SOUTHERN FLOW CORRIDOR
PROJECT IMPACTS ON SEDIMENT TRANSPORT

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EXECUTIVE SUMMARY

The impact of the Southern Flow Corridor project on the current sediment transport regime for the lower Tillamook, Trask, and Wilson Rivers has been analyzed. Levee removal will alter the total transport rates by diverting some flows and suspended sediments out of the channels and into the newly reconnected floodplain areas. The potential for aggradation in the main river channels and sloughs due to the project was identified as the primary process that required detailed evaluation. Changes to channel form due to the project were evaluated for a range of riverine flood conditions and a low-flow, tidally influenced condition.

The Tillamook Bay reaches are formed through a combination of riverine and tidal processes. Closer to the Bay, the tidal forces will be dominant in shaping the channel form while further from the Bay, riverine processes are more likely to dominate. Both processes were examined and their relative influence examined across each reach. For the flood evaluation two methods were used. Both methods evaluated 1 mm sand as the most representative size of sediment in the lower rivers. Outputs from the HEC-RAS model at the peak water level for the 2001 (1.5-yr), 1999 (5-yr), 2007 (22-yr), and 100-yr floods were used in both methods. The first method calculated the excess shear stress for 1 mm sand at each cross section. In the second method, the sediment transport capacity was estimated along each reach using the Engelund-Hansen equation. The relative changes in excess shear stress and sediment transport capacity were compared to evaluate how the project will impact riverine flood flows and processes in each reach. Changes in the tidal prism were examined as an indication of expected channel morphology changes between pre- and post-project conditions due to tides under low river flow conditions.

The results of the riverine flood and tidal analyses were combined and each reach categorized according to its dominant channel forming process and predicted change under with-project conditions. Lower Hall Slough is predicted to have less sediment transport capacity in the long term, mainly due to the spilling of flows into Blind Slough under with-project conditions.

The rest of the reaches are predicted to have neutral or increasing sediment transport capacity. This is attributed to two factors. In the upper reaches, the project generally results in increased in-stream velocities and hence shear stresses by the removal of impediments to flows. In the lower reaches, shear stresses during floods can be lower, but the channels are mostly tidal dominated, so this reduction does not affect long-term channel form. Under low-flow conditions, the project generally has small effects, with the notable exception of Blind Slough, which is expected to undergo significant expansion.

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1 INTRODUCTION

The Southern Flow Corridor project proposes to remove 7 miles of levee and reconnect over 400 acres of floodplain to the adjacent river channels and sloughs. The removal of the levees will provide flood level reductions across most of the lower Wilson, Trask, and Tillamook river floodplains. The project will change the distribution of flood flows between the rivers, sloughs and floodplain, which may lead to changes in the morphology of the channel network. In addition, floodplain reconnection will increase tidal exchange during low river flows, which can also lead to changes in channel form. Deposition of sediment on the beds of the rivers and sloughs is the primary concern, as this could lead to less flood level reduction benefits from the project. Northwest Hydraulic Consultants (NHC) evaluated sediment transport regimes in the rivers and sloughs draining into the south end of Tillamook Bay to address this issue. The evaluation considered both flood and low flow, tidally dominated conditions.

1.1 Sediment Sources and Size

While there is little direct sediment data from the rivers in the project area, studies on sediments in Tillamook Bay provided information used in this analysis. The major sediment sources contributing to the Bay have been identified through sediment core analysis (McManus et al., 1998). Marine derived sands comprise 60% of the sediment, and the remaining 40% is sand and finer sized material from the rivers (Komar et al., 2004). Sediment samples were dominated by fine sands (0.125 to 0.250 mm in diameter) and finer sized sediments (McManus et al., 1998). A few larger sediment sizes between 1 to 3 inches were found in samples from the upper areas of the Wilson River and Hall Slough, but were limited to less than 10% of the measured sediment samples and not found elsewhere in the system (Pearson, 2002).

2 SEDIMENT TRANSPORT DURING FLOODS

The Southern Flow Corridor project proposes removing extensive lengths of levees. Upon removal of these levees, water and sediment will be able to flow out of the river and into the reconnected floodplain area. The floodplain is expected to accrete as fine sediments settle out of the water column and deposit. Larger sediment sizes will remain within the river channel area to deposit on and scour from the river bed with varying flow rates. This analysis determines the ability of channel flows to mobilize and transport these sediments based on the shear stresses acting on the bed material.

2.1 Methods

The analysis applied two different methods to evaluate project impacts on in-channel sediment transport characteristics during floods: The Excess Shear Stress Approach and the Engelund-Hansen Sediment Transport Capacity model. In both cases, the relative change in calculated values is the parameter of interest. There is greater certainty about the computed relative change than the values of sediment transport under the pre- and post-project conditions.

2.1.1 Excess Shear Stress Approach

The ability of a sediment particle to move is dependent on the shear stresses acting on that particle being greater than the minimum shear stress required to initiate movement. When the shear stress exerted by the flow is in excess of the critical shear stress, those grains may be mobilized. The amount of shear stress in excess of critical provides an indication of the amount of sediment that may be moved and a method for evaluating the potential project impacts with respect to sediment transport rate. Excess shear stress values were calculated for the channel network using before and after project hydraulic modeling results. The change in excess shear stress due to the project provides an indication of the expected change in sediment transport capacity.

2.1.2 Engelund-Hansen Sediment Transport Capacity Method

The Engelund-Hansen model (1967) predicts the maximum amount of sediment transport possible for a given flow condition. It was developed for rivers with predominantly sand bed and substantial amounts of suspended sediment. An assumption within the model is that there is an unlimited supply of sediment available in the channel. Therefore, it is possible for the actual transport to be less than the model prediction where the supply is limited. The original model was developed from physical modeling of sediments in the range of 0.58-1.41 mm, and has since been extensively tested against a large range of grain sizes and field data (e.g. Andrews, 1986; Lanzoni and Seminara, 2002; Struiksma et al., 1985; Van Leeuwen et al., 2003; Wu, 2004). As with the excess shear stress approach, pre- and post-project sediment transport capacities were calculated and the difference between the two used to evaluate potential changes to the channel system.

2.1.3 Sediment size evaluated

Sediment transport was evaluated for 1 mm (0.04 inch) size particles. While larger than the typical 0.125 to 0.25mm sands found in the Bay, this size particle accounts for the upstream coarsening of sediment that is common in rivers, and is somewhat conservative, as larger particles have higher critical shear stresses.

2.1.4 Floods evaluated and use of the HEC-RAS model

The analysis used simulation results from the four floods that were used to determine flood reduction benefits of the Southern Flow Corridor project. Table 1 shows the four floods, with their approximate return interval, that were simulated to address the range of flows. Three of these are based on hydraulic model simulations of actual floods that occurred in 1999, 2001, and 2007. The 100-year flood uses a synthetic hydrograph based on statistical analysis of peak flows on the Wilson and Trask Rivers. All simulations were conducted in unsteady flow mode, with flow hydrographs input for rivers and tributaries, and tides at Garibaldi used for the lower boundary condition. Simulating this unsteady flow condition, versus steady state where only a single constant flow is evaluated, is important in a sediment transport analysis as it provides a better representation of the natural system and the gradients in water depth and friction slope that are responsible for generating sediment movement.

Table 1: Floods simulated

Recurrence Interval	Flood Year
1.5-yr flow	2001
6-yr flow	1999
22-yr flow	2007
100-year flow	Synthetic

Simulation results of the main river channels and sloughs were extracted from the hydraulic model for pre- and post-project conditions during the four floods. The analysis area extends from Highway 101 in the east, and Highway 131 to the south, downstream to the Bay (Figure 1). Upstream of the two highways changes to hydraulic conditions due to the project, and hence sediment transport changes, are minimal and were not analyzed.

