STREAM & FLOODPLAIN RESOURCE MANAGEMENT Natural Systems Design P.O BOX 15609 SEATTLE, WASHINGTON 98115

To: **Quinault Indian Nation**

From: Natural Systems Design, Inc.

Date: April 22, 2020

Re: Critical Review of Proposed Chehalis River Basin Flood Damage Reduction Project SEPA DEIS
Hydrology Technical Memo 2: HYDROLOGY and CLIMATE CHANGE TECHNICAL ANALYSES REVIEW

EXECUTIVE SUMMARY

The hydrology and climate change technical analyses prepared in support of the Proposed Project, an expandable flood retention (FRE) facility, and the Draft SEPA EIS (DEIS) document were reviewed by a qualified technical team, including Susan Dickerson, PhD, PG; Tim Abbe, PhD, PEG, PHG; Scott Katz, MS; Leif Embertson, PE; Megan Nelson PE, MS; Kevin Fetherston PhD, PWS; and Torrey Luiting, MS, PWS.

Within the DEIS analysis, the characterization of the types and severity of direct and indirect impacts to aquatic habitat and treaty resources due to the presence and operation of the FRE facility are directly influenced by the associated analyses of hydrology and climate change. For example, the frequency and duration of local and downstream impacts is directly tied to the frequency of peak flows that would trigger FRE operation under current and future climate conditions. The team concluded that the analyses:

- Underestimate the frequency of peak flows that will trigger FRE operation under both current and future climate conditions. Therefore, both the frequency and duration of impoundment and the associated local and downstream impacts are underestimated.
- Neglect to quantify the current and future frequency of backwatering events due to the capacity and operation of the conduits. Therefore, the DEIS fails to assess the associated local and downstream impacts of backwatering in a meaningful way.
- Integrate mid-century and late-century climate change projections in a way that fails to represent a true "high-end" scenario for projected peak flows. Therefore, the maximum impacts of the Proposed Project by late-century are underestimated.
- Underestimate the impact on groundwater and wetlands by using inappropriate groundwater recharge rates and a rudimentary groundwater-surface water analysis. The analysis fails to represent spatial heterogeneity along the Chehalis River floodplain and to account for multi-year and long-term impacts on groundwater-surface water interactions. Therefore, impacts to wetlands and to the quantity and quality of streamflow are underestimated. Groundwater is particularly critical in dry summer months for augmenting streamflow, reducing stream temperature, and maintaining aquatic habitat.
- Fail to account for the ways in which reduced groundwater recharge and storage will amplify climate change projections for lower summer streamflow and higher summer stream temperatures.

Together, these shortcomings in the DEIS analyses result in an underestimation of local and downstream impacts to aquatic habitat and treaty resources. Although the DEIS found significant impacts, the assessment of the DEIS analyses described herein indicates that the scale and intensity of significant impacts is substantially underestimated.

INTRODUCTION

An expandable flood retention (FRE) facility has been proposed as an alternative to accomplish flood damage reduction on the Chehalis River, Washington. Several alternative concepts were proposed, but the Flood Retention Expandable (FRE) facility has been advanced for environmental review under SEPA. The purpose of the facility would be to store water in the upper watershed to alleviate flood damage to developed areas of the lower floodplain near the towns of Centralia and Chehalis.

The quantification of local and downstream impacts from operation of the FRE facility that are described in the DEIS are the result of the analysis of hydrology and of climate change impacts to hydrology, particularly on peak flows. We also reviewed the DEIS characterization of downstream effects on groundwater, wetlands, and streamflow to understand whether impacts to aquatic habitat during the dry summer season are accurately characterized.

ANALYSIS

Frequency of FRE Operation

The evaluation of many of the environmental impacts assessed in the DEIS is based on the frequency of FRE facility operations (i.e., impoundment of water) and duration of time that water is stored in the resulting reservoir. In the DEIS, it is stated that the FRE facility is predicted to operate approximately once every 7 years (current climate), 5 years (mid-century climate conditions), and 4 years (late-century climate conditions), with water being impounded in the reservoir for a maximum of 35 days. These frequencies are utilized to quantify the associated local and downstream impacts on water quality, water quantity, and aquatic habitat quality.

However, our analysis indicates that the FRE facility will be operated more frequently and for a longer duration than presented in the DEIS, particularly under future climate conditions. Thus, local and downstream impacts related to the operation and duration of FRE operation are underestimated in the DEIS. There are three main shortcomings in the DEIS analyses, each of which results in an underestimation of FRE operation frequency:

1. **In the DEIS, the analysis of FRE operation under both current and future climate conditions is based on the recurrence interval determined by an Annual Flood Frequency Analysis only, rather than the frequency with which the relevant peak flow threshold of 38,800 cubic feet per second (cfs) at Grand Mound is exceeded.**

The DEIS estimates FRE operation frequency for current conditions by extracting the streamflow maxima for each water year at the USGS gage at Grand Mound and performing a common flood frequency statistical analysis on the annual data (Log Pearson type 3) to estimate exceedance probability and the associated recurrence interval. Water years run from October 1 to September 30. For future frequency of FRE operation, the analysis of increased magnitude and frequency of peak flows is also based on the annual maximum flows. However, by using only the annual maxima to characterize frequency of FRE operation under both current and future conditions, the analysis does not account for the frequency of high flows over the threshold that triggers operation of the FRE facility and impoundment (i.e., 38,800 cfs at Grand Mound).

Streamflow observations at Grand Mound provide examples of water years in which there are multiple, independent peak flow events that exceed the 38,800 cfs flow threshold at Grand Mound. A portion of the historical record is shown in Figure 1, illustrating that during WY 1989 to 1992 there are 2 annual peaks (peaks marked with open circles above dashed horizontal line in Figure 1) but a total of 4 independent peaks that exceed the 38,800 cfs threshold.

