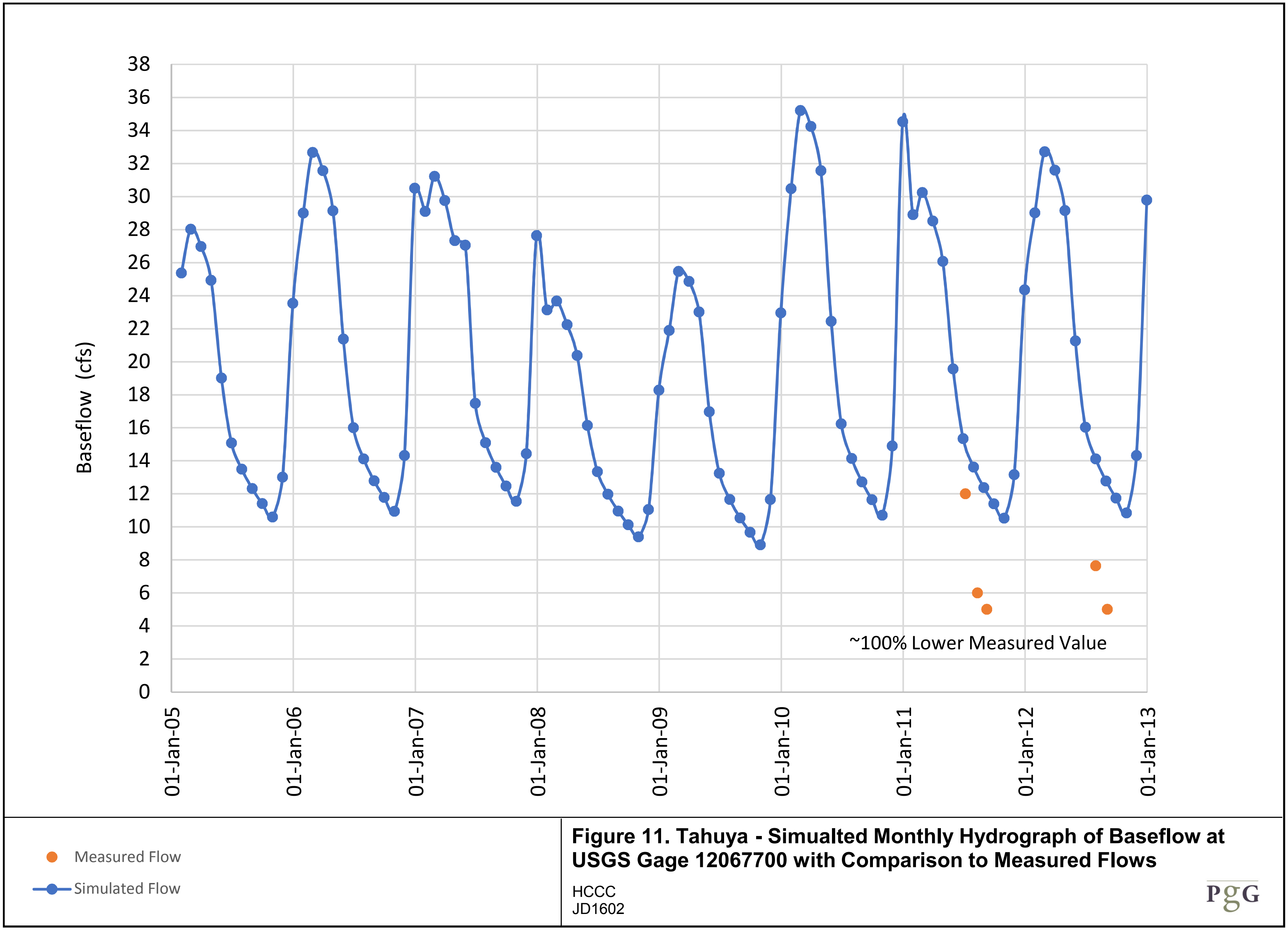

Figure 11. Tahuya - Simualted Monthly Hydrograph of Baseflow at USGS Gage 12067700 with Comparison to Measured Flows