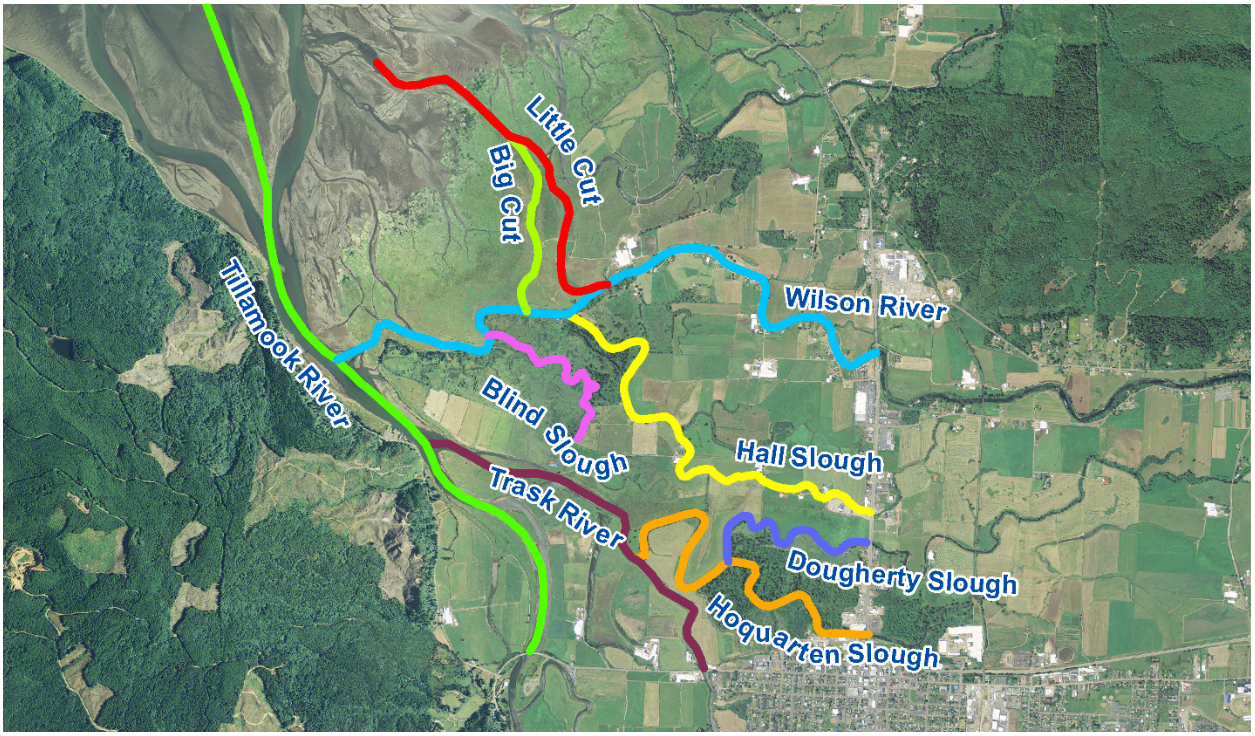

Figure 1: Rivers and sloughs analyzed for riverine flooding

For each reach and flow scenario, required hydraulic variables were extracted from the HEC-RAS model at the time of maximum flow depth (i.e. maximum flood level). However, due to the complex riverine-tidal interactions that occur during floods, the maximum shear stress may not occur during the maximum flow depth. The closer to the Bay the more likely this is the case, as is exemplified by the computed sediment transport rate over a single ebb tide near the downstream end of Wilson River (Figure 2). Transport has a looped hysteresis curve, with the transport rate increasing quickly on the rising limb of the flow and then decreasing slowly. The peak transport rate occurs on the falling limb, just after the peak flow rate. The consequence of underestimating the maximum shear stress is that the calculated sediment transport capacities are lower than the maximum possible for a given flood. However, a review of the hydraulic modeling results showed that the relative change in shear stress between existing and with-project conditions remained the same whether the time of maximum depth or maximum shear stress was used. Therefore, results from maximum flow depths were deemed appropriate for use.

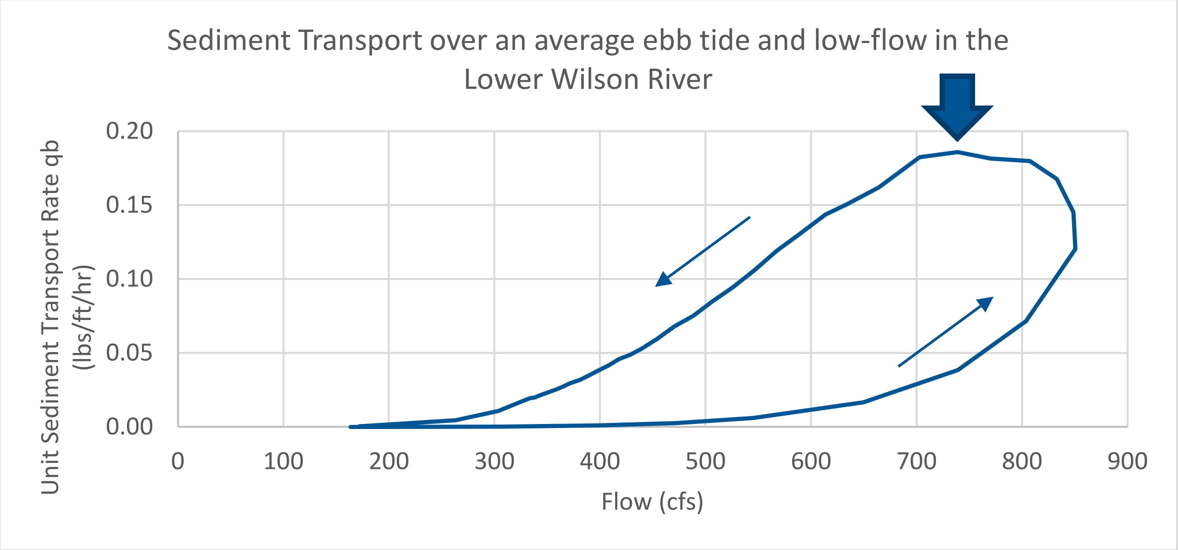

Figure 2: Example of hysteresis in sediment transport rate (large arrow indicates approximate point of maximum transport rate)

2.2 Results

This section first presents results graphically, by reach, of the computed excess shear stress difference and maximum transport rates for pre- and post-project conditions. A narrative summary by reach is given following the figures. For the excess shear approach, the change in shear stress for all four floods are shown. This is the difference in excess shear stress between pre- and post-project conditions. Negative numbers indicate areas where shear stress, and therefore sediment transport capacity, has decreased due to the project. Using the Engelund-Hansen method, sediment transport capacity results are shown for both the pre- and post-project condition. Degradation may occur when the simulated post-project rate is greater than the pre-project rate, and aggradation when the post-project is less. Analysis showed that sediment transport rates modeled for the 2007 (22-year) flow were similar to those for the 100-year flood, and the results for the 2001 (1.5-year) flow were similar to those for the 1999 (6-year) flow, thus for clarity results are shown for only two events.

Note that in some figures, the downstream-connected reaches are also shown. For instance, the Wilson River figures shown the entire reach from Highway 101 downstream to the Bay; however, the Hall Slough figures show the slough and then also the Wilson River downstream of the confluence. This allows visualization of reach wide changes that are anticipated to occur.