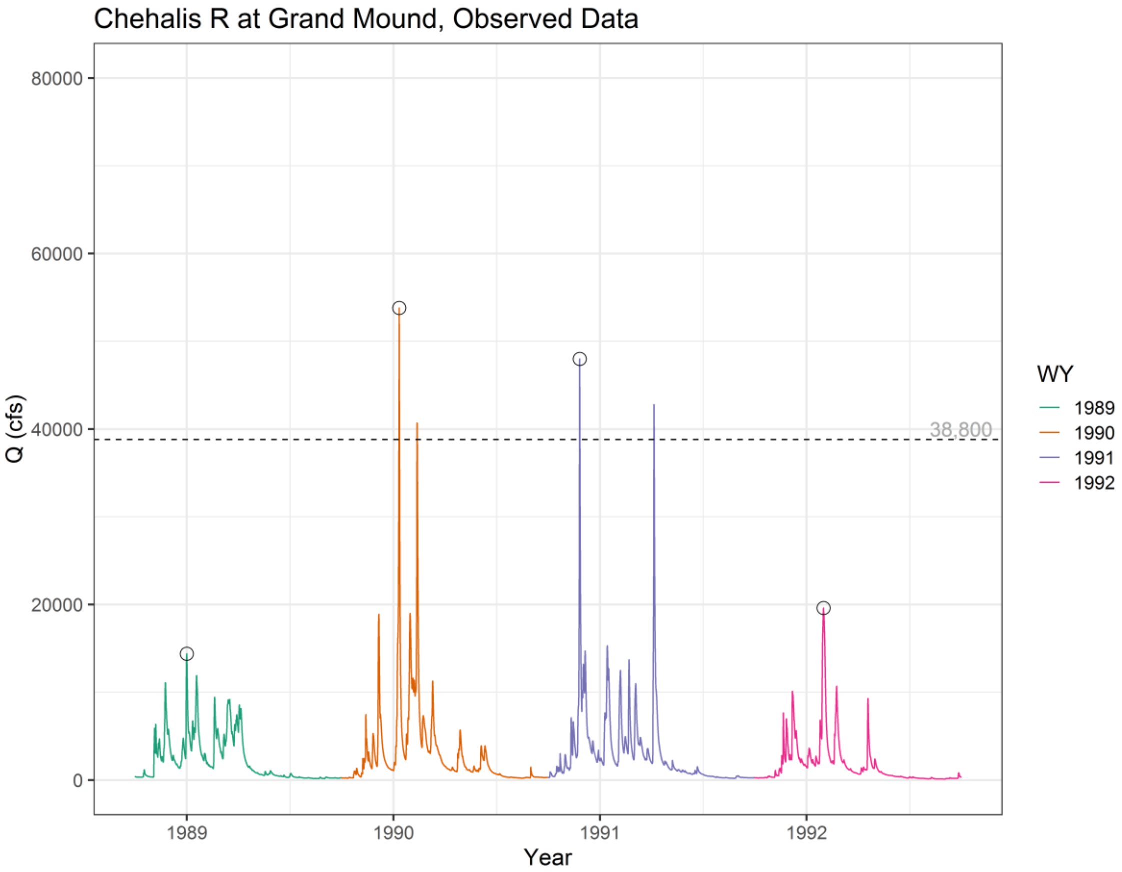

Figure 1. Historical flow record of for the Chehalis River at the USGS Grand Mound Gage (12027500) for water years (WY) 1989-1992. The hydrograph displays instantaneous data downloaded from the USGS website. The FRE operation threshold of 38,800 cfs is denoted by the black dashed line. Annual streamflow maxima used to estimate the flood frequency statistics that form the basis for the DEIS impact evaluation are denoted by black circles. During WYs 1990 and 1991, there would have been two additional flow events for a total of four peak flow events that exceeded the FRE operation threshold, however neither were incorporated into the analysis of the frequency of FRE operation.

Over the entire continuous flow record at Grand Mound, from 1988 to present, there are five annual maximum peaks over 38,800 but a total of seven independent peaks over the flow threshold. The additional peaks that exceed the 38,800 cfs threshold are acknowledged in the notes associated with Figure N-7 in the DEIS, but the DEIS statements regarding the frequency of FRE operation and much of the associated impacts analysis relies on the annual flood frequency analyses only. This shortcoming also applies to analysis of mid-century and late-century hydrology, for which peak flow events that exceed 38,800 cfs will be more frequent than the annual flood frequency analysis suggests. In the DEIS, the projected frequency of future FRE operation is based an annual flood frequency analysis of simulated future streamflow. The average increases in peak flows for mid- and late-century are computed from the hydrologic modeling results and are 12% and 26%, respectively (Karpack and Butler, 2019). These increases are applied to annual flood frequency analysis to estimate a 5-year and 4-year recurrence interval for flows that exceed 38,800 cfs (Table N-5). In contrast, examination of the entire continuous record at the Grand Mound gage (1988-2019) of streamflow, with peak flow values scaled to represent climate change (i.e., following the methodology detailed in Hill and Karpack (2019)), indicates that the

FRE facility would be operated once every 1.8 and 1.4 years, on average, under mid- and late-century climate scenarios. **Thus, the FRE facility will operate more frequently than stated in the DEIS.** The example below illustrates the need for this type of frequency analysis; under future conditions (i.e., estimated by scaling peak flows by 26%) both WY 1996 and WY 1999 experienced multiple, independent peak flows greater than 38,800 cfs (Figure 2).