HCCC
JD1602

PGG

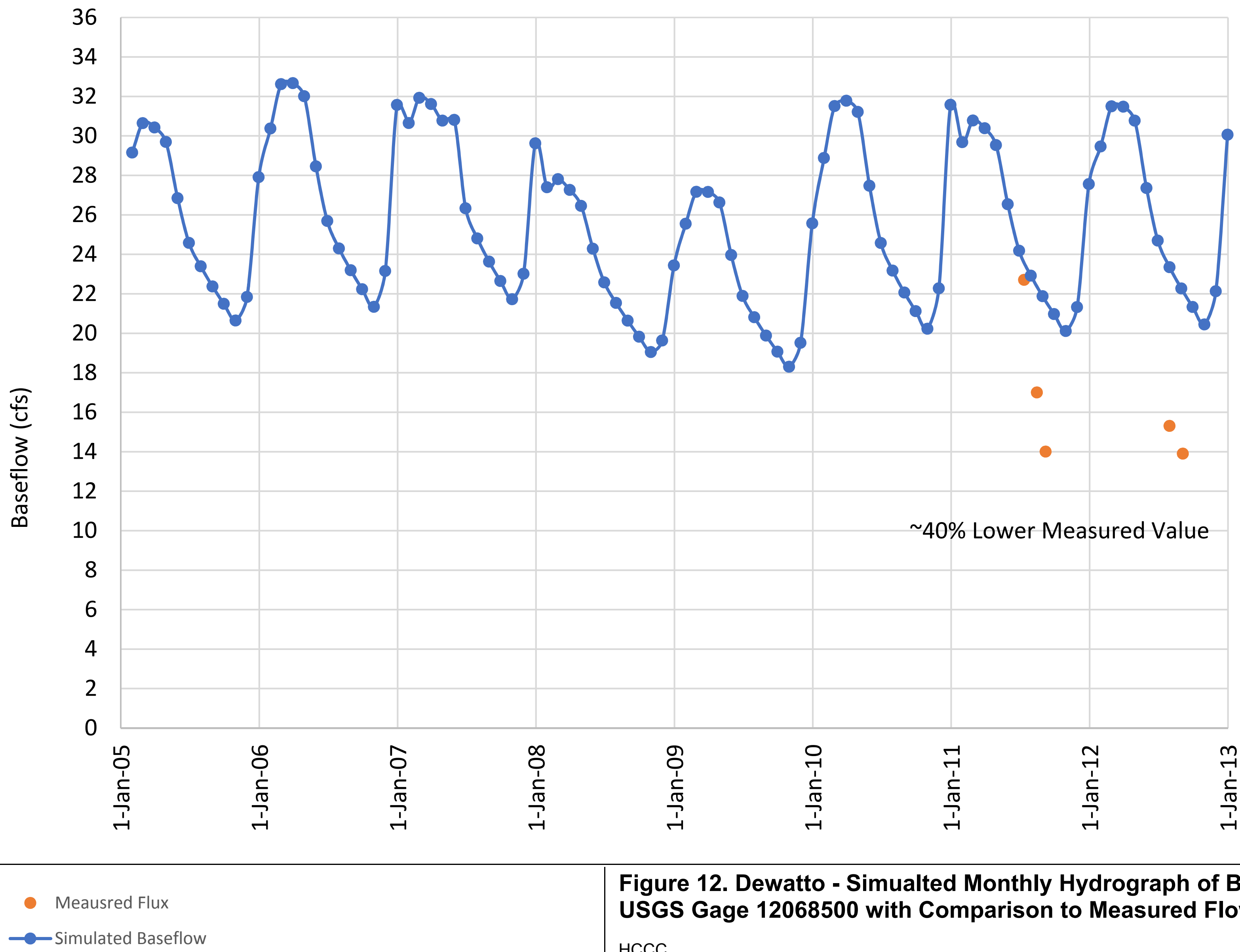

Figure 12. Dewatto - Simualted Monthly Hydrograph of Baseflow at USGS Gage 12068500 with Comparison to Measured Flows