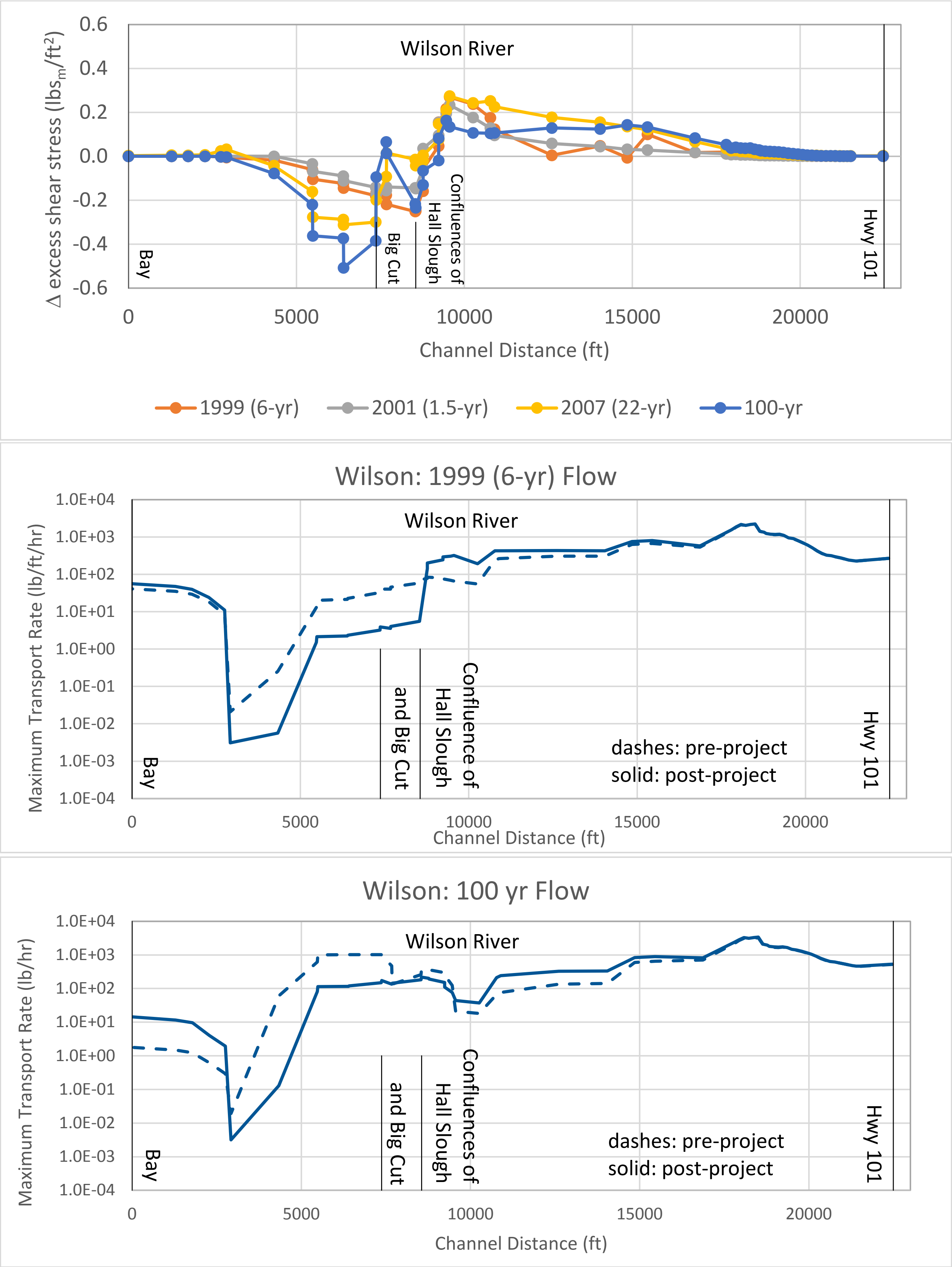

Figure 3: Wilson River excess shear and sediment transport capacity

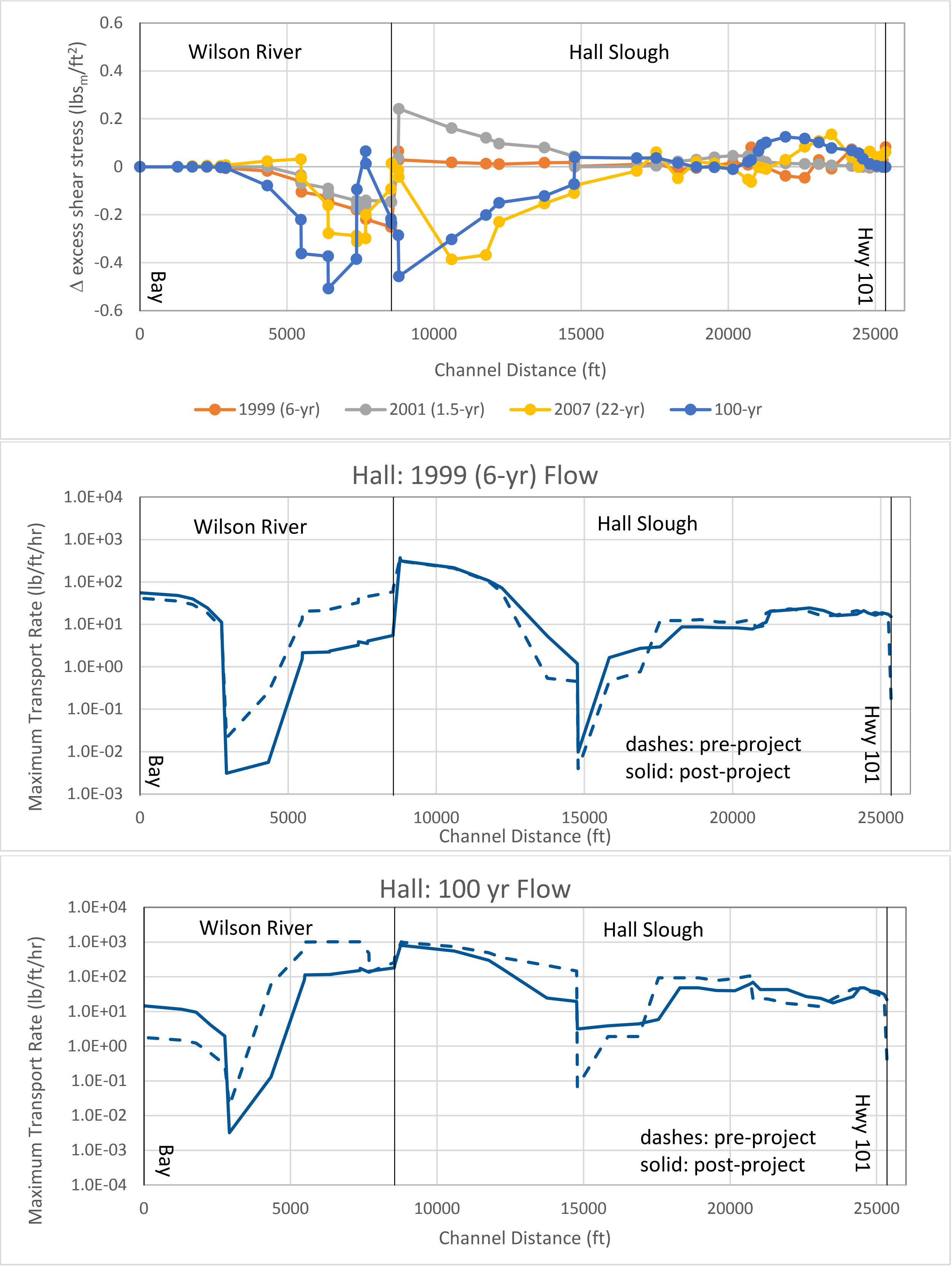

Figure 4: Hall Slough excess shear and sediment transport capacity

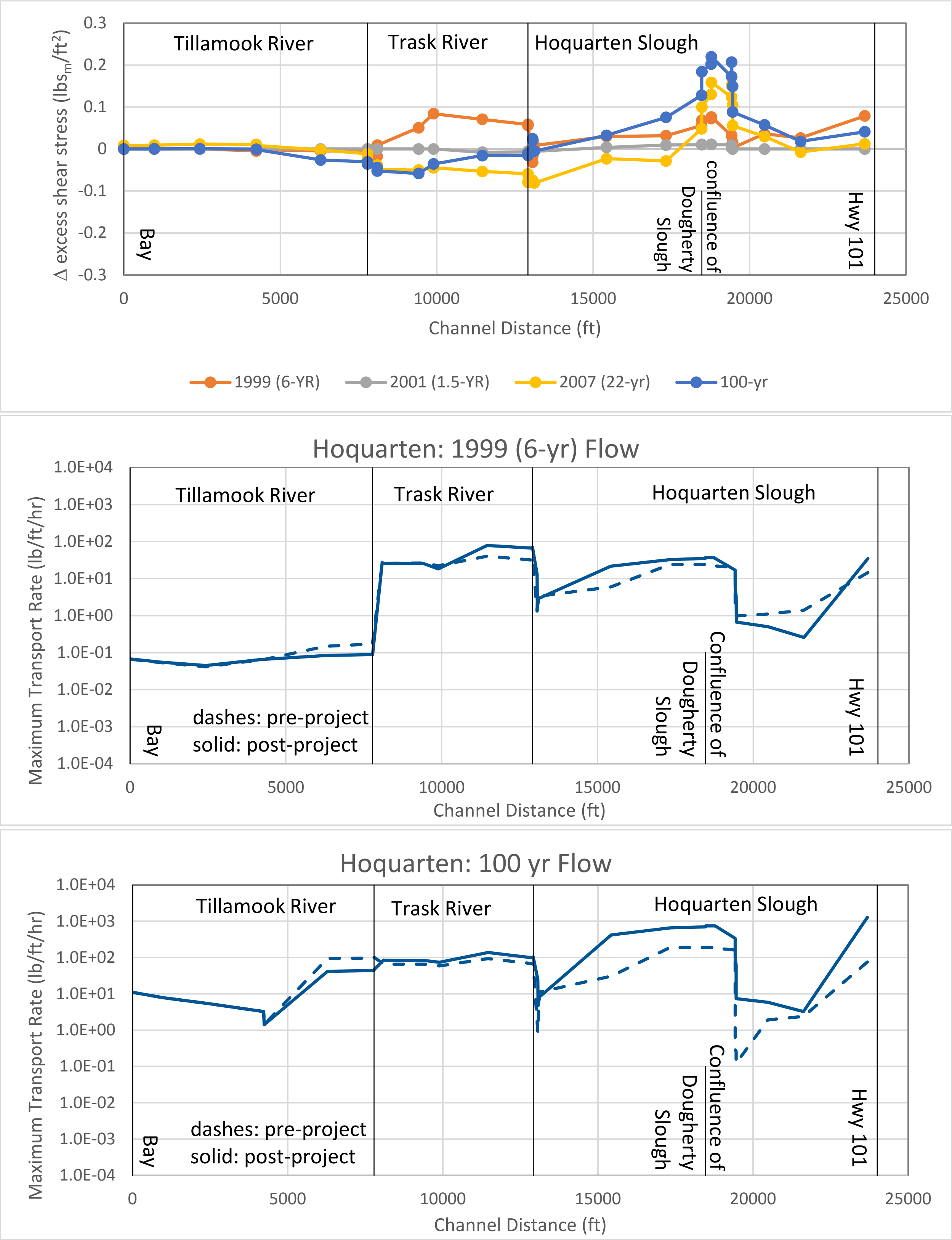

Figure 5: Hoquarten Slough excess shear and sediment transport capacity

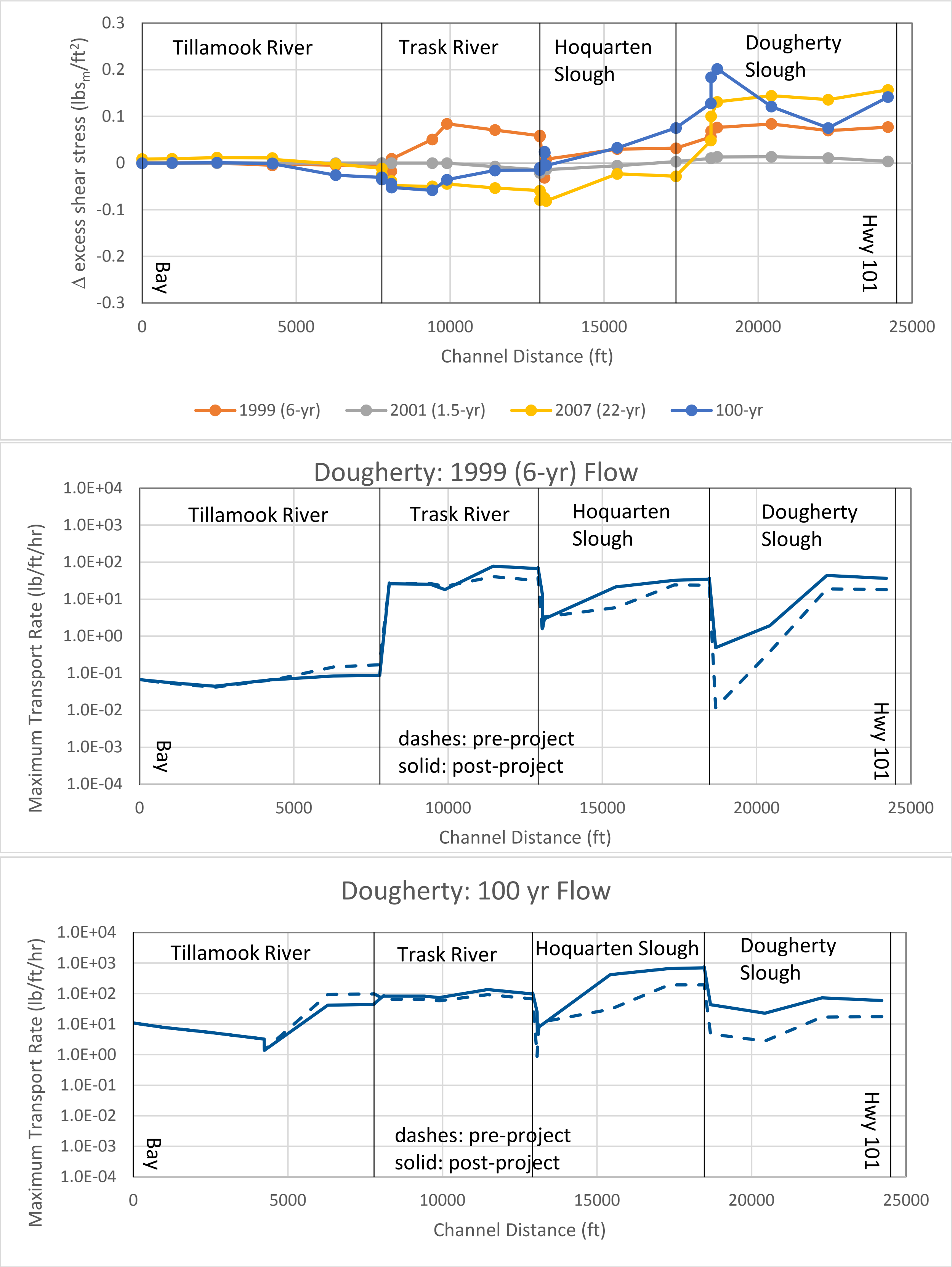

Figure 6: Dougherty Slough excess shear and sediment transport capacity

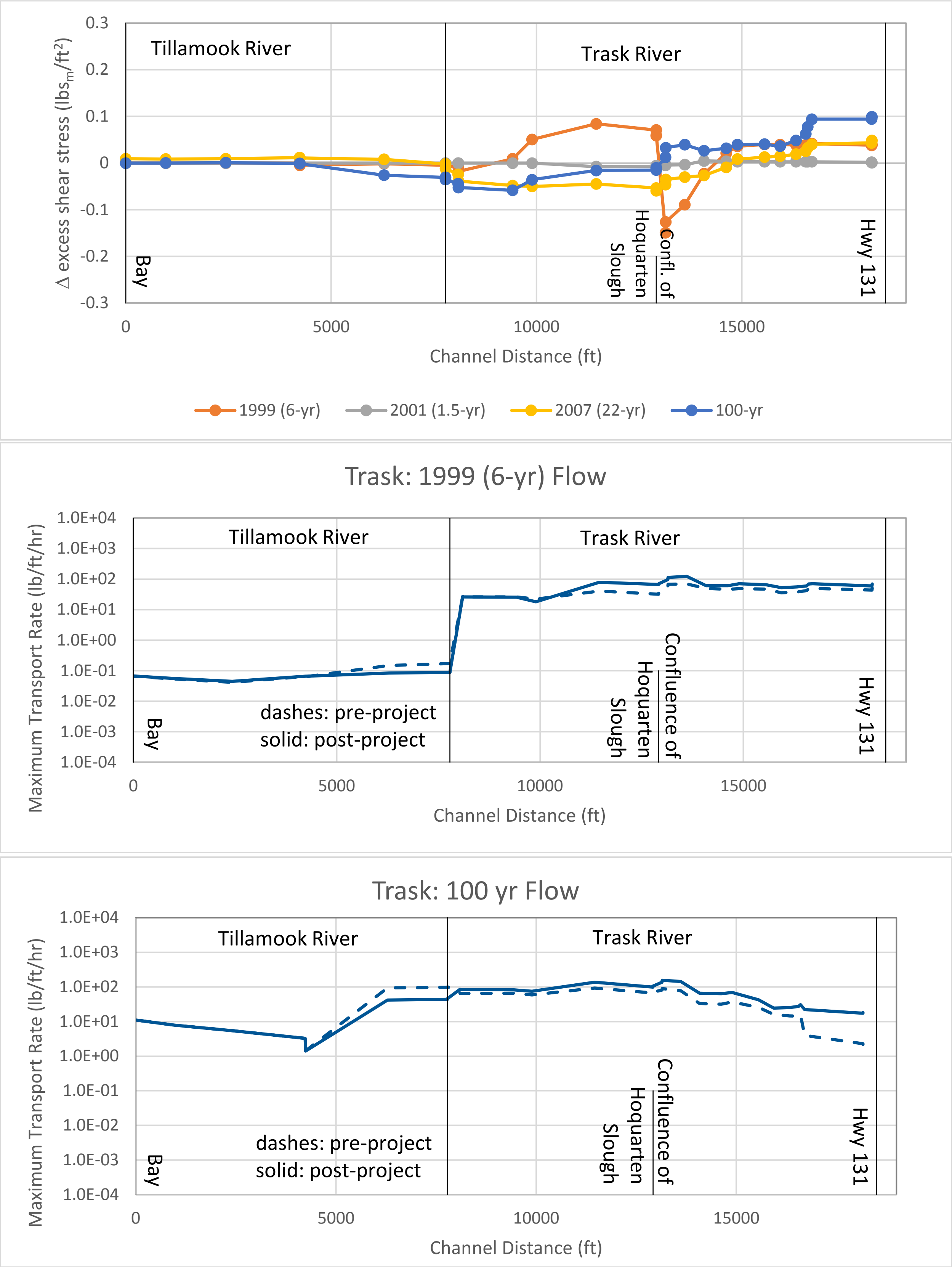

Figure 7: Trask River excess shear and sediment transport capacity

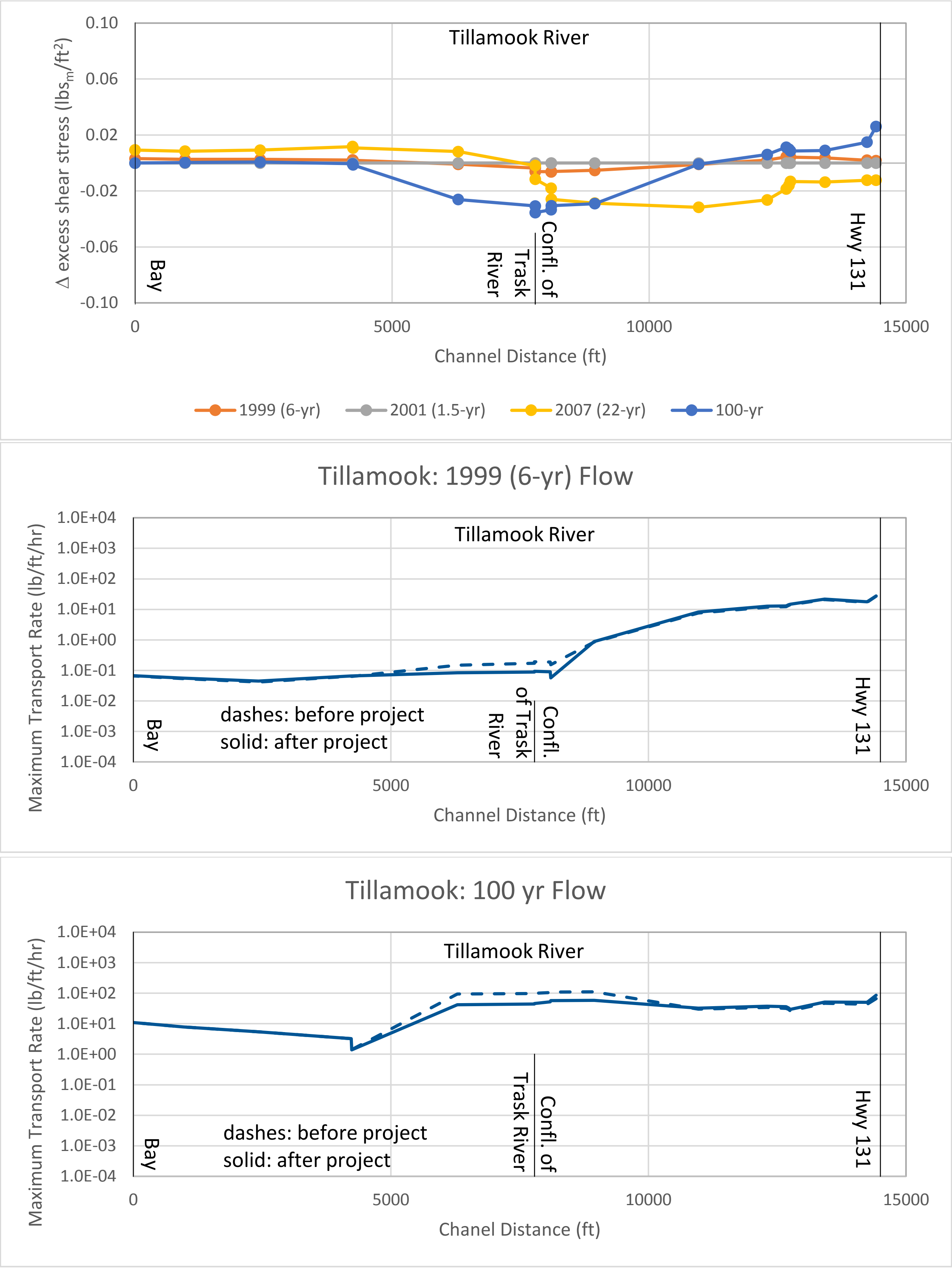

Figure 8: Tillamook River excess shear and sediment transport capacity

2.2.1 Flood Related Sediment Transport Capacity Summary

In general, sediment transport capacity will increase in the rivers, sloughs, and reaches upstream of the northern project area (the Wetlands Acquisition Area). By increasing overbank conveyance here, the project reduces water levels that in turn create steeper water surface slopes, velocities, and shear stresses in upstream channels. This is most consistently seen in the upper Wilson and Trask Rivers, and in Dougherty Slough/lower Hoquarten Slough, which behave similar to the main channels due to Dougherty Sloughs connection to the Wilson River. Upper Hoquarten Slough results are mixed, which is due to the lack of upstream river connection, very rough forested overbanks, and high sinuosity. Hall Slough is unique in spilling flow to Blind Slough mid-reach, which may lead to decreased channel capacity in the lower end. River reaches adjacent to the northern project area (the lower Wilson River and lower Tillamook reaches) show reduced sediment transport capacity due to the large increase in overbank conveyance available. Figure 9 and Figure 10 summarize the predicted changes of the project on sediment transport rates downstream of Highway 101 and Highway 131 during the 100-year and 6-year floods. More detailed reach by reach summaries are given in the following sections.