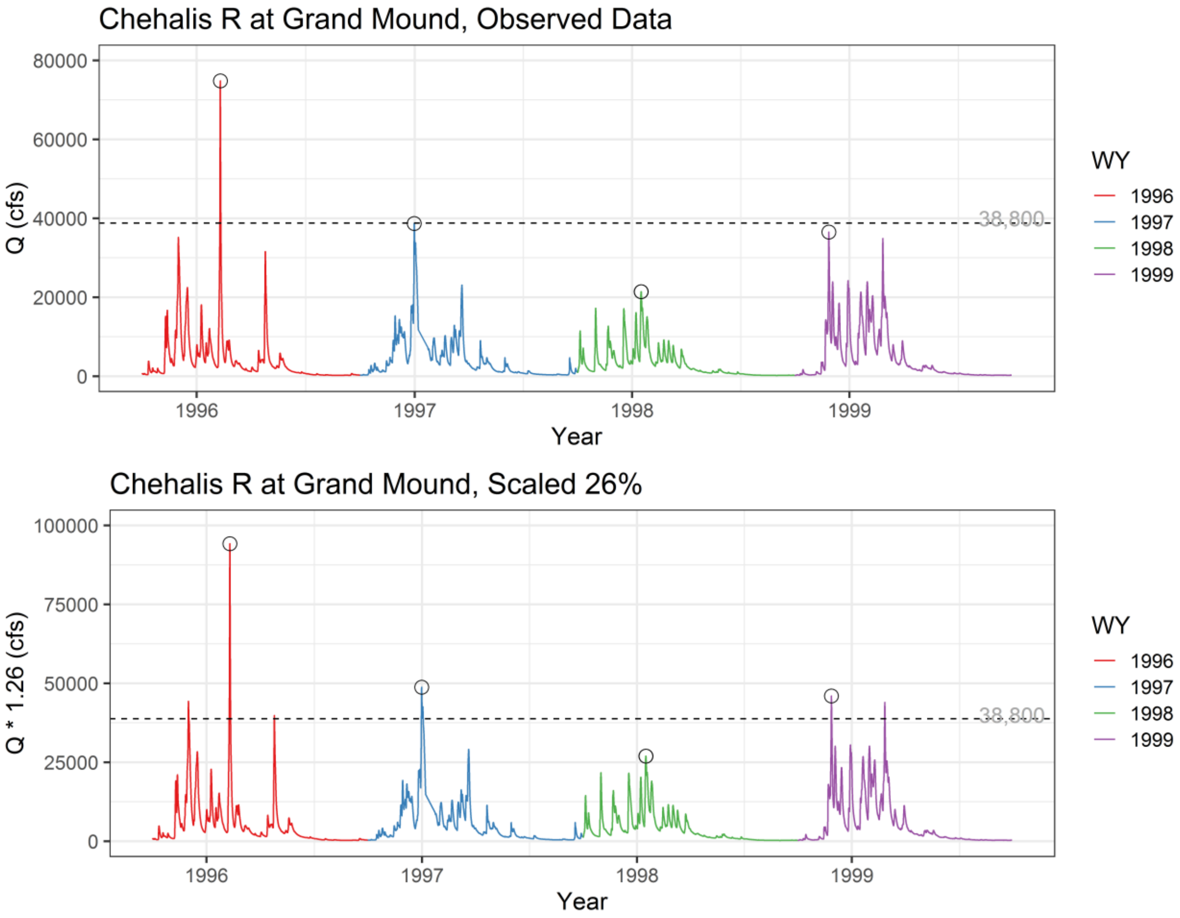

Figure 2. Historical and scaled flow record for the Chehalis River at the USGS Grand Mound gage (12027500) for water years (WY) 1996-1999. The top panel shows the historic data from the gage and the bottom panel shows the historical record with peak flows (i.e., flows with exceedance probability < 1%, after Hill and Karpack (2019)) scaled by 26% to account for increases in flow magnitude due to climate change (I.e., denoted as "late-century" climate projection in the DEIS).

Under historical conditions, there would have only been one flow that exceeded the FRE operation threshold of 38,800 cfs during this time period shown in Figure 2 (note that the peak flow in WY 1997 was 38,700 cfs and was 100 cfs under the threshold). However, when the flow record is scaled to account for projected future conditions, there are six events that exceed the threshold during this time period with WY 1996 and WY 1999 experiencing multiple events. The multiple exceedances of the FRE operation threshold during individual WYs have not been accounted for in many of the analyses used to asses impacts in the DEIS.

2. **The quantification of impacts based on the maximum duration of reservoir impoundment by end-of-century does not account for increased frequency of flows greater than the reservoir outflow rate, and therefore both the maximum duration of impoundment and the associated impacts are likely underestimated.**

The maximum duration of the reservoir pool is stated as ("Up to…") 35 days for the "catastrophic flood" by the end of the century. This does not account for multiple peak flows occurring in sequence, nor for increased frequency of winter flows that would exceed the outflow rate during the drawdown period. A high winter flow that exceeds the outflow rate and occurs while the reservoir is still drawing down from a previous FRE facility closure will extend the duration of impoundment and all associated impacts by:

a. Increasing the volume of water needed to be passed through the reservoir (i.e., inflow greater than outflow);

b. Increasing the duration of higher flows through the culverts; and

c. Re-setting the drawdown period and extending the time needed for debris management and associated slower outflow rates.

