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 Draft SEPA EIS

Hydrology Technical Memo 1: OBSERVED AND PREDICTED FLOWS RELATIVE TO FRE FACILITY OPERATION

BACKGROUND

The Chehalis River Basin Flood Control Zone District proposes to construct a flood retention facility and temporary reservoir, referred to as the Flood Retention Expandable (FRE) facility on the mainstem Chehalis River to reduce flooding and related damages downstream (Proposed Project). The FRE is proposed in response to flood-related damages that occurred during two major floods in 2007 and 2009 and would be located at river mile (RM) 108, upstream of the town of Pe Ell, Washington. The FRE is described as a facility that would operate intermittently to impound flows when a threshold of 38,800 cfs of flow is predicted to occur 48 miles downstream at the USGS Grand Mound, Washington gage on the Chehalis River (i.e. a flow described as a 'major flood event'). The Proposed Project, Local Action Alternative, and No Action Alternatives are being evaluated for environmental impacts through both state and federal processes under the State and National Environmental Policy Acts (SEPA and NEPA respectively). Through both processes, a project level environmental impact statement (EIS) will be developed. The Draft SEPA EIS was publicly distributed on February 27, 2020 for public comment.

The Quinault Indian Nation (QIN) has contracted with Natural Systems Design, Inc. (NSD) to review the Draft SEPA EIS and evaluate the underlying assumptions and conclusions related to stream flows and hydrologic modeling. The review and analysis were conducted by a qualified technical team, including Susan Dickerson-Lange, PhD, PG; Scott Katz, MS; Julia Jay, EIT, MS; Leif Embertson, PE, MS; Torrey Luiting, MS, PWS; and Tim Abbe, PhD, PEG, PHG. The specific assumptions/conclusions and the associated research questions NSD has addressed herein are:

- The Proposed Project and Alternatives chapter of the Draft SEPA EIS states that streamflow *predictions* from the National Oceanic and Atmospheric Administration (NOAA) Northwest River Forecast Center (NRFC) model will be used to inform FRE facility operators about when to begin impounding flows for flood reduction (Section 2.3.2.2 FRE Facility Operations, pg. 15). However, the Draft SEPA EIS evaluates FRE operations using the *observed* streamflow record and not the *predicted* values from the NOAA model. The accuracy of predicted impacts from impounding flows is related to the degree to which the predicted values accurately anticipate observed streamflow and the consequent frequency and duration of impounding flows.

Question: **What is the extent of correlation between streamflow predicted by the NOAA model and streamflow observations made by the USGS at the Grand Mound gage?**

Question 1 – Accuracy of Predicted Stream Flow

Finding

The Draft SEPA EIS describes the environmental impact and flood control benefit of the FRE facility based on the *observed* streamflow record, but the proposed project description states that impoundment will be determined by *predictions* of streamflow from the NOAA Northwest River Forecast Center (Section 2.3.2.2, pg. 15). Furthermore, language in the Draft SEPA EIS Appendix 1 *Proposed Project Description and Alternatives*, indicates that the NOAA model will be consulted between 2 and 4 days ahead of anticipated major flood events and that the predicted flows will trigger FRE facility operation (Draft SEPA EIS Appendix 1 *Proposed Project Description and Alternatives* dated February 2020). Our analysis of this model shows that within the 2- to 4-day forecast window, the relationship between predicted and observed streamflow is highly uncertain during floods large enough to trigger impoundment.

The calculated root mean square error (RMSE) is 11,420-12,700 cfs for the 2-day to 4-day model forecasts when comparing the predicted versus the observed streamflow values for flows greater than the 2-year recurrence interval; this is 29-33% of the 38,800 cfs threshold being used to trigger facility operations. This high level of error demonstrates that the model does not accurately predict streamflow magnitudes in the range of the FRE facility impoundment threshold and because of that, 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. Because analysis of the FRE facility's impacts is conducted using streamflow observations, but the trigger for facility operation/river impoundment is to be based on river flow predictions, the description and analysis of the project's operation is inaccurate

The DEIS did not address the degree of uncertainty/overprediction inherent in the 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 archived prediction data from the NOAA model should have be used in conjunction with the observed USGS streamflow values to assess the FRE facility operations and potential impacts to river processes.