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JD1602

PgG

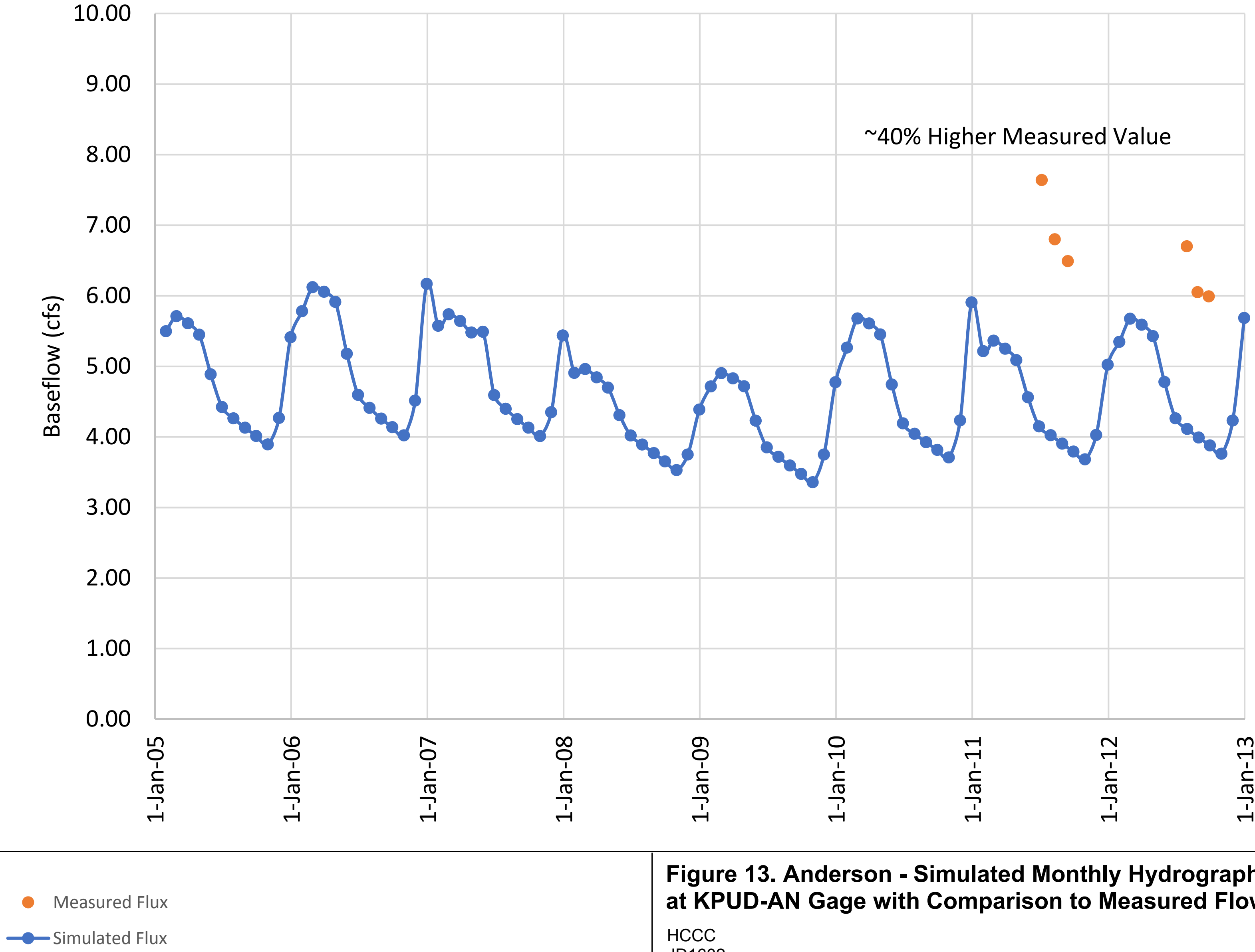

Figure 13. Anderson - Simulated Monthly Hydrograph of Baseflow at KPUD-AN Gage with Comparison to Measured Flows