Projections for increased peak flow magnitudes with climate change are driven by projections for higher precipitation rates, particularly in the fall and winter months. More frequent or more intense rain storms produce more runoff, which generates high streamflow. Higher precipitation rates will increase the magnitude of annual peak flows, which is represented in the DEIS as a 26% increase in peak flows by late-century. Higher precipitation rates will also increase high flow events across the board, likely increasing the magnitude of all winter peaks. This general increase in winter flows will also increases the frequency of flows that exceed the reservoir draw down rate, variously reported in the DEIS and associated appendices as 5,000-6,500 cfs (DEIS, p F-63), as 10,600 cfs (DEIS, p 16), and as 4,320-10,600 cfs (DEIS, p N-50). If the reservoir is storing water and the inflow to the reservoir exceeds the outflow rate (i.e., reservoir draw down rate), the volume of water stored in the reservoir will continue to increase. Thus, draining the reservoir would take longer and the duration of impoundment would be extended.

For example, based on estimated streamflow values for 1988-present at the dam site (which are scaled based on drainage area ratio from data collected at the Doty gage), the number of observational examples during which an incoming flow greater than 6,500 cfs occurs within the 35-day drawdown window after FRE operation begins increases from 1 instance in the historical record to 5 instances in the late-century time series. This increase in flow frequency and magnitude are not reflected in the estimates for the duration of impoundment and thus the impacts associated with impoundment are likely underestimated.

3. **The use of <u>predicted flows</u> to initiate closure of the FRE facility is likely to trigger impoundment of the river more frequently and for a longer duration than assessed in the DEIS, which uses <u>observed flows</u> as the basis for analysis of closure-related impacts.**

The DEIS describes the environmental impact and flood control benefit of the FRE facility based on analysis of the *observed* streamflow record. The DEIS also states that closing the facility will be determined by using *predictions* of streamflow from the NOAA Northwest River Forecast Center (DESI, Section 2.3.2.2, p 15). The DEIS fails to consider that the NOAA dataset of observed flows differs substantially from the flow prediction dataset that would be used to operate the FRE facility.

A comparison of differences between the predicted streamflow and the streamflow actually *observed* in the river values shows that the relationship between predicted and observed streamflow is highly uncertain during floods large enough to trigger impoundment. The DEIS states that the FRE facility will be operated "when flows are forecasted to be above 38,800 cfs at Ground Mound within a 2-day time window (DEIS, p N-49)". Predicted flows made 2 days in advance of storms overpredict the river's observed discharge. The degree of overprediction is 19% of the impoundment threshold on average (I.e. flows were predicted to be 7,160 cfs over what they were later observed to be). If, as stated in the DEIS, the 2-day forecasts will be used to trigger FRE operation, the FRE facility is likely to impound the river at storm events that ultimately fail to reach the trigger of 38,800 cfs of flow as measured at Grand Mound.

The DEIS did not address the degree of uncertainty/overprediction inherent in use of predicted flows. Rather the DEIS analyzes impacts from the impounding of the river based solely on analysis of the *observed* streamflow record. Because the DEIS failed to consider the mismatch between the NOAA predicted flows and the flows actually observed in the river when analyzing impacts from reservoir impoundment, drawdown, and duration, it underestimates all local and downstream impacts associated with frequency and duration of impoundment.

The methods and analysis used to develop these conclusions are presented in detail in the Hydrology Technical Memo 1: Observed and Predicted Flows Relative to FRE Facility Operation.

Backwatering Caused by the Low-Level Outlets

Impacts to river processes associated with backwatering were not evaluated in the DEIS; backwatering would be caused by the capacity of the Low-Level Outlets (LLO's) of the FRE facility when flow exceeds 8,500 cfs. Backwatering occurs when streamflow is obstructed by a natural flow constriction, channel-spanning blockage, or infrastructure that lacks the conveyance capacity to pass the full volume of discharge downstream. Flow velocities are slowed compared to unobstructed open-channel flow, water surface elevation rises, and ponding occurs. Backwatering can inundate bars and channel margins that would otherwise be dry and can reduce sediment transport and trigger sediment deposition at the upstream end of the ponding. Simultaneously, the flow passing through the LLOs would become pressurized, which would increase local scour through the conduits.

The conveyance capacity of the Low-Level Outlets (LLOs) of the FRE facility is limited, and backwatering will initiate at discharges of 8,500 cfs or greater: "For flows over 8,500 cfs, the water would start to pond at the outlet entrances and rise into the reservoir area" (DEIS, p 14). The temporary ponding would occur when the FRE facility is not operational (i.e., not intentionally impounding water) and would extend roughly 300 feet upstream (DEIS, p P-73). Backwatering will cause disruptions to river processes such as bedload transport and downstream flow levels. **The DEIS acknowledges that ponding impacts river processes such as sediment transport (DEIS, p F-69) and transport of large woody material (DEIS, p F-78), fish passage (DEIS, Appendix 1-Attachment A, p G-108), and wildlife habitat and use (DEIS, p F-73). However, the frequency and magnitude of impacts due to backwatering when the FRE is not intentionally impounding water are not quantified.**

Our analysis indicates that the frequency of peak flow events that exceed 8,500 cfs at the FRE facility site when discharge at Grand Mound is lower than the 38,800 cfs threshold is 12 times in 31 years, or approximately once every 3 years, based on estimated streamflow values for 1988 to present at the FRE facility site (and scaled based on drainage area ratio from data collected at the Doty gage). Under the mid-century climate scenario, the frequency is 11 times in 31 years and under the late-century climate scenario it is 9 times in 31 years (note that the decrease in frequency of these events is due to an increase in the frequency of the FRE operation threshold being met). Thus, backwatering would occur and river processes would be impacted more frequently than the DEIS states would occur with the proposed project. The DEIS fails to consider impacts associated with backwatering in any meaningful way despite acknowledging the fact that backwater will have impacts to river processes, fish passage, and wildlife. Backwatering and pressurized flow will additionally have impacts to riparian vegetation establishment, slope stability (due to longer soil saturation duration), and local scour through the LLOs.

