Kilchis Porter Restoration Review

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October 1, 2021
Final Report, Rev. 2

NHC Reference 02006629.0

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EXECUTIVE SUMMARY

The Nature Conservancy (TNC) contracted with Northwest Hydraulic Consultants (NHC) to perform a technical hydraulic review of one completed (Dooher) and one planned (Porter Tract) restoration project on the TNC-owned Kilchis Estuary Preserve. The scope of work was developed in concert with the Tillamook County Creamery Association (TCCA) and Tillamook Bay Flood Improvement District and consisted of twelve items to be addressed. TNC provided all relevant reports, data, and hydraulic models to be reviewed. In the report body the twelve items are addressed individually even though there is some overlap and common elements between them. This executive summary describes the key findings of the review, which in some cases are synthesized from the analysis of several scope items.

Reports, Hydraulic Modeling, and Observed Water Level Data

- The hydraulic analyses completed to date have evaluated Dooher and Porter individual project flood impacts adequately. The analyses have not addressed or only partially addressed normal flow impacts more relevant to agricultural practices on adjacent lands and the combined effects of the Dooher and Porter projects.
- The Dooher model appears to have been calibrated to an incorrect flow. The more recent models used for the Porter project have been updated and are well calibrated for flood analysis. The model will likely need some additional updates to fully evaluate off site water level impacts under normal flow conditions. A set of model refinements and development of a pre-Dooher project model based on the latest existing conditions model is recommended.
- Observed water level data from the gage network is extremely valuable for system analysis. Data collected to date has been of variable quality. A set of recommendations are made on gage rebuilding, relocation, and new gages to improve data quality and future analysis.

Hydraulic Effects of Dooher Project

- The Dooher project initially reduced flood levels in the Kilchis River below Highway 101 by several feet. As the channel has adjusted to the project and filled in these reductions have lessened but reductions of about half a foot persist. The flood level reductions do not extend above Highway 101. The removal of the river levee by the Dooher project allowed more water to flow west, resulting in increases of a few tenths of a foot in flood levels on lands adjacent to Stasek and Neilson Sloughs.
- The largest water level increases from the Dooher project occur in Stasek Slough under normal flow conditions. At very low flow water levels increases are about half a foot. When Kilchis River flows are above 400 cfs (in typical winter flow ranges) low tide and average water levels in Stasek Slough have increased 2-3 feet, and high tides 1-2 feet. This increase persists up to a 2-year flood event. The increase is due to the re-connection of Stasek Slough to the Kilchis River: at higher flows the river at this point runs 2-3 feet higher than where it connects to Hathaway Slough, where Stasek Slough used to drain through. These changes also will have propagated into Neilson Slough.
- Changes in Hathaway Slough water levels are less certain but are believed to be at most a tenth of a foot or so based on very limited gage data, modeling, and anecdotal information. Changes

elsewhere in the surrounding rivers and sloughs due to the Dooher project are similarly on the order of a tenth of a foot or less.

Hydraulic Effects of Porter Project

- The Porter project will have much smaller effects on flood levels than the Dooher project. Up to a tenth of a foot rise is forecast for Hathaway Slough due to increased flow transfer from Stasek Slough. Changes in peak flood levels are generally less than a tenth of foot elsewhere.
- During winter flows the Porter project will lower water levels by 0.4-0.8 feet in Stasek and Neilson Sloughs. This will partially counteract the 2-3 foot increases in water levels the Dooher project created. With increased flow from Stasek Slough, Hathaway Slough will see increases in water level of one to two tenths of a foot on average. Changes elsewhere are typically less than a tenth of a foot.

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APPENDICES

Appendix A 2014 STASEK SLOUGH WATER LEVEL DATA PROCESSING

1 INTRODUCTION

The Nature Conservancy (TNC) has contracted with Northwest Hydraulic Consultants (NHC) to perform a technical hydraulic review of one completed (Dooher) and one planned (Porter Tract) restoration project on the TNC-owned Kilchis Estuary Preserve. The scope of work has been developed by consensus with the Tillamook County Creamery Association (TCCA) and Tillamook Bay Flood Improvement District, and TCCA will pay one-half of the review costs.

1.1 Scope of Work and Organization of Document

The scope of work consists of 12 items to be reviewed. All items are related to project effects on site and area hydrology, or related sediment issues. Prior to addressing the 12 items we provide a reference map and geographic naming convention and an evaluation of three key parts of the analyses relevant to all the items. These are observed water level data, estimation of Kilchis River and tributary flows, and the hydraulic model used for analysis.

Several of the items refer to 'impacts', and we use the same term throughout this document. Our use of this term is limited to changes in water level. We do consider land elevations in our review to provide some additional context. For instance, an increase in water level elevation from 8 to 9 feet is unlikely to have an impact on land use if the land surface is 16 feet but may if the land surface is at 10 feet. However, this review does not judge whether a change in water level may lead to positive or negative outcomes on field productivity, ability to operate machinery in the spring, or other common agricultural concerns, nor do we provide any opinion on the ecological impacts of changes to area hydrology.

1.1.1 Project Partner Review Timeline

A draft version of this review was provided to the project partners on June 2, 2021. A comment review letter was provided to NHC dated August 5, 2021. NHC responded to the letter in writing on August 19, 2021, with a set of clarifying questions and responses. This was followed up with a call between all parties on September 2, 2021, where all questions were resolved and direction for the final report was agreed to.

1.2 Information Reviewed

TNC provided a suite of documents for review, a bibliography for which is included at the end of this report. In addition, the following information was provided to or acquired by NHC:

- Observed water level data in spreadsheet format for various sites, with data from 2014 to 2020. Data from 2012-2014 were collected by PC Trask & Associates under contract to TNC, post-2014 data were collected by TNC directly.
- Delft3D hydraulic model files for the Porter Tract analysis consisting of existing and proposed condition simulations for the large December 2015 flood and a small event in January 2017.
- USGS flow data for the Wilson River near Tillamook Gage.
- USGS StreamStats flow estimates for local tributaries and the Kilchis River.

- NOAA Garibaldi tide gage data.
- LiDAR data used as the basis for the hydraulic model geometry.
- Verbal and email communications with Dick Vander Schaaf, Curtis Loeb, and Leo Kuntz for specific questions, mostly regarding site conditions, that arose during the review.

In addition, NHC developed a rough two-dimensional HEC-RAS hydraulic model of the area shown in Figure 1. The purpose was to provide some validation of the Delft3D model (especially for the connector culvert, where HEC-RAS has much better modeling capabilities), but primarily because it is much easier to extract and display information from HEC-RAS. The HEC-RAS model used a terrain file based on the Delft3D model grid bathymetry with a nominal resolution of 15 feet. We calibrated the model to the January 2017 flood using identical boundary conditions to the Delft3D model. The HEC-RAS model produces similar results to the Delft3D model at high tides and during flood flows but does not do as well at low tides. The model is only valid up to about a 2-year event, as substantial additional effort would be required to enforce accurate levee elevations. Nevertheless, the HEC-RAS model provided useful information and visualization of flow patterns and volumes that are difficult to extract from Delft3D. All model data and discussion presented herein refers to the Delft3D model unless otherwise noted.

1.3 Reference Map and Agricultural Units

The scope of work requests analysis of hydrologic impacts to the project site, adjacent channels, and neighboring agricultural lands. NHC delineated neighboring private agricultural lands into hydrologic units defined by levees, embankments, and channels for reference in this document. For agricultural areas upstream (north) of Highway 101, we only delineated areas where land elevations were below 15 feet. In our opinion, this is a conservative upper limit to the potential area of project impacts. Figure 1 and Figure 2 show these areas. The Hathaway, Stasek, Neilson, and Vaughn Creek units include significant areas at elevations above 15 feet that drain into the project area; Figure 18 shows the entire watersheds for each. Vaughn Creek is unique among these units in that it drains through a series of tidegates from an interconnected ditch network into Hathaway Slough, while as far as is known the Stasek, Hathaway, and Neilson units have no tidegates.

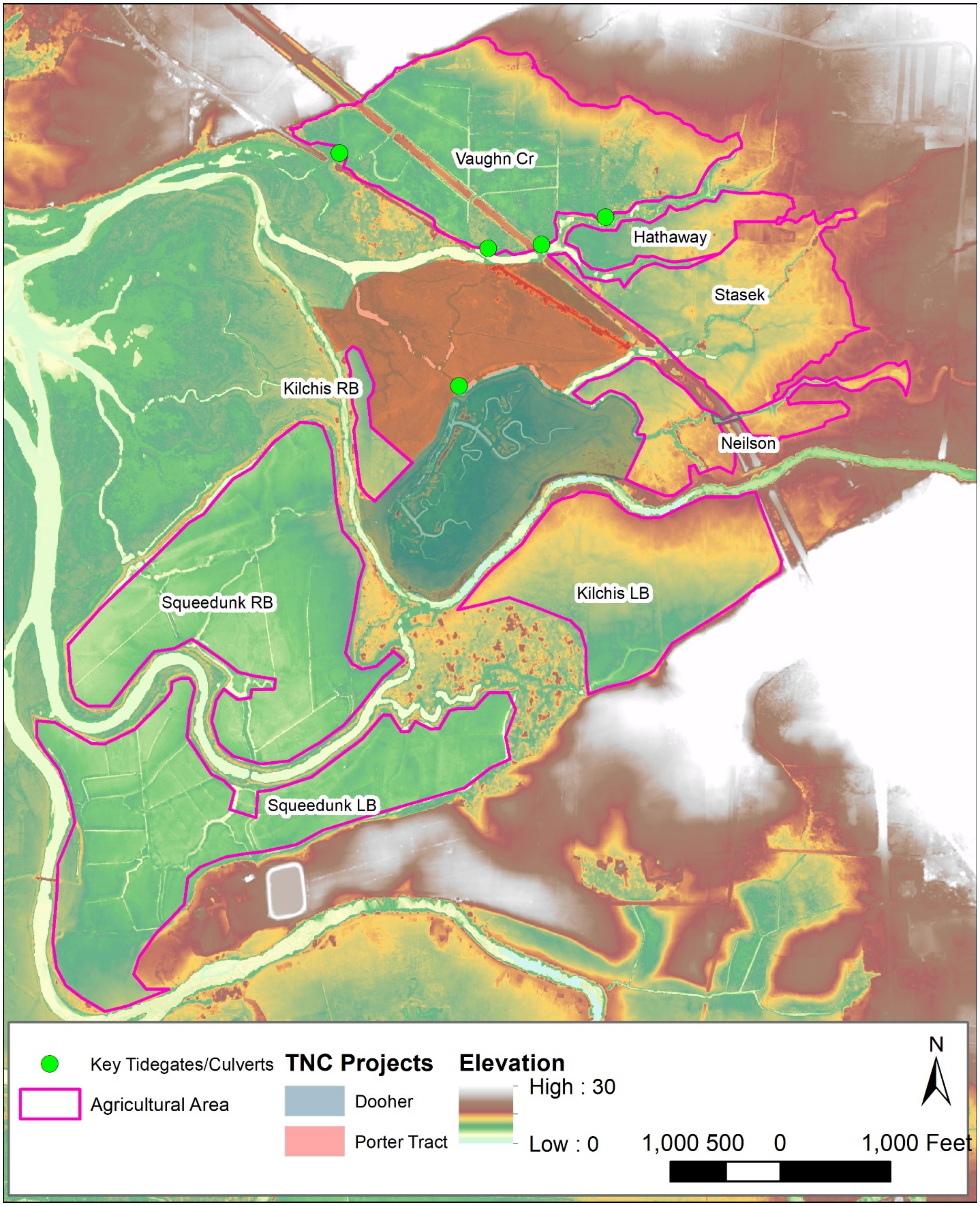

Figure 1: Site map with LiDAR showing agricultural areas potentially affected by TNC projects

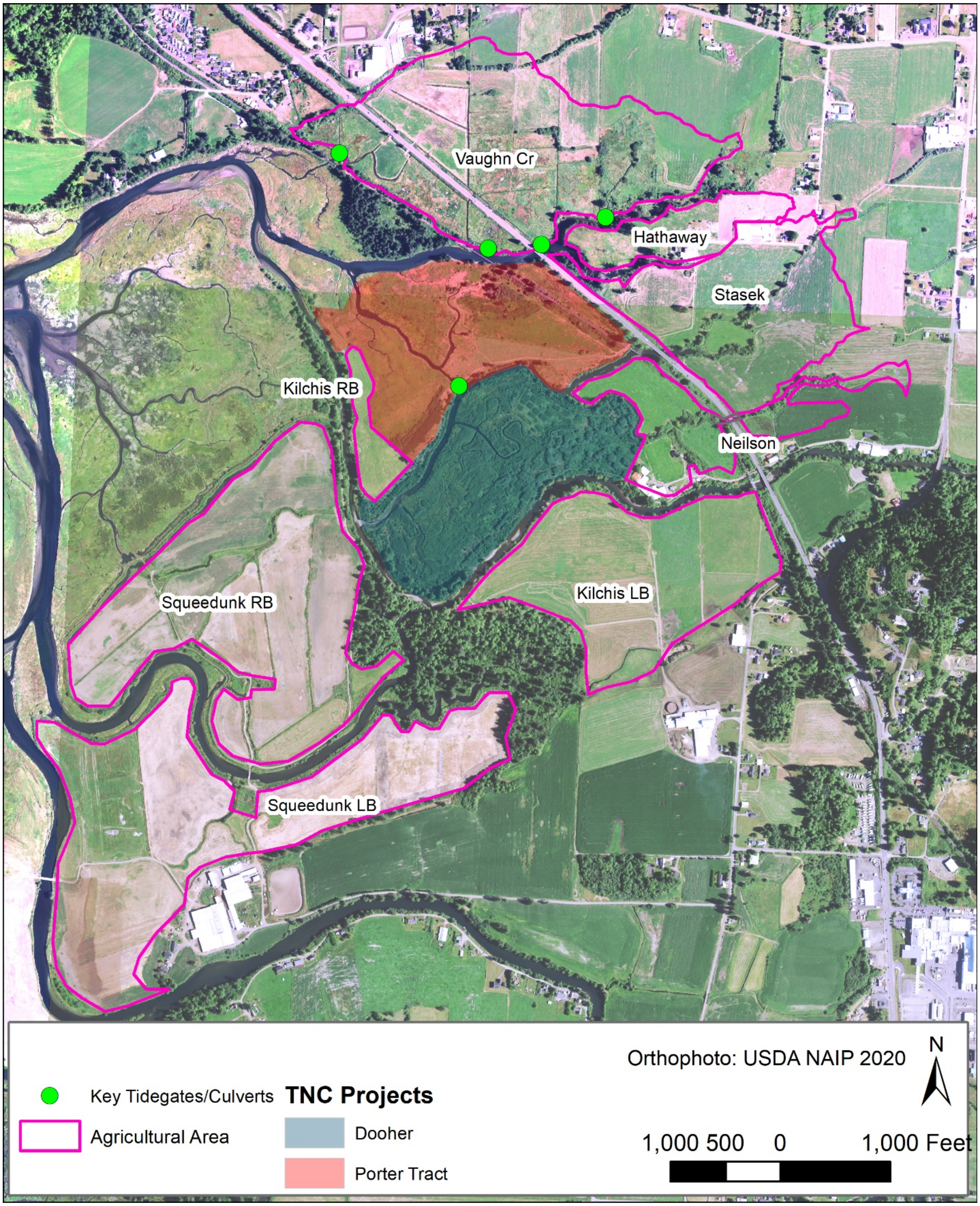

Figure 2: Site map with orthophoto showing agricultural areas potentially affected by TNC projects

1.4 Datums

All elevations in this report, for both water levels and land, are referenced to the NAVD88 datum. Use of this datum allows direct comparison between tides at Garibaldi and at the project site, as well as comparison to land elevations. To correct tides at Garibaldi to the NAVD88 datum, subtract 0.3 feet[1] from published tidal elevations. Tides as given in tide books at other stations in the Bay, particularly upper Bay stations, have much larger but undetermined differences from the NAVD88 datum and cannot be directly compared with elevations given in this report.

1.5 Flow Nomenclature

This report describes Kilchis River flows under 'normal' and 'flood' conditions. Based on NHC's hydrologic analysis (described in section 2.2), a 1.01-year ("annual") flood is around 4,400 cfs. Flows above this threshold are described as flood flows, and below as normal flows. Note that normal flows cover a wide range of conditions from extreme low summer flows through uncommon higher flows that do not quite reach the flood flow criteria. The river is in normal flow condition over 99 percent of the time (Figure 8).

2 DATA AND MODEL REVIEW

NHC first performed a review of the observed water level data, flow estimates and Delft3D hydraulic model inputs and outputs to identify any issues or concerns that might affect our use of these data in our review.

2.1 Observed Water Level Data

TNC (2020) noted that several gages had indications of movement, inaccurate survey control, and instrument failure. Where possible, erroneous data had been corrected or removed by TNC in the spreadsheets provided. NHC's review identified additional data issues on multiple gages. Due to the importance of observed data in answering the scope questions, NHC made a series of corrections to the TNC data for use in our analysis. We believe these corrections result in observed water levels within a few tenths of true values, but in most cases have no way to definitively be certain.

Our primary data quality check method was to compare summer high tide levels to adjacent gages and the NOAA Garibaldi tide gage. During the summer, effects of river flow on water levels are minimal at high tide. Our expectation—based on the relatively small project area, short distance to Garibaldi, and experience with gages operated at the adjacent Southern Flow Corridor project--is that high tides between all gages should be very similar, within a few tenths of a foot. ESA-PWA (2013) reports using a -0.21-foot corrector for tides between Garibaldi and the mouth of the Kilchis River (see also Appendix A). Differences of half a foot or more were investigated further. Low tide comparisons were not as useful

[1] Datum corrector provided by Tillamook County Surveyor for Southern Flow Corridor project.

because low tides vary much more between sites, and most of the gages go dry on low tide. Based on this comparison, NHC made the following changes to the observed water level datasets:

- Pre-2016 Gages (PC Trask operated, pre-Dooher project)
  - Raw 2014 data for Squeedunk and Stasek gages was provided with no datum correction. We estimated correctors for both gages. For the Squeedunk gage, we used Garibaldi tide gage barometric data for pressure compensation, then manually adjusted the datum corrector to achieve a good match between Garibaldi and gage high tides in July 2014. Adjustment to the Stasek Slough data was more involved and is described in detail in Appendix A.
- Post-2016 Gages (TNC operated, post-Dooher project completion)
  - Stasek@Highway, Channel Connector, Neilson, and Ditch gages were determined to be in metric units. These were converted to feet and the TNC-supplied datum corrector applied to generate a time series in feet.
  - Hathaway Slough. This gage was consistently 0.9 feet higher at high tide compared to all the other gages and the Garibaldi gage. The same pattern existed at low tide. This suggests an error in the datum conversion elevation for this gage. We applied a -0.9-foot correction to the time series to match the other gages at summer high tides.