Background

The Draft SEPA EIS describes the FRE facility operations as follows:

> "The FRE facility operators would use flood forecasts from the National Oceanic and Atmospheric Administration (NOAA) Northwest River Forecast Center to identify when the water flow at the Grand Mound gage is expected to exceed 38,800 cfs. This gage would be used because it provides the most consistent and accurate measurement of water for the area. FRE facility operations would begin within 48 hours of the forecasted flood peak." [From page 15 of the Draft SEPA EIS dated February 2020]

In addition, Draft SEPA EIS Appendix 1 *Proposed Project Description and Alternatives*, further clarifies the forecast period from the NOAA model that will be used to predict flows:

> "The FRE facility would retain river flows temporarily, only during floods that are predicted to have a flow rate exceeding 38,800 cubic feet per second (cfs) at the Grand Mound gage (USGS 12027500). When the prediction exceeds 38,800 cfs, water retention would begin within 48 hours of the forecasted

> flood peak. A 48-hour period gives a reasonable amount of time to predict flows with confidence while also providing enough time to reduce flow rates to designated minimum release rates before major flood flows occur." [From page 1-23 of the Draft SEPA EIS Appendix 1 *Proposed Project Description and Alternatives* dated February 2020]

It is later specified that "Grand Mound is approximately 48 miles downstream from the FRE facility site, so the operators of the FRE facility would rely on flooding predictions up to 4 days in advance. The source of the forecast for major flooding would be the Northwest River Forecast Center, operated by NOAA." [From pages 1-24 of the Draft SEPA EIS Appendix 1 *Proposed Project Description and Alternatives* dated February 2020]

These statements indicate that the FRE facility will begin impounding streamflow when the NOAA 2- to 4-day forecast predicts flows above 38,800 cfs at the Grand Mound gage. However, the Draft SEPA EIS describes the general impacts of the project based on the actual frequency of the 38,800 cfs threshold flow as reported by the Grand Mound gage, not the NOAA-predicted frequency. Because the DEIS does not present any assessment of the correlation between the predicted values and the observed values used to quantify the frequency of FRE facility operation, the accuracy of using one data set to trigger FRE facility operation and another data set to analyze impacts to river processes in the DEIS cannot be determined without additional analysis. For example, streamflow was predicted to peak at 48,465 cfs for the flood of December 2015 – an event that would have initiated FRE facility operation and caused impacts to river processes. However, the peak streamflow for that flood was observed to be 36,600 cfs, (2,200 cfs below the threshold for the FRE facility to begin impounding water). Because the peak did not reach the threshold, this event was not included in the impact assessment despite the model predictions indicating that the FRE facility would have been utilized. To determine the extent of correlation between predicted and observed stream flow values and assess how it could influence the frequency of facility operation and subsequent impacts to river processes, NSD investigated the historical relationship between the NOAA prediction of streamflow and the real-time USGS observations of streamflow at the Grand Mound gage.

Methods

For the historical record of predicted streamflow, NOAA provided its archives of model predictions at Grand Mound dating back to 2008. These archives contained the streamflow forecast generated on average once daily. Due to a change in storage structures, NOAA deemed the level of effort required to attain pre-2008 archives to be prohibitive. NSD compared the NOAA-provided data through 2008 to the USGS record of 15-minute streamflow data at the Grand Mound gage by matching the timestamp of the predicted flow as closely as possible to the timestamp of an observed flow. To assess the model's ability to predict flood flows, the data was filtered to only include discharges equal to or greater than 25,960 cfs, i.e. the 2-year recurrence interval flow as this represents a commonly used flow threshold to define the initiation of overbank flooding within a river and it allows the statistical population to be expanded. While observed streamflow data is always subject to error in the reported discharge values (especially for flood flows), the USGS gage at Grand Mound has numerous measurements (10) of stage and discharge at high flows greater than 30,000 cfs and is thus likely quite accurate at these high flows.

Root mean squared error (RMSE) and mean error (ME) were then calculated to gain an understanding of model accuracy in comparison to USGS gage measurements. RMSE and ME were calculated using the equations below, where n = the number of timestamps included in the calculation, predicted = the NOAA model forecasted streamflow, and observed = the USGS 15-minute record of streamflow:

$$RMSE = \sqrt{\frac{\sum(predicted - observed)^2}{n}}$$

$$ME = \frac{\sum(predicted - observed)}{n}$$

NSD used both RMSE and ME to evaluate model accuracy because they relay different things: RMSE is a better measure of overall error since it disregards sign (i.e. direction of the error), and can be understood as saying that the average prediction is off from the average observed value by a certain value of streamflow. ME, on the other hand, gives us an understanding of whether the model tends to over or underpredict observed values, with positive MEs demonstrating an overprediction and negative MEs an underprediction. A model with a high RMSE could have an ME of 0 if the model over and underpredicts with equal frequency.