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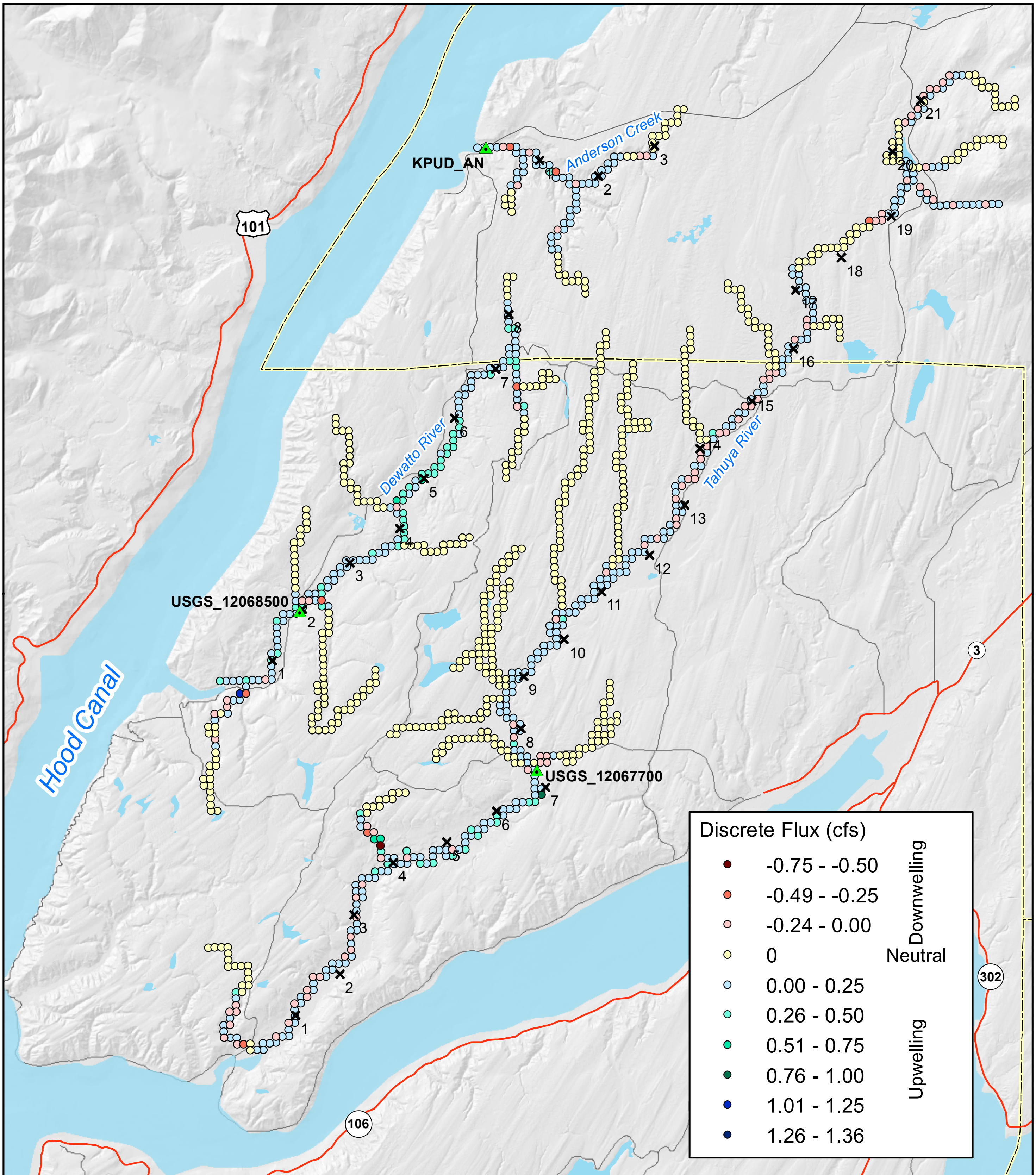
JD1602

PGG



Stream Gages
River Miles
State Routes
County Boundary

0 Miles 5

Figure 14

Simulated Discrete Flux between Groundwater and Surface Water at each Stream Cell in Tahuya, Dewatto, and Anderson under Transient Conditions at the End of October 2009

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Appendix B
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 and Phase 2 of the evaluation of using groundwater data to inform summer chum salmon restoration in eastern Hood Canal. The two literature review focus questions which are highlighted in the literature reviews completed 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 percent 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 percent 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 percent 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.

Garling, M.E., D. Molenaar, and others. 1965. Water Resources and Geology of the Kitsap Peninsula and Certain Adjacent Islands. U.S. Geological Survey Water Supply Bulletin No. 18, Olympia, Washington.

The paper provides detailed information on water resources on the Kitsap Peninsula which includes the project study area. Based on analysis of available records of flow characteristics of major streams in the area, hydrologic and geologic mapping, and additional water sampling, the authors compiled an inventory of the water resources in this area. The Tahuya River is influent between gages 0600 and 0675 (which is approximately between Bremerton and Belfair) and it appears that some of this water is eventually discharged into channels in adjacent stream systems. Although there is no definitive proof, Dewatto Creek may be the recipient of some groundwater discharge from the Tahuya River that would flow through continuous aquifers not hydraulically controlled by surface topography. Based on information available at the time of the report, it was unknown exactly where the Tahuya may feed groundwater into the Dewatto.