Based on logged depth readings near zero and characteristic flat hydrograph shape, we determined that all post-2016 gages except Hathaway and the Kilchis River downstream of Highway 101 go dry on low tides. Since we expect the Hathaway gage to have the lowest low tide readings of all the gages, and this gage does not go dry, this gage serves as a lower limit on low tide levels at the other gages. None of the pre-2016 gages (Hathaway, Squeedunk, Stasek) appeared to go dry on low tide, although the Stasek gage was very close. We did not remove the ‘dry’ gage data but mention it as something to keep in mind when looking at figures in this report.

We used the post-project Stasek near Culvert gage as a key dataset for evaluating project impacts. This gage goes dry at an elevation of 5.0-5.1 feet. Using a comparison with the Hathaway Slough gage and projecting out approximate expected water levels had the gage not gone dry, we estimate that the true minimum low tide at this gage is about 4.8 feet. We checked this across multiple summer periods and have high confidence in this conclusion, within a tenth of a foot or so. We consider this 0.2 to 0.3 feet of ‘missing data’ to be minor. The following discussion uses statistics from this gage with minimum elevations of 5.0 feet, but we have called out our estimate that the true low tides should be about 4.8 feet on the relevant figures and narrative. Figure 3 shows a typical example of how the hydrograph from a dry gage looks compared to one that remains wetted and how we estimated the true minimum low tide elevation for the Stasek Slough gage.

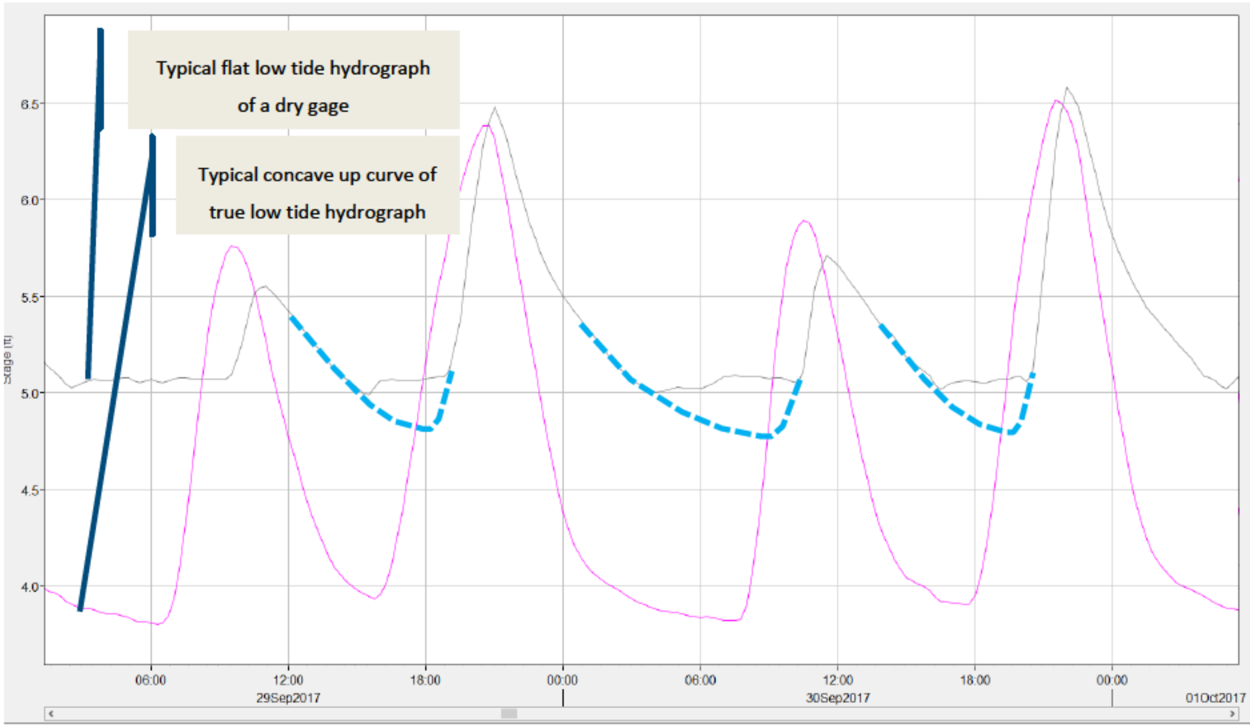

Figure 3: Observed Stasek near Culvert (Gray) and Hathaway (Pink) gage data and estimated true Stasek low tide hydrograph (Blue)

2.2 Kilchis River Flow Estimates and Probabilities

There is no record of long-term stream gage installation on the Kilchis River (we believe there was a short-term Oregon Department of Water Resources gage installed around the 2000s but no online records were found). Therefore, river flows and associated probabilities must be estimated using indirect means, as opposed to flood frequency analysis of an extended gage record. Several different methods and sources have been used for determining Kilchis River flows. These varied by study but were all based on applying a scaling factor to observed Wilson River USGS gage data. Table 1 summarizes the range of flow estimates and scaling factors from the various studies. The following paragraphs review the hydrologic methods and flows used as documented in the reports that were reviewed. We also discuss independent estimates of Kilchis River normal and flood flows developed by NHC.

Table 1: Kilchis River flood flows and scaling factors

Flood Return Interval (yrs)	PWA-ESA 2013 @ Mapes Cr	FEMA FIS 2002/2018 @ Mapes Cr	Behrens (2017) @ Mapes Cr	Kilchis River Direct Application of Cooper (2005) @ Hwy 101	NHC @ Highway 101 scaled from Miami R. (this report)	NHC @ Highway 101 scaled from Wilson R. (this report)
2	4,100	--	--	7,000	7,933	9,625
5	5,000	--	--	9,730	11,530	13,794
10	5,600	11,180	--	11,500	14,007	16,437
20	6,200	--	--	13,800	17,394	19,841
50	6,900	15,190	--	15,500	20,007	22,322
100	--	16,795	--	17,200	22,759	24,744
Wilson River Flood Scaling Factor	22.3%	--	45%	--	--	59%
Wilson River Low Flow Scaling Factor	22.3%?	--	37%	--	--	45%

PWA-ESA (2013) states that "a scaling method based on watershed parameters (area, climate, and soil properties) was used" and refers to Cooper (2005). The equations referenced in Cooper (2005) are incorporated in the USGS StreamStats online streamflow estimation tool (https://streamstats.usgs.gov/ss/). NHC applied StreamStats to the Kilchis River above Mapes Creek, where the Delft3D model has its inflow location, but was unable to replicate the results shown in Table 1 of the PWA-ESA report. The report notes the PWA-ESA numbers had large differences compared to prior hydrologic study flow estimates but attribute the differences to limitations of the USGS regression equations. Given that our use of the Cooper (2005) equations gives results very much in line with those older studies, we believe that an error was made in the application of the regression equations during the Dooher hydraulic analysis. As a result, we believe the flood frequency numbers reported in column 1, Table 1 of PWA-ESA (2013) are about one-half of what they should be. (We also note that the table reports the values for the 2002 FEMA Flood Insurance Study (FIS) 50- and 100-year flows as the 25- and 50-year flows, respectively, but as these flows were not modeled this error did not affect the analysis.)

The main concern with this apparently erroneous flow is that it was used in calibration of the model. PWA-ESA (2013) describes a low-flow and high-flow calibration period. The method to estimate low flows is not stated explicitly; we assume the same scaling factor that was described to estimate high flows was used. If this is the case, the low-flow Kilchis River discharges would have the same magnitude of error as the high flows, but as noted in the report, during low flows the site is tidally dominated so there is less concern with the apparent errors here. The report notes that the model was calibrated to the November 2012 flood, which had a peak of 21,000 cfs at the Wilson River USGS gage (between a 2- and 5-year event based on the observed Wilson River gage record). The Kilchis inflow was then scaled to 4,700 cfs from the Wilson River observed record. This is 22.3 percent of the Wilson peak, whereas correct scaling should use about 58 percent of Wilson River values. Later modeling documented by Behrens (2017) notes "a 10 to 20 percent change in flow rate led to as much as 0.5-1 feet of change in water level", so a 60 percent lower flow would be expected to have a significant impact on water levels. The model calibration of the November 2012 event undersimulated both low tides and the flood peak by one-half to one foot: both issues can be explained by inputting too low a river flow.

Loeb (2014) documents model upgrades and analysis of the regulatory 100-year flood event. The report states a base flood (100-year) flow of 15,600 cfs was used, referencing the 2002 FEMA FIS for Tillamook County. This is slightly greater than the 15,360 cfs reported in the FIS, which may be due to adding in local tributary inflows but is consistent with the expected value for this flood. We do note that NHC's analysis indicates higher estimates for flood flows may be warranted for future modeling work.

Behrens (2017) documents extensive model upgrades and used a different method of scaling Wilson River flows to create Kilchis River flows using only drainage area, referencing Oregon State University and USGS Texas studies. This method results in a scaling ratio of 37 percent for flows lower than 1,000 cfs and 45 percent for larger flows. Using the NHC approaches described below, the scaling ratio for low flows would be 45 percent and 59 percent for flood flows, resulting in the estimated NHC flows 8 percent and 14 percent higher than those used in Behrens (2017) for low and high flows, respectively. These differences are small and well within the uncertainties of estimating flows in ungaged basins. We conclude the methods used in Behrens (2017) give reasonable (though perhaps somewhat underestimated) estimates of Kilchis River flows from low flow through large floods.

NHC also developed scaling ratios independently as part of this review. In our opinion, generating the basin scaling ratios using the USGS coastal Oregon-specific equations developed by Cooper (2005) for flood flows and Risley et.al. (2009) for low flows, as implemented in StreamStats, is the most appropriate method, as this approach accounts for more variables found to be important in estimating flows, not just basin area. These scaling ratios are then applied to the Wilson River observed flow record to generate a simulated Kilchis River flow record that can be used for statistical analysis. This appears to be the method that was incorrectly applied in PWA-ESA (2013).

For low flows, NHC generated monthly 50 percent exceedance interval flow estimates for the Wilson River and Kilchis River using the equations of Risley et.al. (2009), then took the mean of the monthly scaling ratios, to produce a scaling factor of 45 percent. For flood flows, we calculated the ratio of the estimated Kilchis and Wilson River peak flows for each of the 2- through 100-year events. The ratio ranges from 55 percent for the 2-year flood to 61 percent for the 100-year flood; we used an average of 59 percent to scale flood flows. We cross checked this information by applying the same procedures to scale flows from the Miami River watershed, which had a USGS gage operating in it for several decades.

Comparing Kilchis River flood quantiles from the observed gage records of both the Miami and Wilson Rivers versus those calculated directly using Cooper (2005) shows both rivers produce higher flood flows than the Cooper equations predict. This implies that the Kilchis River, located between these two basins both geographically and in drainage area, also may produce higher flood flows than those predicted by the Cooper equation. Using the Cooper equation to generate the scaling factor but using observed

Wilson River flows for the base dataset addresses the potential underestimation using Cooper directly for the Kilchis could create. One other difference between this NHC analysis and those reviewed is that we calculated scaled flows for the Kilchis River at the Highway 101 bridge. While the model extends up to Mapes Creek, there is an additional 10 percent increase in drainage area by Highway 101 that should be accounted for in the modeling (this does not include estimated inflow from Stasek, Hathaway, or Vaughn Creek drainages).

In summary, the initial modeling conducted for the Dooher project appears to have a substantial error in flow estimates that affected the calibration and therefore the confidence in the ability of that model to simulate accurately across a range of flows. Subsequent generations of the model used better flow estimates. Comparison with flows produced by adjacent basins, using region-specific scaling factors, and accounting for basin area between Mapes Creek and Highway 101, indicate that both low and flood flows may be larger than those used in all the analyses to date. Regardless, there will always be substantial uncertainty in estimating flows in ungaged basins. Given these uncertainties, use of flow sensitivity testing in future modeling, rather than investing substantial effort in additional hydrologic analysis, is recommended.

2.3 Delft3D Hydraulic Model

NHC reviewed all hydraulic modeling reports supplied for the project and the model input and output files used for the Porter Tract analysis. There have been several generations of the hydraulic model, with increases in model domain, updates to topographic data, and updates to the design incorporated over time. Additional modeling work was done after the significant changes to bed and floodplain topography caused by the large December 2015 flood interacting with the newly completed Dooher project. The analysis was done in Delft3D using its two-dimensional formulation. Topography for most of the model domain was derived from LiDAR, with supplemental ground- and boat-based survey points added in channels, within and adjacent to the Dooher and Porter sites. The computational grid resolution is 15 feet.

The more recent Delft3D models have demonstrated good calibration to both low-flow/tidally-dominated conditions and floods. The observed data used for the calibration is limited to TNC lands and the Kilchis River channel immediately adjacent. The 15-foot cell resolution can accurately simulate the Kilchis River, floodplain areas, and primary sloughs in the project area—Stasek, Hathaway, Neilson, and Porter—but is too coarse to capture smaller channels and drainage ditches.

Virtually all the reports reviewed focus on flood impact evaluation of the Dooher or Porter projects. The few short sections that discuss low-flow/tidally-dominated conditions focus mostly on high-tide peaks with no discussion of low-tide or average water level impacts that are generally more important for agricultural drainage impacts analysis. We have been able to glean model results for partial low flow analysis because the simulations generally included a few days prior to and after the flood.

Overall, we found the models well suited for flood analysis and normal flow analysis for the Kilchis River and primary sloughs in the area. The models were not set up to allow a detailed agricultural drainage impacts analysis, particularly in the Vaughn Creek unit. In our answer to Item 4, we recommend a series of model improvements to address this.

3 SCOPE OF WORK QUESTIONS

3.1 Dooher Project Impacts Analysis

1) How did the Dooher project impact water levels in Hathaway Slough, Stasek Slough, and the Kilchis River (adjacent to the project site)?

We discuss flood and normal flow impacts separately. By 'normal' flow we mean all non-flood flows, including both summer low flows and higher but frequent winter flows.

3.1.1 Flood Impacts

Flood impacts are described in two reports (Loeb, 2014; PWA ESA, 2013). The model scenarios used were a steady flow 100-year flood of 15,600 cfs and a 5-year flood of 4,700 cfs[2]. Downstream tidal boundaries were between 10 and 11.6 feet. For the 4,700 cfs simulation no change in peak stages is noted.

For the 100-year flood the Dooher project had significant impacts on Kilchis River flood levels: by removing the levee along the river and the one that bordered Stasek Slough, significant flow now spills out of the river to the north. For the 100-year flood run, reductions in Kilchis River flood stages of up to two feet at the levee removal location were predicted, and around one foot closer to Highway 101. The reduction tapered off at the Squeedunk Slough entrance. Downstream of Squeedunk Slough, increases in peak flood levels of about a tenth of a foot were predicted, due to more flow being diverted into this reach by the project. Peak water levels on TNC lands and adjacent sloughs were not reported, but based on the Kilchis River data, we expect that increases on the order of 0.1 foot likely occurred in Stasek, Neilson, and Hathaway Sloughs.

The 100-year flood was also run with an 'evolved bed condition' accounting for expected change in the Kilchis River due to the project. This condition added several feet of sediment to the main channel in the area of levee removal and assumed some scour upstream from there to the Highway 101 Bridge. Post-December 2015 flood surveys show that the riverbed has evolved fairly closely to these predictions. The reduction in flood levels in the Kilchis River between Highway 101 and Squeedunk Slough is reduced to less than half a foot, but the small rise downstream of Squeedunk Slough is also removed. No results for adjacent sloughs or floodplains were reported.

In summary, the modeling indicates that the project has reduced large flood levels in the Kilchis River between Highway 101 and Squeedunk Slough, possibly by half a foot or more. Sedimentation in the channel induced by the project has led to smaller flood level reductions over time. Flood levels in Stasek, Neilson, and Hathaway Sloughs and surrounding floodplain have perhaps seen rises of 0.1 foot or so.

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[2] See prior discussion on Kilchis River flows. Our estimates of a 5-year flood based on USGS StreamStats and basin scaling from the Wilson and Miami River gages is 11,500 cfs. Using our estimates this flow is significantly less than a 2-year event.

3.1.2 Normal Flow Impacts

The Dooher project reports reviewed focused on flood impacts, with the associated model simulation run for short time spans covering only the flood modeled and a few days on either side. Therefore, we have relied almost entirely on the observed gage data provided to evaluate impacts to normal flows. Fortunately, we have data from both Hathaway and Stasek Slough gages for pre- and post-project periods, although the pre-project Stasek Slough data has a higher level of uncertainty than the other observed data (see Appendix A).

3.1.2.1 Stasek Slough

Water level changes in Stasek Slough due to the Dooher project are significant and vary by season. We present the differences in a variety of different figures in this section, but perhaps the simplest way to visualize the difference for wet season conditions is to plot Stasek Slough stage from a pre- and post-project time when river flows and high tides were very similar (Figure 4). This figure shows that while high tides in Stasek Slough closely match those in Garibaldi, minimum low tide levels were increased by around two feet, reducing the tidal amplitude from over three feet to one foot.

We applied some averaging to the timeseries data to better evaluate seasonal changes in water level due to the Dooher project. Figure 6 shows averaged Hathaway and Stasek Slough water levels. The stage was developed by first creating daily maximum, minimum, and average water level records (the daily maximum and minimum are a close surrogate for higher high and lower low tides). We then averaged these data over a semi-monthly (i.e., approximately bi-weekly) period, which provides better estimates of longer duration water level trends and makes for clearer figures.

Referring to Figure 6, summer maximum average levels have increased from 7.3 to 7.9 feet. Minimum levels have increased from 4.2 to 4.8 feet, and mean levels increased from 5.1 to 5.6 feet. Prior to the Dooher project, maximum water levels were a few tenths lower than Hathaway Slough, average water levels similar, and minimum water levels about 0.2 feet higher. The smaller amplitude (difference between highs and lows) is attributed to the muting effect of the connector culvert on flow exchange between Hathaway and Stasek Slough prior to Dooher project construction. Post-construction, the connector culvert still limits flow out to Hathaway, but Stasek Slough sees much more inflow from the Kilchis River connection. This creates the increases in water levels over the summer months.

