Technical Memorandum

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Subject: **Hydraulic Analysis at Mary's River Lumber Mill, SR 107 Bridge, and the Wastewater Treatment Plant on the Wynoochee River**

Introduction

The Mary's River Lumber Company Mill is located on the north bank of the Chehalis River near Montesano, WA about 1,400 feet upstream of the SR 107 Chehalis River Bridge. The site is about 13.4 miles upstream from the mouth of the Chehalis River. Due to significant change in the alignment of the Chehalis River near the lumber mill, there is concern about the potential for bank erosion if a cutoff of the meander bend immediately upstream of the lumber mill were to occur. A meander cutoff could direct high velocity flows directly at or parallel to the banks adjacent to the lumber mill and cause the thalweg to shift toward lumber mill, resulting in bank erosion and damage to several mill structures. Therefore, the City is evaluating options for bank protection measures near the lumber mill where the river would most likely impinge on the bank, or a possible bypass that would cut off the meander bend before it breaks through and directs flow at the Mary's River Lumber Mill. The City is also looking to protect the Waste Water Treatment Plant (WWTP) and its settling lagoons from high flows in the Wynoochee River. Potential impacts to SR 107 due to a possible bypass will also be evaluated. The location of the project sites are shown in Figure 1.

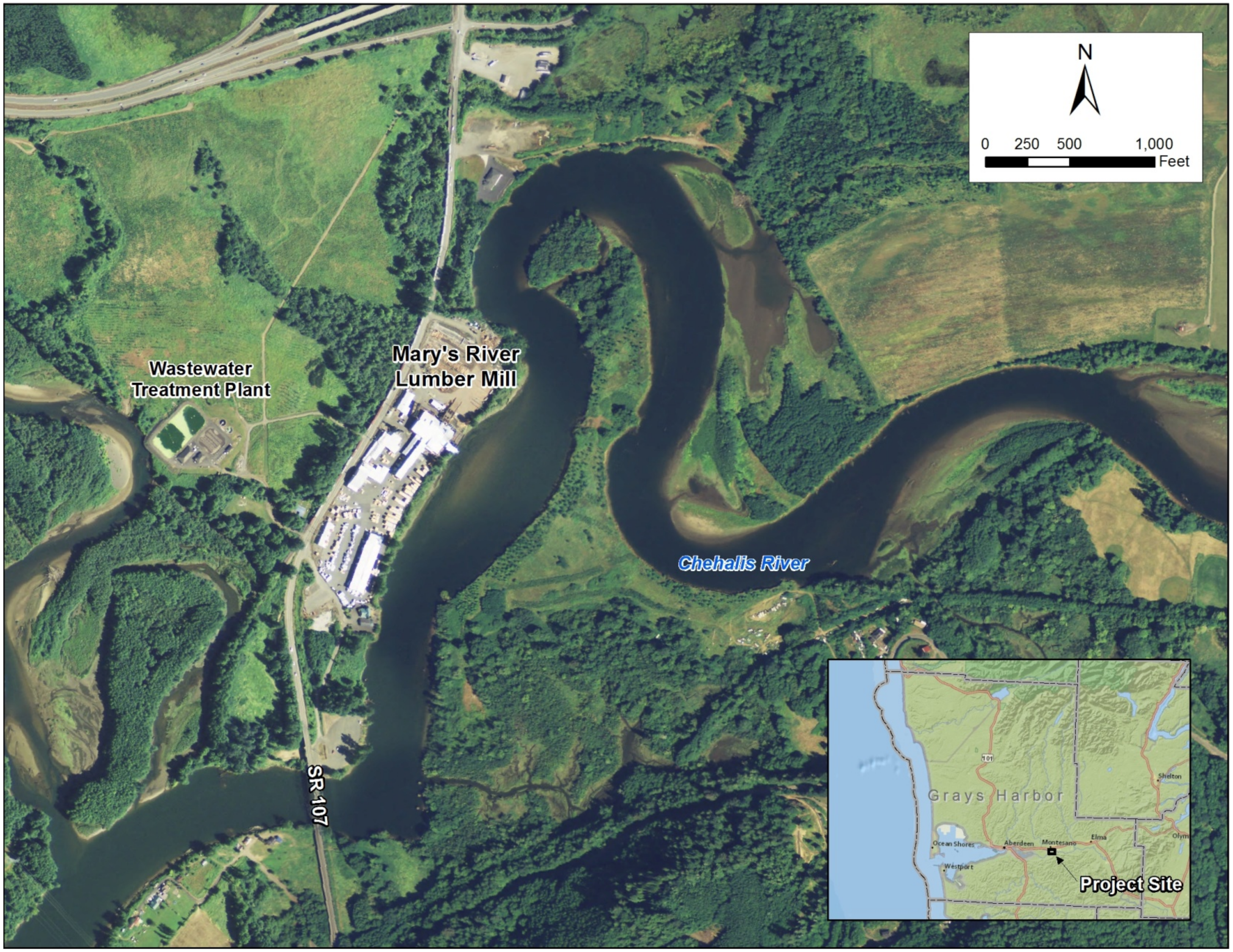

Figure 1. Location Map.

The City contracted Parametrix to design the bank protection for the Mary's River Lumber Mill site. WEST Consultants, Inc. (WEST) was subcontracted by Parametrix to perform the hydraulic, scour and geomorphic analyses in support of the bank protection design. As part of this project, WEST obtained historic aerial photographs of the Mary's River Lumber Mill vicinity. An evaluation of the photographs was conducted to obtain an understanding of how the active channel of the Chehalis River changed through recent history. The evaluation or historic aerial photography and hydraulic and scour analyses are documented in this memorandum.

Unless otherwise stated, all elevations within this memorandum are referenced to the North American Vertical Datum of 1988 (NAVD88).

Analysis of Historic Aerial Photography

Historic aerial photographs were obtained from various sources. Photos were located for the years 1953, 1962, 1967, 1972, 1975, 1981, 1985, 1990, 1997, 1999, 2005, 2006, 2009, and 2011.

To characterize the history of channel movement in the vicinity of the lumber mill, an analysis was conducted by comparing the boundaries of the active channel reflected in the historic aerial photographs.

The active channel alignments delineated from each of the historic aerial photographs from 1953 to 2006 are shown in Figure 2. Figure 3 shows the active channel alignments for years 2006 to 2011. The figures show that the bank adjacent to the mill has not experienced significant erosion, while the land across the channel from the mill has been eroding due to the migration of the meander bend. It is apparent that the meander immediately upstream of the mill will be cutoff in the near future. A meander cutoff will likely result in more direct flows impinging against the bank adjacent to the mill. Observations made from these figures and the aerial photographs are summarized in Table 1.

Based on the review of historic aerial photographs, it is apparent that the planform of the active channel upstream of the lumber mill is highly dynamic and has changed significantly within the last 54 years. If no action is taken, the observed pattern of channel migration can be expected to continue in the future, resulting in the cutoff of the meander immediately upstream of the lumber mill. Large changes in the bank alignment tend to occur during large flood events, such as the 1996 and 2006 floods. The erosion rate of the meander across from the lumber mill was estimated by measuring the minimum distance between the upstream and downstream meanders. The estimated erosion rates are provided in Table 2.

Table 2 summarizes: (1) the minimum distance between the meanders upstream from the mill; (2) the calculated incremental erosion rate, which corresponds to the rate of erosion between two sequential records; (3) long term erosion rate, which corresponds to the rate of erosion since 1953; and (4) any miscellaneous notes. As shown in the table, the distance between the meanders has decreased from 890 feet to 200 feet over 58 years, the long term erosion rate has been about 12 feet per year since the early 1980's, and the maximum rate of change (65 feet per year) occurred as a result of the 2006 flood event.