2.2.2 Wilson River

Sediment transport capacity is predicted to increase in the upper portion of the reach and decrease downstream (Figure 3). The transition occurs around the confluences of Hall Slough, Little Cut, and Big Cut. Under post-project conditions, this is where the levees that confine flows in the Wilson River end and the flows can spread out over the project area. In addition, the multiple channels (Wilson River, Big Cut, and Little Cut) and low tidal marsh offer multiple paths to flow into the Bay. By removing levees, the project lowers water levels close to the Bay tide levels in the project area. This water level reduction propagates up the Wilson River. As a result, water surface slope, velocities and shear stress all increase in the Wilson River above Hall Slough, leading to the increased sediment transport capacity.

2.2.3 Hall Slough

Even under existing conditions Hall Slough floods in a unique manner. Flow in the lower end of Hall Slough reverses during larger floods. This reverse flow combines with flows arriving from the upstream reaches of Hall Slough and spills over the left bank berm into the Blind Slough area downstream of Goodspeed Road. This results in low velocities and shear stress in the Slough, and a “sag” in the water surface where spill to Blind Slough occurs.

The project will remove the left bank berms that impede this process and increase the spill into Blind Slough. Sediment transport capacity increases in the area of spill into Blind Slough (around station 15,000). Overall water surface slopes, velocities, and sediment transport capacities are low in Hall Slough. Hall Slough does not have a direct connection to the Wilson River upstream , so there is very little sediment introduced to the system during floods. The most likely area where some reduction in capacity may occur is in the downstream end, where reverse flows could pull some sediment into Hall Slough from the Wilson River.

2.2.4 Hoquarten Slough

Changes to sediment transport capacity in Hoquarten Slough between Highway 101 and the confluence with Dougherty Slough are mixed (Figure 3). Unlike the other reaches, there are no consistent trends in changes to velocities, despite the reduction in peak flood levels. Sediment transport capacity is predicted to decrease in the 6-year event and increased in the 100-year event. Because the reach has no upstream main channel connection to provide sand size sediment, and overall channel sediment transport rates are low, the chance of channel aggradation occurring due to reduced sediment transport capacity is less than elsewhere.

Downstream of the confluence with Dougherty Slough a more consistent pattern is seen, with increased flow, velocities and sediment transport capacity occurring, and positive excess shear differences for three of the four floods. In this regard, the segment is behaving in a similar manner to the upper Wilson River, and is more similar to Dougherty Slough (discussed next), than upper Hoquarten Slough.

2.2.5 Dougherty Slough

Dougherty Slough shows consistent increases in sediment transport capacity that continues downstream through the lower end of Hoquarten Slough. Dougherty is the only slough with an upstream connection to the Wilson River, and behaves in a similar manner to it, with the project causing decreased water levels, increased velocities and increased shear stress in the channel (Figure 6).

2.2.6 Trask River

Similar to the Wilson River, the project is expected to increase sediment transport capacity in the upstream part of the reach and decrease it in the lower reach (Figure 7). The reduction in water surface elevation results in higher velocities and shear stresses in the channel upstream of Hoquarten Slough. Downstream of Hoquarten Slough the project greatly increases the overbank conveyance area on the right bank. This is a transition zone where the differences in sediment transport capacity decrease and then becomes negative near the confluence with the Tillamook River.

2.2.7 Tillamook River

Sediment transport capacity is predicted to increase slightly in the upper end of the analyzed reach, where the river is confined between levees (Figure 8). Similar to the Wilson and Trask Rivers, the lower flood levels downstream results in increased velocities and shear stresses in the confined channel. As the river approaches the confluence with the Trask, excess shear stress and sediment transport capacity are reduced. This is related to the large overbank flow area now available due to the levee removal along the right bank of the Trask and Tillamook Rivers. This reduction in capacity persists through the end of the project area where the Wilson River joins. Downstream of this, in the Bay, changes are negligible.

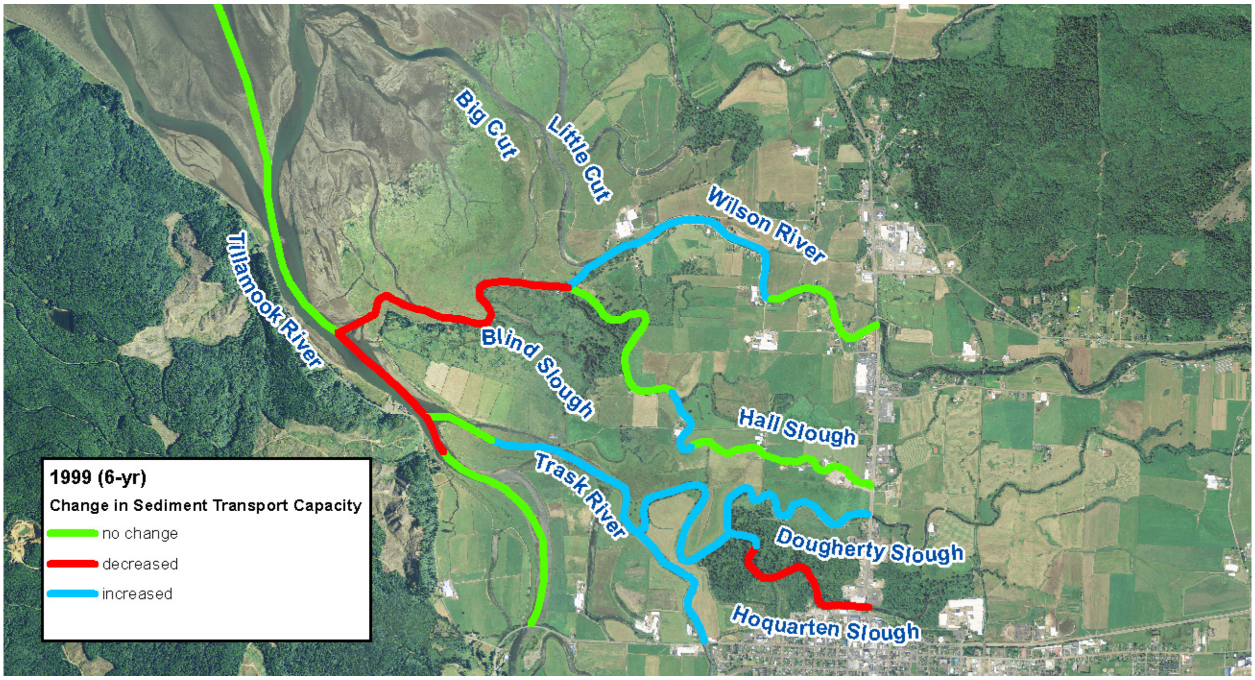

Figure 9: Expected change in sediment transport rate post-project for the 6-year flow