The greatest change to Stasek Slough is seen in the winter months. Minimum and mean water levels rose on the order of 1.5 to two feet during the wet season once the project was constructed. Maximum winter water levels are generally about one foot above Hathaway maximum water levels, whereas minimum and average water elevations are two to three feet higher. The greater difference in the minimum and average levels between Stasek and Hathaway sloughs, and the fact they occur in the winter, is an indication that these changes are related to Kilchis River flows. In Figure 7, Kilchis River mean daily flows are plotted versus stage in Stasek Slough for pre- and post-project conditions. Post-project water levels are much more sensitive to increasing Kilchis River flows. At very low flows post project water levels are about 0.6 feet higher than pre-project water levels, but at 1000 cfs post project water levels are over 2.5 feet higher than pre-project conditions.

We interpret this to indicate that at very low flows, bay tides (which were not changed by the project) dominate hydraulic behavior, while even relatively small increases in river flow lead to sharp increases in slough water levels. This finding was indirectly described in Behrens (2017), who noted high sensitivity in the hydraulic model to Kilchis River scaling assumptions – a 1 to 1.5 foot change in stage for a 10-20 percent change in river flow.

The greatest project effects are seen between flows of about 400 and 5,000 cfs. On an annual basis, flows are within this range about 36 percent of the time (Figure 8). On a mean monthly basis, flows exceed 400 cfs from November through April (Figure 9), which corresponds with the increases in winter season stage shown in Figure 7. Pre-project data is limited at higher flows, but it can be seen the two curves are converging, which falls in line with the flood modeling predictions that there is little difference in pre- and post-project water levels during floods greater than about a 2-year event.

The increases in winter water levels in Stasek Slough are most likely caused by the connection of Stasek Slough to the Kilchis River as part of the Dooher project, implying that stages in the Kilchis River at the Stasek Slough breach are much more strongly influenced by Kilchis River flows than at the river's confluence with Hathaway Slough.

The increases in water levels in Stasek Slough on TNC lands propagate upstream under Highway 101, where both Stasek and Neilson Sloughs flow through private lands. The relatively small low-lying areas of the Stasek and Neilson units may see increased frequency of inundation in the winter months. When water levels in Stasek Slough exceed about 11 feet, water spills over the north bank upstream of Highway 101 and flows into Hathaway Slough.

3.1.2.2 Hathaway Slough

Hathaway Slough water levels are shown in purple in Figure 6. There is minimal pre-project data, covering a few late summer months in 2012. Comparing minimum, maximum, and average curves with the post-project data, no significant change has occurred for summer months. For instance, the averaged low tides have remained around an elevation of five feet in all years shown.

However, we believe it likely that there have been some increases in winter water levels due to the Dooher project, driven by the significant increases observed in Stasek Slough. Figure 10 plots Stasek and Hathaway Slough observed water levels, as well as the difference between them, and estimated Kilchis River flows. At the beginning of the period with very low river flows, the differences vary between +1 and -1 feet, indicating bi-directional flow in the connector culvert between the two sloughs. Once flows begin to rise, the difference increases to two to three feet on average and is always positive, indicating continuous one-way flow from Stasek Slough to Hathaway Slough through the connector culvert. Once flows exceed about 3,000 cfs, Stasek Slough water levels exceed 11 feet (Figure 5). At this elevation, water begins to spill from Stasek Slough to Hathaway Slough over the floodplain on TNC property and also over a low point just upstream of Highway 101 (mentioned as an observation by Leo Kuntz in his 'staircase' memorandum (Kuntz, 2017)). This evidence indicates that flows into Hathaway Slough have been increased by the Dooher project during winter months. Increasing flows in tidal sloughs almost always result in reduced (higher) low tides. In contrast, it typically takes far larger flow increases to affect high tide levels, so we believe it unlikely that the probability of overtopping of the west side Hathaway Slough dikes into the Vaughn Creek unit has been increased. We do not know the magnitude of the increase from available model data, observed data, or reports. We therefore do not know if they are significant or not, although Leo Kuntz's observations in his letter imply that Hathaway Slough was not affected nearly to the degree that Stasek Slough was by the project.

3.1.2.3 Kilchis River

The focus of the Dooher project reports on floods and the lack of Kilchis River gages spanning project implementation mean that there was not enough information to quantitatively evaluate changes to normal water levels in the Kilchis River between Highway 101 and Squeedunk Slough. With the two to four feet of aggradation measured in the reach where the levee was removed after the December 2015 flood, we expect water levels during summer low flows to be similarly increased. The increase in water level is reduced as Kilchis River flows increase, and once flows begin to spill over the removed levee section, post-project water levels are lower than pre-project water levels (based on the flood modeling described previously). We can infer that Hathaway Slough water levels are in large part driven by Kilchis River levels at their confluence, so the relatively small change we see in Hathaway Slough water levels between pre- and post-project conditions likely reflects similarly small changes in the Kilchis River here. We believe it likely there is some increase in low tide levels in the river around where Stasek Slough was connected and extending both up- and downstream some distance due to significant tidal exchange into Stasek Slough induced by the project. However, there is no modeling or observed data to validate this.

2) What were the hydrological impacts of the Dooher Project regarding both drainage and flooding on farm properties adjacent the Dooher property and Stasek Slough?

The analysis discussed in the previous section provides the information needed to answer this question, which we address on an agricultural unit (Figure 1) basis in Table 2.

Table 2: Dooher project water level impacts on agricultural units

Agricultural Unit	Flood Impacts	Normal Flow Impacts
Vaughn Creek	A rise of 0.09 feet is predicted at the mouth of Hathaway Slough for the base flood run (Loeb, 2014), which would lead to flood level increases of this magnitude or less in Vaughn Creek. The area is diked so flood levels must exceed the dike height to inundate the area.	This unit is most sensitive to increases in Hathaway Slough water levels, due to its low ground elevations and tributary inflow. Flows into Hathaway Slough from Stasek Slough have increased to an unknown degree, which may have affected winter drainage function, but whether the increases are significant is unknown. The two upper tidegates that drain the area would be the most likely to have reduced function if Hathaway Slough water levels have indeed increased during winter months. The west tidegates drain almost directly to Tillamook Bay and are less likely to be affected. Summer hydrology appears to be unaffected.
Hathaway	See above.	The western portion of this unit has lower ground elevations (about eight feet on the LiDAR), and would be affected similarly to Vaughn Creek if Hathaway Slough winter water levels have risen to a significant degree. Summer hydrology appears to be unaffected.

Agricultural Unit	Flood Impacts	Normal Flow Impacts
Stasek	A small decrease in base flood water levels is predicted at Stasek Slough under Highway 101. Upstream the decrease is expected to be no greater than this and is most likely less due to overland flood flows from up valley. Extrapolation of the water level increases seen during normal winter flows indicates there may be some increase in flood levels during smaller, more frequent floods.	Winter water levels have risen several feet in Stasek Slough due to the project, and these rises are expected to have propagated upstream of Highway 101. The lower elevation areas of the unit close to the highway now see overtopping flow during higher winter river flows and likely a generally higher water table in the wet season. Summer minimum and mean water levels have increased about one-half foot.
Neilson	Same as Stasek unit.	Neilson Slough water levels are driven by Stasek Slough levels, which have increased up to 3 feet in the winter. The area downstream of the highway between Neilson and Stasek Sloughs has land elevations around 10 feet and is the most likely area to be affected. The rest of this unit is mostly three to four feet higher and less likely to be impacted. Summer minimum and mean water levels have increased about one-half foot.
Kilchis LB	The project reduced flood levels in the Kilchis River by one-half foot, leading to decreased frequency, duration, and volume of overtopping flows into this unit.	Elevations in this unit are highest near the river and slope to the south. Drainage is out into Squeedunk Slough, which is unaffected by the project. No impacts to either winter or summer hydrology in the unit are anticipated.
Kilchis RB	This unit is undiked high tideland (elevation 9-10 feet). Increases of 0.2 feet are expected in the base flood scenario (note this is well below the expected 100-year tide). Increases of about a foot during a 2-year flood event are indicated.	Winter water levels have likely increased several feet here based on Stasek Slough water level data. Summer hydrology appears to be unchanged.
Squeedunk RB	Minor decreases in flood levels possible due to more flow diverting to the Kilchis River and less into Squeedunk Slough. Along the Kilchis River portion of the levee see the Kilchis RB above.	No change expected as the unit drains west to Squeedunk Slough, which appears to be unaffected by the project.
Squeedunk LB	Minor decreases in flood levels possible due to more flow diverting to the Kilchis River and less into Squeedunk Slough. Highest risk is likely from Wilson River and coastal flooding, not the Kilchis River.	No change expected as the unit drains to Squeedunk Slough, which appears to be unaffected by the project.

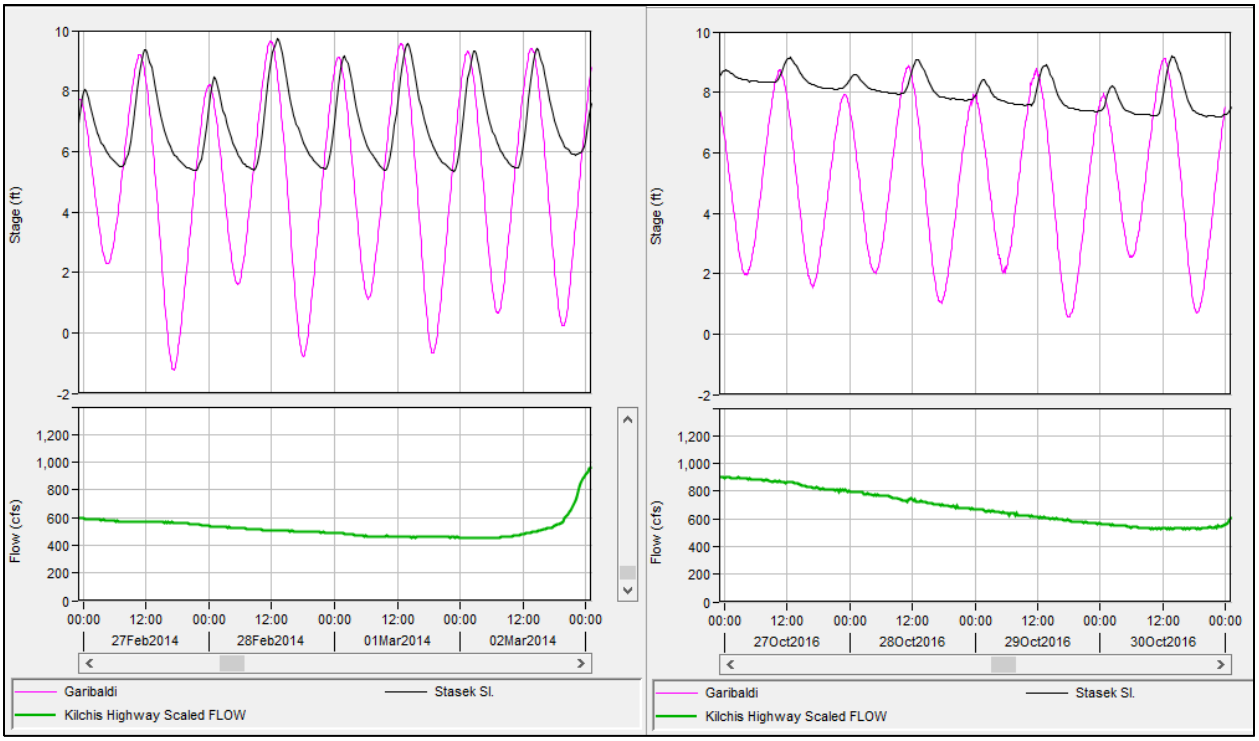


Figure 4: Comparison of Stasek Slough water levels pre- (left) and post- (right) Dooher project under similar river flow and high tide conditions. Note that high tides remain closely matched with Garibaldi high tides but low tides increase by around two feet.

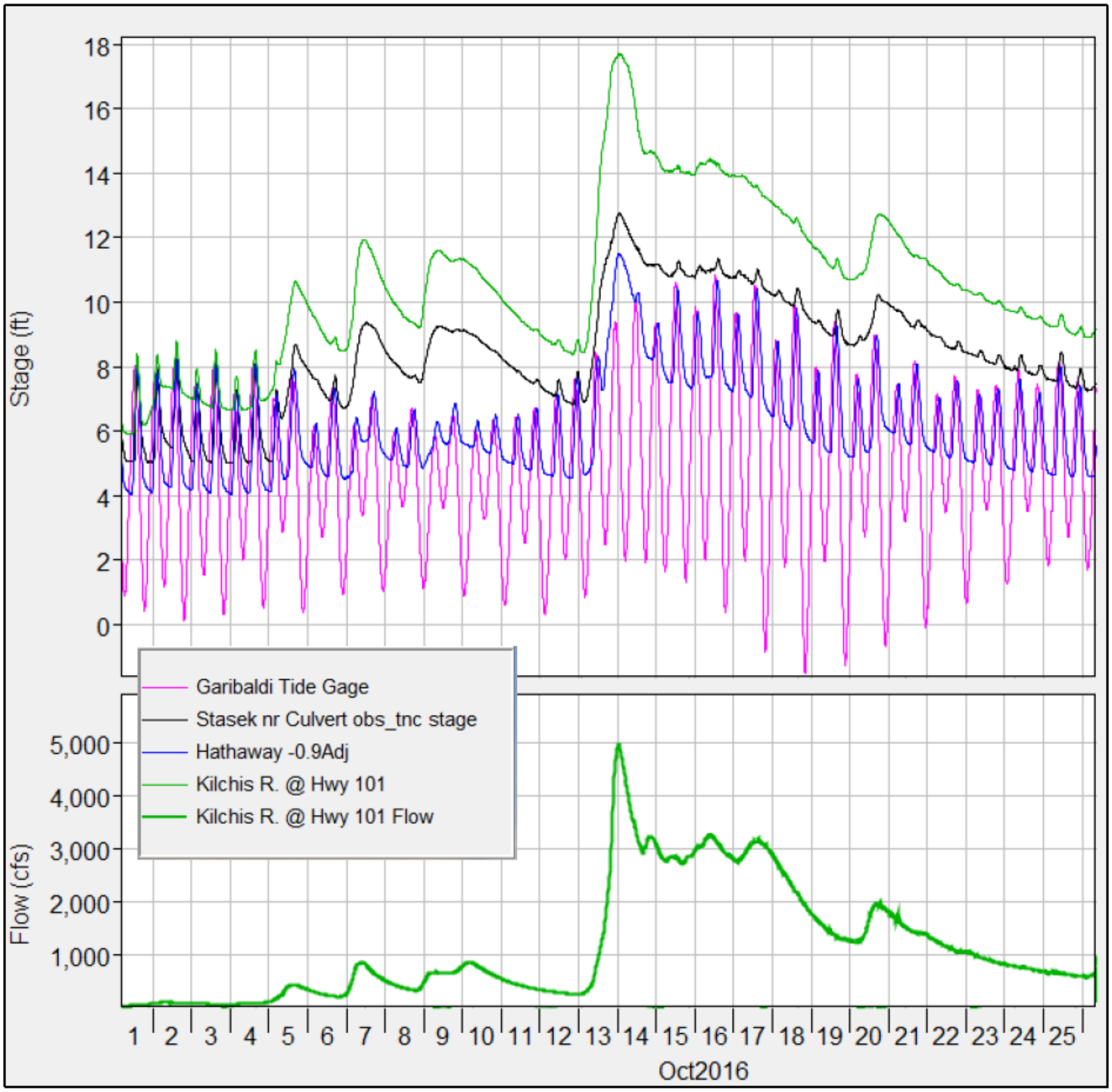


Figure 5: Observed stage and flow data for October 2016

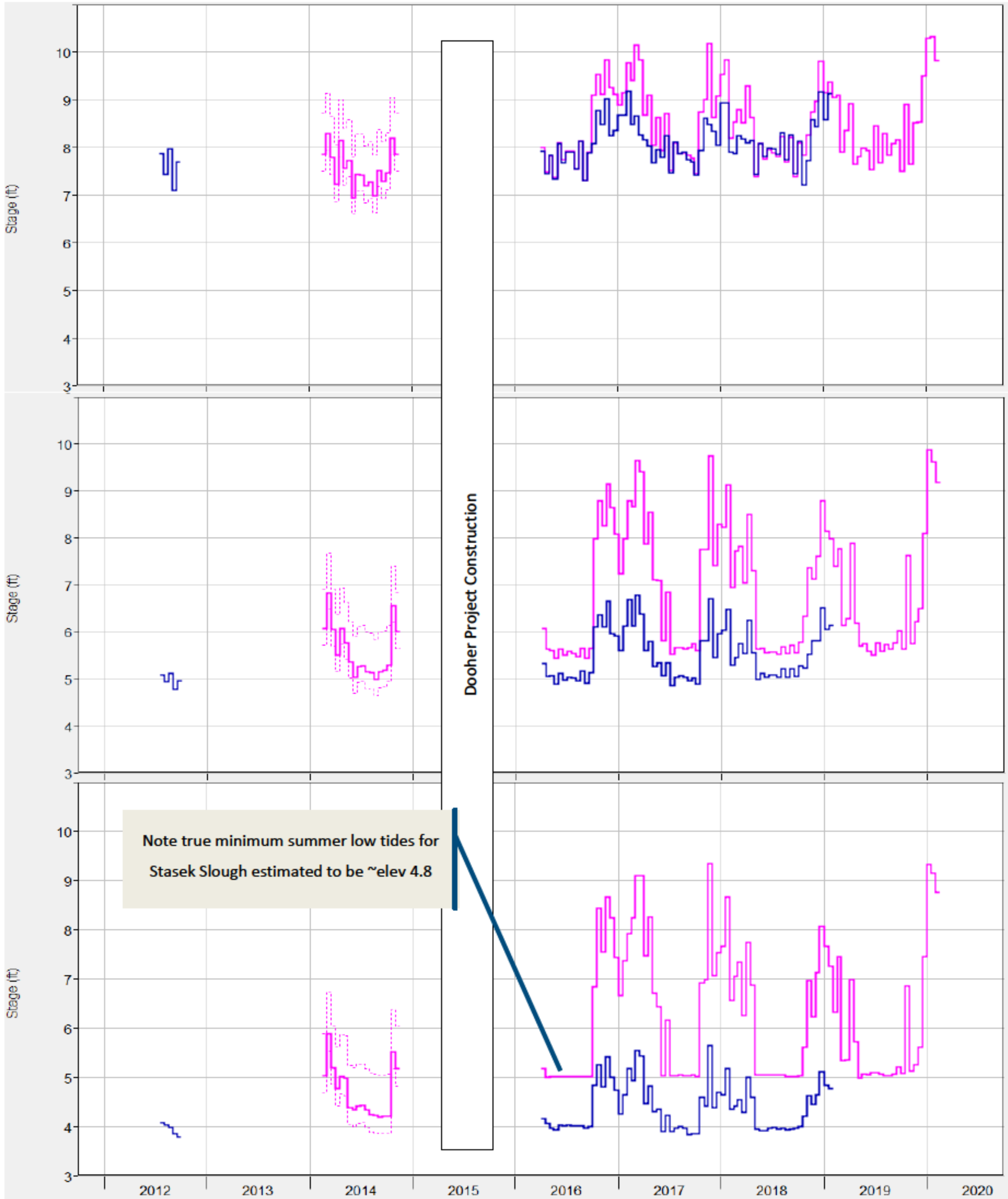


Figure 6: Observed semi-monthly averaged maximum (top), mean (middle), and minimum (bottom) of daily water levels for Hathaway Slough (blue) and Stasek Slough (pink). Dashed lines for 2014 Stasek Slough data indicate upper and lower uncertainty bounds.