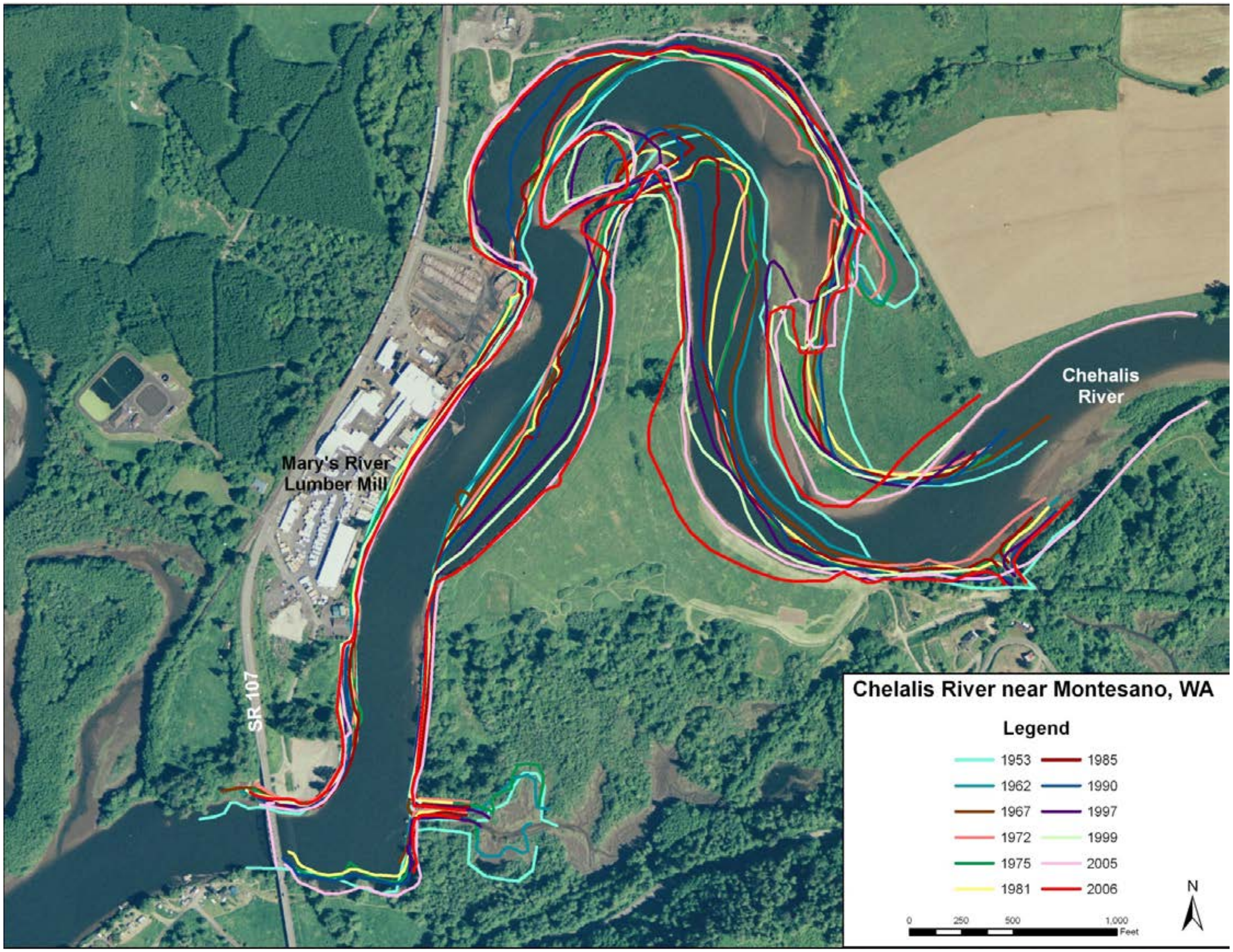

Figure 2. Historic alignments of the active channel for the Chehalis River between 1953 and 2006 (2005 aerial used as background)

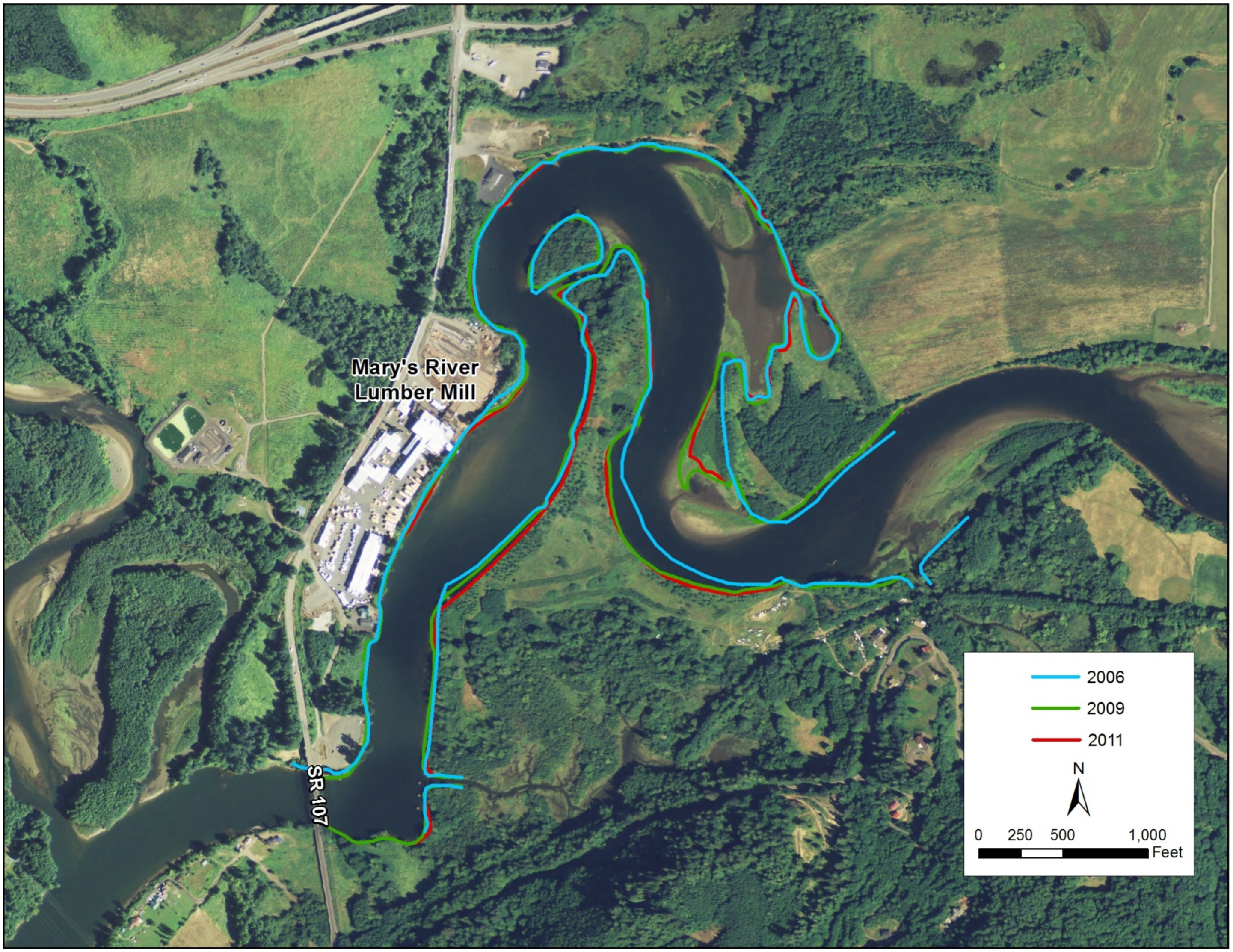

Figure 3. Chehalis River channel alignment for 2006, 2009, and 2011 (2011 background aerial)

Table 1. Summary of observations from historical aerial photograph comparison.