We computed the RMSE and ME for the 2-day, 3-day, and 4-day streamflow forecasts in order to account for the range of possible FRE facility operation protocols outlined in the Applicant's purpose and objectives for the Proposed Project (i.e. "…water retention would begin within 48 hours of the forecasted flood peak" and "…the operators of the FRE facility would rely on flooding predictions up to 4 days in advance." (From page 1-23 of the Draft SEPA EIS Appendix 1 *Proposed Project Description and Alternatives* document, dated February 2020). These represent forecasts made by the NOAA model 2 to 4 days ahead of time. For example, the 2-day prediction made on January 1st is for streamflow on January 3rd.

Results and Discussion

The results of statistical analysis comparing predicted to observed streamflow demonstrate that using the NOAA model does not accurately predict observed flows greater than the 2-year recurrence interval between the 2-day or 4-day forecast periods (Table 1. Comparison of the NOAA model's 2- to 4-day forecasted streamflow to USGS-observed streamflow at Grand Mound for 2008-present.). While the sample size for each forecast since 2008 which exceeded the 2-yr recurrence interval flow is relatively small, this data represents the full data set available for analysis.

Table 1. Comparison of the NOAA model's 2- to 4-day forecasted streamflow to USGS-observed streamflow at Grand Mound for 2008-present.

MODEL ACCURACY FOR FLOWS >2-YEAR RECURRENCE INTERVAL (25,690 CFS)	RMSE (CFS)	ME (CFS)	N
2-day forecast	12,660	7,160	59
3-day forecast	11,420	-340	24
4-day forecast	12,700	-10,120	21

The 2-day, 3-day and 4-day forecast have RMSE of 12,660 cfs, 11,420 cfs, and 12,700 cfs respectively, whereas the ME is +7,160 cfs for 2-day predictions, -340 cfs for 3-day predictions, and -10,120 cfs for 4-day predictions.

The average high flow prediction differs from the observed values by 11,420-12,700 cfs on average., and the model tends to overpredict streamflow in 2-day forecasts and underpredict streamflow in 4-day forecasts. To put this in context, the threshold for FRE facility impoundment is 38,800 cfs and an error of 11,420-12,700 cfs is

29-33% of that threshold. This high level of error demonstrates that the model does not accurately predict streamflow values in the range of the FRE facility impoundment threshold and demonstrates that the DEIS should have investigated and acknowledged the model's accuracy and utilized the archived prediction data from the NOAA model in conjunction with the observed USGS streamflow values to assess the scope and scale of FRE facility impacts to river processes.

Figure 1 and Figure 2 illustrate the relationship between observed and predicted values at high flows for both the 2- and 4-day forecasts. For both forecasts, the points cluster around the 1:1 line near the origin, but the scatter increases as flow increases. Above 25,690 cfs (i.e. the 2-yr recurrence interval flow), the majority of points in the 2-day forecast (Figure 1) are well above the 1:1 line, indicating that the predicted value is greater than the observed value. In the 4-day forecast (Figure 2), the predicted values are well below the 1:1 line for flows greater than the 2-year recurrence interval, indicating that the predicted value is lower than the observed value.