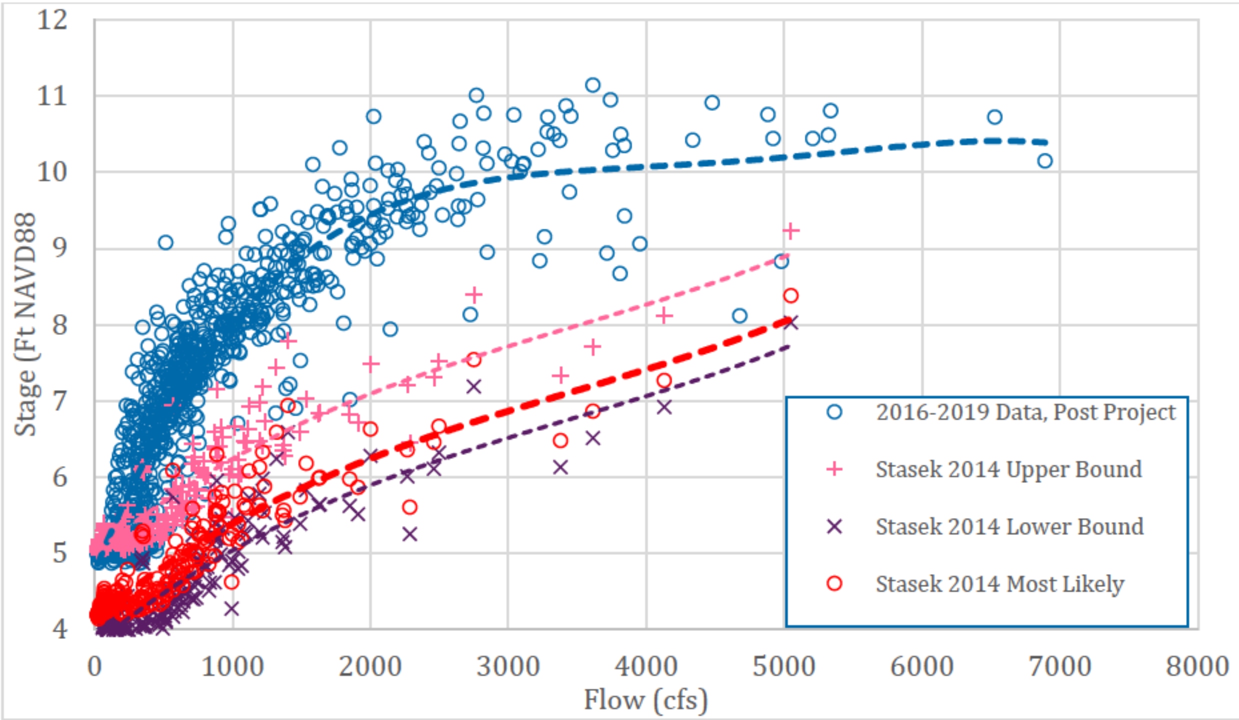


Figure 7: Stasek Slough stage vs estimated Kilchis River flow pre- and post-Dooher project

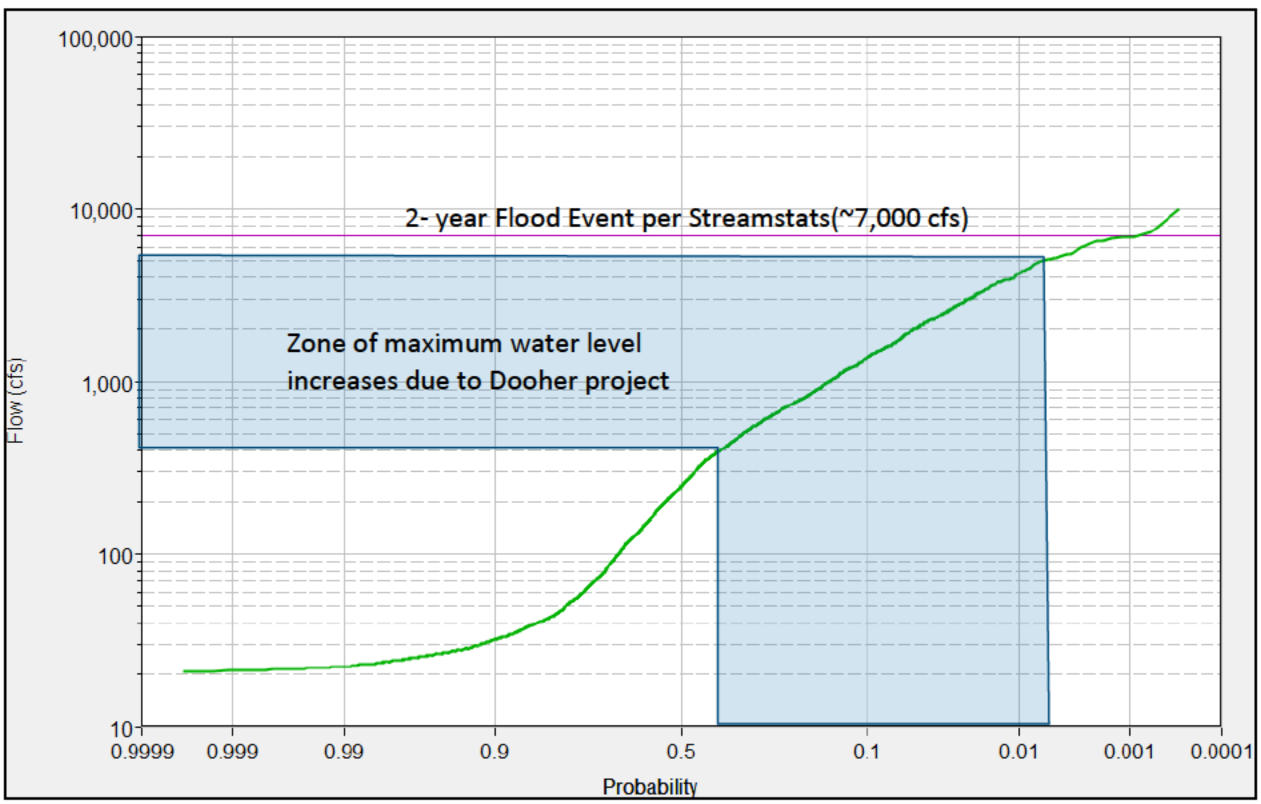


Figure 8: Estimated Kilchis River annual flow duration curve WY2012-2020

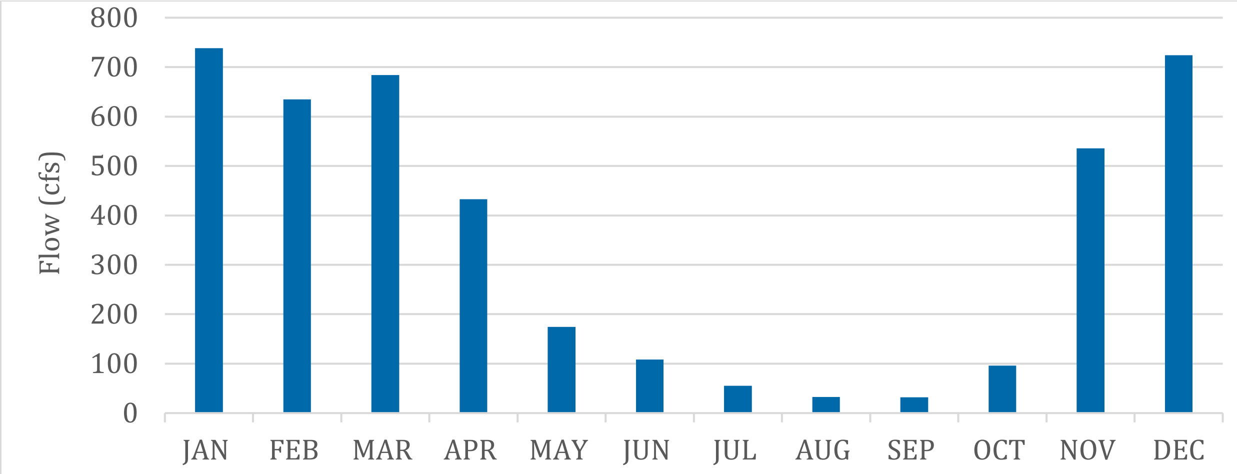


Figure 9: Median monthly estimated Kilchis flows

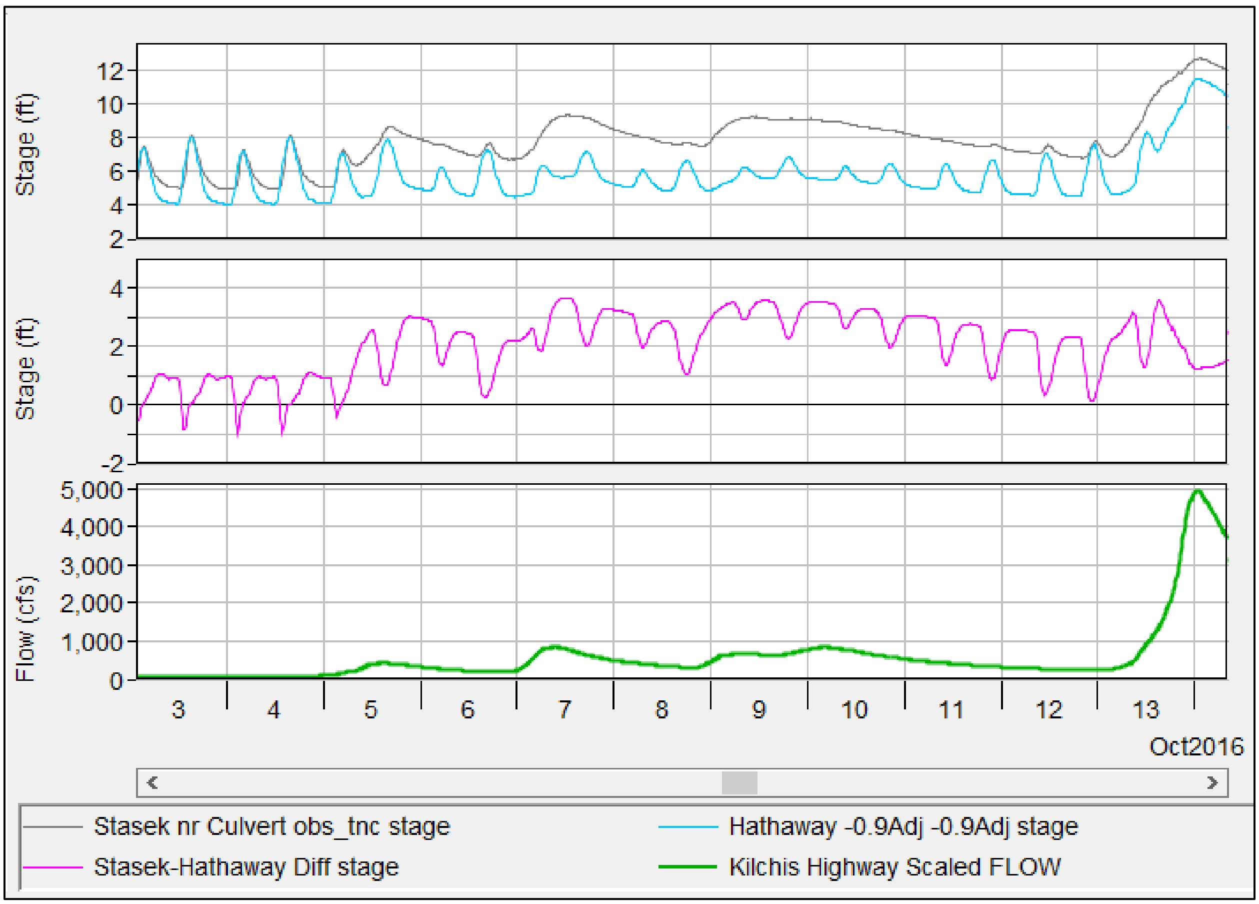


Figure 10: Stasek and Hathaway Slough observed water surface elevation (top), difference in stage (middle), and Kilchis River flows for reference (bottom).

3.2 Kilchis Porter Project Impacts Analysis

3) 3a. What are the anticipated impacts of the Kilchis Porter Project to neighboring farm properties regarding both drainage and flooding? 3b. How do the impacts of the initial Dooher and proposed Porter projects combine?

The Dooher project had a greater impact on area hydrology than the proposed Porter project will. By removing large portions of the Kilchis River levee and the berm along Stasek Slough, and connecting Stasek Slough directly to the river, the Dooher project has provided much greater connectivity between the river, Stasek Slough, and Hathaway Slough at all flows. The main impact of the Porter project will be to further increase the flow and connectivity between Stasek and Hathaway Slough by removing the existing four-foot box culvert and widening the connector channel to 35 feet.

We evaluated the expected impacts by analyzing model results for the large December 2015 flood and a small event in January 2017 (NHC, 2019). This modeling effort used the latest updated model, which included updated post-2015 flood channel survey, various other improvements, and recalibration as documented in Behrens (2017). The with-project simulations used the latest design plans. Both simulation periods contain times of low to moderate flows that allowed evaluation of drainage impacts as well as flood impacts.

3.2.1 Drainage Impacts

For drainage impacts, we analyzed normal flow conditions, represented by the first four days of the December 2015 simulation (Figure 11) and the first day and a half and last four days of the January 2017 simulation (Figure 12). This period includes flows up to about 4,000 cfs, which is exceeded only about one percent of the time (Figure 8).

Figure 13 presents the stage differences for both simulations as stage difference versus flow plots. This figure shows that, below about 500 cfs, differences in water levels between existing and post-project conditions are less than 0.2 feet and oscillate about zero (Figure 12, first day and a half). The largest differences occur between around 1,000 cfs and 2,500 cfs, with Stasek Slough water levels up to 0.8 feet lower than under existing conditions and Hathaway Slough water levels up to 0.5 feet higher. As flows increase further, the differences diminish. Stasek Slough stage differences tend towards zero, but Hathaway Slough shows a persistent small rise of about 0.1 feet through the flood peak. This change is attributed to greater connectivity between the sloughs due to the culvert removal, allowing more effective drainage of Stasek Slough but routing this water into Hathaway Slough. The Porter project is essentially reducing the head difference between the two sloughs. The effects of these changes in the sloughs propagate upstream of Highway 101; Figure 14 illustrates a representative time period with water surface differences plotted.

Based on the modeling, we expect very little change in hydrology in the area during summer low flow months when flows are below 500 cfs. During the winter, Hathaway Slough will see water level increases up to 0.5 feet at times, with average increases of perhaps 0.2 feet; this could affect drainage from the Vaughn Creek and Hathaway units. The increases will mostly occur on the low tide. Water levels in the Stasek and Neilson units will go down, up to 0.8 feet at certain flows and averaging perhaps 0.4 feet. The largest decrease in water level occurs on the low tide for these units. The changes on all units are at their maximum when river flows are between 1,000 and 2,000 cfs. Water levels on the Kilchis RB unit will be reduced by a lesser amount. Water levels in Squeedunk Slough are expected to be reduced by less than a tenth of a foot, but no measurable impact on either of the Squeedunk units or the Kilchis LB unit is expected.

The net effects of the combined Dooher and Porter projects vary by area. In the Stasek-Neilson units, the Dooher project raised average and low-tide water levels by several feet during winter months. The Porter project will tend to reduce average and low-tide water levels, but on the order of a few tenths of a foot to half a foot, so the net result will still be increases of several feet in water levels in these units. For Hathaway Slough, the Dooher project effects have not been quantified but are believed to be increases on the order of one or two tenths of a foot at average and low-tide water levels. The Porter project will add a further increase in average and low tide water levels of another one or two tenths of a foot.

3.2.2 Flooding Impacts

Changes in flood water levels due to the Porter project are less than the changes predicted under normal flow conditions. Project induced increases in water surface elevations tend towards zero as flows exceed 6,000 cfs on the Kilchis River for both Stasek and Hathaway Sloughs, although the latter sees a small persistent increase of about 0.1 feet through all but the very peak of the floods (Figure 11, Figure 12, Figure 13). This increase will be seen in the Vaughn Creek, Hathaway, and Stasek units for floods large enough to overtop the banks and dikes (Figure 15).

Reductions to mainstem Kilchis River stages due to the Porter project are less than 0.05 feet near the railroad and about 0.1 feet at Squeedunk Slough. The other agricultural units are expected to not see any measurable difference (we caution against giving much weight to the apparent flood reduction in the Squeedunk LB unit shown in Figure 15 due to the lack of attention and calibration data that section of the model has seen).

3.2.3 Impacts Due to Combined Projects (Question 3b)

Question 3b is difficult to answer with the available information because no modeling has been performed directly comparing pre-Dooher project conditions with proposed post-Porter+Dooher conditions. Synthesizing the various reports, model outputs, and observed data we have discussed in the prior sections, we can summarize what we know in the following tables.