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. 2003. Salmonid habitat limiting factors Water Resource Inventory Areas 15 (west), Kitsap Basin and 14 (North), Kennedy-Goldsborough Basin. Washington State Conservation Commission, Olympia, Washington, June 2003.

This report analyzed possible limiting factors for salmon bearing reaching within WRIA 14 and 15. The report states that Hood Canal summer chum were historically present in Big Beef Creek, Anderson Creek, Dewatto River, and Tahuya River. Summer chum in these systems spawn from mid-September to late October, a month earlier than Hood Canal fall chum. Premature emergence for summer chum is noted to occur when eggs are buried less than 20 cm deep. After hatching, the fry remain in gravel from 6 to 25 days. Summer chum typically make the transition from freshwater to brackish and saline water in less than 12 hours. The report also notes that the preferred juvenile salmonid rearing temperature is 14 degrees Celsius. The report lists specific details for each watershed. The details for the three systems that were analyzed for Phase 2 work are listed below.

Anderson Creek watershed drains approximately 5 square miles (sq mi). The mainstem is 4 miles long with an additional 13 miles of tributaries. A culvert at Nellita-Hintzville Road is a complete barrier on the upper mainstem. Lower reaches of the stream are characterized by riparian wetlands and beaver activity. Floodplain connectivity was rated poor. Large woody debris was rated as fair to poor. Percent pools and pool frequency were rated good to poor. Temperature was monitored near Seabeck-Holly Road from 1992 to 1994 and 2001. Temperature was rated good. No DO information reported. Forests cover 97 percent of the Anderson Creek Watershed. As of 1995, impervious surfaces covered 3.4 percent of the watershed and was projected to be 12.4 percent in the future.

Dewatto River watershed drains 23 sq mi of land. Mainstem is 8.7 miles in length with about 30 miles of tributaries. Land cover is dominated by second growth timber and dense underbrush. A culvert on stream 15.0420C is a partial barrier. A culvert near river mile 1.0 on Windship Creek is at least a partial velocity barrier. Pool frequency was rated poor on the lower reach. Temperatures were monitored from 1994 to 1997. Temperature was rated fair to poor. No DO information reported. No information available to assess percent impervious surface.

Tahuya River watershed drains 45 sq mi of land and is the largest stream on the Kitsap Peninsula. The mainstem is 21 miles long with an additional 65 miles of tributaries. Logging has been the dominant land use in the Tahuya Watershed both historically and at the present time. For the lower Tahuya River subwatershed (mouth to Unnamed Stream 15.0453 (river mile 6.7)) tributaries have two complete barrier culverts and two partial barrier culverts. Streambank stability was rated fair to poor. Temperature was monitored in 1994 and 1996. Temperature was rated fair. No information was available for DO. The middle reach of the Tahuya River loses surface flow to the water table. The Dewatto River is believed to be a recipient of some of this water (Garling and Molenaar 1965).

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 percent 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 percent) 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 Department of Fish and Wildlife. 2017. SalmonScape interactive mapping. Washington Department of Fish and Wildlife, Olympia, WA. URL: http://apps.wdfw.wa.gov/salmonscape/map.html. (Last accessed April 7, 2017).

This website lists historic salmon access on various streams throughout Washington. The information was reviewed regarding summer chum access for the Tahuya, Dewatto, and Anderson watersheds. Tahuya access extended to river mile 8.85. Dewatto access extended to river mile 4.89. Anderson access extended to river mile 1.66.

Washington Department of Fisheries. 1975. A catalog of Washington streams and salmon utilization. Seattle, WA: 4 vols.

This document catalogs the salmon utilization of streams within Washington state and is divided into WRIAs. Information for WRIA 15 was reviewed as part of Phase 2 work for the project. The information for Dewatto and Anderson Creeks states that the creeks are extremely productive for their size and support a variety of salmonid species. The report states that there is a gage station on Dewatto that has recorded stream flows for 22 years. The 22-year average flow for the Dewatto system was 69.1 cfs. The report states that the earliest run of chum salmon enters into the Dewatto system in September and spawns through the month in the lower two miles of the stream. This run is reported to total up to 4,000 spawners each year. The timing of the run for Anderson is reported to be the same, however, spawner totals and locations aren't listed. Maps are provided for the extent of chum access in the system. For the Tahuya system no flows are discussed. The report states that there are runs of coho, chum, and Chinook salmon in this system. The report states that the earliest run of chum salmon enter into the system in early September and spawn through early October in the lower three miles of the system.

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. InfoRation 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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