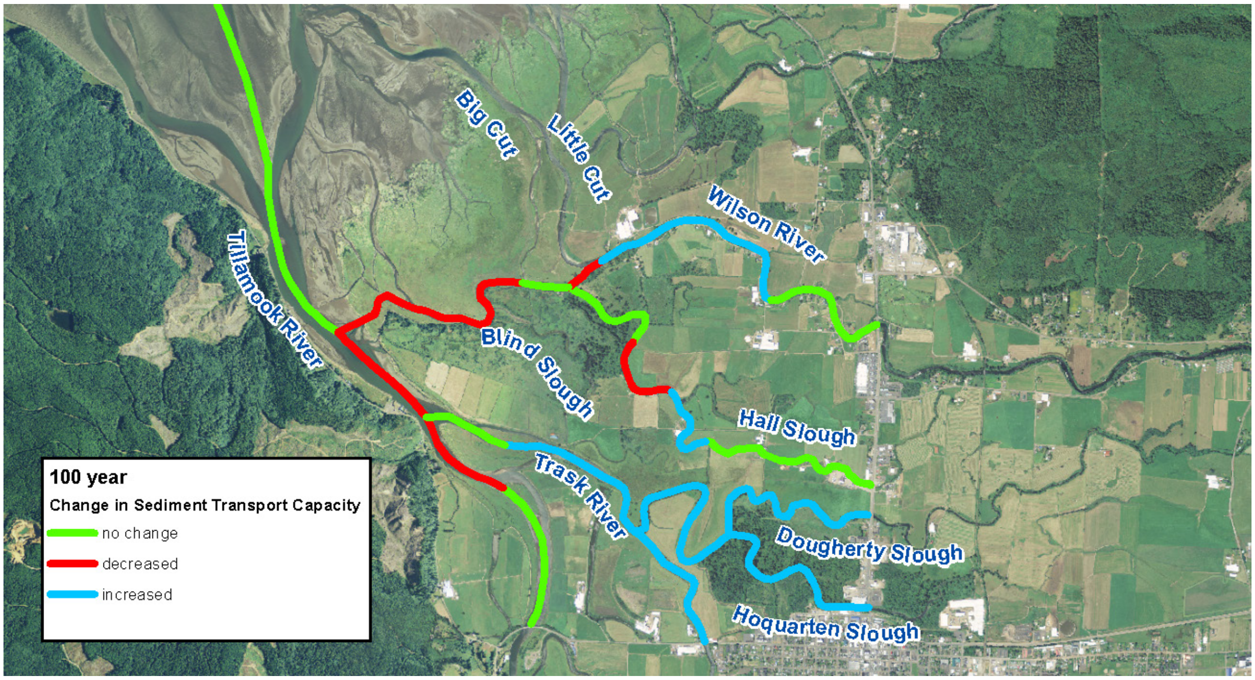

Figure 10: Expected change in sediment transport rate post-project for the 100-year flow

3 TIDAL CHANNEL MORPHOLOGY

The tides in Tillamook Bay have a strong influence on flow and sediment transport in the area's rivers and sloughs, especially under low river flow. O'Brien (1966) developed simple regime equations that predict the cross sectional area of inlets to bays and lagoons as a function of the tidal prism of the waterbody. The tidal prism is typically defined as the volume of water between mean lower low water (MLLW) and mean higher high water (MHHW) that drains through a specific location The approach has been extended to predict changes in the channel geometry in tidal marshes, including evaluation of expected change to channel form with tidal marsh restoration through the removal of levees (Williams and Orr, 2002), as is happening in the Southern Flow Corridor.

Tidal prism volume can be calculated in a channel by summing outflow over one ebb tide. For the analysis, the HEC-RAS model was used to simulate a typical two-month period with observed Garibaldi tides and average June river inflows. From this simulation, a tidal cycle that closely matched both MHHW and MLLW was selected as being representative of the tidal prism.

Outflow during the ebb tide at river and slough confluences, the upper extents of project area of influence, and a few other key locations were extracted from the model results and summed for both pre- and post-project conditions. The resulting tidal prisms are shown in Table 2 and Figure 11. Numerous studies have found that channel area scales approximately linearly with tidal prism, so the ratio of post- to pre-project tidal prism volumes is a direct measure of the expected change in cross sectional area due to the project (e.g. Byrne et al., 1980; D'Alpaos et al., 2010; Kraus, 1998; Langbein, 1963).

The majority of the river reaches will experience minimal impact during tidally driven conditions, as defined by less than a 5% change in the tidal prism ratio. This includes most of the Wilson River, Dougherty and Hoquarten Sloughs. Significant reductions in sediment transport are expected in downstream portions of Hall Slough based on the tidal prism volume dropping by 14%. The decrease in Hall Slough tidal prism is related in part to the diversion of a portion of high tides to Blind Slough under with-project conditions. The sediment transport in Big and Little Cuts is predicted to increase based on the change in flow volume. The largest increase in tidal prism is expected for Blind Slough, for which the prism volume more than doubles. This is expected, as almost the entire northern restoration area will drain through Blind Slough once the levees are removed. Though this is a large impact on Blind Slough, the increase of the Blind Slough flow volume is around 10% of the lower Wilson River volume, so major changes are not expected to propagate into the Wilson River. Tidal prism in the Trask River above Hoquarten Slough is expected to decrease by 5% to 9%, while it increases in the lower Tillamook River by up to 10%.

Table 2: Tidal prisms at select locations

Location	Pre-Project Volume (acre-ft)	Post-Project Volume (acre-ft)	Ratio of Post- to Pre-Project
Wilson River – at Hwy 101	2571.63	2560.83	1.00
Wilson River – u/s of Hall Slough	1881.11	1841.20	0.98
Mid Hall Slough	67.50	66.00	0.98
Hall Slough at mouth	294.10	253.23	0.86
Blind Slough at mouth	77.26	181.33	2.35
Wilson River – d/s of Blind Slough	1936.67	1855.74	0.96
Big Cut at mouth	128.52	161.40	1.26
Little Cut at Bay	330.10	359.60	1.09
Dougherty Slough – at Hwy 101	436.96	430.58	0.99
Dougherty Slough – at mouth	664.40	651.77	0.98
Hoquarten Slough – at Hwy 101	196.59	192.48	0.98
Hoquarten Slough – d/s of Dougherty Slough	625.83	640.12	1.02
Hoquarten Slough – at mouth	1641.51	1630.05	0.99
Trask River – at Hwy 131	1475.19	1339.29	0.91
Trask River – at Hoquarten Slough	3318.41	3156.17	0.95
Tillamook River – at Hwy 131	3362.94	3461.43	1.03
Tillamook River – below Trask	8384.14	9232.16	1.10

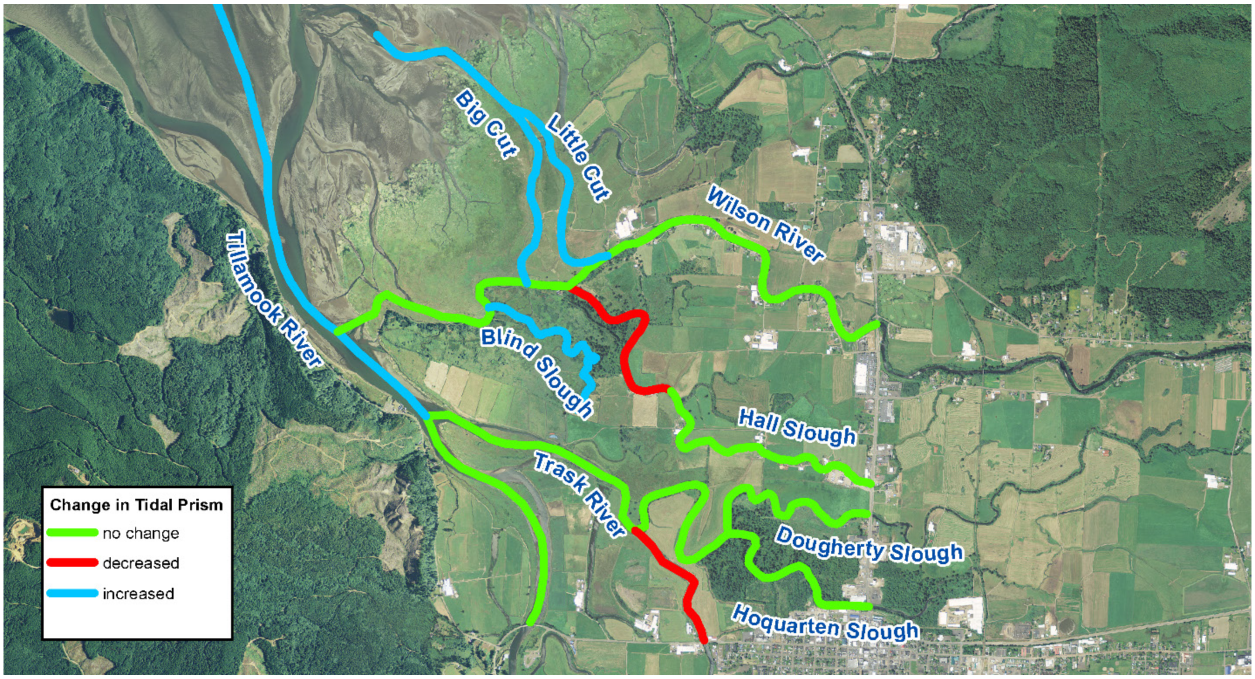

Figure 11: Expected change in tidal prism as a result of with the project for low-flow conditions