Years	Notes
1953	This aerial photograph covers a large area. There are either barges or floating logs existing in front of the lumber mill. The alignment of the river is fairly straight and has a narrower width than the existing conditions. The photographs indicate alignments of the river or side channels located immediately to the east and southeast of the lumber mill.
1962	This aerial photograph covers an area of the Chehalis River from the SR 107 bridge to about 1.7 miles upstream. In general, the conditions of the Chehalis River in this photograph are similar to the conditions reflected in the 1953 photograph. There are several areas of the river in front of the lumber mill that contain floating logs.
1967	This aerial photograph covers about the same area as the 1962 photograph, and the alignment of the river is similar to the alignment seen in the 1962 photograph.
1972	This aerial photograph covers about the same area as the 1962 and 1967 photographs. There are fewer logs on the river in front of the lumber mill. There is a slight increase in the river width within the meander immediately upstream of the lumber mill.
1975	This aerial photograph covers about the same area as the 1962, 1967, and 1972 photographs and the condition of the river is similar to the condition reflected in the 1972 aerial.
1981	The changes since 1975 include the formation of a small side channel in the point bar of the bend immediately upstream of the lumber mill and no floating logs in front of the lumber mill.
1985	The conditions reflected on this aerial are similar to the conditions reflected on the 1981 aerial.
1990	The changes since 1985 include the outer bank of the meander bend immediately upstream of the lumber mill shifting to the west towards SR 107, and a slight change of the conditions on the point bar of the bend immediately upstream of the lumber mill.
1997	Significant changes are evident in this aerial. The outer bank of the meander immediately upstream of the lumber mill migrating to the west, the bank across from the lumber mill's migrating to the east, the side channel on the point bar immediately upstream of the lumber mill has enlarged, and riparian vegetation cover a larger area of the point bar north of the side channel.
1999	The conditions reflected on this aerial are similar to the conditions reflected on the 1999 aerial.
2005	This aerial covers a large area similar to the 1953 aerial. The changes since 1999 include the installation of stream barbs, which were constructed in 2002, on the outer bank of the meander bend immediately upstream of the lumber mill. The bank across from the lumber mill shifted further to the east.
2006	The only noticeable change reflected in this aerial includes the migration of the outer bank of the upstream most meander further to the west towards the lumber mill.
2009	The east side of the meander breakthrough area eroded significantly. The western side did not change significantly.
2011	Both sides of the meander breakthrough area show erosion continuing.

Table 2. Summary of erosion rates for the ground opposite of the Mary's River lumber mill.

Year	Minimum Distance between Meanders Upstream of Mill	Incremental Erosion Rate (feet/year)	Long Term Erosion Rate (feet/year)	Notes
1953	890	-	-	-
1962	850	4.4	4.4	-
1967	850	0.0	2.9	-
1972	760	18.0	6.8	A relatively large flood event occurred on 1/22/72.
1975	705	18.3	8.4	-
1981	570	22.5	11.4	-
1985	530	10.0	11.3	-
1990	505	5.0	10.4	A relatively large flood event occurred on 1/11/90.
1997	415	12.9	10.8	A significant flood event occurred on 1/9/96.
1999	375	20.0	11.2	-
2005	355	3.3	10.3	In 2002, bank protection measures were installed on the outside of the meander bend immediately upstream of the mill.
2006	290	65.0	11.3	A significant flood event occurred on 1/13/06.
2009	240	16.7	11.6	December 2007, January 2009 events occurred
2011	200	20.0	11.9	-

Hydraulic Analysis

An unsteady flow hydraulic analysis was conducted to obtain the hydraulic characteristics of the Chehalis River in the vicinity of the lumber mill, WWTP, and SR 107. The analysis was conducted using the Corps of Engineers River Analysis System (HEC-RAS Version 4.1.0) standard-step backwater computer program. Recently, a HEC-RAS hydraulic model of the Chehalis River has been updated using funding from the Flood Authority and Corps of Engineers. The updates included extending the model downstream to Aberdeen and adding the Wynoochee River. WEST Consultants was involved in both efforts and performed more than two-thirds of this combined work. The hydrographic surveys on the Chehalis River completed previously by the Parametrix team for the study area have been combined with 2012 Lidar data obtained from the Puget Sound Lidar Consortium website (http://pugetsoundlidar.ess.washington.edu/) to create updated cross sections in the Mary's River vicinity. Some of these cross sections have been added to the model to provide necessary resolution in the study reach. The locations of the cross sections in the model for the projects vicinity are shown in Figure 4. Ineffective flow boundaries were set in the model to define the active flow area of each cross section. The hydraulic roughness coefficients used in the model are based on calibration to observed data. A roughness coefficient of 0.042 was assumed for the active channel of the river, and between 0.07 and 0.09 assumed for overbank areas.

The downstream end of the model is located in Grays Harbor. The Mary's River Lumber project

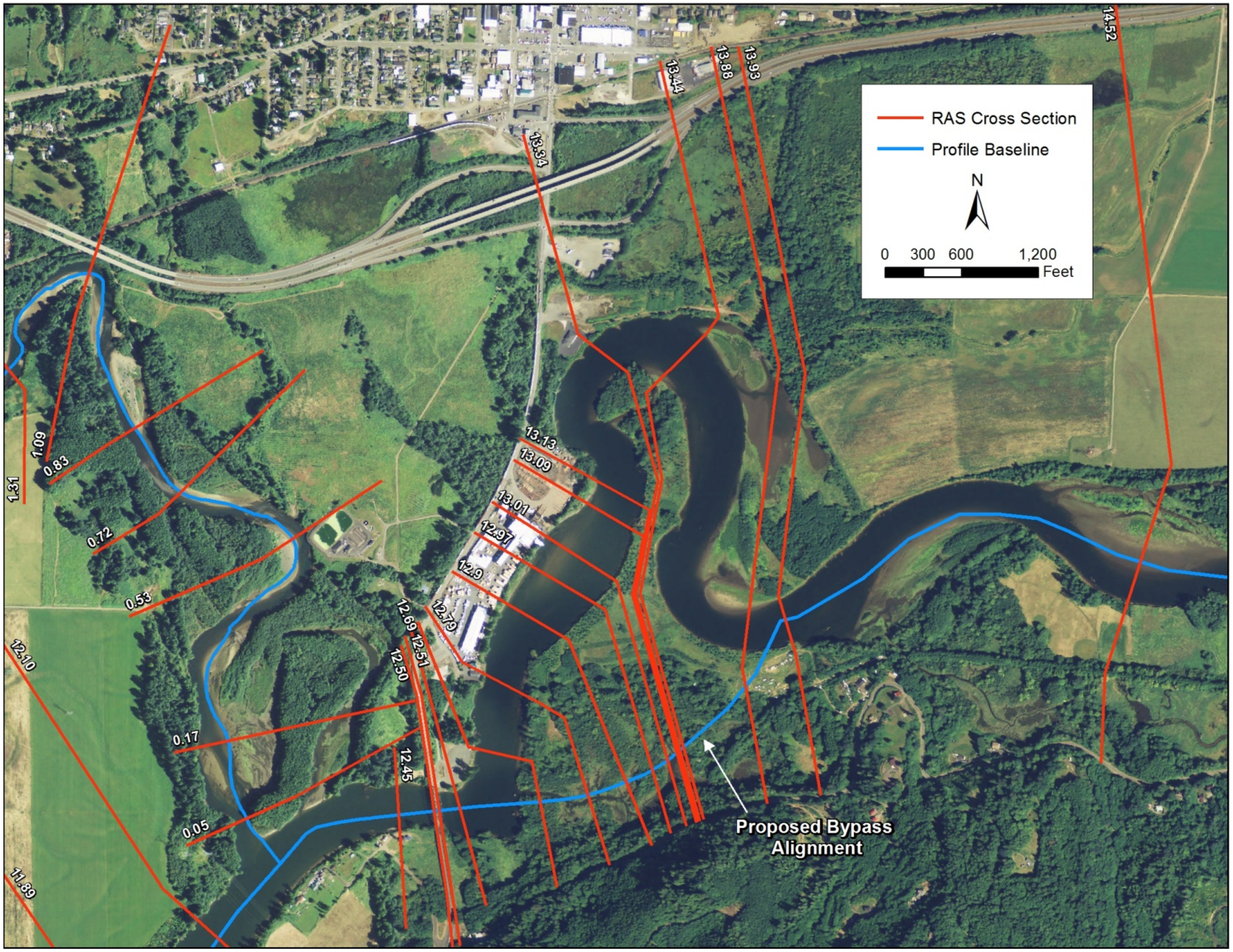

Figure 4. Cross section locations and possible bypass flow path.

area and SR 107 are tidally influenced. The starting water surface elevation used in the HEC-RAS hydraulic model is the actual tide for the 1996, 2007, and 2009 events. For the 100- and 500-year events, a synthetic sinusoidal tide from mean lower low water (MLLW) to mean higher high water (MHHW) in a diurnal cycle is used (shown in Figure 5). The elevations are based on MLLW and MHHW at the NOAA tide station at Aberdeen (No. 9441187). Maximum water surface elevation, velocity, and shear stress were extracted from the time series for each event near the project site.