Table 3: Summary of inferred flood impacts of combined Dooher-Porter projects on agricultural units

Agricultural Unit	Flood Impacts Dooher Project	Porter and Combined Project Impacts
Vaughn Creek	A rise of about 0.1 feet in Hathaway Slough is estimated. This will slightly increase the frequency and depth of overtopping into this unit from river floods. Note a separate risk not affected by the project is overtopping from extreme tidal events.	An additional rise of about 0.1 feet for a total increase of 0.2 feet in Hathaway Slough, leading to corresponding increases in Vaughn Creek.
Hathaway	See above.	See above.
Stasek	Negligible decrease in large flood water levels is predicted in Stasek Slough under Highway 101. There may be an increase of a few tenths of a foot around the 2-year flood.	No change in large flood levels. Porter may result in decreases of a tenth of a foot or less in small flood levels, but not enough to make up for the increase caused by the Dooher project.
Neilson	Same as Stasek unit	Same as Stasek unit
Kilchis LB	The project significantly reduced flood levels in the Kilchis River, leading to decreased frequency, duration, and volume of overtopping flows into this unit.	A small additional decrease in river levels from Porter (less than 0.1 feet) would provide minor additional flooding reductions.
Kilchis RB	This unit is undiked high tideland (elevation 9-10 feet). Increases of 0.2 feet are expected in the base flood scenario (note this is well below the expected 100-year tide). Increases of about a foot during a 2-year flood.	No change to a decrease of 0.1 feet from Porter. Net result is very little difference from existing (post-Dooher) conditions.
Squeedunk RB	During large floods, Squeedunk Slough water level may have decreased by 0.1 feet, but Kilchis River water levels are predicted to increase by 0.2 feet. Net change to flood risk in the unit depends on relative dike heights on the river and slough, but changes due to project are expected to be at most a few tenths of a foot.	Possibly another minor decrease in flood levels for net decreases of 0.1-0.2 feet in Squeedunk Slough. Due to levees and tidal dominant location, impacts to diked agricultural lands are likely negligible.
Squeedunk LB	Minor decreases in flood levels possible due to more flow diverting to the Kilchis River and less into Squeedunk Slough. Highest risk is likely from Wilson River and coastal flooding, not the Kilchis River.	No additional impacts.

Table 4: Summary of inferred drainage (normal flow) impacts of combined Dooher-Porter projects on agricultural units

Agricultural Unit	Drainage Impacts of Dooher Project	Porter and Combined Project Impacts
Vaughn Creek	An increase in water levels in Hathaway Slough of unknown magnitude (but likely on the order of a tenth of a foot) is likely to have occurred. This may have slightly reduced drainage capacity.	An additional rise from Porter averaging about 0.2 feet, added to whatever increase occurred due to the Dooher project. This may slightly reduce drainage capacity.
Hathaway	See above.	See above.
Stasek	Significant increases in winter water levels of several feet. Much of this unit is at higher ground elevations that may not be impacted by this rise.	Porter will decrease winter water levels 0.4-0.8 feet. Net result is still expected to be 1.5 to 2 feet higher than pre-Dooher project water levels.
Neilson	Same as Stasek unit	Same as Stasek unit
Kilchis LB	None	None
Kilchis RB	Winter water levels have likely increased several feet here based on Stasek Slough water level data.	No change to a small decrease of 0.1 feet from Porter. Net result is several feet of increase from pre-Dooher project conditions.
Squeedunk RB	No change	No change
Squeedunk LB	No change	No change

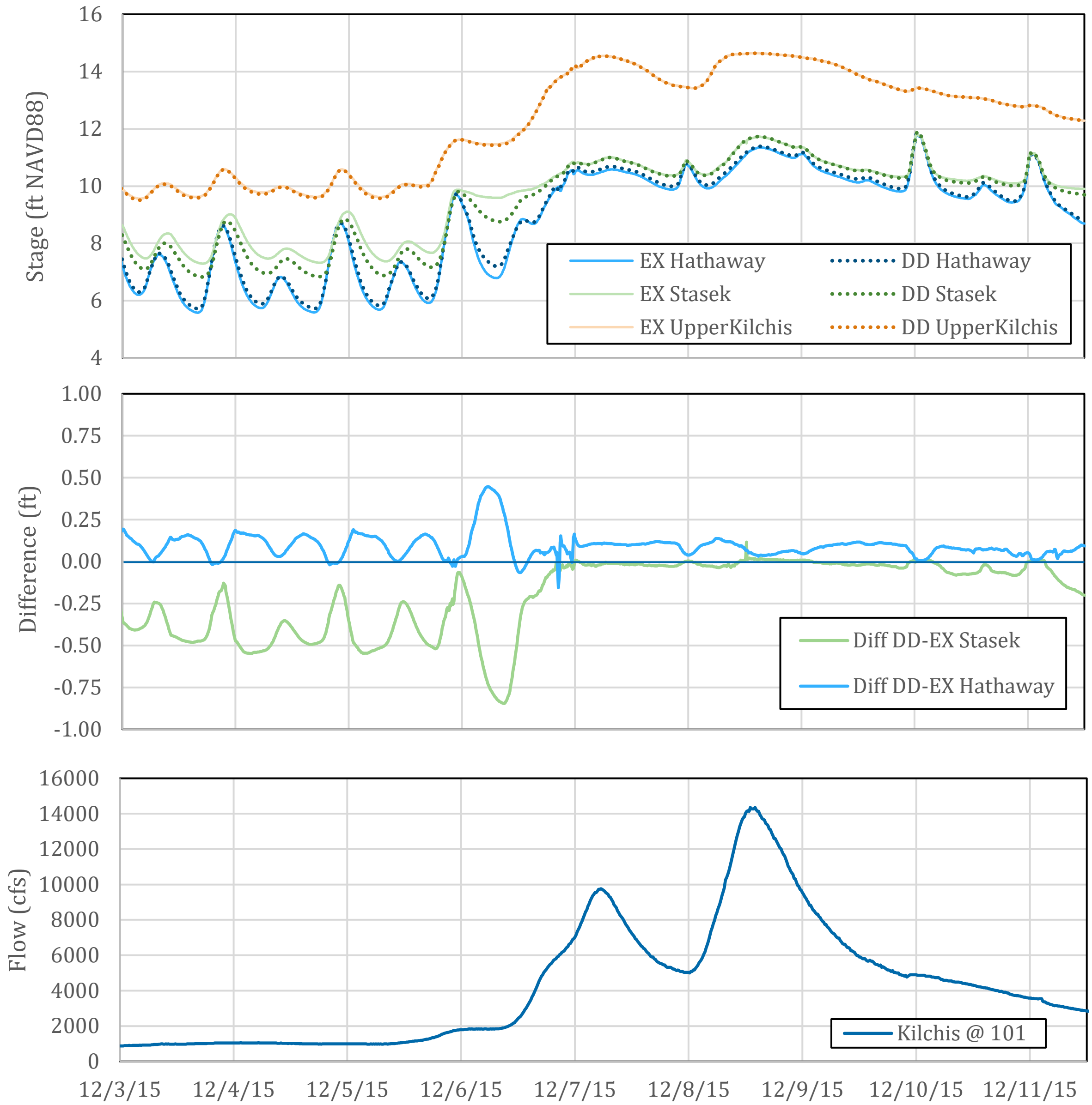


Figure 11: Comparison of existing conditions (EX) and proposed Porter project (DD) - simulated stage (top), difference in stage (middle), and Kilchis River flow (bottom) for the December 2015 flood

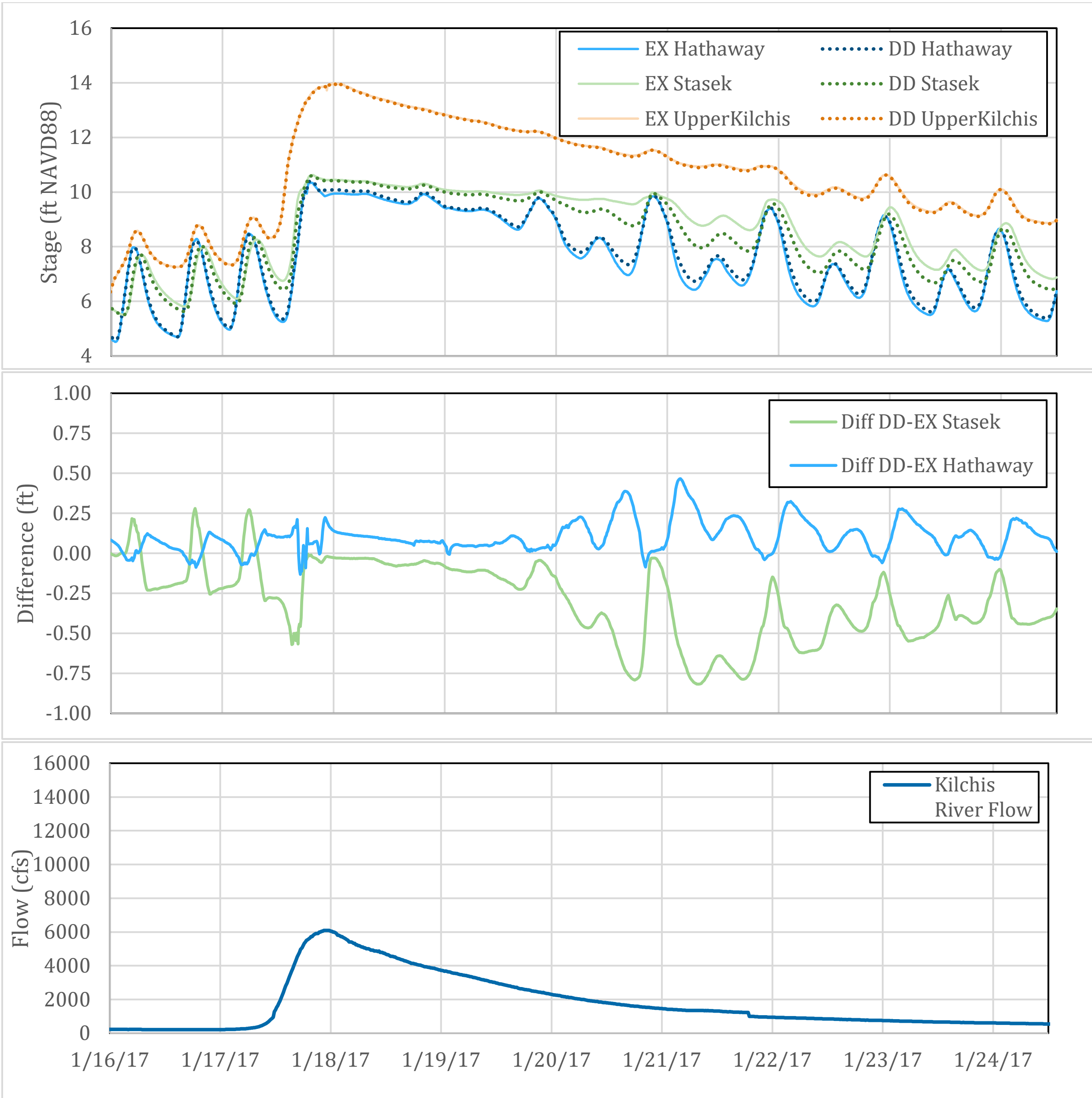


Figure 12: Comparison of existing conditions (EX) and proposed Porter project (DD) - simulated stage (top), difference in stage (middle), and Kilchis River flow (bottom) for the January 2017 flood

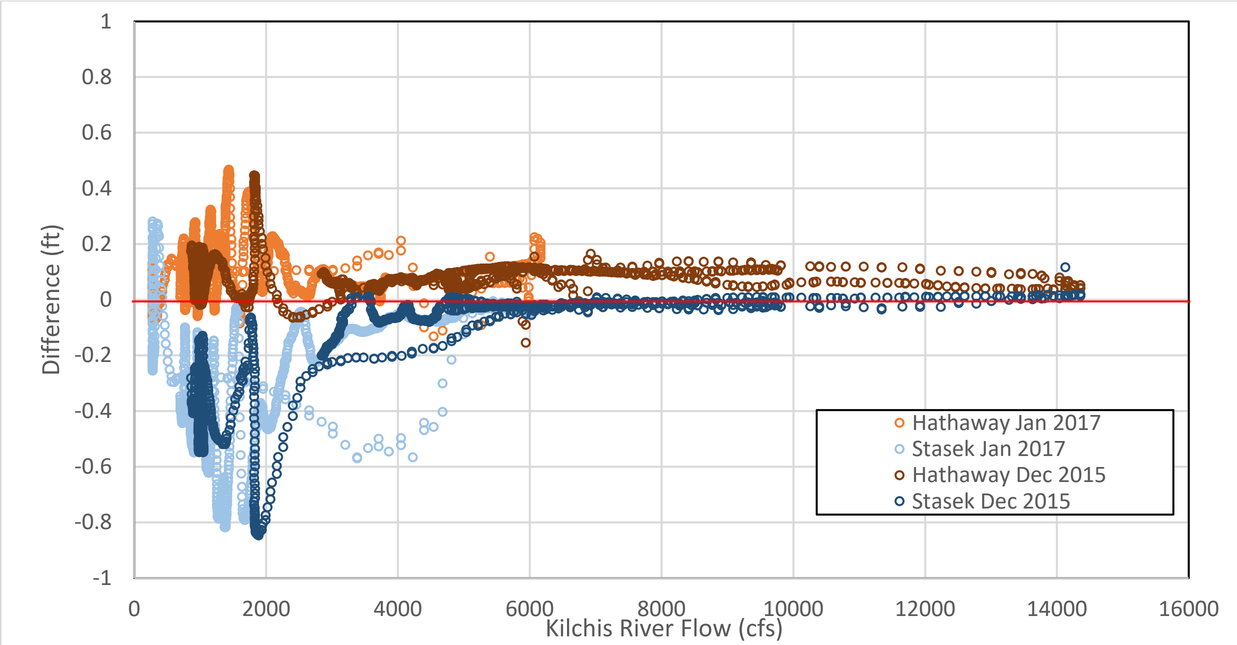


Figure 13: Difference in stage between existing and proposed Porter project conditions versus Kilchis River Flow

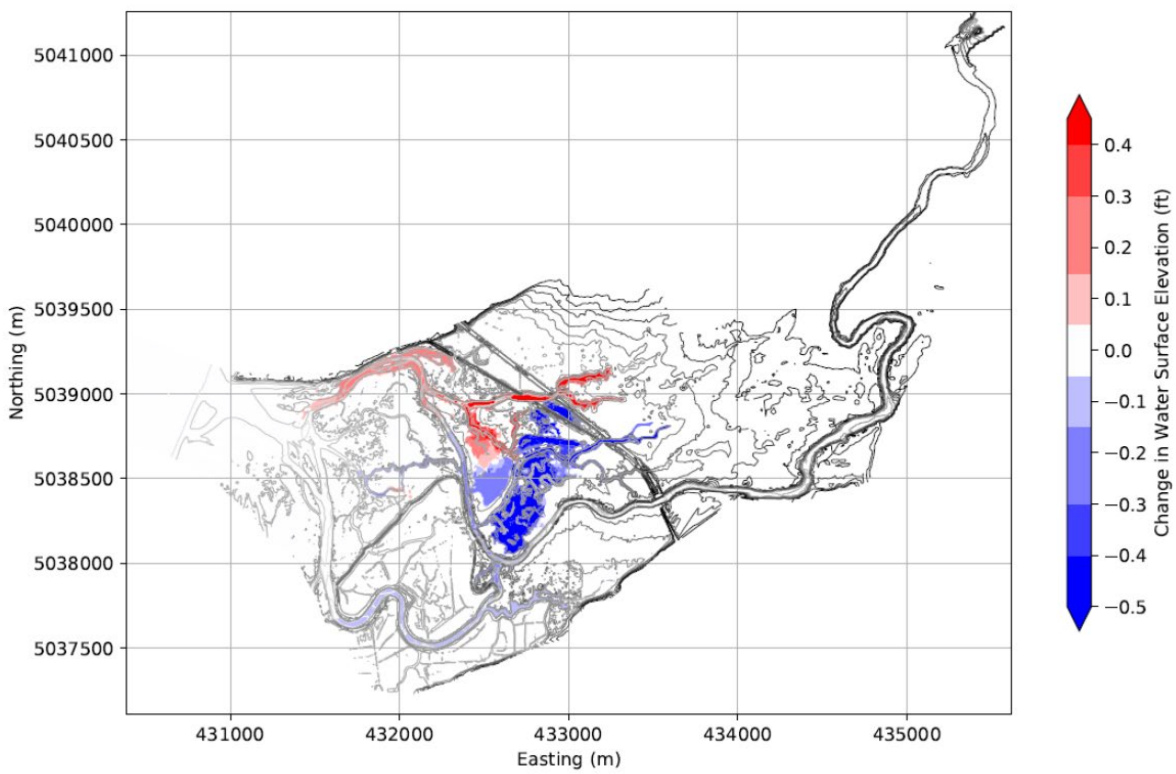


Figure 14: Change in water surface elevation due to Porter project on December 6, 2015 18:00 (Ebb tide) from (NHC, 2019)

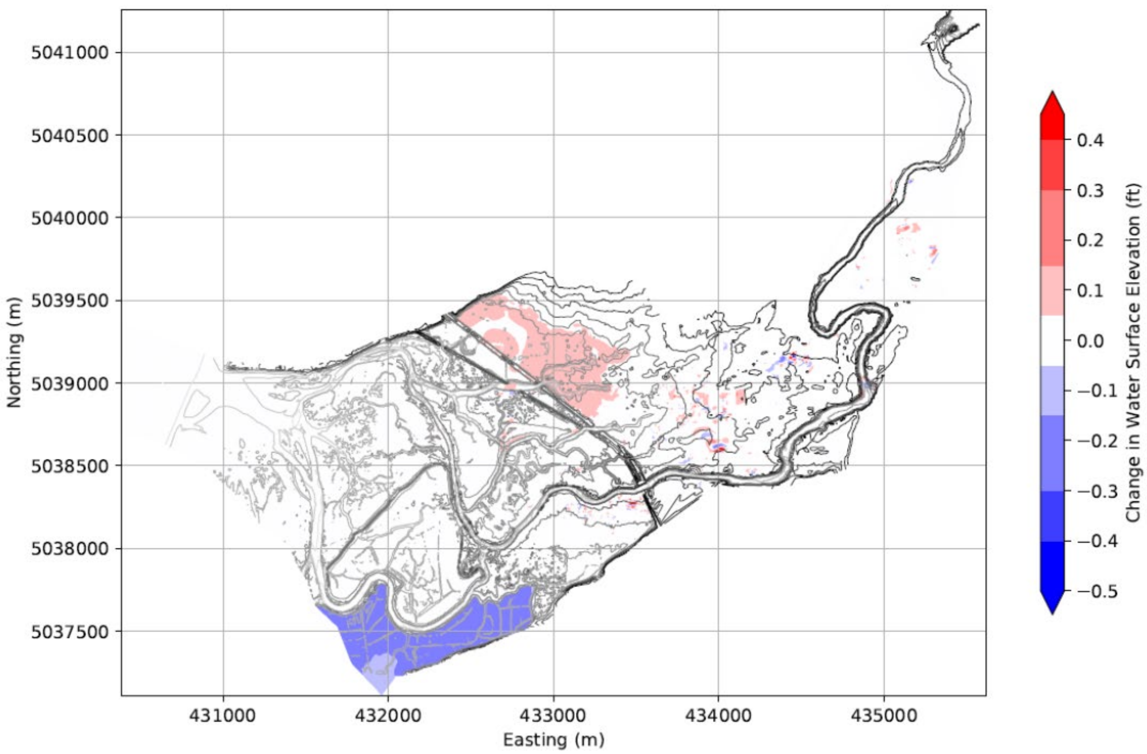


Figure 15: Change in water surface elevation due to Porter project on December 9, 2015, 11:00 (flood peak) from (NHC, 2019)

4) Review and, if needed, propose updates to the model, report and findings associated with Kilchis Porter permit.