Magnitude of Climate Change Impacts on Peak Flows

The streamflow projections used to evaluate the "maximum effects" of the FRE with climate change are based on a 26% increase in annual peak flow by the end of the century, which does not reflect a high-end climate change scenario. Therefore, all late-century impacts related to the frequency of FRE facility operation are likely under-estimated.

The climate change modeling that was used to analyze impacts of the proposed project in the DEIS (Karpack and Butler, 2019) utilizes 3 driving meteorological datasets, one for historical conditions, one for mid-century conditions, and one for late-century conditions. The datasets were chosen for this iteration of climate change modeling to utilize dynamically-downscaled datasets, which likely improves representation of atmospheric river events over previous iterations, which were based on statistical downscaling. However, for this iteration the modeling team dropped the ensemble approach, in which multiple Global Climate Models (GCMs) are used to characterize the uncertainty associated with the numerical modeling platforms. The commonly-used ensemble approach for modeling climate change impacts to hydrology accounts for the range of precipitation projections among different GCMs. Essentially, some of the mathematical relationships in each GCM is different and therefore the models produce different predictions for precipitation. In particular, the Geophysical Fluid Dynamics Laboratory (GFDL CM3) model is the model being used to represent late-century hydrology for the DEIS. In comparison to the other Coupled Model Intercomparison Project 5 (CMIP5) projections for late-century precipitation in the Columbia River Basin, the GFDL model provides a high-percent change scenario for Annual and for February-May precipitation (11% and 28% change, respectively; see Rupp et al. 2017, Figure 10). However, the GFDL model represents **a moderate-percent change scenario for October-January precipitation** (9% change). For context, the other thirty-five CMIP5 GCM projections for October-January precipitation range from –4% to 25% with a median value of 7%.

Given that the **majority of peak flows in western Washington occur in late fall through winter**, the GFDL CM3 model does not provide a high-end scenario for the impacts of climate change on peak flow generation in rain-dominated watersheds. The 26% increase in annual peak flows that is used in the DEIS analysis for late-century represents averaging across sites and across recurrence intervals (see App B of Karpack and Butler, 2019); however, this number <u>does not reflect a range of GCMs</u>. The ensemble approach is a well-established method to characterize the range of possible future hydrological conditions, given the range of climate projections; for example, a recent state-of-the-art modeling effort in the Columbia Basin used 10 GCMs, citing motivation that the choice of GCM is a key contributor to uncertainty in results (Chegwidden et al. 2019). Regarding this issue for the Chehalis Basin climate change modeling, Mauger and Karpack (see App C in Karpack and Butler, 2019) state:

> "The primary limitation of this study is the lack of sufficient climate projections to reliably estimate the range among projections: **two global climate models is simply not sufficient to do this…studies generally indicate that 6-10 different model projections are needed** in order to develop a representative estimate of the mean and range among projections."

Furthermore, preliminary results from the next generation of GCMs that are currently under development indicate higher climate sensitivity and larger increases in temperature and changes in precipitation, which suggests that use of a high-end climate scenario for characterizing future impacts is appropriate (Hausfather, 2019).

Analysis of Groundwater-Surface Water Interactions

The potential effects on groundwater, and therefore wetlands and baseflow, from the loss of over-bank groundwater recharge are underestimated. The statement that the "FRE facility operation would result in no adverse impacts on surface water quantity downstream" (DEIS, p N-62) is unsupported by the assessment. The DEIS analysis (1) neglects the role of groundwater to contribute to wetlands and floodplain waterbodies outside the area of direct infiltration and contributions to baseflow (i.e., low dry season flows), (2) underestimates groundwater recharge rates during floods, and (3) fails to account for multi-year groundwater-surface water interactions.

1) The DEIS does not sufficiently assess the linkages between impacts to groundwater and impacts to wetlands, floodplain water bodies, and baseflow downstream of the FRE facility. The DEIS focuses on the area affected by impacts to groundwater as the acres no longer inundated during a major or catastrophic flood with the implementation of the Proposed Project (i.e., 3,514-4,679 acres in Table N-13). However, as noted in the conceptual model of groundwater flow in the Centralia-Chehalis Lowland portion of the Chehalis basin (Figure 6 in Wilson et al., 2019 and in Pitz et al. 2005, and reproduced below as Figure 3), groundwater moves laterally in the subsurface and typically contributes water to streamflow in the Chehalis basin.

The DEIS fails to sufficiently assess impacts to wetlands, floodplains, and surface flows that are within the area of the floodplain that will continue to be inundated but down-gradient (i.e., receives groundwater flow from) of the area of floodplain that will no longer be inundated during a major or catastrophic flood. The wetlands discipline report (DEIS, Appendix O) notes that "the reduced area of inundation could also potentially affect groundwater levels and groundwater infiltration in the downstream floodplain on a periodic basis" but refers to the analysis within the water discipline report (DEIS, Appendix N) and the Potential Groundwater Level Effects Analysis (Wilson et al., 2019), both of which are insufficient for the reasons described below.