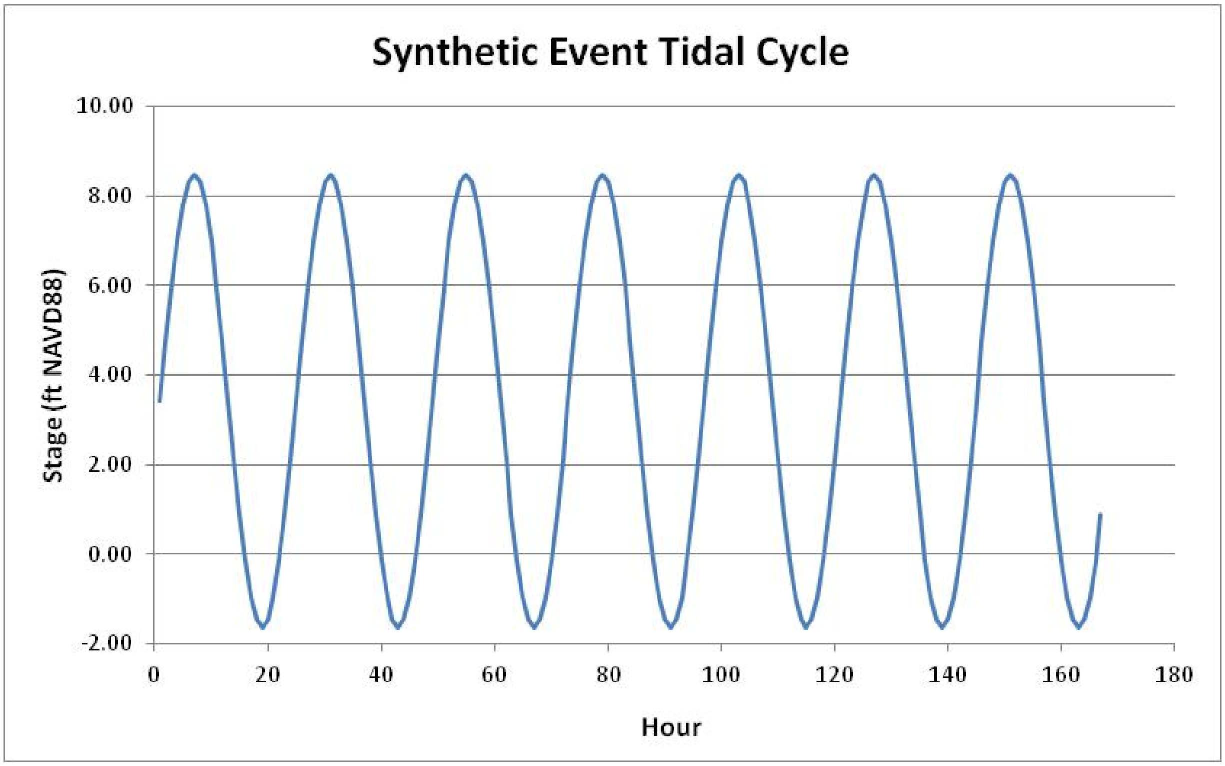

Figure 5. Tidal cycle for synthetic flow events (100- and 500-year events)

Table 3. Discharge and starting water surface boundary condition.

Event	Lumber Mill Vicinity Approximate Maximum Discharge (cfs)	Downstream Boundary Condition
1996	102,170	Observed tide
2007	96,270	Observed tide
2009	81,270	Observed tide
100-year	117,640	Synthetic Tidal
500-year	169,930	Synthetic Tidal

The results from the HEC-RAS model are summarized in Table 4 and Table 5. Table 4 summarizes the calculated water surface elevations at the downstream end of the lumber mill, near the main saw of the lumber mill, and at the upstream end of the lumber mill for the various flow and downstream boundary conditions. Table 5 summarizes the maximum average channel velocities and shear stresses for the various flow and downstream boundary conditions (representing the channel average at the time of the maximum value).

Table 4. Maximum water surface elevations for the Chehalis River near the Mary's River Lumber Mill.

Discharge Event	*Approx-imate Discharge (cfs)	Maximum Water Surface Elevation (NAVD88 ft)		
		Downstream End (RS 12.79)	At Saw Structure (RS 13.01)	Upstream End (RS 13.13)
1996	102,170	18.34	18.99	19.13
2007	96,080	17.85	18.48	18.62
2009	82,630	18.20	18.63	18.73
1% exceedance (100-yr)	116,420	19.43	20.11	20.25
0.2% exceedance (500-yr)	168,670	22.82	23.60	23.75

*Discharge is for time of maximum water surface elevation, not necessarily maximum flow.

Table 5. Maximum average channel velocities and shear stresses for the Chehalis River near the Mary's River Lumber Mill (for the breakthrough scenario).

Discharge Event	Discharge (cfs)	Velocity (ft/s)[1]	Shear Stress (lbs/ft^2)[1]
1996	94,690	7.7	1.00
2007	96,030	7.5	0.96
2009	82,160	7.0	0.86
1% exceedance (100-yr)	116,330	8.1	1.10
0.2% exceedance (500-yr)	166,480	9.5	1.50

Notes:

1. Maximum velocity and shear stress are tidally influenced in this area - therefore time of maximum occurrence may not correspond to maximum flow.
2. The velocity and shear stress values represent the channel average at the time of the maximum.

Riprap Evaluation

Calculations were performed to determine the required riprap size for bank protection. The calculations were performed using the guidance provided in Hydraulic Design of Flood Control Channels (USACE, 1994). This equation was used due to the correction factor available for the bend angle. Other riprap sizing equations were used for comparison purposes – some calculated a similar size and some calculated a smaller size. The riprap size was computed using the following equation:

$$D_{30} = S_f\, C_s\, C_V\, C_T\, d \left[\left(\frac{\gamma_w}{\gamma_s\ \gamma_w} \right)^{0.5} \frac{V}{\sqrt{K_1\, gd}} \right]^{2.5}$$

where D_{30} is the riprap size of which 30% is finer by weight, S_f is the safety factor (2), C_s is a stability coefficient (0.3), C_V is a vertical velocity coefficient (1.22), C_T is a thickness coefficient (1), d is the local depth of flow (19.58) in the same location as V, γ_w is the unit weight of water (62.4 lbs/ft^3), γ_s is the unit weight of stone (165 lbs/ft^3), V is the average channel velocity (6.21ft/s), K_1 is the side slope correction factor (1.18) , and g is the gravitational constant (32.2 ft/s^2). Values listed near the descriptions are for the 100-year event. The D_{50} (converted from D_{30}) for the 100-year event is 1.3 feet, corresponding to heavy loose riprap. The riprap classification for the 500-year event is also heavy loose riprap. Results are summarized in Table 6.

Table 6. Summary of riprap sizing calculations.