The modeling and reporting to date have addressed flood impacts well but have not considered impacts to agricultural drainage during normal flow conditions, which is clearly an area of concern to stakeholders. We recommend consideration of a series of model updates, modeling of new scenarios, and upgrading the existing gage network to better evaluate agricultural drainage. We assume that updated findings and reporting would flow out of this new work.

3.2.3.1 Model Inputs

Geometry and Grid Size

For the Porter model(s), the representation was generally good except for three issues in the Vaughn Creek unit. To the north of the Porter Tract (off TNC lands), there is a dike built across an unnamed slough that conveys at least part of the flow of Vaughn Creek (Figure 16). The dike is not large, and in fact neither LiDAR dataset examined captured it, and since no ground survey was conducted in this area it was not represented in the model (Figure 17). From a hydrologic standpoint, it makes logical sense to build a dike here; otherwise, high tides would routinely flood under Highway 101 and inundate the low-lying areas to the north. Leo Kuntz confirmed the existence of this dike, noting there were two tidegates in it, and he had repaired it several times over the years.

Due to the small opening under the railroad tracks and the 15-foot grid resolution, the model does not capture the true low point of the opening. The LiDAR elevations are around five feet, and the true bottom of channel is probably at least three feet lower, but the model mesh resolution imposes an artificial barrier with an elevation around nine feet in the opening. This is probably two to three feet lower than the true dike elevation at a minimum but does keep out most normal tides from the area to the north.

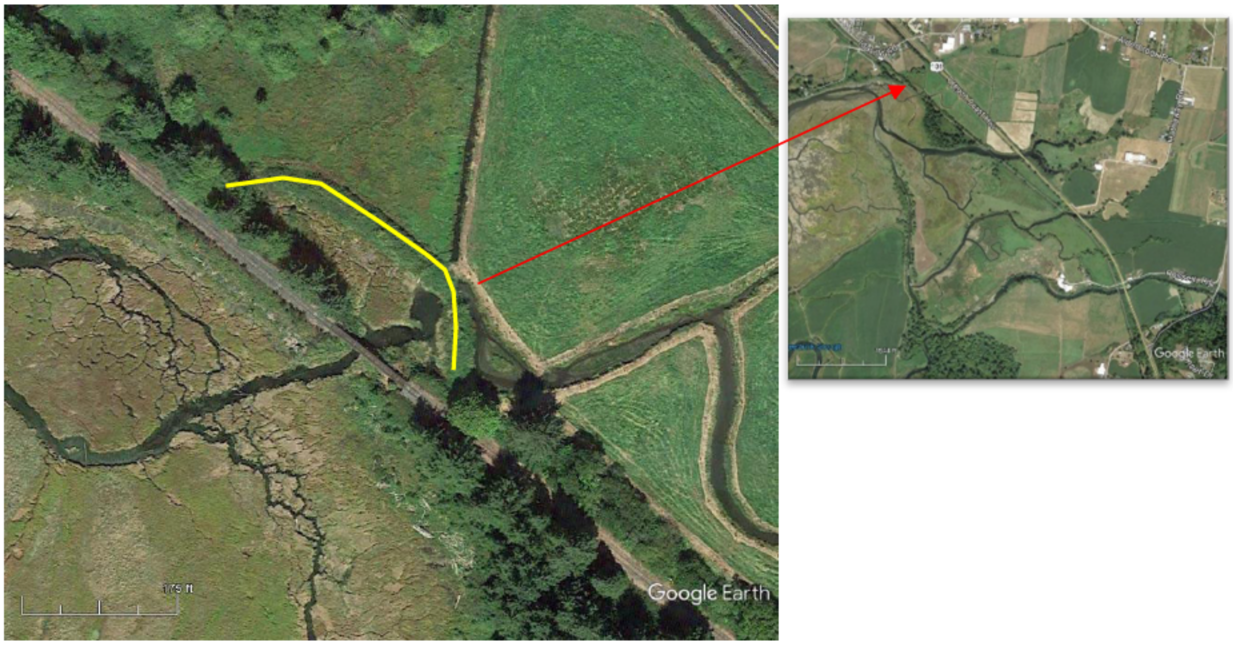


Figure 16: Left - Vaughn Creek Levee - centerline shown in yellow. Right - location on floodplain (August 2016 Google Earth Image)

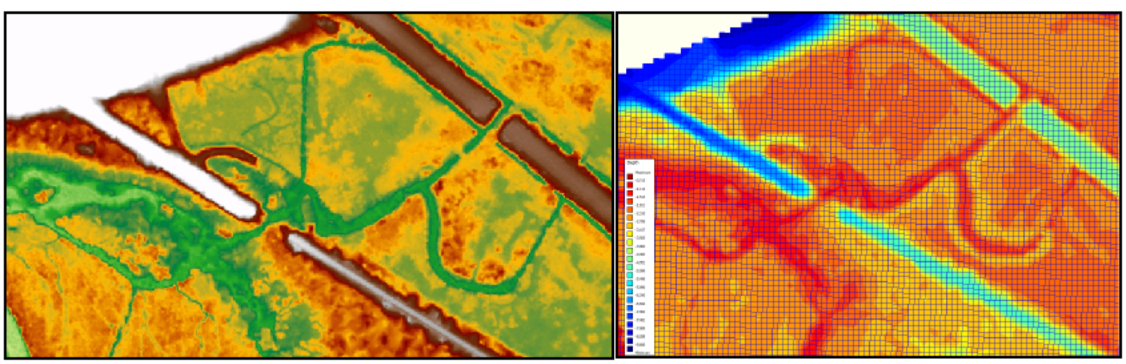


Figure 17: Left - LiDAR image showing apparent gap in levee, Right – model mesh showing same gap

There are two other small openings in Highway 101 in this area that the model probably does not represent well due to their small size and mesh resolution, thereby artificially restricting flow through them during large floods. Accurate accounting for floodplain storage volume in diked ditch networks is an important component for drainage analysis. In the Vaughn Creek unit, most of the volume is contained in a network of small ditches. The current 15-foot grid size of the model is likely too coarse to capture the available storage volume of this ditch network. Either reducing the model grid size or developing an alternate method to accurately capture ditch storage volume should be implemented.

Local Tributary Inflows

The Dooher model report (PWA ESA, 2013) notes a local tributary inflow was included for Hathaway Slough. The report has a flood frequency table that includes 50 cfs as the Hathaway Slough inflow for a 2-year flood event. However, the rest of the report, including sections on calibration, low-flow, and flood simulations, does not document how flows were estimated or used for Hathaway Slough in the model. It is unclear what was included in the assumed tributary area for the Hathaway Slough model input. We applied the USGS StreamStats model (https://streamstats.usgs.gov/ss/) for the total watershed above the railroad including the Vaughn Creek, Hathaway, and Stasek sub basins (Figure 18). The 2.2-square mile watershed generates a 2-year flood flow estimate of 146 cfs; the same source reports for a 17-year gage record on adjacent Patterson Creek (1.9 square miles) the 2-year flood was estimated at 107 cfs. This suggests that total local inflows for the Dooher model may be underestimated. No tributary inflows appear to have been used in any of the Porter Tract models.

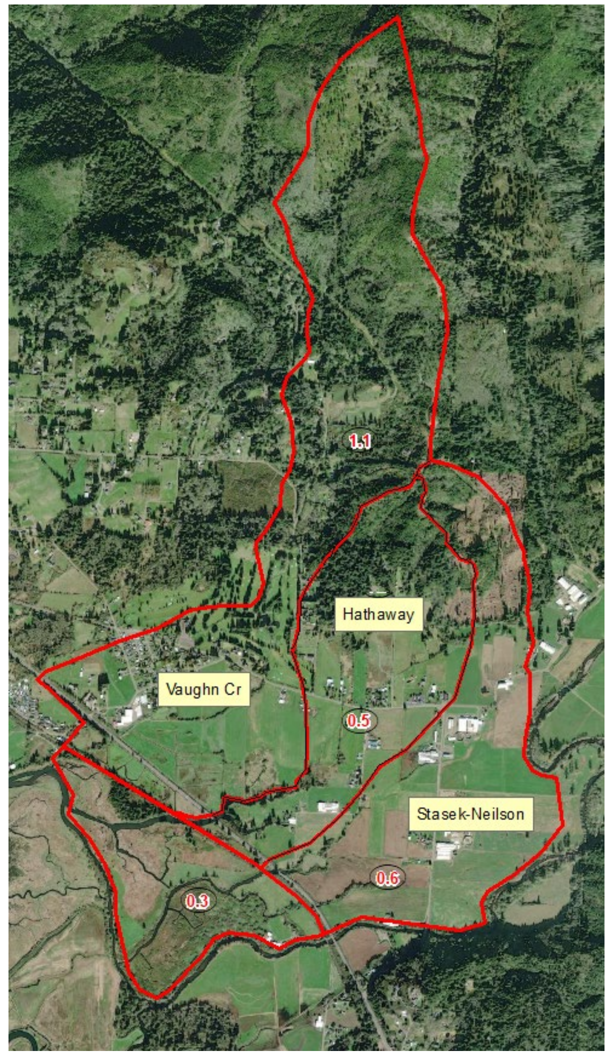


Figure 18: Approximate tributary watersheds

Estimation of local tributary inflows is a key component for a robust drainage analysis. We recommend that flow estimates be developed or measured in the field for the sub-watersheds shown in Figure 18 and applied at appropriate model locations. Summary results from the StreamStats analysis are shown in Table 5. One caution is that subsided areas with significant lengths of dike along tidal channels may have much more inflow from seepage through and under the dike than from hillside tributaries. Vaughn Creek is the hydrologic unit in this area where this might be an issue.

Table 5: Combined tributary flood and median monthly flow estimates

	Flood Flow Estimates											
Return Interval	2	5	10	20	50	100						
Flow (cfs)	147	211	254	311	354	397						
	Median (50% Exceedance) Monthly Flow Estimates											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (cfs)	19.7	17.1	13.2	8.4	5.0	3.3	1.9	1.2	1.1	4.5	10.7	19.5

Culverts and Levees

The only culvert represented in the model is the connector culvert that transfers flow between Stasek and Hathaway Sloughs. For large flood modeling, not including small tidegated culverts is a reasonable assumption: they will be closed during the rising limb and through the peak of the flood, and their conveyance capacity is small compared to overall flood flows when open. However, for hydraulic analysis of normal flows, especially if evaluating potential impacts to adjacent agricultural lands is important, these culverts should be represented in the model. There are believed to be at least four additional tidegated culverts that discharge into Hathaway Slough from the Vaughn Creek unit that should be included. We also recommend checks to the Delft3D culvert flow calculations against some models with better culvert simulation routines such as HEC-RAS or HY-8.

Most of the key levees in the area, both on and off TNC lands, have been surveyed and incorporated into the model. There may be a few additional small levees that need survey and incorporation into the model in the upper Hathaway and Vaughn Creek units.

Roughness

Delft3D models use the Chezy coefficient to represent the frictional resistance to flow caused by the ground. It is intuitive that water can flow with less resistance across smooth surfaces, such as a sand-bedded channel, than rough surfaces, such as a densely vegetated tidal marsh. Most two-dimensional models with both floodplain and channel components use multiple roughness values to classify the land surface, for instance into channel, low grass pasture, tidal marsh, and forest. The Kilchis models all use a single roughness value for the entire model domain. The roughness value used – 53 for the newer models – is appropriate for sand-bedded channels such as the very lower end of the Kilchis, the surrounding sloughs, and Tillamook Bay. It is a very low roughness value to use for a gravel-bed river such as the Kilchis and especially for any floodplain with tall grass, brush, or trees.

Projects can also change surface roughness over time. For the Dooher project, as the site vegetates, floodplain roughness is clearly increasing (Figure 19). None of the reports reviewed mentioned any consideration of modeling changes to site roughness over time.

While the model has reproduced water levels well using a single roughness, we recommend mapping spatially varying roughness parameters onto the model, with consideration of evolved roughness parameters based on planting zones. This will increase confidence in use of them model across a full range of hydrologic conditions.

Figure 19: Dooher project vegetation changes from 2015 (top, Google Earth) to 2020 (bottom, USDA NAIP)

3.2.3.2 Model Simulations

First, we recommend developing a set of new normal flow model simulations. These simulations should include one or more typical steady-state summer and winter river flows with matching local tributary inflows. They should be run for a minimum of two weeks to cover one complete spring-neap tide cycle. Analysis of the model outputs should focus on water levels in the agricultural units. Ideally this new modeling would be calibrated to gage data, including new gages recommended in the next section.

Second, we recommend developing a pre-Dooher project geometry and running all flood and normal flow simulations with this geometry. Developing this geometry should not be too difficult if the pre-project survey data are still available. One of the key uncertainties identified to date is the impact, if any, that the Dooher project had on Hathaway Slough water levels. How important the projected impact from the Porter project is (on the order of tenths of a foot) depends in part on how much this impact builds on the impacts from the Dooher project.

Gaging Network Upgrades

We recommend a series of gage upgrades to remedy some of the issues that limited the usefulness of the data in our analysis. Upgrades and new gages would also increase confidence in model outputs. Specific recommendations include:

- Rebuild all gages that go dry during summer low tides so they no longer do so.
- Strengthen gage installations as needed to minimize potential for shifts or sensor movement.
- Install staff gages and crest stage gages, or other means of independent datum checks, to be performed at each gage download.
- Consider installing new gages on the Kilchis River at Squeedunk Slough, on Squeedunk Slough just downstream of the inlet, at the Stasek Slough outlet to the Kilchis River, and in the Vaughn Creek unit near one of the tidegates.
- Unless needed for ecological purposes, two of the gages in the Stasek Slough network could be removed and used elsewhere.

Note that we discuss some further field data collection options in our response to question 12.

5) If anticipated impacts are identified, what proposed actions could be considered to mediate or mitigate impacts to neighboring farm properties?

We believe it premature to propose actions to mitigate impacts. Repeating what we stated at the beginning: a water level impact does not necessarily equate to a land use impact such as reduced field productivity. This report is focused strictly on water level impacts. Our recommendation is to first complete the proposed updates described in answering Question 4. At the same time, documentation of impacts to agricultural land use could be undertaken. Once both are completed, the stakeholders will have a clear understanding of what and where land use impacts have occurred and have the technical tools needed to develop and evaluate alternatives to mitigate them. Development of mitigation alternatives will need to consider factors beyond technical feasibility; proposing alternatives at this stage based strictly on hydrologic considerations runs the risk of developing solutions that may be unrealistic for multiple reasons.

We do note that the proposed Porter project appears to provide partial mitigation for the water level rises in Stasek Slough caused by the Dooher project. The balancing rise in Hathaway Slough caused by the proposed project is much smaller and presumed less likely to cause land use impacts.

3.3 Additional Review Items

6) Review the "staircase" theory per L. Kuntz 2017 NM memo, and the Kilchis River gradient from Highway 101.

Leo Kuntz's hydraulic analysis of the effects of the Dooher project on area hydrology (Kuntz, 2017) is in agreement with our analysis of observed gage data and model outputs that we presented in answering questions 1 and 2. The 'staircase' theory is a convenient and easily visualized representation of typical tidally influenced river behavior.

In tidally influenced rivers, gradient is always changing even if river flow is constant. The lower the river flow, the greater the tidal influence. As flows increase, they 'fill in' the low tide without affecting high tides very much – these tend to match those in the Bay. Eventually at higher flows and floods, low tides are completely filled in, and water levels begin to push above high tide levels.

Simulated water surface profiles from high, mid, and low tides for different flows are shown in Figure 20. The figure shows high tides in the Kilchis River at Stasek and Hathaway Sloughs are very similar, but Hathaway Slough is one to three feet lower during mid and low tides. This agrees with the observed gage data already discussed (Figure 10). The point made in the Kuntz letter is that better drainage is obtained from connecting to the river at Hathaway Slough, as was the case for Stasek Slough prior to the Dooher project. This is somewhat of a simplification: the connector culvert restricted flow from Stasek to Hathaway prior to the Dooher project, and even without the culvert we would expect some head loss between the two sloughs. Squeedunk Slough also complicates things to some degree. In keeping with the staircase analogy, Squeedunk is another staircase that offers an alternate route to Tillamook Bay. Nevertheless, the basic point made in the letter is borne out by both the observed and modeled data.