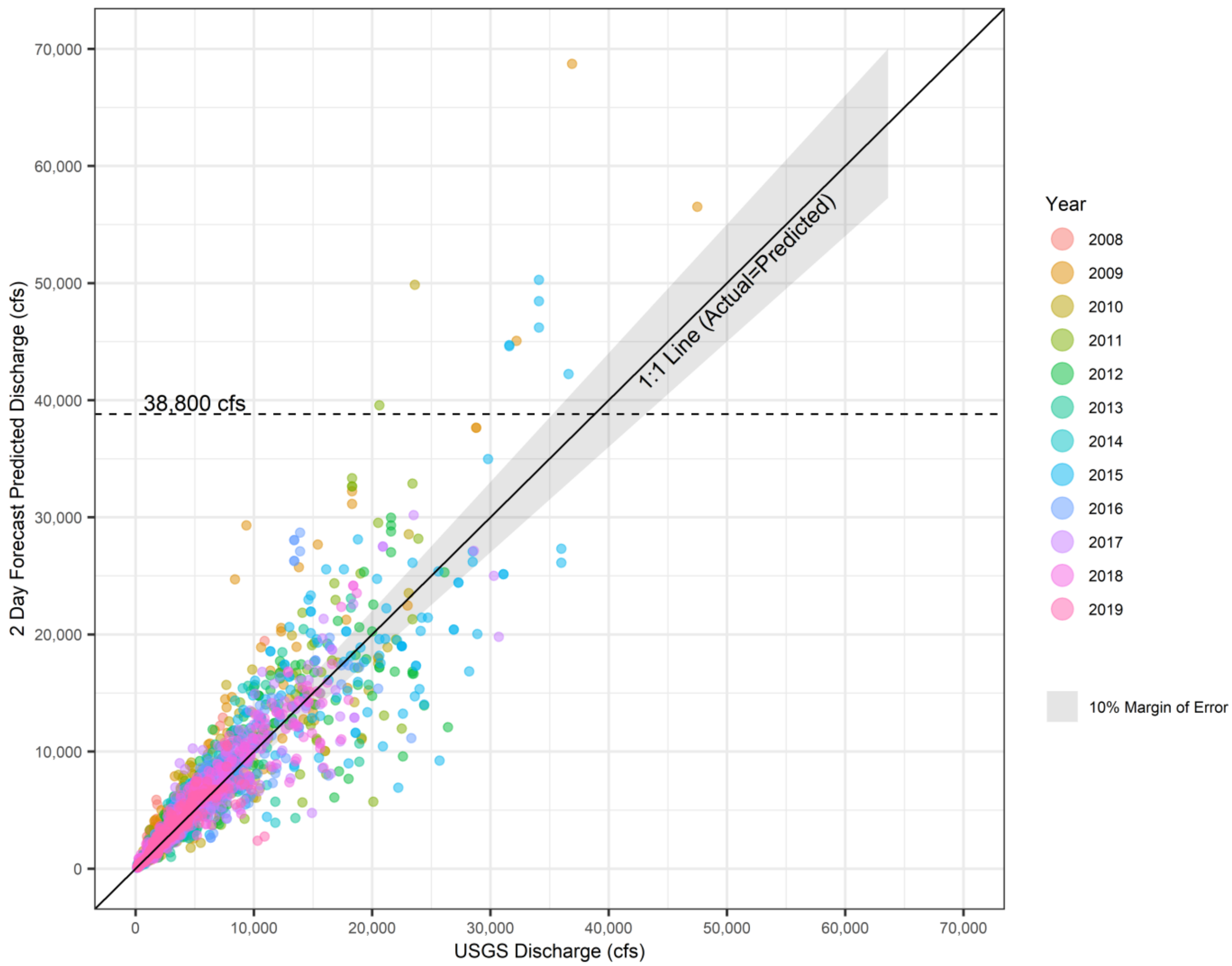

Figure 1. NOAA 2-day predicted streamflow vs. USGS 15-minute recorded streamflow at the Grand Mound Gage. Each point represents one timestamp. For a perfect model, in which predicted streamflow = observed streamflow exactly, all points would fall on the black 1:1 line.