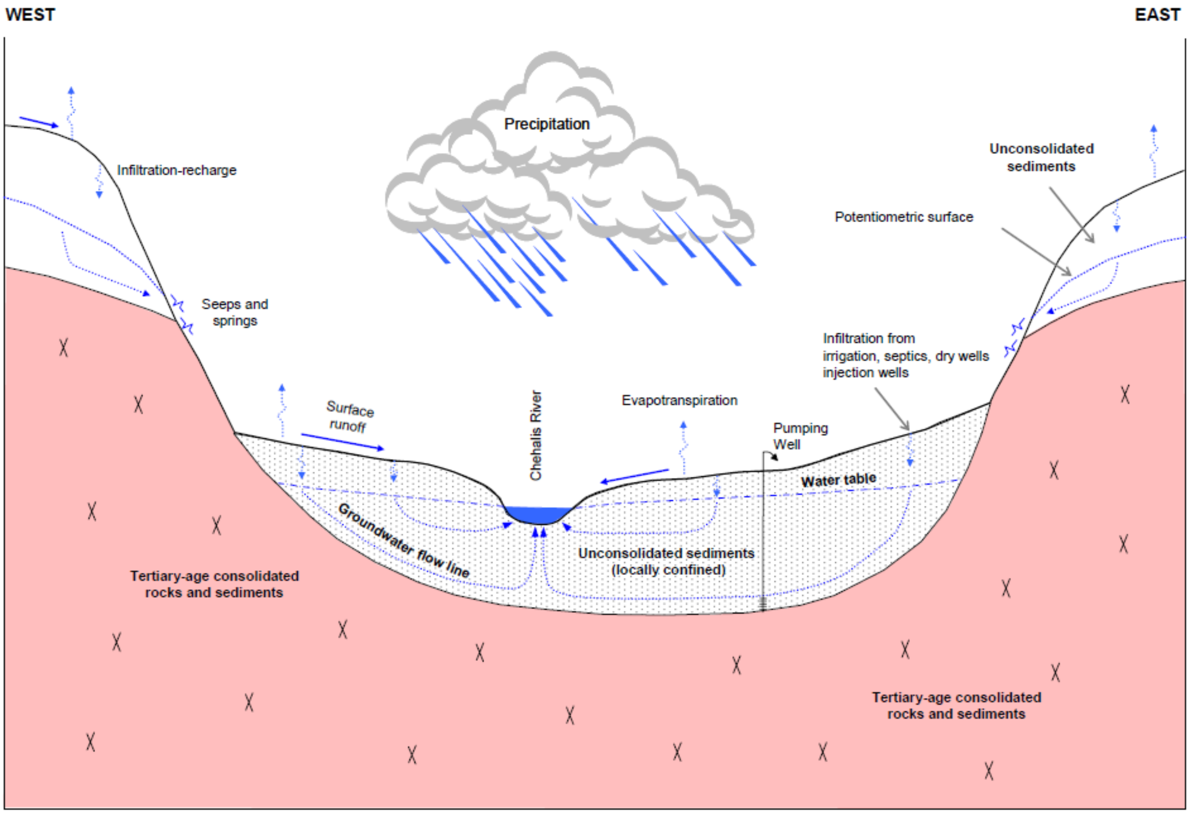

Figure 6 - Generalized conceptual model of groundwater flow in the Centralia-Chehalis lowland

Figure 3. Conceptual model reproduced from Wilson et al., 2019 and in Pitz et al. 2005, presenting "typical surface and groundwater interactions in the surficial aquifer of the Chehalis Basin" (Wilson et al., 2019). Note the subsurface connection where the groundwater that infiltrates into the floodplain near the valley walls contributes to surface water in the channel.

2) Groundwater recharge rates from overbank flows are underestimated by up to a factor of 6. For estimating the reduction of recharge based on reduced flood inundation, the DEIS uses maximum groundwater recharge rates based on previous water budget studies by the USGS (Gendaszek and Welch, 2011) of 0.6 to 2 inches/day (DEIS, p N-70 and O-60). Based on these rates, the DEIS concludes that "overbank flood recharge is a relatively minor contributor to total groundwater recharge in the Chehalis River floodplain". The rates that are presented assume non-ponded infiltration, which is controlled by the hydraulic properties of the soils. However, during an overbank flood the depth of water provides pressure that drives increased infiltration rates (i.e., pressure head), and the maximum rates that are used to support the statement of "minor" contribution are up to 6 times lower than estimates of recharge rates during overbank flows. Locally, modeling in the Newaukum River valley based on equations in Doble et al. (2012), suggest recharge rates of 2-12 inches/day during a 4-day overbank flood for a total of 8 to 48 inches (4 feet) of recharge (Abbe et al., 2019). In contrast, the DEIS estimates recharge of 0.6 to 6 inches during a major flood (DEIS, p N-70). The Newaukum rates are also congruent with published literature for recharge during overbank floods, including 1.4 feet during one flood (Zhang et al., 2017) and 5 feet during two floods (Workman and Serrano, 1999).

Thus, the rate of groundwater recharge from large, overbank flows is underestimated in three ways:

d. The lost groundwater recharge from the area that is no longer inundated under the Proposed Project is underestimated because the groundwater rates utilized are low.

e. The analysis does not account for the reduction in groundwater recharge due to the reduction in inundation depth (i.e., from reduced pressure head) over the entire floodplain with the Proposed Project. The DEIS reports on the expected reduction of depth of inundation (e.g., DEIS, p P-83), but neglects to characterize how this reduction in depth also reduces groundwater recharge over the entire floodplain.

f. The DEIS states that “Floods of this magnitude do not occur frequently enough to be a significant source of groundwater recharge” (DEIS, p N-69), which is based on underestimated frequency of FRE operation (see above).

By underestimating impacts to groundwater recharge, the impacts to wetlands, floodplain water bodies, and baseflow are also underestimated.