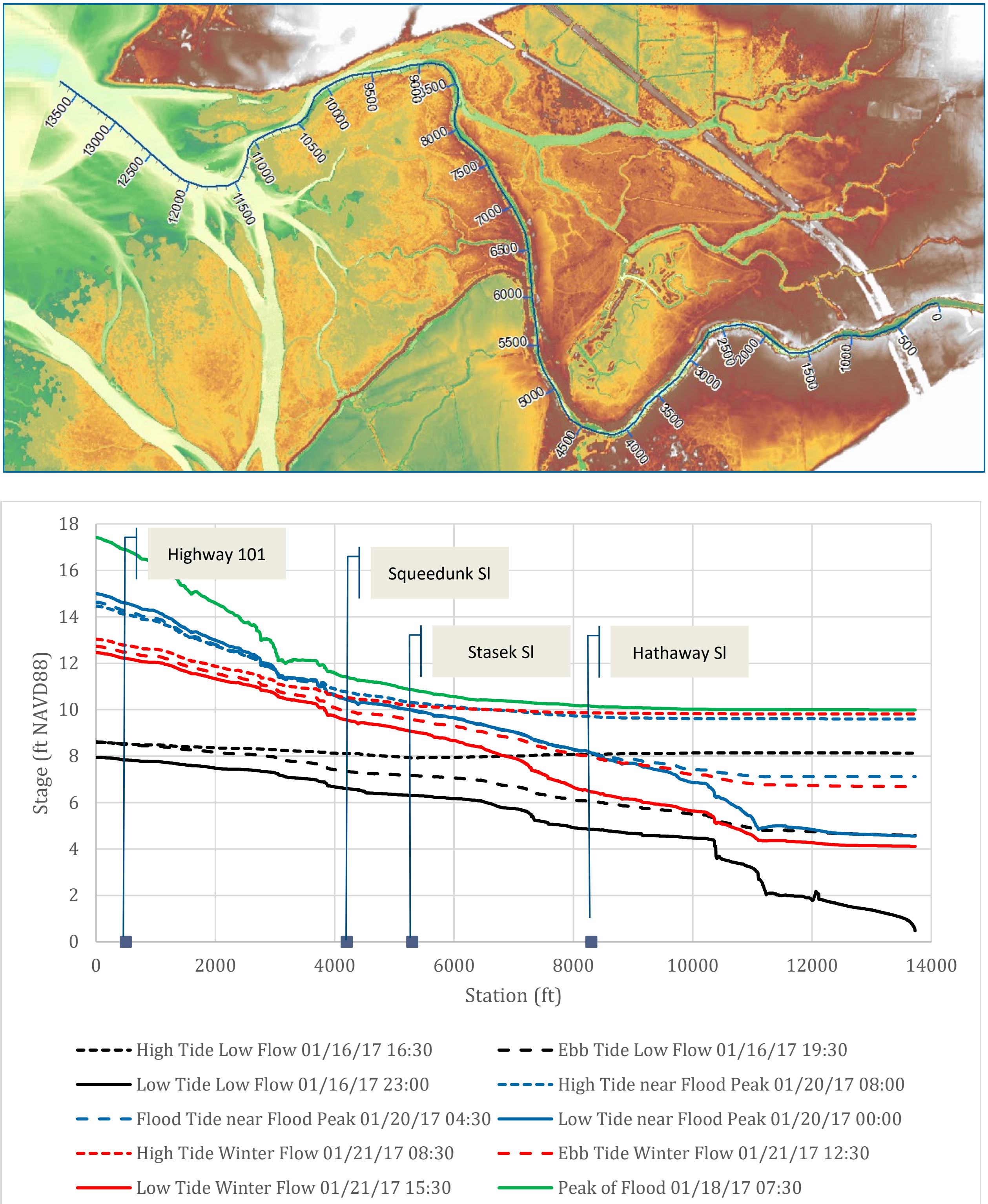


Figure 20: Simulated Kilchis River profiles at various flows and tides

7) Review the flow control function of the existing box culvert on the Porter property and potential effects on drainage and flooding on farm properties adjacent to Hathaway Slough.

The existing box culvert exerts a strong control on water levels in Stasek Slough and regulates flow from Stasek into Hathaway Slough during normal winter flows. In the summer, water levels are more equalized throughout the area and the box culvert appears to have a much smaller effect on water level regulation. The degree of regulation is most evident in the water surface elevation difference between Hathaway and Stasek Sloughs that has already been discussed. Comparison of the Hathaway and Connector Channel (located just downstream of the culvert) gages shows close matches, especially at normal winter flows (i.e., October 19-20, Figure 21), indicating that most of the water surface differential between the Stasek and Hathaway Sloughs occurs at the culvert, rather than being distributed downstream along Porter Slough. This is a strong indication that the culvert is restricting flow.

Under normal flow conditions, the HEC-RAS model predicts flow through the culvert to be about 70 to 100 cfs towards Hathaway Slough. Under low flow conditions, flow reversals of 50 cfs occur on the flood tide (bottom, Figure 22). With higher river flows, reversals are minimal or missing, meaning the culvert is always flowing towards Hathaway Slough regardless of the tide. This flow is drawn in from the Kilchis River via Stasek Slough. The culvert has minimal effect during floods compared to the total flow over the floodplain between the Kilchis River and Highway 101 (top, Figure 22). Another indication of the regulation provided by the culvert is shown by the effects of removing it, as is proposed for the Porter project. We have discussed previously the reduction in stage in Stasek Slough and increase in stages in Hathaway Slough; Figure 22 (bottom) shows how removing the culvert and widening the channel doubles the flow through the cut between Stasek and Hathaway Sloughs during non-flood periods, explaining this effect.

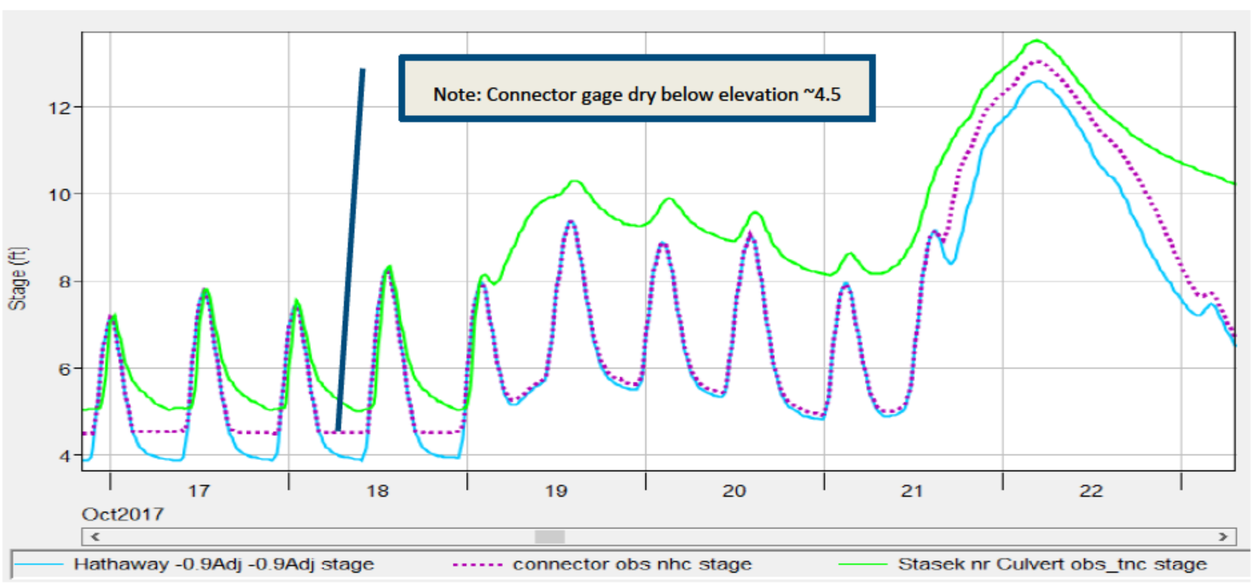
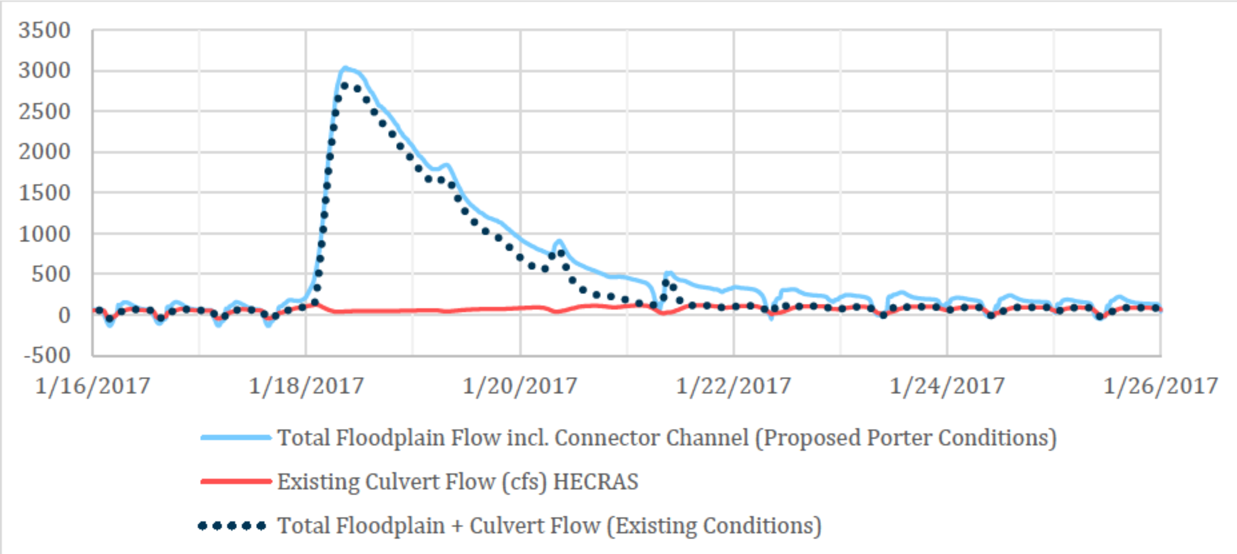


Figure 21: Observed water levels at the Stasek, Connector, and Hathaway Slough gages October 2017



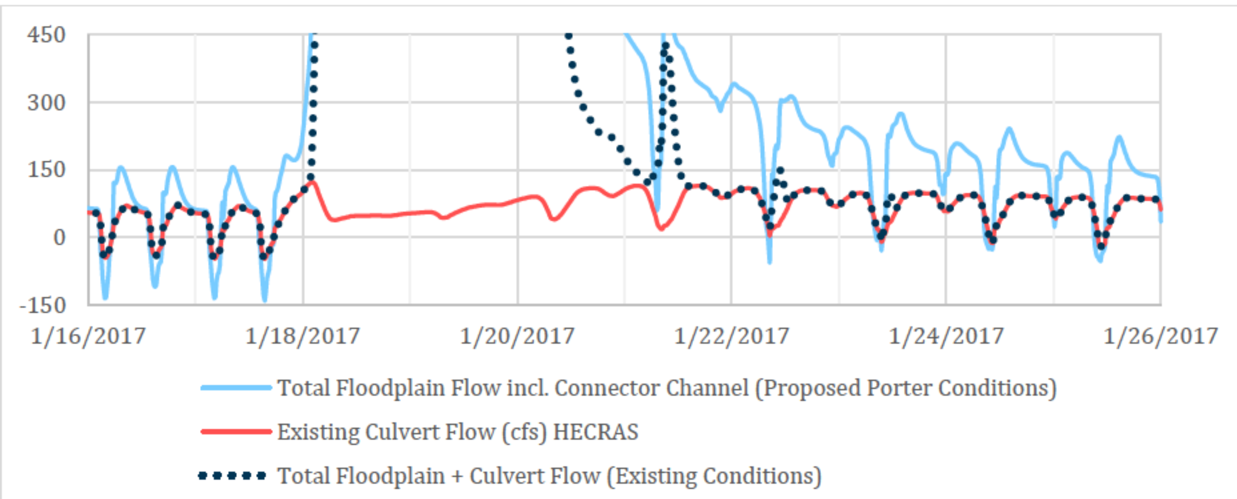


Figure 22: Simulated HEC-RAS flow in connector culvert/channel and total floodplain flow under existing and proposed Porter project conditions. Bottom figure is close-up to show non-flood (contained in channel/culvert) flows.

8) Review Stasek Slough water levels versus Hathaway Slough levels and timing with tides.

Detailed water level comparisons have been discussed in answering Question 1. Timing of tides between all lower Kilchis areas is very close (Figure 5).

9) Analyze effects of proposed Hathaway Slough levee removal.

Analyzing the effects of this element of the proposed Porter project in isolation from the other elements would require additional modeling effort. Our examination of LiDAR, the Dooher design plans, and Porter plans leads us to believe that the Dooher project removed most of the levees that were impediments to flow in the area. Our opinion is that removal of the existing culvert and widening of the

Stasek-Porter Slough connector channel is the most consequential action of the proposed Porter project, and removal of levees probably only has small secondary effects on flood hydraulics. The reasons why the levees proposed for removal as part of the Porter project will not have a significant effect can be seen in Figure 23. The north bank Stasek Slough levee blocks flow, but there are wide expanses of floodplain on either side that the flow already uses. Flow is parallel to the two Hathaway Slough levee removals and both sides are flooded, so these structures do not block the flow in any meaningful way.

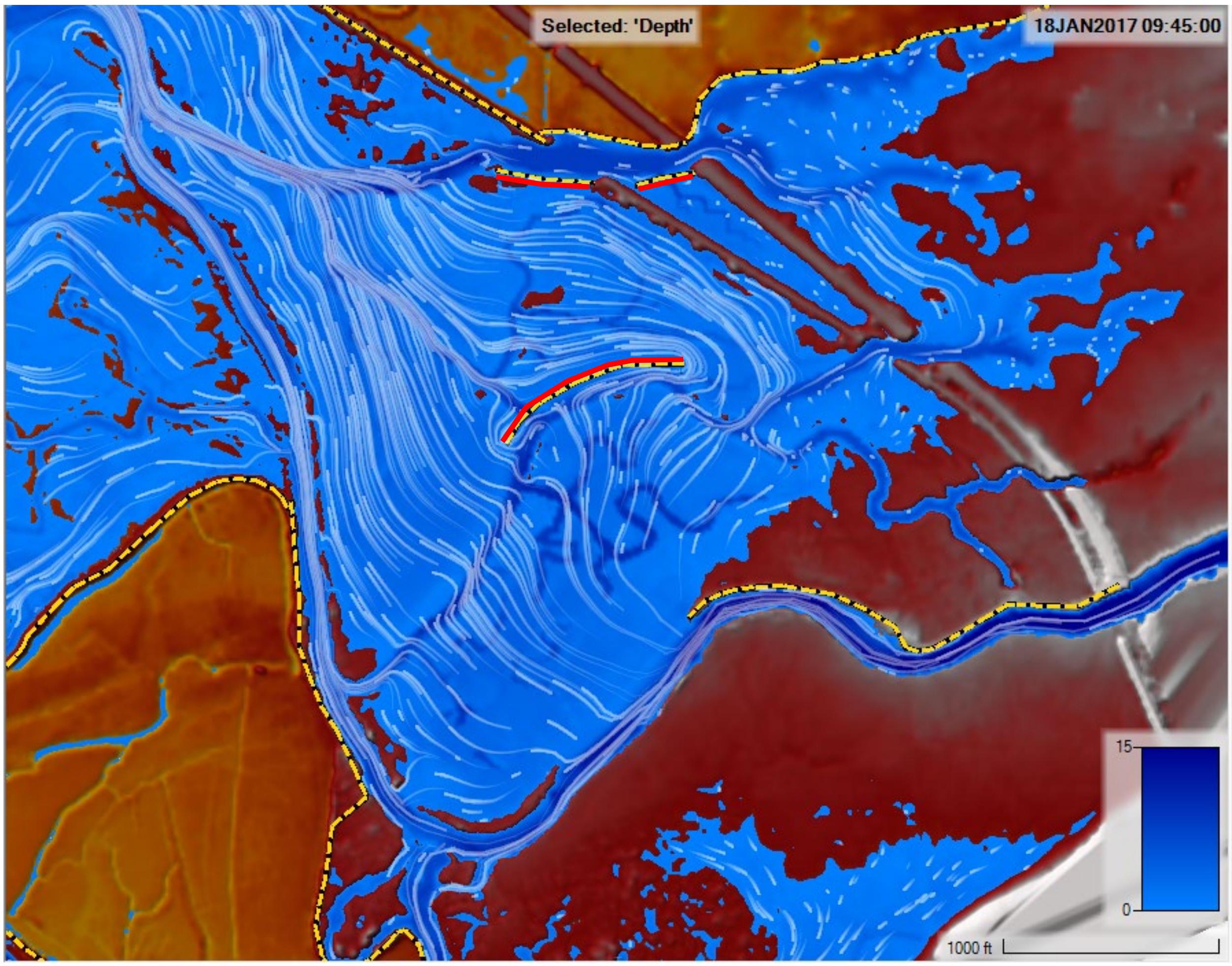


Figure 23: Flowpaths and depths during peak of January 2017 flood from NHC HEC-RAS model. Levees to be removed as part of Porter Project outlined in red.

10) Analyze Dooher levee removal effects on the Kilchis River east of Highway 101.

Our opinion is that the hydraulic models developed for this project are well suited for use in evaluating changes to flood levels throughout the lower Kilchis River valley. These models show decreases (about one to two-tenths of a foot) in flood levels at Highway 101, tapering off to no change by the Alderbrook Road bridge. Upstream of here, the Dooher project has no effect on flood levels. Because even in large floods there is no overtopping of the right bank of the Kilchis between Highway 101 and Alderbrook Road (Figure 24), there is probably no effect from this small reduction on overbank flooding to the north, including the Vaughn Creek, Hathaway, Stasek, and Neilson units. There may be reductions on the order of a tenth of a foot or so in overbank flooding on the south bank between the highway and Alderbrook Road.

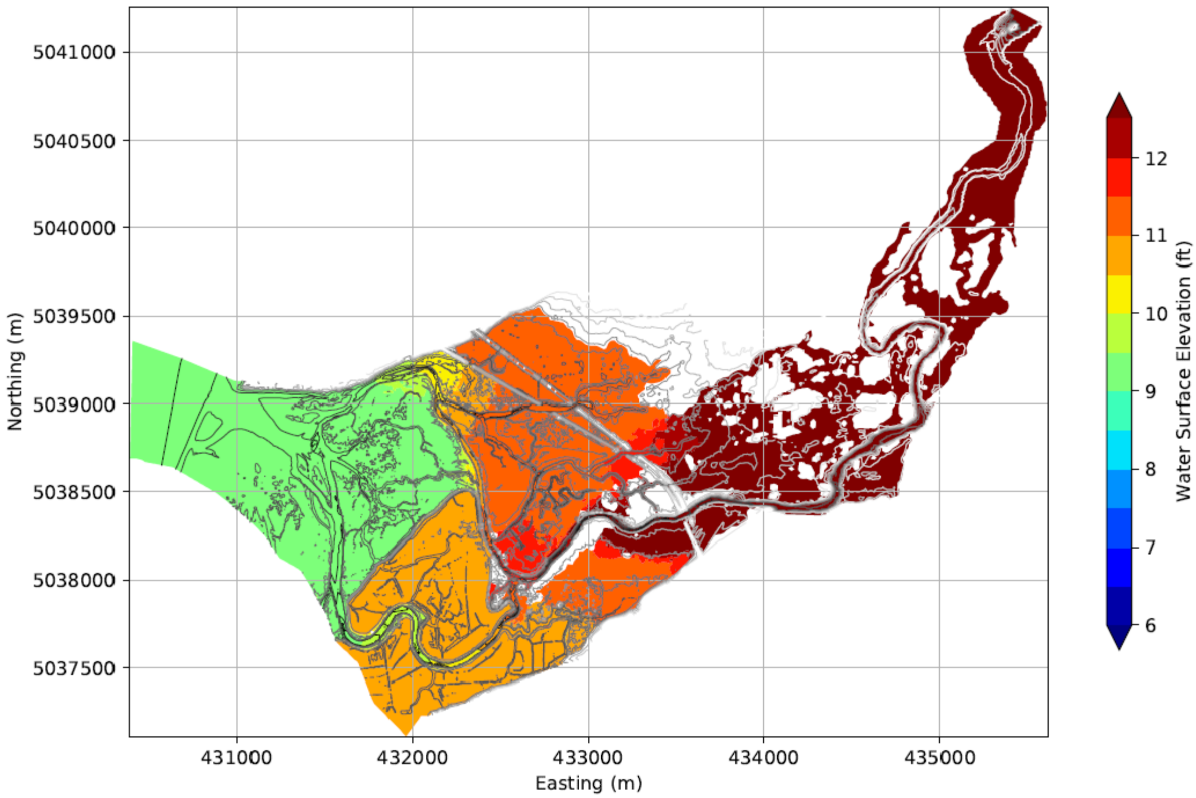


Figure 24: Simulated water surface elevation on December 9, 2015 01:00 - Existing Conditions (from NHC (2019))

11) Review land accretion on former Dooher lands post-2015 TNC project and potential changes.