Discharge Event	S_f	C_s	C_V	V	d	K_1	D_{50}	Riprap Class
1% exceedance (100-yr)	2.0	0.3	1.22	6.21	19.58	1.18	1.3 ft	Heavy Loose

Scour Estimate

An analysis was completed to estimate the maximum scour depth anticipated near the proposed bank protection. The analysis was conducted assuming that the river had cutoff the meander as reflected by the alignment shown in Figure 6**.**

The design of a resistive bank erosion protection measure must account for potential scour depths anticipated near the structure. Therefore, the scour elevation at the structure was estimated for the 1996, 2007, 2009, 100-, and 500-year flood events. The type of scour anticipated at the structure includes only bend scour. Long-term degradation was not considered because the project site is located within a reach that is typically depositional, and some of the other scour components, such as thalweg migration, are accounted for in the equation used to estimate the bend scour. Bend scour is associated with scour along the outside of a bend caused by transverse or “secondary” currents created by the bend. Material scoured from the outside of a bend is characteristically deposited along the inside of the bends downstream. The bend scour elevation was estimated using the equation developed by Zeller (Simons, Li and Associates, Inc., 1985). The results of the scour calculations are summarized in Table 7. It is recognized that the results of the bend scour evaluation are based on assumed conditions. Compared to observed minimum historic profile elevations, the assumed analysis conditions may not represent the most severe scour conditions that could occur. To minimize risk for the revetment design, it is recommended that a maximum scour of elevation -50 ft NAVD88 be considered.

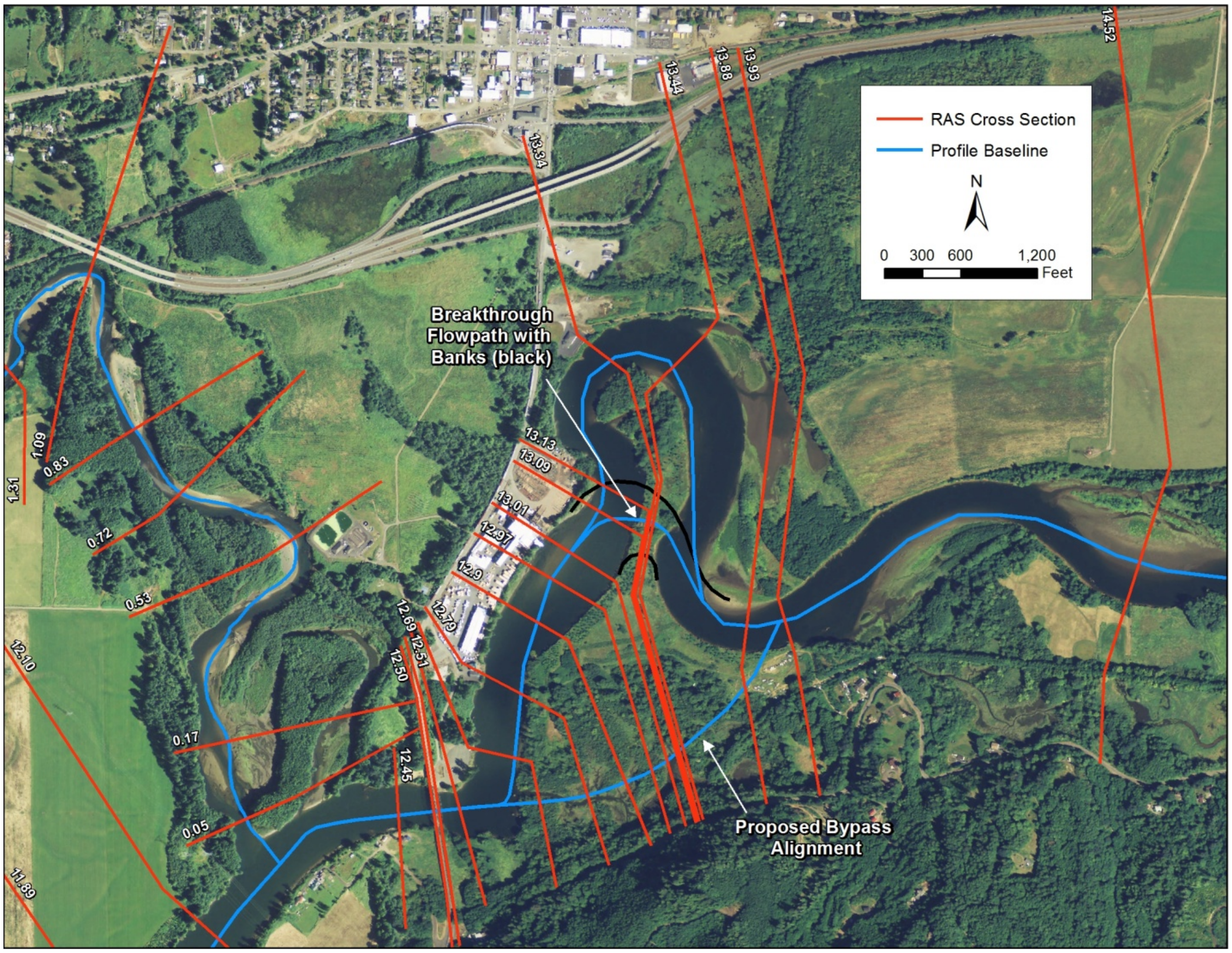

Figure 6. Assumed breakthrough scenario.

Table 7. Results of scour calculations.

Event	Scour Elevation (feet, NAVD88)
1996	-41.5
1% exceedance (100-yr)	-41.9
0.2% exceedance (500-yr)	-44.0

Recommendations for Erosion Protection Measures

If the Full Channel Bypass is not implemented, the recommended extents of the bank protection measures are shown in Figure 7. In general, the erosion protection measure would be located along the portion of the bank from near the upstream extents of the lumber mill to approximately 1700 feet downstream to tie into existing bank protection. This would cover most of the bank adjacent to Mary's River Lumber. If the breakthrough did occur, the entire length near the lumber mill would be on the outside of the bend, making it susceptible to erosion. Currently, the upstream portion of the bank is on the inside of the bend, and the downstream portion on the outside of the bend. Potentially, extending the bank protection to tie into existing protection near the downstream end of the mill site could also protect SR 107 from future right bank erosion by keeping the channel aligned with the bridge opening. If the entire bank is not protected, the protection should start at the upstream end and proceed downstream as far as feasible. Any remaining unprotected bank should be monitored periodically, and after large flow events to see if measures are needed to prevent further erosion. If the specified rock size cannot be placed under the deck, than a smaller size should be utilized or a resistive turf reinforcement mat should be utilized.

Details of the erosion control measure are provided in Figure 14. It is recommended that the top of the revetment extend to the top of the bank. The riprap revetment should consist of Heavy Loose Riprap (based on WSDOT specifications, D_{50} of 2.2 feet) along the bank and along the toe of the embankment. Recommended layer thickness is 5.25 feet with a geotextile fabric filter. To prevent failure of the structure from undermining, a launchable toe should be placed along the toe of the bank. The volume and dimensions of the launchable toe are based on the recommendations provided in EM 1110-2-1601, *Hydraulic Design of Flood Control Channel* for an estimated scour elevation -42 feet. The volume per foot of bank protection is 700 ft^3. If the entire 1,700 is protected a volume of approximately 44,074 cubic yards would be required. The configuration of bank protection is shown in Figure 8.