3) The analysis of groundwater-surface water interactions is based on 3 years of observations (2016-2018) at 3 hydrogeologic cross section locations and 1 year of observation (2018) at 3 additional locations, which is not sufficient to characterize the spatial or temporal range of groundwater-surface water interactions; therefore, no conclusions can be drawn about the impacts on surface water quantity or surface water temperature from reduced groundwater recharge. Along with recharge rates that account for pressure head during flooding (see #2 above), a multi-year groundwater-surface water model that captures the range of hydrogeologic settings along the Chehalis River is needed to accurately characterize the effects on (a) baseflows and (b) extreme low flows, i.e., the 7Q10 flow, or the lowest 7-day average flow that has a recurrence interval of 10 years.

One to three years of data is insufficient to characterize the time scales over which groundwater recharge and storage contributes to baseflow, potentially augmenting flows and reducing water temperatures in extreme dry years. For the proposed project, groundwater recharge would be reduced during FRE operation, estimated in the DEIS as once every 7 years under current conditions and once every 4 years under late-century conditions. To sufficiently characterize groundwater contributions to floodplain water bodies and baseflow, the time scale of the analysis must exceed 7 years and must include a peak flow event that would meet the threshold for FRE operation. The 1 to 3-year analysis period in the DEIS did not include any peak flows above 38,800 cfs at Grand Mound. The need for several years of analysis or modeling is also supported by the scientific literature. For example, multiple years of streamflow and groundwater data from a published study by Hunt et al. (2018) suggest a multi-year lag time, in which the amount of groundwater contribution to dry season streamflow is decoupled from the amount of groundwater recharge from floodplain inundation during that same year. In that study, the groundwater contribution to baseflow was highest three years following an increase in overbank flow frequency and duration, despite lower inflows (and likely less duration of inundation) during that particular year.

The eight hydrogeologic cross sections used to determine that impacts to groundwater are minor are insufficient to represent the hydrogeologic settings in which groundwater impacts are likely to be largest. In gaining reaches the lateral subsurface flow direction is toward the stream (i.e., the stream is gaining surface water from groundwater), whereas in losing reaches the lateral subsurface flow direction is away from the stream (e.g., see Figure 7 in Wilson et al (2019)). Thus, in gaining reaches, groundwater recharge and storage that originates within the alluvial valley but farther away from the stream is an important contributor to wetlands and floodplain waterbodies that are located closer to the stream, as well as contributing to surface flow in the stream itself. The DEIS analysis lacks sufficient data collection or modeling to characterize impacts to wetlands and streamflow within the gaining reaches that are most likely to be affected by a reduction in groundwater recharge. In particular, a comparison of Figure 8 (Gaining and losing reaches mapped along the Chehalis) to

Figure 15 (Hydrogeologic cross sections) in Wilson et al. (2019) shows that no data were collected in any of the three gaining reaches upstream of and at the confluence with the South Fork Chehalis. Rather, the only data collected upstream of RM 80 was located in a losing reach.

It should be noted that Wilson et. al (2019) state that cross section S004 at RM 93.5 is located in a *gaining* reach, referencing Ely et al. (2008), who actually map it as a *losing* reach (i.e., Figure 8 of Wilson et al. (2019). The data presented in Wilson et al. (2019) suggest that the stream is gaining at that cross section within the losing reach, which further underscores the need for greater spatial representation in the analysis.

Given that the modeled change in inundation depth by mid-century is a reduction of 9.4 feet near Doty (DEIS, Table N-10), the amount of change in groundwater recharge is likely to be substantial and the groundwater-surface water connections in the gaining reach at Doty (Figure 8 of Wilson et al. (2019)) need to be assessed. In addition, none of the gaining reaches in the wide alluvial valley that extends from Centralia to Rochester were analyzed. The floodplains along these gaining reaches are predominantly composed of soils that are classified as Hydrologic Soil Group A, which has the highest conductivity and therefore the highest potential groundwater recharge during overbank flows.

To characterize impacts of the Proposed Project to wetlands and streamflow from reduced groundwater recharge, a calibrated, coupled surface water-groundwater model run over a longer time frame is required. The assessment in the DEIS is ad hoc and not representative at the spatial or temporal scales over which the impacts of the Proposed Project would be realized. **Particularly given the context that minimum instream flows are commonly not met at Grand Mound (DEIS, p N-21) and that temperature standards are commonly exceeded, the lack of assessment for the multi-year connection between reduced flood inundation and groundwater contributions to baseflows is a major oversight in the characterization of impacts to aquatic habitat.**

Amplification of Future Low Flows

The potential for impacts from the FRE facility to amplify the climate change impacts to low flows and stream temperature are not considered in the DEIS assessment of groundwater or wetlands. Projections for future streamflow during the dry summer season indicate that low flows will further decrease into the future. Climate change modeling for the DEIS estimates a 11% and 16% in average summer flows by mid- and late-century, respectively (Table 2 of Hill and Karpack, 2019). In addition, previous hydrologic modeling of climate change impacts for the Chehalis River at Grand Mound projected that the lowest 7-day average streamflow with a recurrence interval of 10-years (i.e., the 7Q10, which is a commonly used low flow metric) is projected to decrease by late century (Figure 4; Hamlet et al., 2013). The previous modeling utilized the ensemble approach, with nine GCMs (red dots in Figure 4) and two emissions scenarios (A1B and B1, shown as columns in Figure 4) from the IPCC Fourth Assessment (AR4). The reduction in extreme low flows by end of century for the A1B scenario (i.e., a medium emissions scenario) in extreme low flows is 5% on average (black horizontal dash in Figure 4) and ranges up to 9% in the ensemble of GCMs.

Although these reductions in low flow are projected to occur independently from the Proposed Project, several of the impacts quantified in the DEIS including loss of wetlands and reduction in groundwater recharge will amplify the projected lower low flows in the future, resulting in more severe impacts to aquatic habitat. By not considering projections for low flows along with impacts to groundwater recharge and wetland the late-century impacts to aquatic habitat and treaty resources cannot be quantified in a meaningful way.