4 SYNTHESIS OF RESULTS

The river and slough reaches analyzed in this report occupy the complex transition area between fully river flood dominated and fully tidal dominated channel forming processes. The relative importance of the two varies, not only over the reaches, but also seasonally. During periods of reduced flow in the system, sediments may deposit in some of the reach areas. These sediments will transport downstream with the next increased flow. The net result is one of continued transport through the system. Overall, the area analyzed is already in a net aggradational state, which is consistent with its position at the head of the Bay and rising sea level.

Based primarily on this sediment transport analysis, but also considering prior reports, field visits, and anecdotal evidence from long-time residents, each reach has been classified as to whether riverine flooding or tides are the dominant process. The results are summarized in Table 3 and Figure 12.

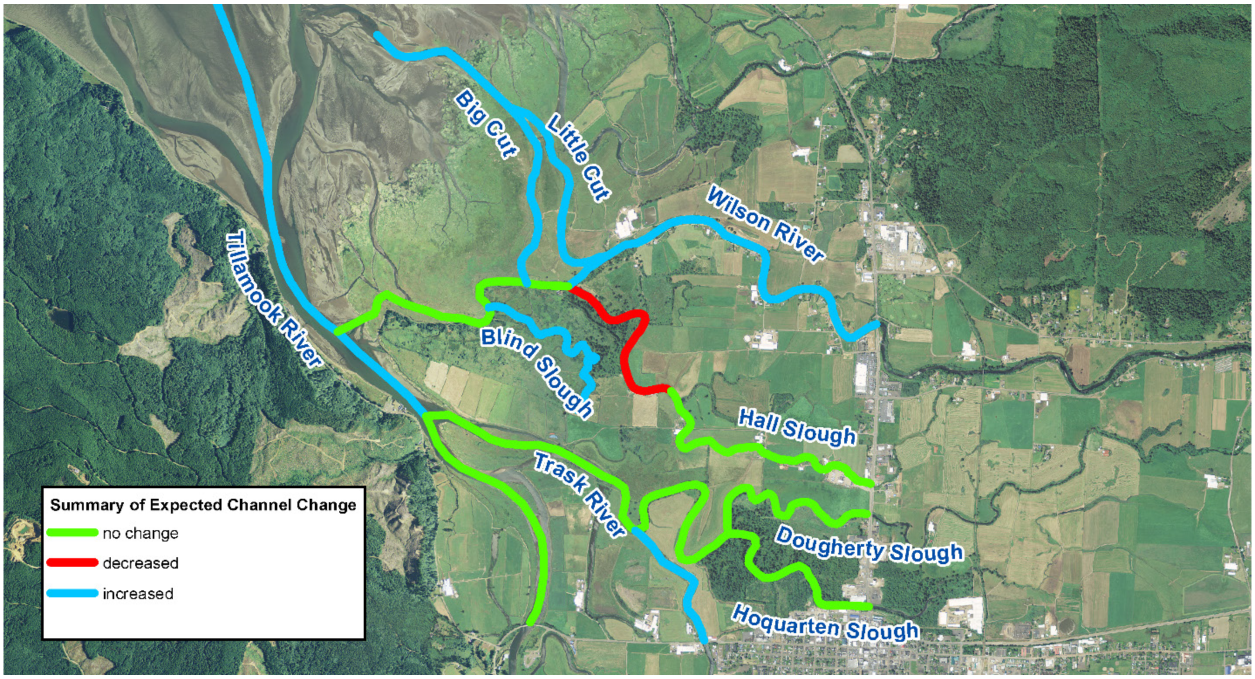

Figure 12: Summary of expected changes to channels with project

Table 3: Summary of expected changes to channels with project

	Predicted Change			**(Red=Decrease, Green=Minimal Change, Blue=Increase)**	
Reach	**6-yr Flood**	**100-yr**	**Tidal**	**Dominant Influence**	**With-Project Change in either Channel Area or Sediment Transport Capacity**
Wilson River – u/s of Hall Slough	🟦	🟦	🟩	Riverine	**Increased**
Wilson River – d/s of Hall Slough	🟥	🟥	🟩	Tidal	**Minimal Change**
Upper Hall Slough	🟩	🟩	🟩	Tidal	**Minimal Change**
Lower Hall Slough	🟩	🟥	🟥	Tidal	**Decreased**
Blind Slough	--	--	🟦	Tidal	**Increased**
Dougherty Slough	🟦	🟦	🟩	Mixed	**Minimal Change**
Hoquarten Slough – above Dougherty	🟥	🟦	🟩	Tidal	**Minimal Change**
Hoquarten Slough – below Dougherty	🟦	🟦	🟩	Mixed	**Minimal Change**
Trask River – above Hoquarten Slough	🟦	🟦	🟥	Riverine	**Increased**
Trask River – below Hoquarten Slough	🟦	🟦	🟩	Mixed	**Minimal Change**
Tillamook River above Trask River	🟩	🟩	🟩	Tidal	**Minimal Change**
Tillamook River – below Trask River	🟥	🟥	🟦	Tidal	**Increased**
Big Cut/Little Cut	--	--	🟦	Tidal	**Increased**

The upper Wilson and Trask River reaches are flood dominated due to their steeper slopes and confinement by levees. The other reaches were all categorized as either tidally formed or mixed. Tidally dominated reaches includes reaches close to the Bay, and Hall and upper Hoquarten Sloughs, which do not have upstream connections to main river channels and hence have less frequent river flooding.

Dougherty Slough is listed as a mixed reach. The reach is unique in having both tidal slough characteristics similar to Hall and Hoquarten Sloughs, but also having a direct upstream connection to the Wilson River. While there is less certainty about the dominant influence in the reach, the analyses indicates the slough will either not change significantly, or possibly enlarge to a small degree if riverine floods processes are of more importance.

The other mixed reach is the Trask River between Hoquarten Slough and the Tillamook River confluence. Under existing conditions this reach riverine flood processes are clearly important, as the reach is confined between high levees for some distance, resulting in increased water levels. The greatest changes to flood conveyance width are created by the project in this area. Removal of the levees will also facilitate much greater tidal exchange to the north than currently occurs. These changes will tend to increase the importance of tidal processes in channel formation, but it is not clear to what degree. Regardless, it is most likely that the net channel change will be minimal, based on results from the riverine and tidal analysis.

The greatest change in channel area will occur in Blind Slough. Removal of the levees and plug across the slough will allow most of the daily tides that inundate the northern restoration area to drain through the slough unimpeded.

The only reach that shows a risk of aggradation is lower Hall Slough. Removal of levees along the left bank of Hall Slough will allow both flood waters and high tides to spill into Blind Slough rather than flow through the lower end of Hall Slough.

Overall, most reaches are predicted to have neutral or increasing sediment transport capacity. This is attributed to two factors. In the upper reaches, the project generally results in increased in-stream velocities and hence shear stresses by the removal of impediments to flows. In the lower reaches, shear stresses during floods can be lower, but the channels are mostly tidal dominated, so this reduction does not affect long-term channel form. Under low-flow conditions, the project generally has small effects, with the notable exception of Blind Slough, which is expected to undergo significant expansion.

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