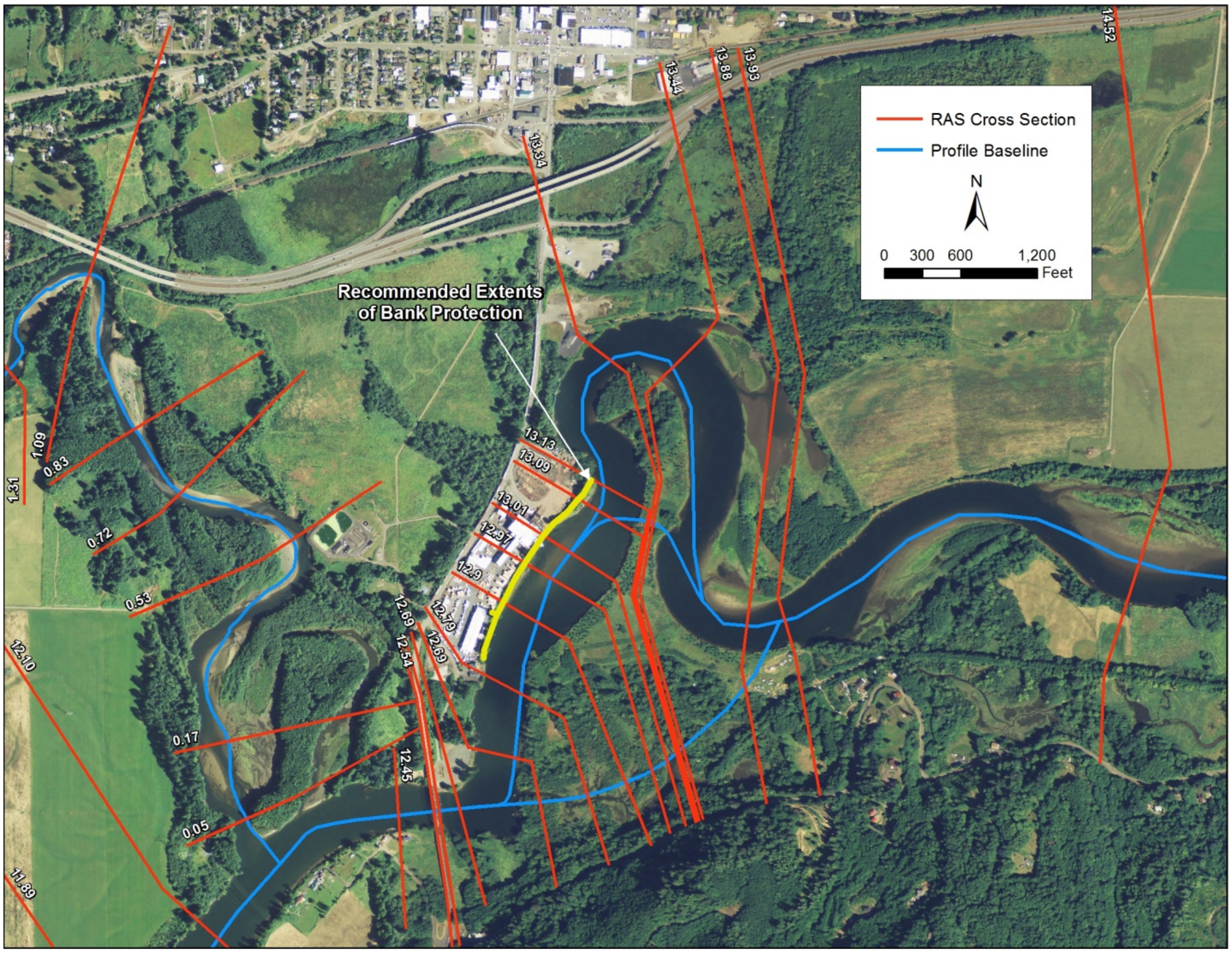

Figure 7. Recommended extents of bank protection.

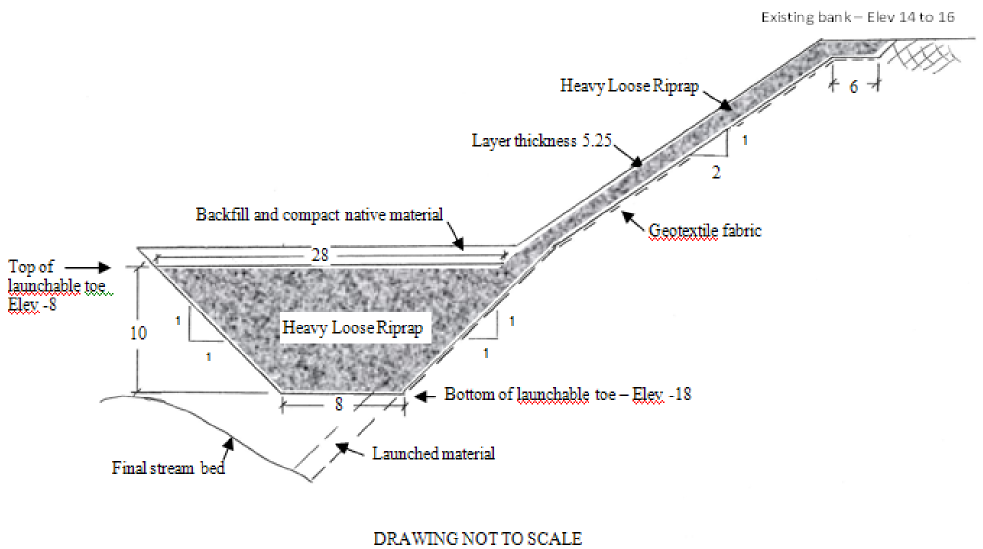

Figure 8. Riprap protection configuration (distances and elevations in feet).

Impacts at SR 107

A change in the Chehalis River flow paths or overflow paths have the potential to alter hydraulic characteristics at the SR 107 bridge. The SR 107 bridge is already experiencing scour around its foundations. The hydraulic characteristics at the bridge are compared to existing conditions to determine any potentially adverse impacts from Chehalis River modifications. Comparison scenarios will include the Breakthrough, a High Flow Bypass, and a Full Channel Bypass, bypassing the large meander upstream of the lumber mill. The layout for these configurations is shown in Figure 6.

For the High Flow Bypass, it is similar to existing conditions until the water surface elevation gets above 10 feet near the upstream end of the large meander. At 10 feet and above, flow will split off and follow the bypass channel as well as proceed down the main stem of the Chehalis River. The main stem cross sections were split to create main stem and separate Bypass Reach cross sections. Lateral structures were used to allow flow to move from the bypass to the Chehalis main stem, or vice-versa. A channel approximately 240 feet wide with 2V:1H slopes was cut into the bypass reach along the centerline shown in Figure 6. A typical cross section is shown in Figure 9. The thalweg followed is shown in Figure 10.