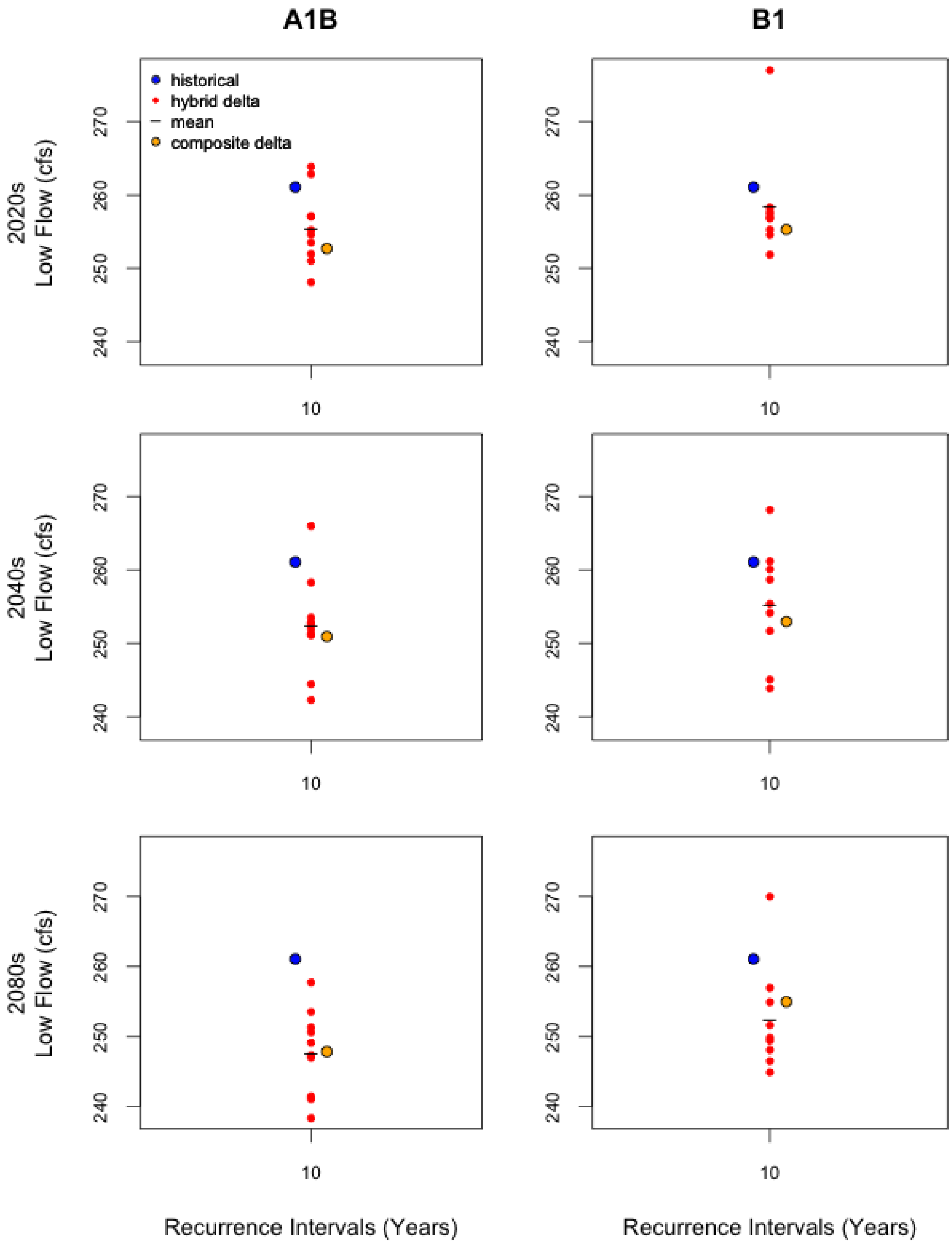

Figure 4. Projected reductions in extreme low flows, represented by the 7Q10 (see text) at the Chehalis River at Grand Mound from a previous modeling effort (Hamlet et al., 2013). Data accessed at *http://warm.atmos.washington.edu/2860/products/sites/?site=6004*.

CONCLUSIONS

Based on our understanding of the Proposed Project, it is our conclusion that:

- All impacts related to the frequency of FRE facility operation under current and future conditions are under-estimated.
    - The FRE facility will operate more frequently than stated in the DEIS. Whereas the DEIS reports a 5- and 4-year recurrence interval for mid- and late-century (Table N-5), we estimate that the FRE facility would be operated once every 1.8 and 1.4 years under mid- and late-century climate scenarios.
    - The use of predicted flows to initiate the FRE facility is likely to cause the facility to operate more frequently than what is assessed in the DEIS, which is based on analysis of the observed flows.
- Impacts to river processes associated with backwatering caused by the Low-Level Outlets (LLOs) of the FRE facility when flow exceeds 8,500 cfs during times when the reservoir is not filled were not evaluated in the DEIS. Therefore, impacts on sediment transport, riparian vegetation establishment, slope stability, aquatic habitat, and local scour in the LLOs are underestimated.
- Impacts to groundwater recharge are substantially underestimated.
- The DEIS fails to represent relevant spatial heterogeneity and fails to account for multi-year and long-term impacts to groundwater-surface water interactions. Impacts to wetlands and in-stream aquatic habitat, particularly in the dry summer months when groundwater contributions to aquatic habitat are most important, are underestimated.
- The DEIS fails to account for the ways in which reduced groundwater recharge will further amplify the projections for lower summer streamflow and higher summer stream temperatures and the combined effects on aquatic habitat.

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