Land accretion (sedimentation) on the Dooher project site is documented in Behrens (2017). Sedimentation was quantified by comparing a 2015 as-built survey with a re-survey completed in 2017. The Kilchis River thalweg was also re-surveyed. It is important to note that a large flood occurred in December 2015 shortly after project completion. Even without the project, a flood of that size would be expected to mobilize significant amounts of sediment, although the Dooher project clearly affected the distribution of sediment deposition. The following is an edited version from section 2.1 of Behrens (2017) discussing changes on the Dooher site:

> Most of the channel network received at least 1-2 feet of deposition, with Channel 1 receiving up to seven feet of deposition in some areas. Deposition was largest (4-7 feet) at the channel edges…closest to the sections where the Kilchis River levee was lowered….Field observations after the 2015 flood event indicated that two large mounds of gravel up to two-feet thick accumulated at the upstream end of Channel 1, as well as a large mound of fine sediment and organic materials in and near Channel 1b. Changes in the adjacent marsh plain… were smaller, ranging from zero to one feet of deposition in

> most areas.... Sediment also accumulated in Stasek Slough, between its connection with Channel 1 and the confluence with the Kilchis River.... Aerial images available after 2015 indicate that a deltaic structure formed at the breach… the available points suggest deposition of 1-4 feet in Stasek Slough in the vicinity of the inlet to Channel 1 and the breach, and less deposition farther upstream.

This report also documents channel changes in the Kilchis River. Upstream of Squeedunk Slough, where the levee was lowered, changes generally matched predictions given in (Loeb, 2014), with two to four feet of deposition and some scour upstream of that (Figure 6 in Behrens (2017)). Deposition is evident in aerial photos taken before and after the December 2015 flood (Figure 25).

Multiple model simulations have been completed to evaluate the effects of changes to in-channel bed elevations. It is unclear if the updated modeling included observed floodplain accretion, but we consider that to be of minor importance compared to in-channel changes. The observed channel sedimentation patterns have been consistent with those predicted in Loeb (2014). Given the good calibration of the various hydraulic models to floods, we believe the overall impacts on flood levels caused by the observed changes to the riverbed to date have been accurately characterized. With the observed bed sedimentation in the area of the Dooher levee removal, the reduction in peak water levels in the Kilchis River is less but still lower than pre-project conditions. Effects of channel sedimentation and scour on water levels in the Dooher and Porter Tract properties and agricultural lands to the north are generally a tenth of a foot or less. In summary, the hydraulic effects of the Dooher project and proposed Porter Tract project are fairly insensitive to changes in Kilchis River bed levels, at least to the magnitudes that have been observed since 2012.

Figure 25: Kilchis River in October 2015 and August 2016 (photo Google Earth)

1. Photos taken during low tide, estimated 25 cfs river flow both periods.
2. Red arrows indicate areas of deposition due to December 2015 flood and Dooher Project
3. Note channel spanning bars downstream of both Squeedunk Slough and Stasek Slough

12) Analyze flooding and changes to subsurface water levels in adjacent farming properties, as well as the attributions of identified changes. Specifically, does the information currently available allow site specific subsurface water analysis? If yes, how was this analysis conducted? If no, what data is needed to conduct such an analysis?

Please refer to the previous discussion on agricultural drainage analysis. We believe the data and models developed to date are not sufficient to answer this question. All the work to date has also been strictly related to surface water. However, in this setting, subsurface water levels in adjacent farming properties should generally correlate with water levels in surrounding ditches, channels, and sloughs.

For higher elevation undiked lands (such as those around the eastern portion of the Stasek unit), average water levels would be expected to correlate best with groundwater levels. In lower diked areas, low tide levels are the most critical in determining drainage functionality – in many cases drainage only occurs during a few hours over the low tide.

One option to help evaluate this question would be to augment the existing surface water gage network with additional shallow groundwater piezometers. This would allow mapping of groundwater gradients, identification of areas with significant groundwater-surface water exchange, and estimation of soil permeability based on attenuation of tidal signature compared to nearby surface water gages. A key component of this would be rebuilding most of the existing surface water gages to ensure they do not go dry on low tides (see Question 4). Knowing whether any drain tile has been installed within the area would also be important. The most complete evaluation would involve numerical modeling of the coupled surface water-groundwater system. MODFLOW is the most common model in use for this application. Acquisition of observed shallow groundwater data would still be critical to allow calibration and validation of the model. The advantage of having a validated numerical groundwater model is that, in the same way as the surface water hydraulic models, proposed actions can be evaluated for potential impacts prior to implementation. Should further analysis of subsurface water levels be desired, we recommend engaging a hydrogeologist.

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APPENDIX A

2014 STASEK SLOUGH WATER LEVEL DATA PROCESSING

TNC provided raw water level logger data for the Stasek Slough gage from February 18 to November 22, 2014, before the Dooher project was completed. At this time, Stasek Slough was connected to Hathaway Slough through the connector culvert but was otherwise diked off from tidal influence. The logger data was recorded as absolute pressure. No datum conversion was available. The following describes NHC's processing of the data to convert it to NAVD88 water levels.

The first step was to convert the data to water depth. This was accomplished by subtracting barometric pressure obtained from the NOAA Garibaldi gage for the period of record, creating a water depth data set. Minimum depths recorded were about 0.15 feet, and no indication of the gage going dry is evident in the low tide data. Standard practice would then be to apply a datum corrector to adjust the water depths to water levels on NAVD88 vertical datum. Because no datum corrector was available for this dataset, we were required to estimate the corrector using indirect methods. With these methods, we were able to put bounds on the possible ranges and estimate the most likely datum corrector.

The upper bound datum corrector relies on the fact that under normal river flows, all bayside gages in upper Tillamook Bay have very similar high tides to those at Garibaldi when using a consistent NAVD88 datum. This has held true when comparing gage data collected by the Corps of Engineers, Institute for Applied Ecology, NHC, Tillamook Estuaries Partnership, and TNC since the late 1990s. There is no physically plausible reason why Stasek Slough would have higher high tides than gages outside the dike system under normal river flows. Therefore, the upper bound for Stasek Slough data is that it should not exceed the matching high tides observed at Garibaldi.

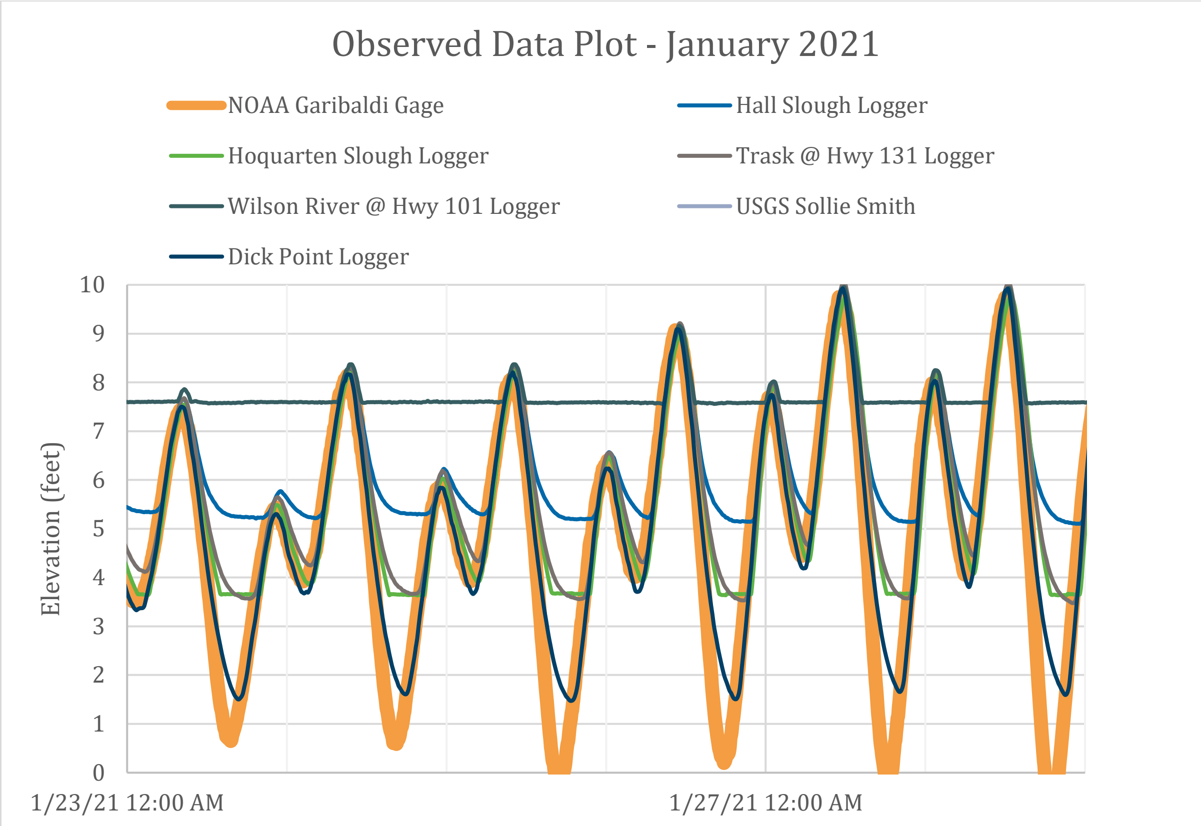

Figure A-1: Upper Tillamook Bay water levels from TEP gages showing all high tides matching Garibaldi high tides. The same holds true for TNC gages on the Kilchis River outside the dikes.

The lower bound on the dataset relies on the fact that Stasek Slough drains to Hathaway Slough, where TNC has operated a gage both pre- and post-Dooher project. Across the years of data available, low tides at this gage have consistently bottomed out at around elevation 4 during low river flows. Stasek Slough should never get lower than Hathaway Slough; therefore, the lower bound on Stasek Slough water levels is that low tides should not fall below elevation 4.

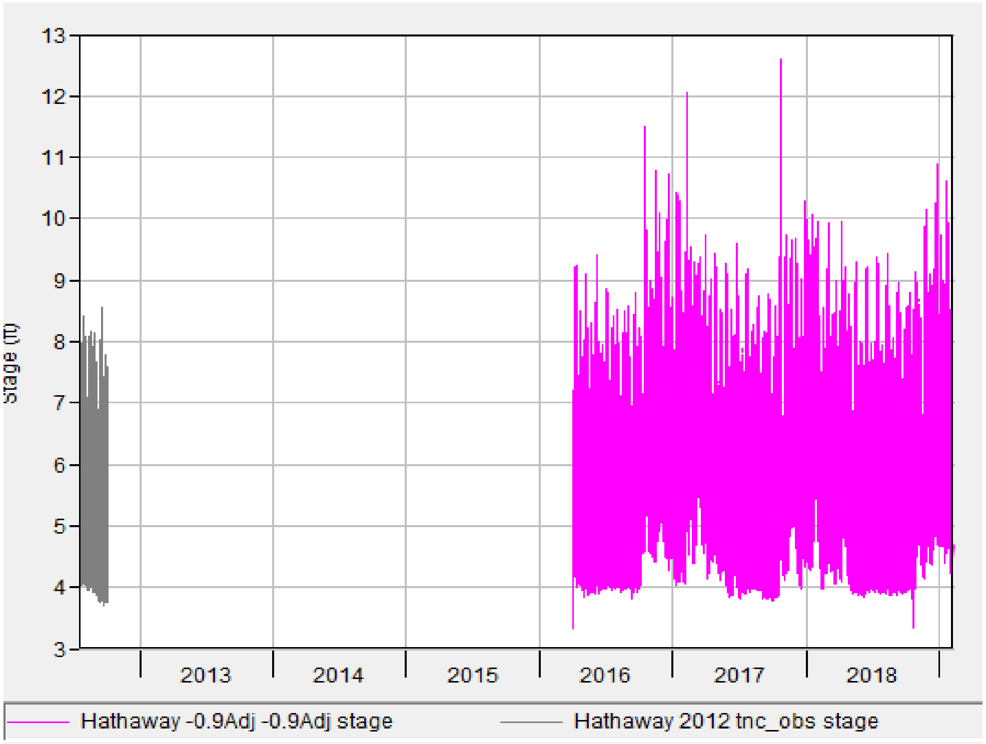

Figure A-2: TNC Hathaway Slough observed data showing lower limits are around elevation 4 for both pre- and post-Dooher project datasets.

The 'most likely' water levels were determined using hydraulic modeling. A coarse HEC-RAS model of pre-Dooher project conditions was created with the dikes in place and the connector culvert between Stasek and Hathaway Sloughs. Two periods were run: the first two weeks of March 2014 and July 2014. The March simulation had a small flood event and higher baseflows. Kilchis River inflows for the model were scaled directly from Wilson River USGS gage records using a 0.45 factor. The July simulation used a constant 100 cfs inflow for the river representing summer low flows. Downstream boundary conditions for both simulations were observed Garibaldi tides. The optimal datum corrector was determined by adjusting the corrector until it best matched the high and low tides and amplitude of the simulated water levels at the gage site. Priority was given to matching the July simulations when there is much less uncertainty introduced by effects of river and tributary flows. A constraint on this corrector was that it had to fall in between the upper and lower bound correctors.

The end result was datum correctors ranging from 3.7 feet on the low end to 4.9 feet on the high end, a range of 1.2 feet. The most likely value was determined to be 4.05 feet. Due to the uncertainties inherent with this methodology, all three datasets (upper bound, lower bound, and most likely) are shown on report plots whenever Stasek Slough 2014 data is utilized. An example of the results for July 2014 is shown below.

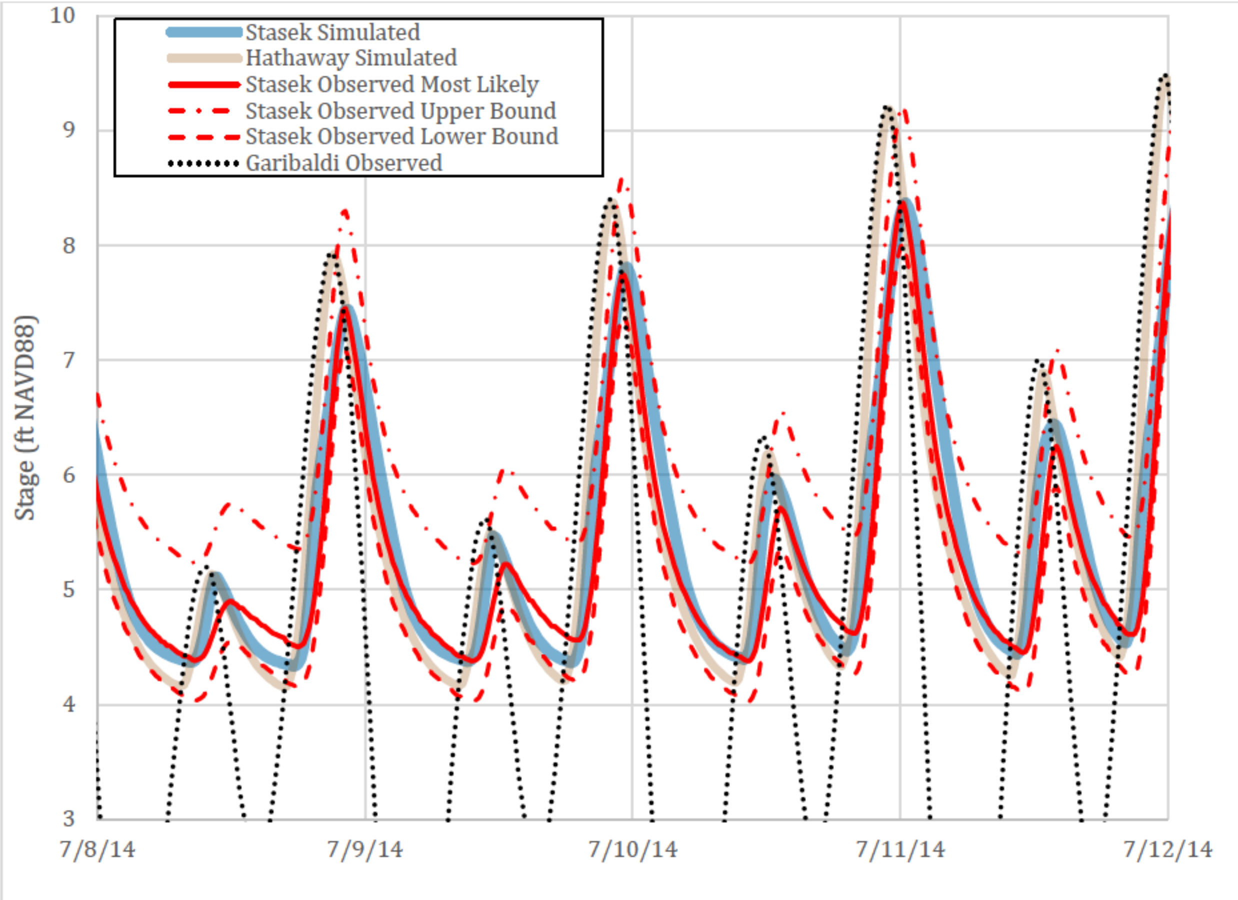

Figure A-3: Sample of observed and simulated data used to develop Stasek Slough 2014 datum correctors.

Figure Notes:

1. Most likely corrector selected by adjusting most likely observed line to match Stasek simulated data.
2. Note tidal muting caused by connector culvert evident in the higher highs and lower highs and earlier high tide for Hathaway Slough versus Stasek Slough (simulated data).