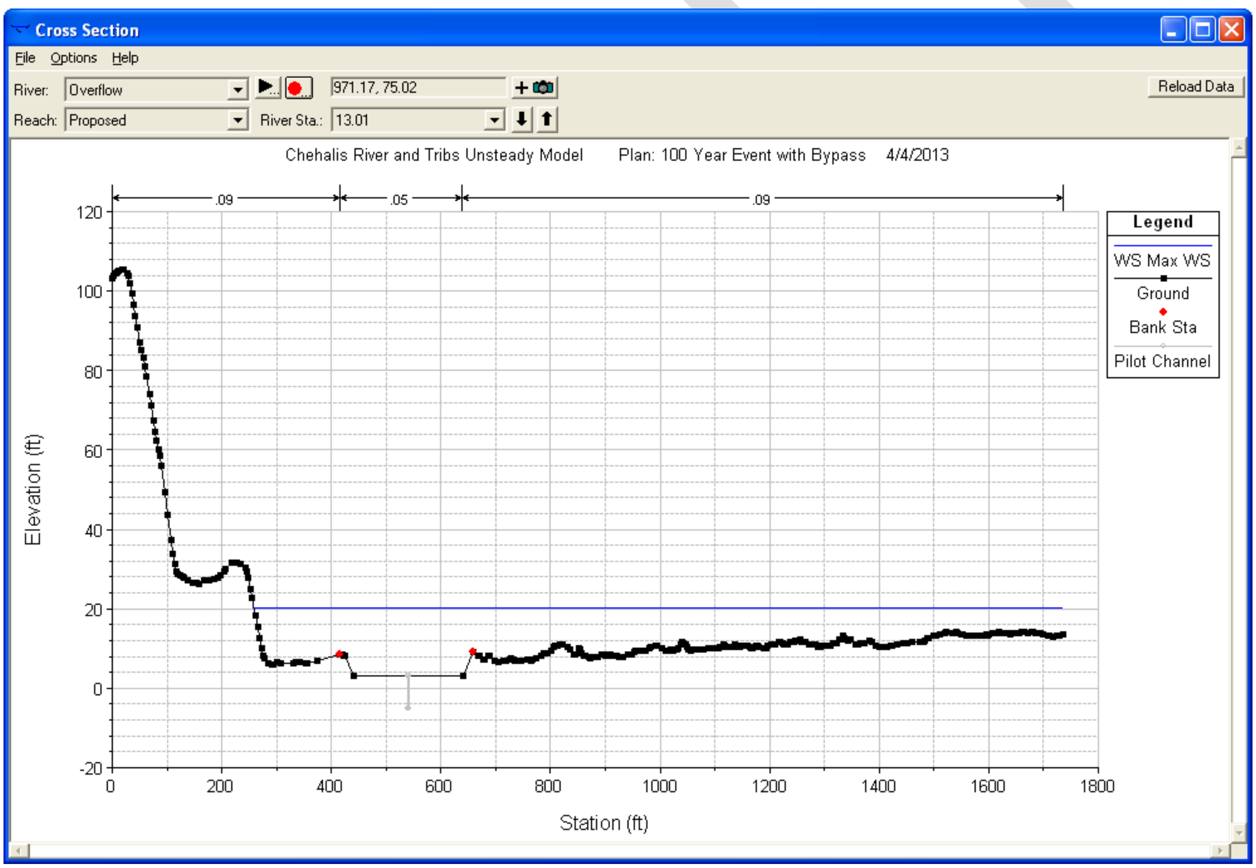

Figure 9. Typical cross section cut for the High Flow Bypass

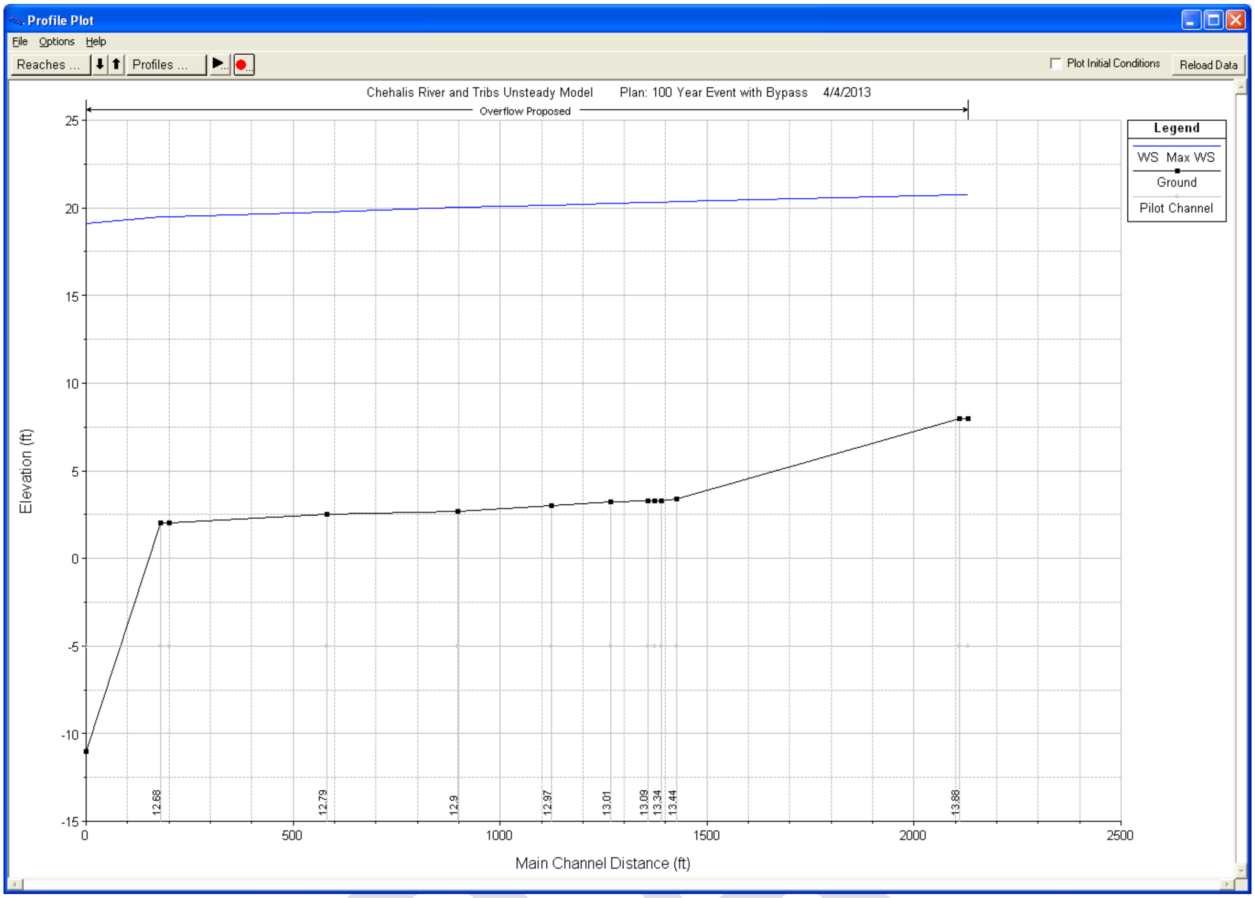

Figure 10. Thalweg used for High Flow Bypass (distance 180 to 2130).

In the Full Channel Bypass scenario, a full channel was cut into the bypass, and the main stem of the Chehalis was routed through the bypass. Main channel and overbank reach lengths were adjusted accordingly. A typical cross section cut is shown in Figure 11. The assumed thalweg followed for the Bypass Reach is shown in Figure 12. Since the large meander would be cut off by the Full Channel Bypass, flow in the large meander would decrease, which would likely cause an increase in sedimentation in that portion of the "old channel".

Model results indicate a minimal change in hydraulic characteristics at SR 107 due to any of the scenarios. The largest velocities occur at the upstream face of the bridge, so comparisons will be made there. The worst case was an increase in the maximum velocity of 0.03 ft/s for the 2007 event with the High Flow Bypass. The largest increase in velocity at any time of all the modeled timeframes was 0.38 ft/s for the 500-year event with the Full Channel Bypass. A benefit to the Full Channel Bypass would be that the approach flow to SR 107 would be aligned with the bridge opening. Currently there is a sharp bend going into the bridge opening. Table 8 summarizes the changes in velocity due to the different scenarios. The comparison results are based on assumed conditions so actual results may be different.

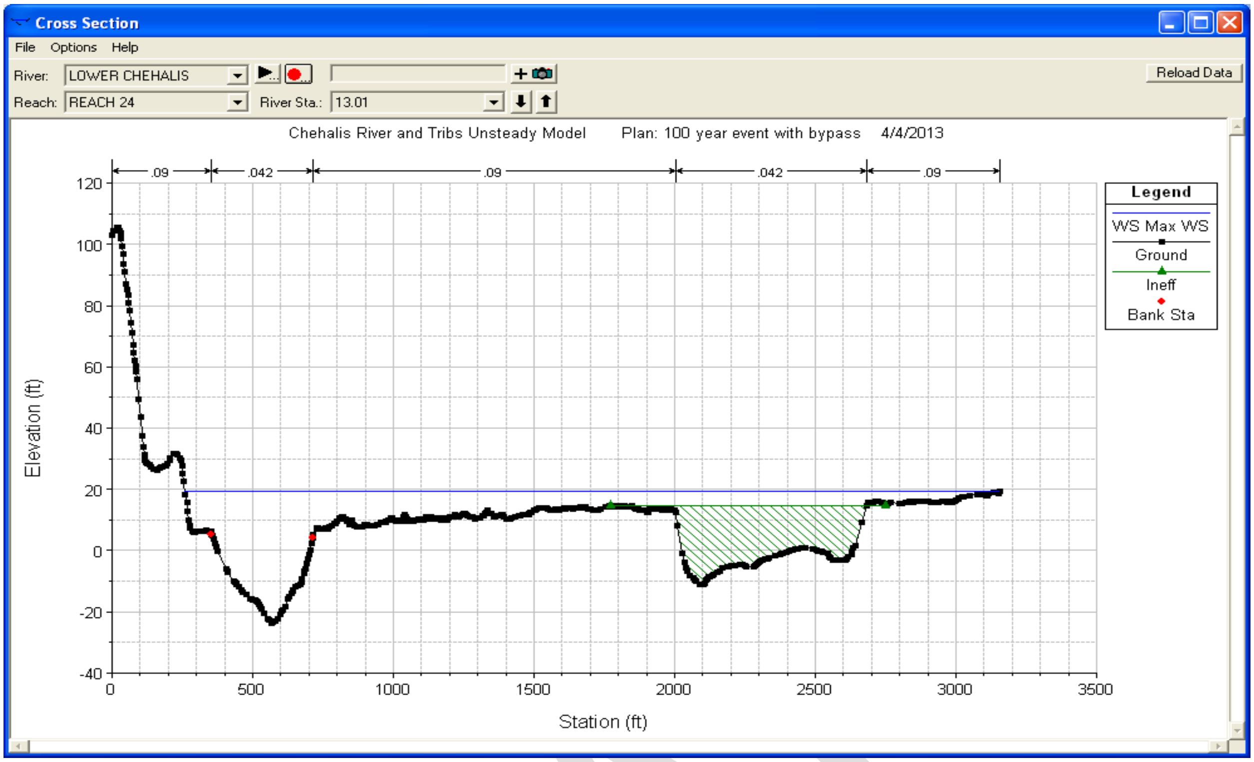

Figure 11. Typical cross section cut for the Full Bypass (old main channel ineffective).