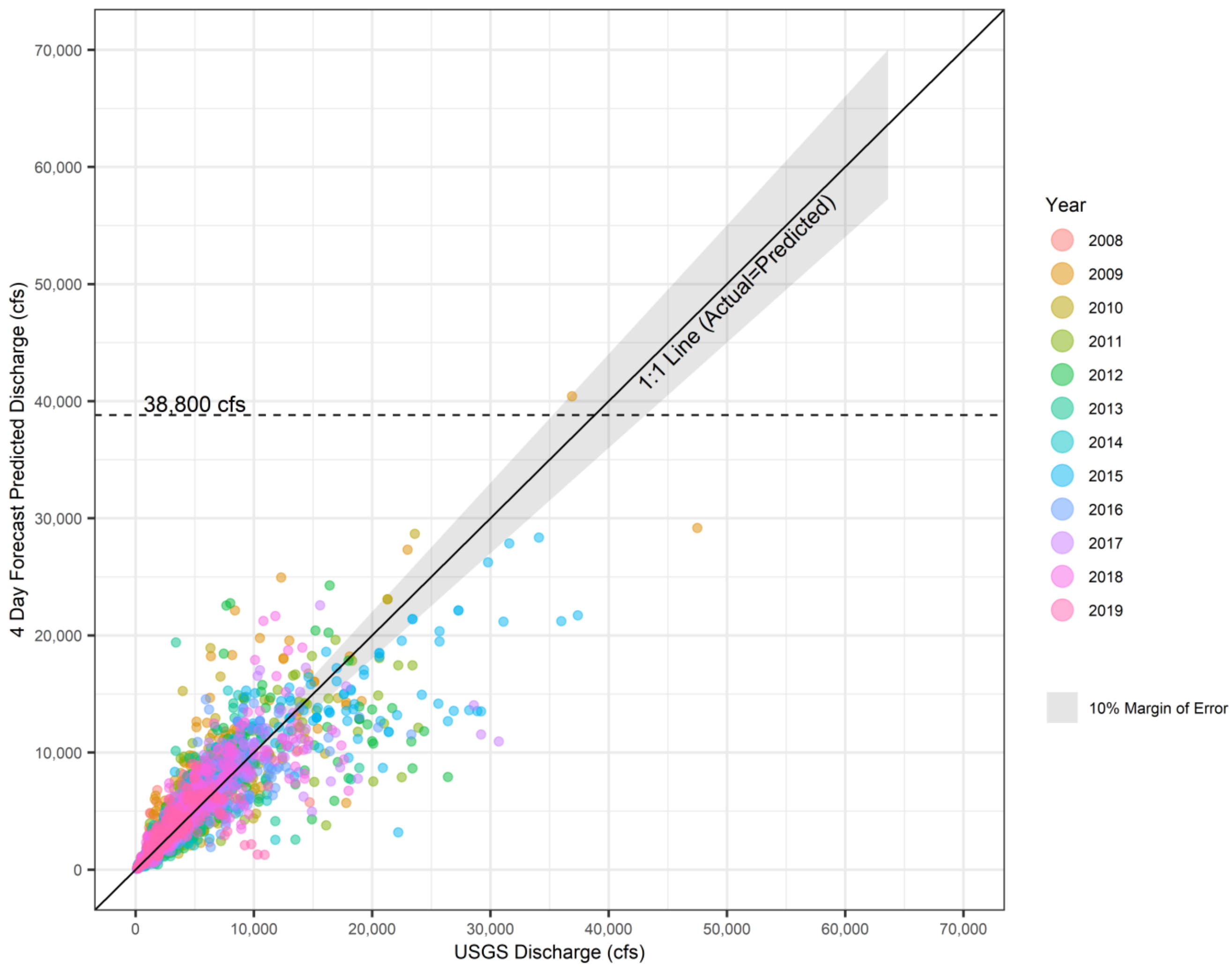

Figure 2. NOAA 4-day predicted streamflow vs. USGS 15-minute recorded streamflow at the Grand Mound Gage. Each point represents one timestamp. For a perfect model, in which predicted streamflow = observed streamflow exactly, all points would fall on the black 1:1 line.

These results demonstrate that impacts associated with FRE facility operation have not been accurately represented in the Draft SEPA EIS because the modeled streamflow values upon which operations are based do not accurately predict the observed flows used in the DEIS to determine impacts. The relationship between predicted and observed flows changes depending on how far out the forecast is, I.e., 2 days out the model predicts *higher* flows than end up being observed, 3 days out the model over and underpredicts with nearly equal frequency, and 4 days out the model flips to predicting *lower* flows than end up being observed. For example, the FRE facility would have likely been utilized in 2010 when the 2-day prediction of 49,850 cfs was made. However, that flood reached only 23,600 cfs and thus the FRE facility would have been utilized prematurely, impounding flows and affecting river and floodplain processes for a flood well below the 38,800 cfs described throughout the DEIS as the 'trigger' for activation of the facility.

Because the stated purpose of the FRE facility is to reduce flooding, it is reasonable to anticipate it will be operated conservatively and thus that the operators will rely on the 2-day NOAA model predictions which over-predict flow; if this is the case, the FRE facility will impound flows more frequently, creating more frequent environmental impacts than those assessed in the DEIS for an approximately 7-year recurrence interval flow of 38,800 cfs and the associated formation of a 'temporary' reservoir .

CONCLUSIONS

- The DEIS describes the environmental impact and flood control benefit of the FRE facility based on analysis of the *observed* streamflow record. But the DEIS also states that closing the facility will be determined by using *predictions* of streamflow from the NOAA Northwest River Forecast Center. 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.
- An analysis of the 2- to 4-day forecasts from the NOAA streamflow model as it relates to USGS observed streamflow at Grand Mound shows that the model is not accurate at predicting observed flood flows greater than the 2-year recurrence interval. For such high flows, the model has an RMSE of 11,420-12,700 cfs, which is 29-33% of the threshold that would trigger FRE facility impoundment.
  - The high level of error demonstrates that the model does not accurately predict streamflow values in the range of the FRE facility impoundment threshold and because of that, the FRE facility is likely to be operated at a greater frequency than evident in the observational record which was used in the DEIS to analyze impacts.
  - Because analysis of the FRE facility's impacts is conducted using streamflow observations, but the frequency of FRE facility operation/river impoundment is to be based on river flow predictions, the description of the project's operation is inaccurate. 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, **the DEIS underestimates all local and downstream impacts associated with frequency and duration of impoundment.**
- It would be more accurate to utilize the archived data from the NOAA model, in conjunction with the USGS streamflow record, to describe the project's operation and determine impacts, as flow impoundment would occur more frequently than when frequency is described based on the predicted values; thus the associated impacts would be more accurately determined.