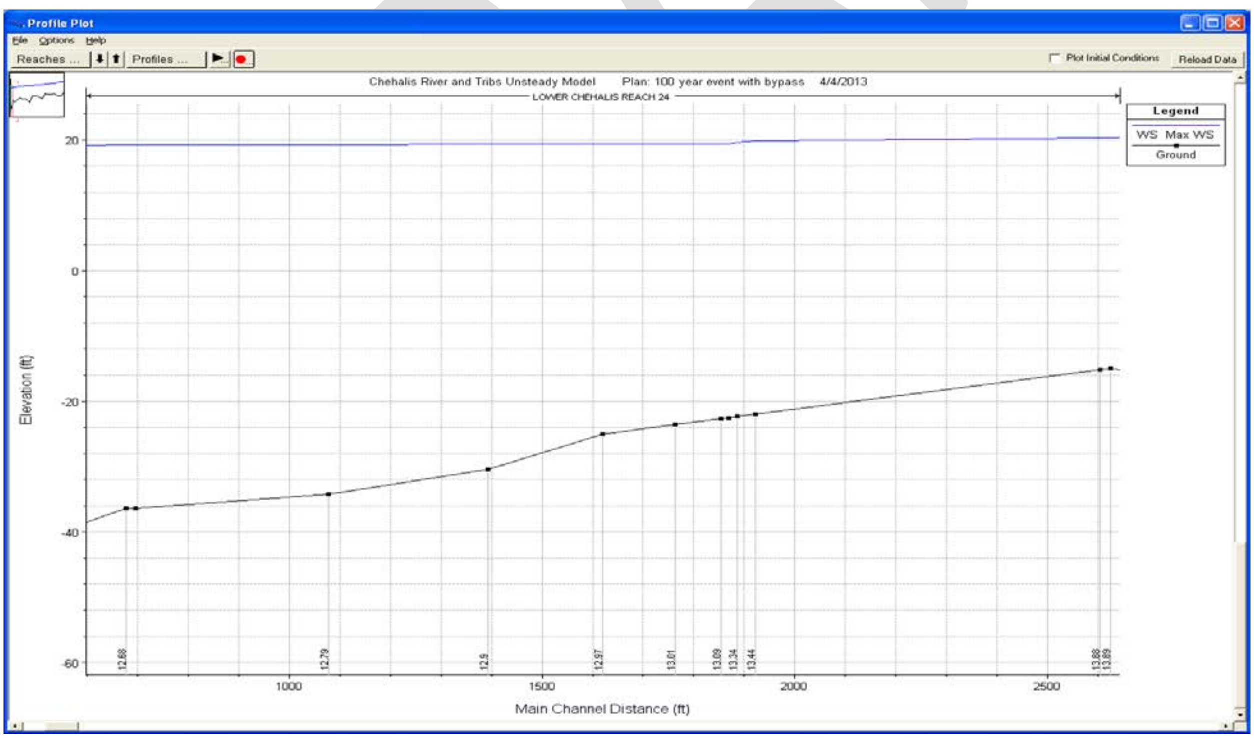

Figure 12. Thalweg for Full Channel Bypass.

Table 8. Summary of velocity changes compared to Existing Conditions at SR 107 for different scenarios.

Event		1996	2007	2009	100-year	500-year
Existing Conditions	Maximum Velocity (ft/s)	9.01	8.63	7.77	9.89	12.93
Meander Breakthrough	Maximum Velocity (ft/s)	9.01	8.64	7.78	9.89	12.93
	Increase in maximum velocity (ft/s)	0.0	0.01	0.01	0.0	0.0
	Maximum increase in velocity at any time (ft/s)	0.08	0.09	0.11	0.07	0.10
High Flow Bypass	Maximum Velocity (ft/s)	9.01	8.66	7.79	9.89	12.93
	Increase in maximum velocity (ft/s)	0.0	0.03	0.02	0.0	0.0
	Maximum increase in velocity at any time (ft/s)	0.09	0.10	0.16	0.09	0.10
Full Channel Bypass	Maximum Velocity (ft/s)	9.01	8.63	7.78	9.75	12.93
	Increase in maximum velocity (ft/s)	0.0	0.0	0.01	-0.14	0.0
	Maximum increase in velocity at any time (ft/s)	0.22	0.18	0.22	0.24	0.38

Water Surface Elevation at Wastewater Treatment Plant

The City of Montesano would like to avoid having any sewage interaction at the WWTP with the Wynoochee River during significant flood events. Anecdotal information (from City of Montesano) indicates that the 2009 event came within 6 inches of the top of the bank. For the 100-year event the modeled water surface elevation is 19.54 feet. Similar results were found for the 2009 event. With the superelevation likely to occur due to the WWTP being at the outside of a sharp bend would add 0.64 feet to the water surface elevation. The 100-year water surface elevation would be approximately 20.2 feet, so the WWTP should be protected to 21.2 feet to provide 1 foot of freeboard (WSDOT standard) for the 100-year event. The anecdotal evidence suggests that the model results are a bit low. Since the 100-year event is about the same as the 2009 event, and the 2009 event was at approximately 20.75 feet (top of berm elevation estimated at 21.25 feet), we recommend raising the berm around the storage ponds to 22.5 feet for 100-year event protection. The 500-year water surface elevation at the WWTP is 22.3 feet with the superelevation included.

Conclusions

WEST conducted an evaluation of historic aerial photographs obtained for the Chehalis River near the Mary's River lumber mill in Montesano, WA. The channel alignments delineated from the historic photographs are shown in Figure 2 and 3. Observations made from these figures and the aerial photographs are summarized in Table 1.

The information for the last 58 years demonstrates that the planform of the Chehalis River is highly dynamic and the river will eventually cutoff the meander bend near the lumber mill in the near future if no action is taken. The erosion rate of the land remaining between the meanders upstream from the lumber mill was estimated using the historic bank alignments obtained from the aerial photographs and the rates are summarized in Table 2.

If the cutoff of the meander bend occurs, the thalweg of the river will shift towards the bank adjacent to the lumber mill and the banks will experience impinging flow, high flow velocities, and shear stresses. These changes will cause bank erosion that could result in damage to several mill structures. WEST completed hydraulic and scour analyses in support of a bank protection design for the site. A detail of the bank protection measure is provided in Figure 8.

The full channel bypass would relieve pressure on the breakthrough area and likely make the bypassed bend aggradational. With the Full Channel Bypass the channel would be aligned to the bridge opening instead of a sharp bend prior to the bridge opening.

Hydraulic impacts at SR 107 due to Chehalis River modifications are not significant, as seen in Table 8. However, the bridge is already experiencing scour problems. Whether or not any changes are made to the Chehalis River in the bridge vicinity, measures should be taken to protect the bridge, or the bridge should be monitored for scour.

In order to prevent sewage interaction with the Wynoochee River the WWTP should be protected to elevation 22.5 feet for the 100-year event, and to elevation 23.3 feet for the 500-year event.

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